# Thermal Energy Efficiency Improvement Handbook

# คู่มือการจัดการพลังงานความร้อนภายในโรงงาน

The Energy Conservation Center Japan

# THERMAL ENERGY EFFICIENCY IMPROVEMENT HANDBOOK (TEEI HANDBOOK)

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Prepared by
Department of Industrial Promotion, Ministry of Industry, Thailand
Thailand Environment Institute
Committee Members and Authors for TEEI Handbook Preparation in Thailand
and
The Energy Conservation Center, Japan
(On Behalf of Ministry of Economy, Trade and Industry of Japan)

## [Contents]

# PART – 1 Executive Summary

# Chapter 1

## What are the Good Points of this Handbook?

As energy is important for living of human life, the energy source is becoming limitation. While growth rate of industrial sector increases rapidly, the use of thermal energy is also increasing. Therefore, energy conservation is important for conserving energy in the future as well as energy use has impact to environment in global and country levels.

We know that global temperature increases due to various environmental changes from the past 100 years, it effects our environment such as increasing of ice melting, high sea level, epidemiology of diseases. The international forums believe that it occurs from the increasing of $CO_2$ quantity in the atmosphere. One important source of $CO_2$ emissions is from energy sector. It became agreement of inter-government under United Nations Framework Convention on Climate Changes.

Consideration of air pollution at local or country levels found that SOx, NOx and dust etc. are produced from fuel use of both industrial and transportation sectors. It effects to health. Besides, most of industries are SME, 98% of industries, which they are lack of technology, knowledge and awareness for energy conservation, well management, financial budget and personal. Therefore, SME is our target group.

We can define energy use into two types: electricity and thermal energy. For electricity, Thai government and EGAT have implemented several projects on electricity related to management and behavior. It uses the common knowledge and technologies which most mitigations can be done by factories themselves.

If we need the factories to reduce more energy use, we should focus and emphasize on thermal energy due to inadequate knowledge and technology. For this issue, factories need supports both knowledge and technology.

As a result, this handbook is produced for all above reasons. The objective is to disseminate the knowledge that “SME can reduce their thermal energy uses by themselves by passing through the use of this friendly handbook”. In addition, some parts of this book are suitable for CEO, some are suitable for engineers, and some are suitable for operators.

**Why must we do energy conservation?**

Energy conservation effects to indirect impacts of macro economic, social and environment as well as direct impacts of business and got successful in many cases. In general, many large businesses in the world have seriously established energy conservation with systematic and continuous implementation. This is because the CEO or owner of these businesses are support and push all industrial sections to participate the conservation, which lead to positive reduction of investment cost, increase profit and their images to society and community, as can be seen from case studies below:

**Case study 1: Mazda Motor Corporation in USA**

In 1995 Mazda Motor Corporation (Japan) conducted an energy conservation program with the participation of all staff levels. This program has created working teams comprised of 870 staff from all its plants. The program has an energy reduction target of 5% from the reduction efforts in (1) non-operating period, (2) overtime operating period, and (3) normal operating period.

From the active and participatory implementation of the program, in 1996 the corporation overhauled and replaced some machines, costing 47,000,000 yen, and succeeded energy reduction of a value of 9,487,000 yen per month (or 113,844,000 yen per year). This reduction, accounted for 10%, was above its target. Besides, the company achieved awareness raising among the staff in terms of energy conservation, and enjoyed the pride of participation.

**Case study 2: Sagamihara Plant, NEC Corporation in Japan**

The Sagamihara Plant is a principal base for research/development and mass production of semiconductors, and consumes a large amount of energy, including steam. The steam is used for heating water/chemicals, and as a heat source for air-conditioning of the clean room. The company once found that heat loss from the generated steam was considerable.
Accordingly, in April 1995 NEC launched a two-year heat loss prevention program. The inspection process discovered that the generated steam lost its energy through a number of ways. These included the declining of efficiency of the water tube boiler in summer season, excessive blow down, dropping temperature of the hot well tank, and inappropriately insulated steam pipe. To overcome these problems, the company set its

targets as follows: (1) maintaining the efficiency of the boiler system at 80% or more throughout the year, and (2) providing full insulation for the steam supply line (excluding expansion joints).

As a result of the plant-wide priority effort involving a number of small working groups, the good management of boiler operations increased the boiler efficiency to 81% from 73%. Accompanying with the full insulation, the company could totally save its fuel consumption equivalent to 34.146 million yen/year, reduce $CO_2$ emission equivalent to 760 tons/year, and increase the waste heat recovery of 10,596 x $10^6$ kcal/year.

**Conclusion**

Energy conservation management activity can be done by self-management activity in the factory that the owner level commands on implementation related to policy while the factory manager and engineers can use this handbook as a reference. In addition, the operators can also use this handbook for self-energy conservation and they can monitor the implementation on conservation by themselves.

# Chapter 2

## Road Map to Successful: How to Conserve Thermal Energy?

### Roadmap to Successful

Energy conservation is not new and complicated issue. The step of implementation is similar to ISO 9002, ISO 14000 or cleaner technology but the key points of energy conservation are (1) it is implemented step by step, seriously and continuously, (2) CEO must be interested and integrated energy conservation to production process, daily work schedule (behavior of working) as one part of business. The basic process of energy management is shown below.

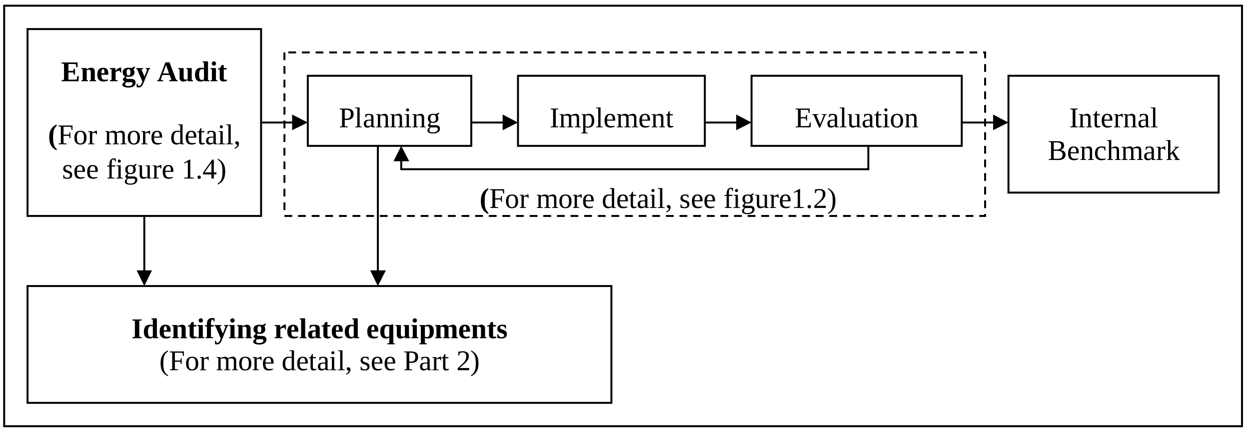



Figure 1.1: Process of energy management system

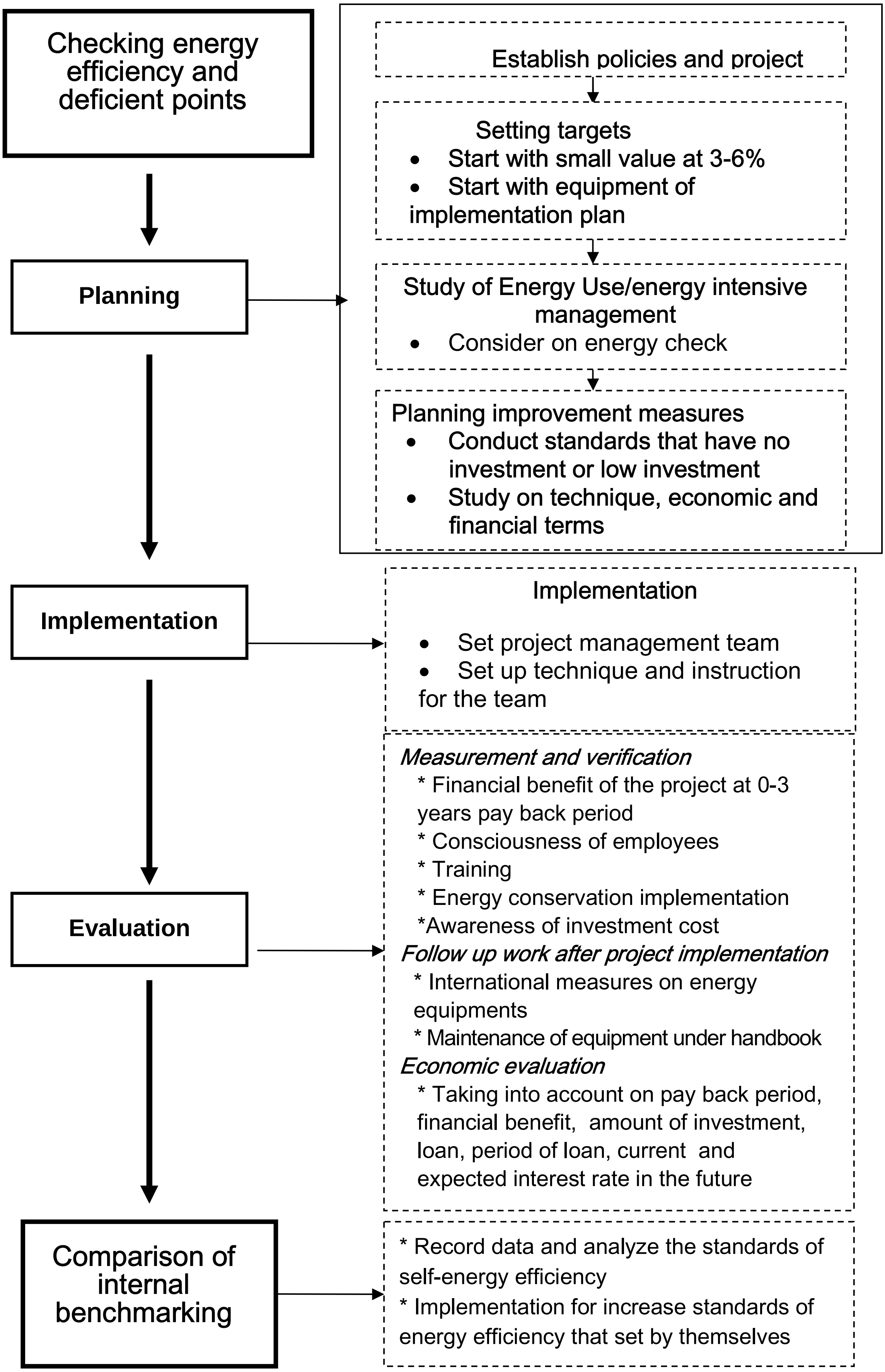

Checking energy efficiency and deficient points
Planning
Implementation
Evaluation
Comparison of internal benchmarking
Establish policies and project
Setting targets
• Start with small value at 3-6%
• Start with equipment of implementation plan
Study of Energy Use/energy intensive management
• Consider on energy check
Planning improvement measures
• Conduct standards that have no investment or low investment
• Study on technique, economic and financial terms
Implementation
• Set project management team
• Set up technique and instruction for the team
Measurement and verification
* Financial benefit of the project at 0-3 years pay back period
* Consciousness of employees
* Training
* Energy conservation implementation
*Awareness of investment cost
Follow up work after project implementation
* International measures on energy equipments
* Maintenance of equipment under handbook
Economic evaluation
* Taking into account on pay back period, financial benefit, amount of investment, loan, period of loan, current and expected interest rate in the future
* Record data and analyze the standards of self-energy efficiency
* Implementation for increase standards of energy efficiency that set by themselves

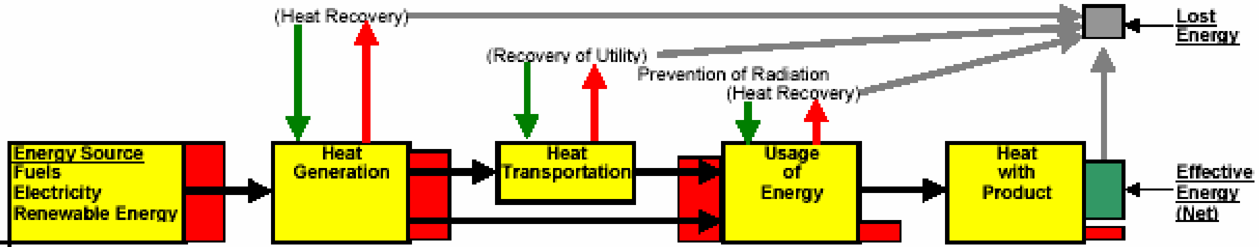
Figure 1.2

## What is the Cycle of Thermal Energy Use

After we have already known the steps of planning and energy management. We should understand what the thermal energy use is and its cycle in production process of industries, including the opportunity to thermal energy loss in production process. This process help the users to audit and improve the equipment systemically

**Efficient Use of Thermal Energy : Overview of Basic Flow**

**Necessity of Energy Audit**
(1) Measurement of Energy / Material Balance
(2) Identification of Points to Improve
(3) Provision of Recommended Improvement

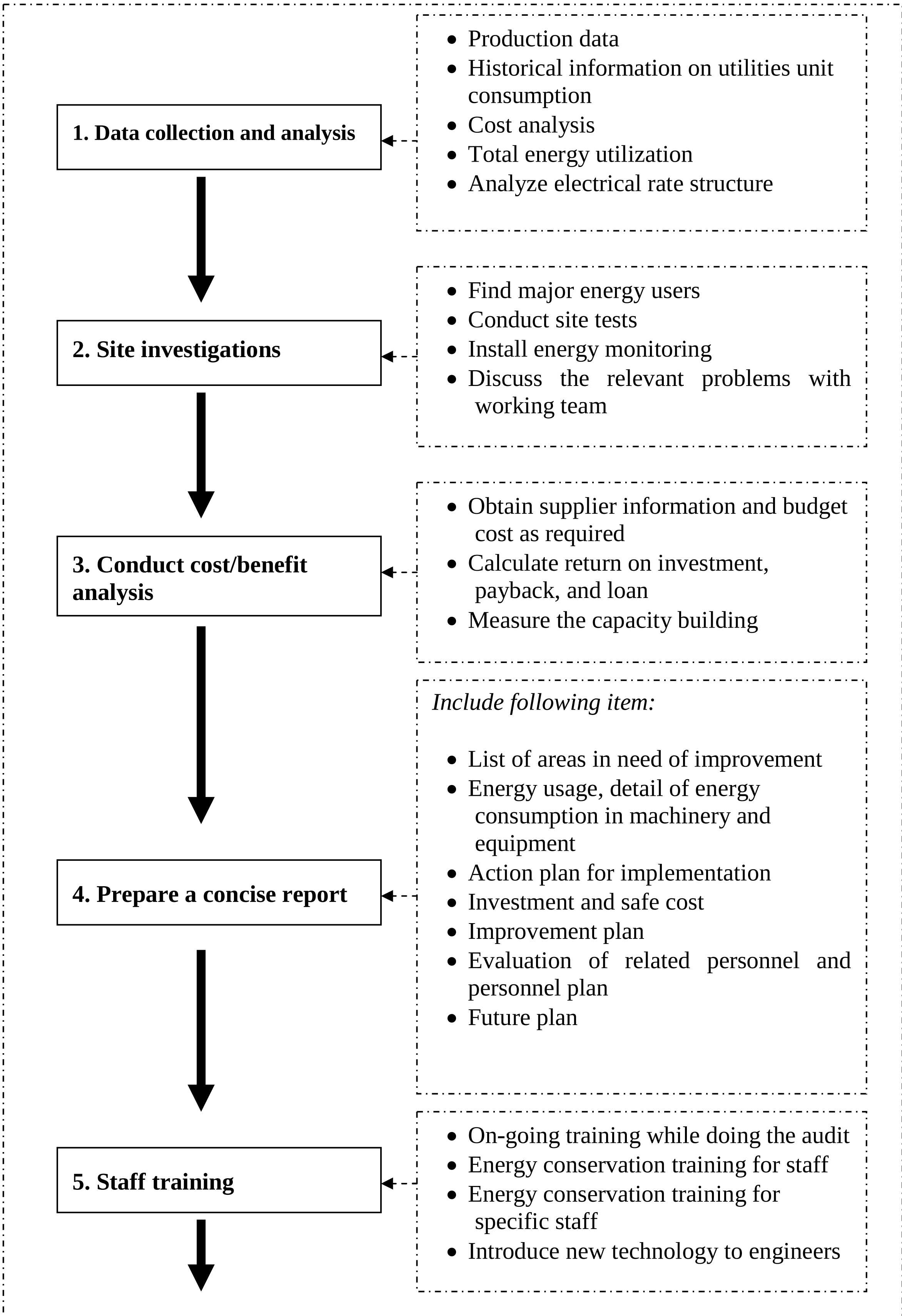



| Basic Guideline for Energy Conservation | Energy Source | Heat Generation | Heat Transportation | Usage of Energy | Heat with Product |
|---|---|---|---|---|---|
| 1. Rationalization of Fuel and Combustion | Optimized Selection of Energy Souce | Furnace, Boiler Chiller, etc. | | | |
| 2. Rationalization of Heating / Cooling / Heat Transfer | | | Minimization / Optimization | Efficient Heater Cooler, etc | Appropriate Cooling, etc. |
| 3. Prevention of Heat Loss through Radiation and Conduction | Insulation / Lining etc. | Insulation / Lining etc. | Insulation / Lining etc. | Insulation / Lining etc. | Insulation / Lining etc. |
| 4. Recovery and Utilization of Waste Heat | | Heat Recovery | | Heat Recovery | Utilization for Next Process |
| 5. Rationalization of Conversion of Heat to Driving Force | | | | Efficient Transmission | |
| 6. Prevention of Electric Power Loss by Resistance | | | | | |
| 7. Rationalization of Conversion of Electric Power to Driving Force or Heat, etc. | | Electric Heater etc. | | Electric Heater etc. | |
| 8. Others (Optimization of Process, etc) | | | | | |

**Figure 1.3**

## How to Audit Thermal Energy

The another important key of thermal energy reduction is auditing system. The auditing system should be continuously done by energy team from small groups to managing level. Auditing system is shown in below.


1. Data collection and analysis
Production data
Historical information on utilities unit consumption
Cost analysis
Total energy utilization
Analyze electrical rate structure
2. Site investigations
Find major energy users
Conduct site tests
Install energy monitoring
Discuss the relevant problems with working team
3. Conduct cost/benefit analysis
Obtain supplier information and budget cost as required
Calculate return on investment, payback, and loan
Measure the capacity building
4. Prepare a concise report
Include following item:
List of areas in need of improvement
Energy usage, detail of energy consumption in machinery and equipment
Action plan for implementation
Investment and safe cost
Improvement plan
Evaluation of related personnel and personnel plan
Future plan
5. Staff training
On-going training while doing the audit
Energy conservation training for staff
Energy conservation training for specific staff
Introduce new technology to engineers

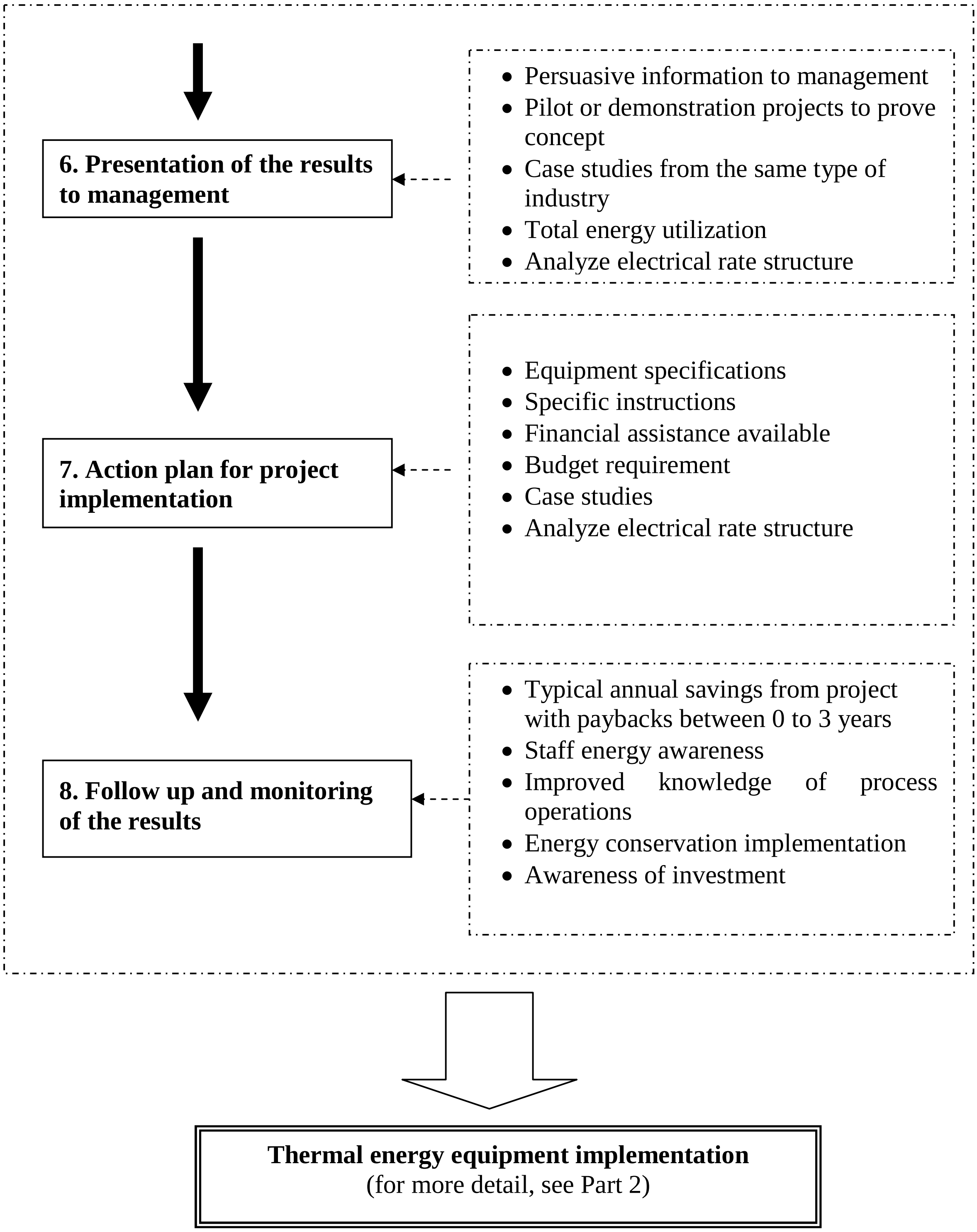

6. Presentation of the results to management
Persuasive information to management
Pilot or demonstration projects to prove concept
Case studies from the same type of industry
Total energy utilization
Analyze electrical rate structure
7. Action plan for project implementation
Equipment specifications
Specific instructions
Financial assistance available
Budget requirement
Case studies
Analyze electrical rate structure
8. Follow up and monitoring of the results
Typical annual savings from project with paybacks between 0 to 3 years
Staff energy awareness
Improved knowledge of process operations
Energy conservation implementation
Awareness of investment
Thermal energy equipment implementation
(for more detail, see Part 2)

**Figure 1.4**

**How to know that This Year is better than Last Year**
(How to do In-house Benchmarking)

This section is on how to benchmark in each factory.
Originally, “benchmarking” is a very useful tool in the business management, meaning setting targets against which the performances are monitored.

In the competitive industry, a company may measure its own performances by means of *figures* and compare them with those of the other companies with the best practices. If its figures are worse than the others, then “the best practice figures” may be adopted as the new targets for the company – this process is benchmarking.

However, this process is actually very difficult for the following two reasons:
(1) The benchmark figures shall be derived from the analysis of detailed information including raw materials, production processes, product grades etc. to assure accurate comparison.
(2) Such detailed information is too difficult to get, because they are usually confidential in nature.

Accordingly, a practical way of starting benchmarking activities is to do “in-house benchmarking” as the first step. In-house benchmarking can be done in a company in the following manner:
1. If the company has several factories, then the figures can be compared among those factories to establish common benchmarks.
2. Inside the one and same factory, the figures can be compared for consecutive years. (Like this year versus last year.)

To do in-house benchmarking for the purpose of energy conservation, it is firstly important to collect and analyze all the necessary data, as already explained in the preceding section “How to audit Thermal Energy, Data collection and analysis”. Then the data are to be properly accumulated in the form of “In-house energy database” so that person in that company can share the common data and discuss on the same ground. Based on the detailed analysis with technical and economic factors taken into consideration, the best or desired performances are summarized into the figures as internal benchmarks. They are used as targets or standards for the operation, and every year are revised to give new benchmarks.
This kind of in-house benchmarking will give an excellent basis for the subsequent benchmarking in an original sense (comparison with the outside.)

## Conclusion

CEO has to use the results from auditing to improve both technique and management to change awareness and behavior. It also needs to conduct process systematically and continuous then it will be effective to production, benefit, their image to community and social, and their image in term of environmental conservation

## Chapter 1
## Boilers and Steam Utilization

### 1.1 Steam Utilization

Most of Industries use heat Energy in Production Processes. They typically produce heat by burning fuels and boiling water to become steam and distributing it to all heat processes as shown in Fig 1-1. Steam may be used directly or indirectly via heat exchangers. Condensing water from heat exchangers can be reused as feedwater.

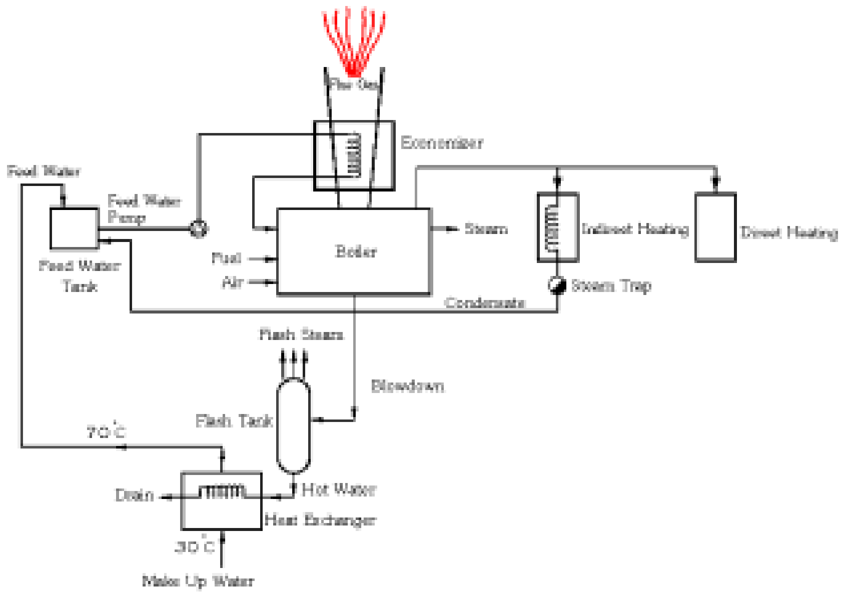



Fig **1**-1 Steam generation and use

- **Why steam is used as heat medium?**

Because of high heating capacity and low operating cost, Steam is usually used as heat medium to distribute heat to processes.

- **Types of Boilers**

There are 2 major types of Boilers, Water tube and fire tube boilers

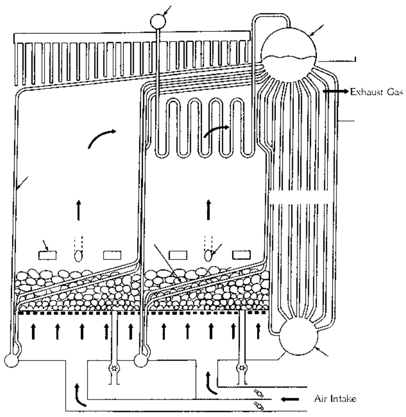



Fig 1-2 Water tube boilers

In boiler operation, fuels are burnt and produce hot gas transferring heat to water. Water tube boilers are different from Fire tube boilers that the water is in the tube and hot gas is around outside. Because of this structure, Water tube boilers have better response to steam demand and they can produce steam at high pressure and high capacity

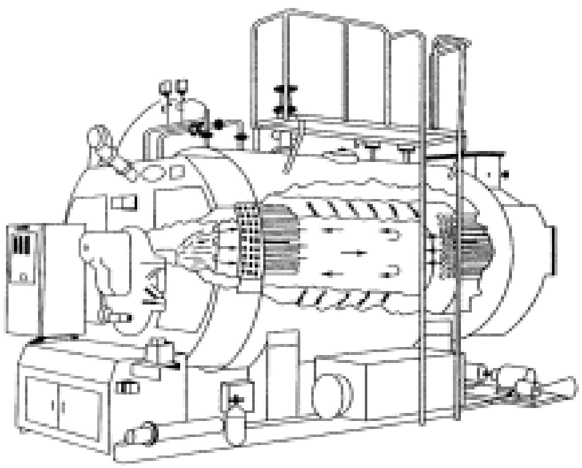


Fig 1-3 Fire tube boilers

For Fire tube boilers, hot gas is in tubes and water is outside. Fire tube boilers are usually low pressure or small boilers which are common in industry.

- **Boiler efficiency**

In general boiler efficiency is about 80-85% that means 100 units of fuel heat can produce only 80-85 units of steam heat. The rest energy is losses with flue gas, surface radiation and water blown down as shown in Fig 1-4

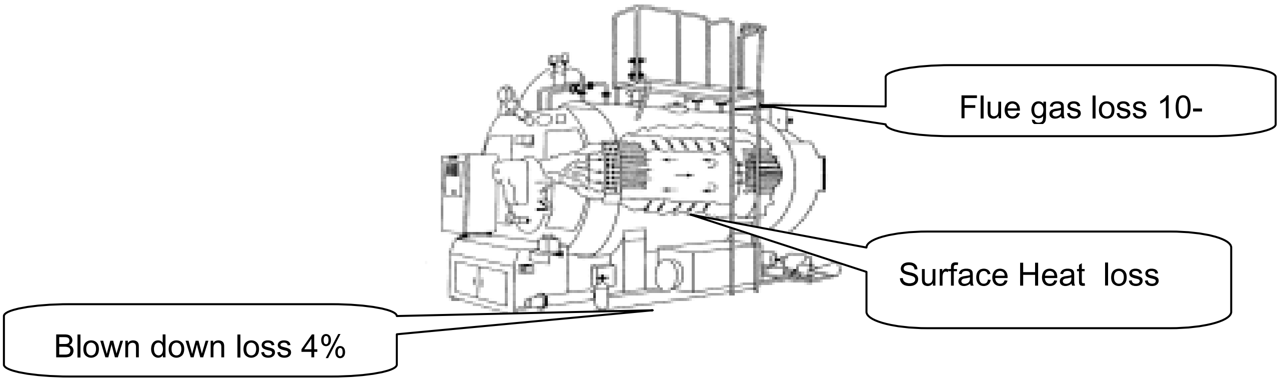



**Fig 1-4 Boiler losses**

Fuel + air → heat energy

Heat energy → Steam energy + Flue gas energy loss + surface energy loss + blown down energy loss

In the following section, the measures to reduce these losses will be described

## 1.2 Measures to improve steam utilization efficiency

This section will describe measures to improve steam utilization efficiency as follows

(1) Measures to improve combustion efficiency
(2) Measures to reduce Stack loss
(3) Measures to reduce Blowdown loss
(4) Measures to recover condensate
(5) Measures to reduce Surface heat loss
(6) Measures to use steam efficiently

(1) Measures to improve combustion efficiency

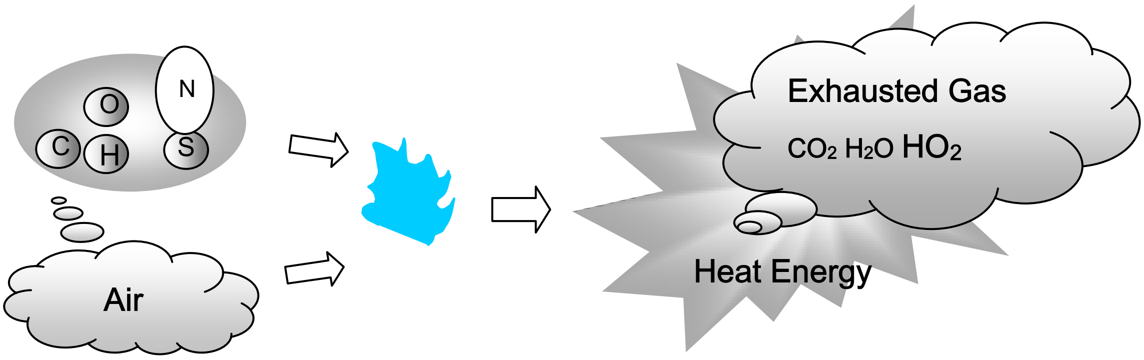



Figure 1.1-1 Combustion

- What is Combustion?

Combustion is a process in which fuel elements react with oxygen to give heat and exhausted air.

Completed Combustion (so-called highest efficiency combustion) is the combustion where the oxygen and fuel elements completely react, producing mainly carbon dioxide, sulfur dioxide, steam and the highest amounts of energy. This efficiency depends on fuel types, quantity of air and the burner.

- How fuel types affect combustion efficiency?

Solid fuel has the lower combustion efficiency in comparison with gas and liquid fuels. This is because of its lowest air to fuel contact surface. Also, the fuel with higher viscosity, presenting larger droplets in the fuel spraying process, lower contact surfaces, and undermines its combustion efficiency.

- Quantity of air in the combustion.

Insufficient amount of air in combustion produces carbon monoxide, soot, smoke, incombustible fuel and less energy. The combustion efficiency is low. On the other side too much air incurs more loss.

- How important is a burner?

A filthy, clogged and damaged burner results in a poor mixing of fuel and air, and thus lowers

Appropriate air ratio in the combustion

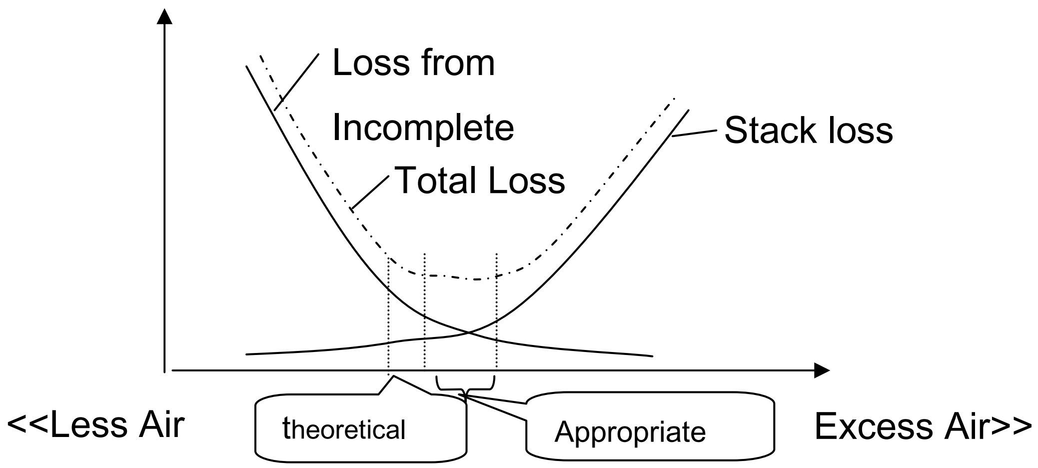



Figure 1.1-2 Appropriate air ratio for combustion

**Must know**: In practice, we do not adjust to theoretical air and fuel ratio. This is because all of fuel cannot entirely contact with air, especially solid fuel. Therefore, we need to feed extra air, which are called " **excess air**" .

o How to know the optimum air combustion?

Appropriate air in each type of fuel can observe from oxygen content and carbon dioxide content in exhausted air as shown in Table 1.1-1.

Table 1.1-1: Appropriate air for fuel

| Type of Fuel | Oxygen (%) | Carbon dioxide (%) | Carbon monoxide (ppm) | Excessive air (%) |
|---|---|---|---|---|
| Fluid fuel | 3-4 | 12-14 | <200 | 10-20 |
| Gas fuel | 1-2 | 9-10 | <200 | 10-20 |
| Solid fuel | 12-13 | 12-13 | <200 | 50-70 |

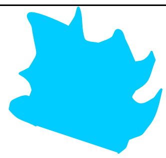
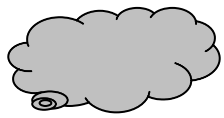
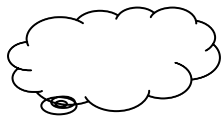
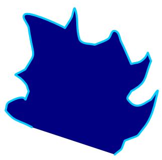
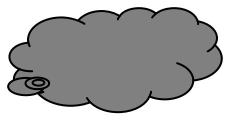
Carbon monoxide content in flue gas represents the degree of incomplete combustion. Normally it should be less than 200 ppm.

Oxygen, carbon dioxide or Carbon monoxide contents can be read from flue gas analyzers which can be electronic cells or chemical reaction. Otherwise operators can observe the combustion by visual.

How to observe combustion?

To measure oxygen and carbon dioxide contents in exhausted air need exhausted gas analyzer. However, there is easy way to notice color and appearance of flame, and soot smoke as following:

Table 1.1-2: Air control by observing flame and soot smoke

| Quantity of air | Frame appearance | Soot smoke |
|---|---|---|
| Optimum air |  Red and short stable flame |  grey |
| Excess air |  White and long unstable flame |  White or no colour |
| Less air |  Dark red flame |  dark |

o Burner Technology

Burners are devices which feed fuels and air to combust. One objective of burners is homogenous bend of fuel and air to achieve high combustion efficiency.

O Gas burners

Gaseous fuel is the easiest fuel to burn. There are 2 types of gas burners, pre-mix and Nozzle mix burners. In pre-mix type, Gas fuel and air are mixed before injected into a nozzle. Fig 1.1-3 shows nozzle mix burner which is prevalent in industry

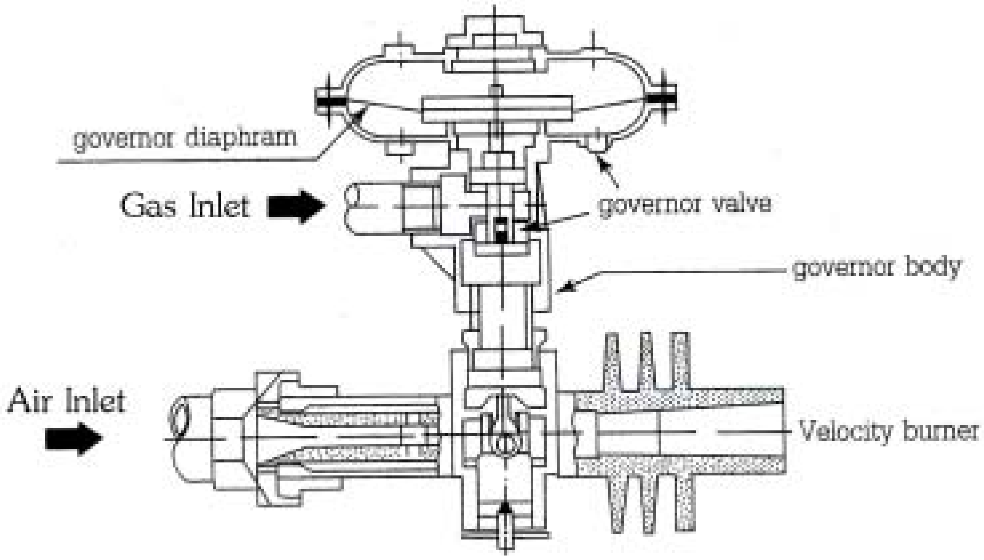
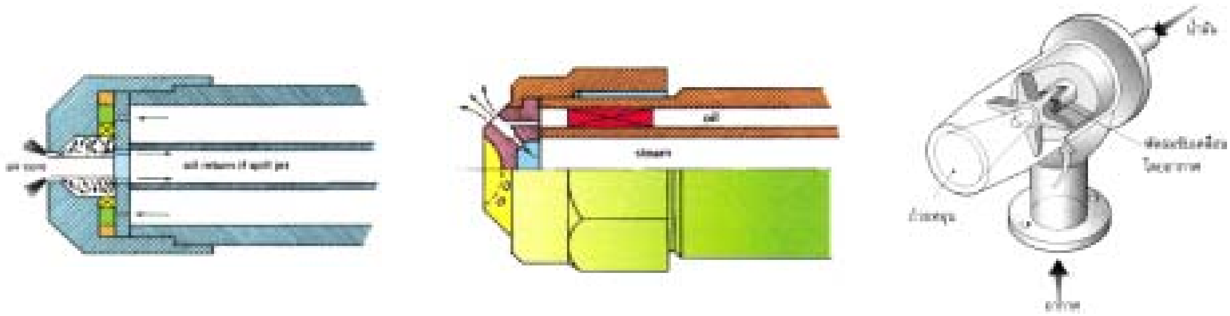



Fig 1.1-3 Nozzle mix burner

O Oil Burners

There are 3 types of oil burners, Pressure burners, Air/Steam atomizing burners and Rotary Cup burners. Fig 1.1-4 shows each type of burners.




a. Pressure type b. Steam/Air Atoning type c. Rotary Cup type

Fig 1.1-4 Oil burners

Table 1.1-3 Characteristic of oil burners

| | Air/Steam Atomizer | | Pressure type | Rotary Cup |
|---|---|---|---|---|
| | Low Pressure | High Pressure | | |
| capacity | 1.5-180 L/h | 10-5000 L/h | 50-10000 L/h | 10-300 L/h |
| Media | Air/Steam | Air/Steam | - | - |
| Oil Pressure | 0.1– 1 Barg | 0.2-9.0 Barg | 14-18 Barg | 0.5-10 Barg |
| Injection Pressure | 0.4-2.0 Barg | 2-10 Barg | - | 1-3 Barg |
| Advantages | Low cost | Good spraying no blocking | Low cost quiet | Low Cost |
| Disadvantages | Need blowers | Need Power Supply | Low response Need oil pumps | For large boilers only |

O Combustion of Solid fuel

By comparison, Solid fuels are cheapest so they are more prevalent. Solid feeding is quite different from those of liquid or gas fuels. Common types of solid fuel combustion are mainly

O Grate stoker Combustion

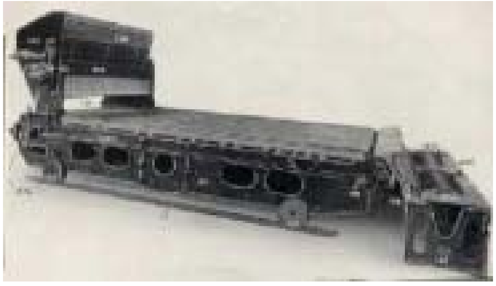
Coal is laying on a grate which can be fixed or travelling types. In travelling grate, Coal will be fed at one side and then the iron chain will bring it moving and burning along the combustion chamber. The combustion air comes from beneath of the grate. This type is the most popular in Solid combustion.

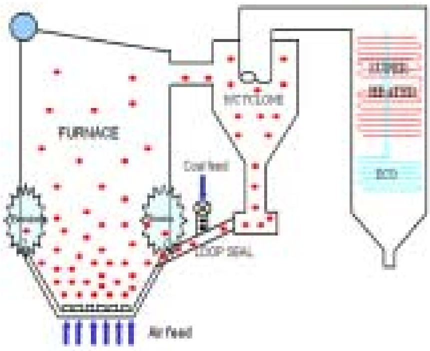
O Pulverized Coal Combustion

For this combustion type, Coal will be grinded to small particles of 50 micron and injected into the combustion chamber like oil burners.

O Fluidized bed combustion

Fluidized bed combustion is a modern technology in solid combustion. It uses air to blow fuel ball or refectory sand up while combusting. This leads to higher heat transfer. Because of lower combustion temperature, the furnace is smaller and produces less pollution.



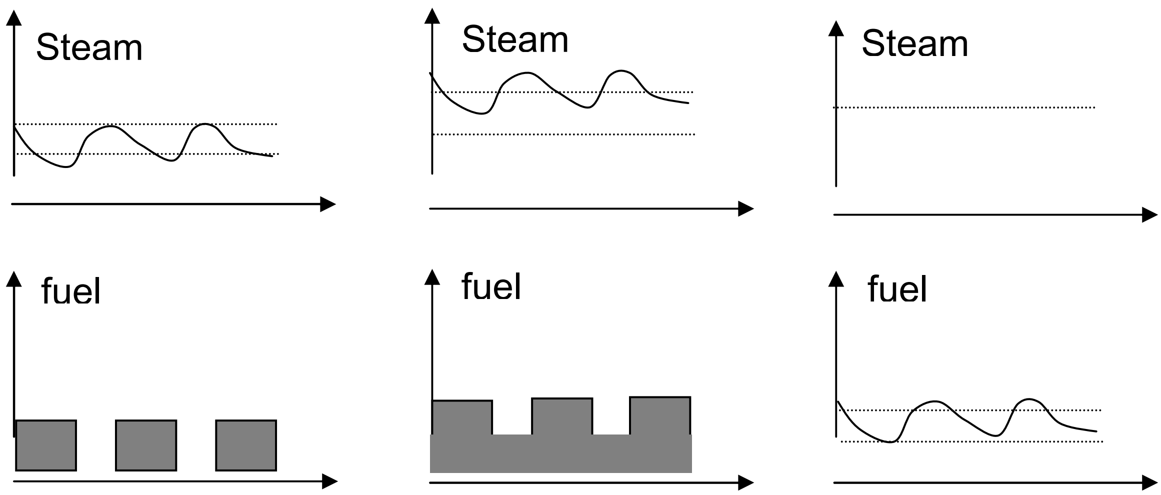



a. Grate stoker combustion b. Pulverized Coal Combustion c. Fluidized bed

Figure 1.1-5 Solid fuel combustion

O How burners work?

Most burners operate in 3 different methods, On-Off control which turns on and off burners to maintain Steam pressure, High-Low fire which has multiple steps of fuel injection and Modulation Control which varies fuel injection with Steam demand.

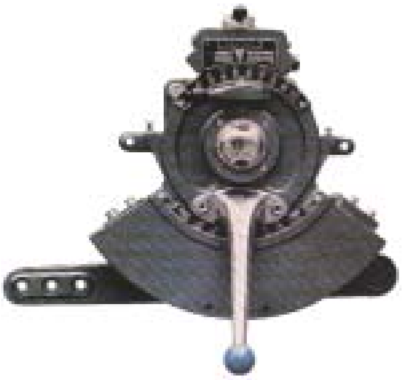



On-Off Control High-Low firing Modulation Control

Fig 1.1-6 Burner Control

o How burners control fuel and air ratio?

Burners control both fuels and air via fuel control valves. And air dampers. Fig 1.1-7a shows a Cam type which cam radius controls damper position and Fig 1.1-7b Shows a wheel switch type which damper position is controlled by pre-set switches.



a. Cam type b. Wheel switch type

Fig 1.1-7 Fuel and air Control

- Combustion Improvement

We can improve combustion efficiency by means of

1. Cleaning burners every week. Dirts and soots obstruct air and fuel flow.
2. Controlling combustion air ratio to the standard in table 1.1-3
3. Monitoring Oil Pressure regularly and Control it to commissioning figure .
4. Monitoring Heavy Oil Temperature regularly and control at recommended value in Table 1.1-4

Table 1.1-4 Recommended oil temperature

| Fuels | Appropriate Temperature |
|---|---|
| Heavy Oil type A | 90 |
| Heavy Oil type C | 110 |

5. Always Heating up heavy oil with Steam instead of Electricity
6. Draining and removing deposits and water in Oil tank every year
7. Using appropriate burner size if your burners always operating at low load
8. Insulating oil heaters
9. Reducing moisture and size of Solid fuel before burning

- Calculation

How much of heat energy fuels can give us?

Heat energy from fuel = Quantity of fuels x heating value

Heating values of different fuels shown in Table 1.1-5

Table 1.1-5 Heating Values

| Types of fuels | Fuels | Heating value (British) | Heating Value (SI) |
|---|---|---|---|
| Solid | Bitomenous | 6,297.16 kcal/kg | 26,,366.21 kJ/kg |
| | Lignite | 2,500.24 kcal/kg | 10,468.50 kJ/kg |
| | Saw Wood | 2,598.14 kcal/kg | 10,878.41 kJ/kg |
| | Paddy rice | 3,438.72 kcal/kg | 14,397.92 kJ/kg |
| | Bagasse | 1,798.16 kcal/kg | 7,528.90 kJ/kg |
| Liquid | Gassoren | 8,245.76 kcal/L | 34,525.00 kcal/L |
| | Deseil | 8,697.10 kcal/L | 36,414.76 kcal/L |
| | Heavy Oil Type A | 9,857.66 kcal/L | 41,274.02 kcal/L |
| | Heavy Oil Type C | 9,117.38 kcal/L | 38,174.47 kcal/L |
| Gas | NG | 8,763.96 kcal/Nm3 | 36,694.47 kJ/Nm3 |
| | LPG | 11,992.53 kcal/kg | 50,220 kcal/kg |

Example The factory uses heavy oil Type C of 12,000 litres per month.

Heat energy Consumed = 12,000 x 9117.38 Kcal/L

= 109,408,560 Kcal/month

o **What air ratio is?**

Air ratio is a value that indicates how much intake air is more than theoretical air , for example , at 30% excess air the air ratio is 130/100 = 1.3

Air ratio can be calculated from percentage of oxygen content in flue gas

$$m = \frac{O_2}{21 - O_2}$$

Where $m$ = air ratio

$O_2$ = percentage of oxygen content in flue gas

(2) Measures to Reduce Flue Gas Loss

- How flue gas loss happens?

Thermal energy from fuel combustion that transfers through heat exchanger surface is used for boiler to produce steam Due to, the efficiency of each heat exchange surface is different, therefore leading to various flue gas loss. Generally, it losses approximately 10-30%.

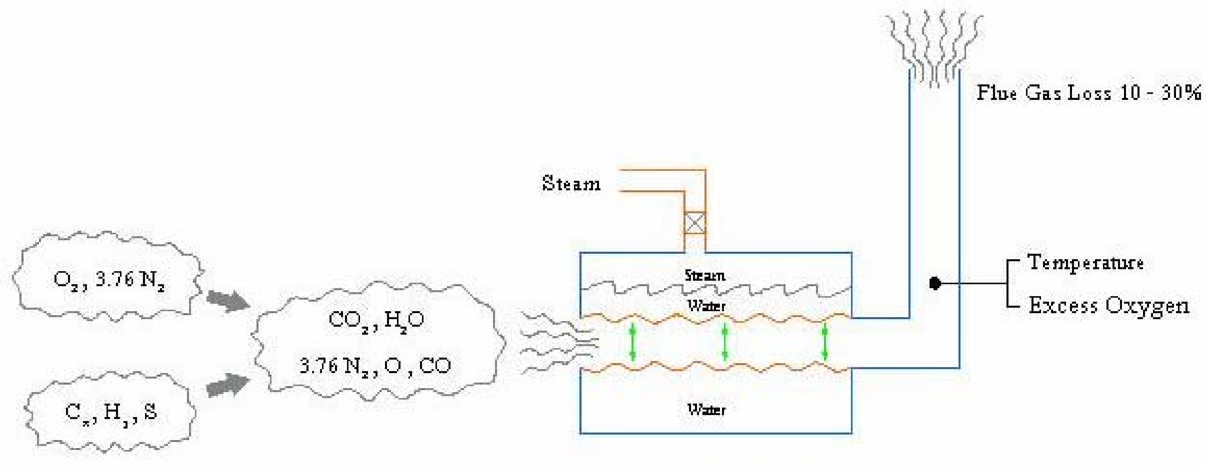



Figure 1.2-1 Flue Gas Loss

- What are factors of flue gas loss?

1.Inappropriate air for combustion: If there is excess air, air will conduct heat from combustion chamber to stack, which can notice by higher temperature. Therefore, we need to adjust appropriate air ratio to each type of fuel.

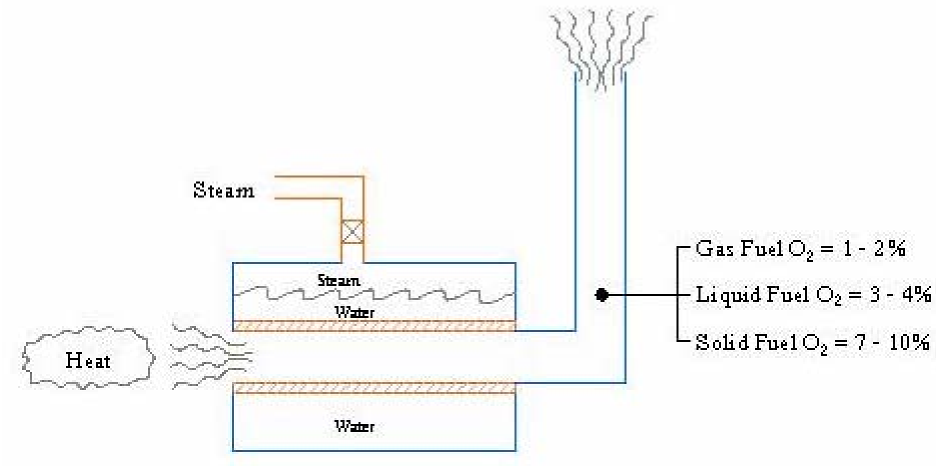



Figure 1.2-2 Appropriate excess air for each fuel combustion

2. Soot: Soot occurs from fuel combustion. In addition, soot from solid fuel is greater than its from liquid fuel and gas fuel. As soot has bigger molecule than smoke, it will accumulates at heat exchange surface. When accumulation gather more, it will cause to high temperature in exhaust gas and higher in flue gas loss. As a result, every 1 millimeter of soot will consume much more fuel around 15-20%.

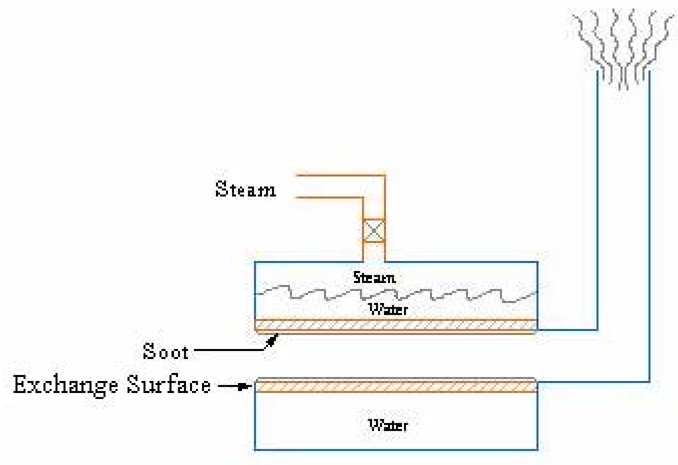



Figure 1.2-3 soot from heat exchange surface at the fire side

3. Scale: Scale happens when dissolved minerals in boiler water reach high levels, it comes out as a hard shell formed on the hot surfaces of boiler. In common, scale on heating surfaces will reduce the ability of heat transfer from hot combustion air to boiler water. High stack temperatures or ruptured on fire tubes are common problems related to scale build up. In every 1 millimeter of scale consumes higher 2% of fuel than usual.

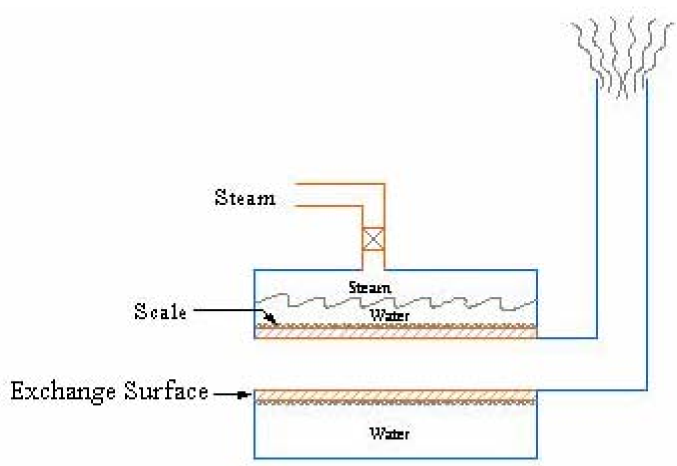



Figure 1.2-4 Scale from heat exchange surface at the water side

o What is the standard of exhaust gas temperature?

The factors, such as inappropriate air, soot and scale, causes higher temperature and heat loss from exhaust gas. Therefore, boiler users should check exhaust gas temperature regularly by recording exhaust gas temperature after adjust air ratio and clean heat exchange surface. Normally, exhaust gas temperature should not exceed value in table 1.2-1 plus the different of ambient temperature minus 20 $^{O}$C. If exhaust gas temperature is much more over the value, this might happen because of small boiler room. Furthermore users should keep recording of exhaust gas temperature after operation. Soot from the stack should be cleaned to reduce heat loss when exhaust temperature increases more than 20$^{O}$C.

Table 1.2-1 Standard of exhaust gas temperature ($^{O}$C)

| Capacity of boiler | Solid fuel | | Liquid fuel | Gas fuel | Processing |
|---|---|---|---|---|---|
| | screening | Fluidized bed | | | Waste heat |
| Boiler for electric generation | - | - | 145 | 110 | 200 |
| Other boilers | | | | | |
| 30 ton/hr or higher | 200 | 200 | 200 | 170 | 200 |
| 10 to 30 ton/hr | 250 | 200 | 200 | 170 | - |
| 5 to 10 ton/hr | - | - | 220 | 200 | - |
| less than 5 ton/hr | - | - | 250 | 220 | - |

Comment: This standard is 20 $^{O}$C at ambient temperature, 100% Full load and clean heat exchange surface.

o How to calculate heat loss?

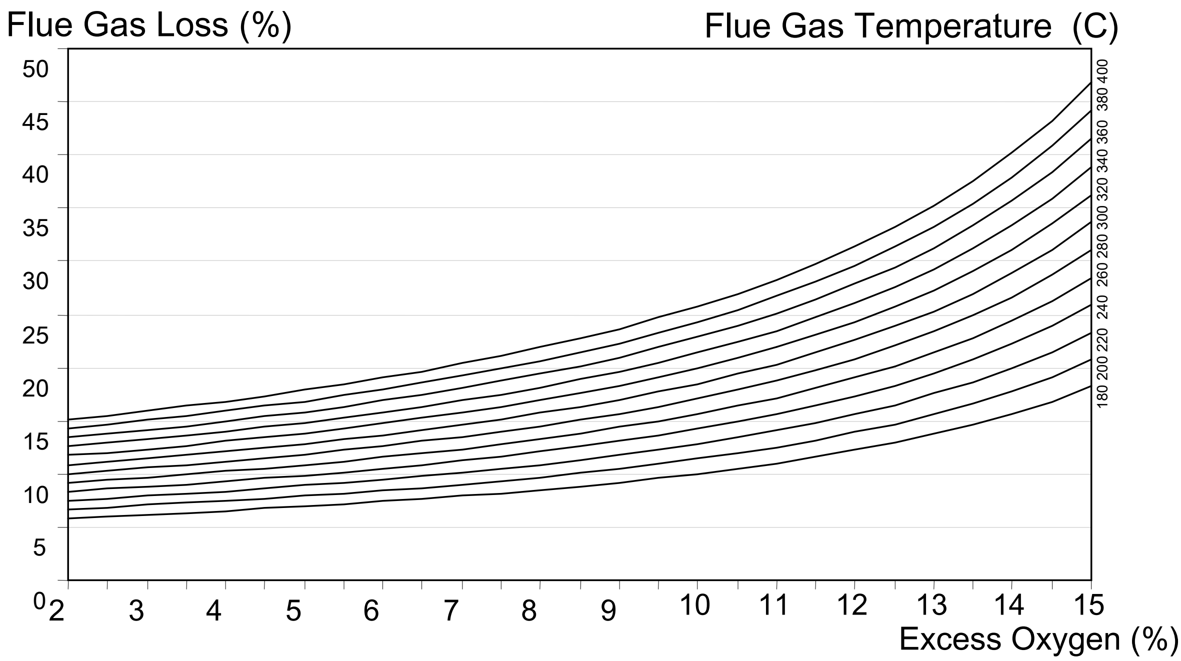
Quantity of stack heat loss from each set of boiler is different, depending on the condition that user can be seen in the tables (table 1.2-2, 1.2-3 and 1.2-4 or figure 1.2-5,1.2-6 and 1.2-7), which are represented 3 types of fuels: bunker oil, bituminous coal and natural gas. Furthermore, the users should know information as follow.

1. Type and quantity of fuel consume per year
2. Oxygen quantity in exhaust air

3. Exhaust gas temperature from stack

An example of using fuel table or figure is that bunker oil grade C, exhaust gas temperature at 260 °C and oxygen in exhaust air 8% produce 13.29% of heat loss from stack (as shown in the table 1.2-2). The heat loss value can calculate to fuel loss by using percentage of heat loss multiply with total fuel consumption per year. (13.29/100 * total fuel).

Figure 1.2-5 Percentage of flue gas loss from stack for bunker oil Grade C



## Table 1.2-2 Percentage of flue gas loss from stack for bunker oil Grade C

| Oxygen in exhaust air (%) | exhaust air temperature from stack (c) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 2.0 | 5.89 | 6.70 | 7.52 | 8.36 | 9.19 | 10.03 | 10.87 | 11.72 | 12.57 | 13.42 | 14.27 | 15.13 |
| 2.5 | 6.04 | 6.87 | 7.72 | 8.57 | 9.43 | 10.29 | 11.16 | 12.02 | 12.89 | 13.77 | 14.65 | 15.53 |
| 3.0 | 6.20 | 7.06 | 7.93 | 8.80 | 9.68 | 10.57 | 11.46 | 12.35 | 13.24 | 14.14 | 15.04 | 15.95 |
| 3.5 | 6.37 | 7.25 | 8.15 | 9.05 | 9.95 | 10.86 | 11.77 | 12.69 | 13.61 | 14.53 | 15.46 | 16.39 |
| 4.0 | 6.55 | 7.46 | 8.38 | 9.31 | 10.24 | 11.17 | 12.11 | 13.05 | 14.00 | 14.94 | 15.90 | 16.86 |
| 4.5 | 6.75 | 7.68 | 8.63 | 9.58 | 10.54 | 11.50 | 12.46 | 13.43 | 14.41 | 15.38 | 16.37 | 17.35 |
| 5.0 | 6.95 | 7.91 | 8.89 | 9.87 | 10.86 | 11.85 | 12.84 | 13.84 | 14.84 | 15.85 | 16.86 | 17.88 |
| 5.5 | 7.17 | 8.16 | 9.17 | 10.18 | 11.20 | 12.22 | 13.24 | 14.27 | 15.31 | 16.35 | 17.39 | 18.44 |
| 6.0 | 7.40 | 8.42 | 9.46 | 10.51 | 11.56 | 12.62 | 13.67 | 14.74 | 15.81 | 16.88 | 17.95 | 19.04 |
| 6.5 | 7.65 | 8.71 | 9.78 | 10.86 | 11.95 | 13.04 | 14.13 | 15.23 | 16.34 | 17.44 | 18.56 | 19.67 |
| 7.0 | 7.92 | 9.00 | 10.12 | 11.24 | 12.36 | 13.49 | 14.63 | 15.76 | 16.90 | 18.05 | 19.20 | 20.36 |
| 7.5 | 8.20 | 9.33 | 10.49 | 11.56 | 12.81 | 13.98 | 15.15 | 16.33 | 17.52 | 18.70 | 19.90 | 21.09 |
| 8.0 | 8.51 | 9.68 | 10.88 | 12.08 | 13.29 | 14.50 | 15.72 | 16.95 | 18.17 | 19.41 | 20.64 | 21.89 |
| 8.5 | 8.84 | 10.06 | 11.31 | 12.56 | 13.81 | 15.07 | 16.34 | 17.61 | 18.88 | 20.16 | 21.45 | 22.74 |
| 9.0 | 9.20 | 10.47 | 11.77 | 13.07 | 14.37 | 15.69 | 17.00 | 18.32 | 19.65 | 20.99 | 22.32 | 23.67 |
| 9.5 | 9.60 | 10.92 | 12.27 | 13.62 | 14.99 | 16.35 | 17.73 | 19.10 | 20.49 | 21.88 | 23.27 | 24.68 |
| 10.0 | 10.02 | 11.41 | 12.82 | 14.23 | 15.65 | 17.08 | 18.52 | 19.96 | 21.40 | 22.85 | 24.31 | 25.77 |
| 10.5 | 10.49 | 11.94 | 13.41 | 14.90 | 16.38 | 17.88 | 19.38 | 20.89 | 22.40 | 23.92 | 25.45 | 26.98 |
| 11.0 | 11.01 | 12.52 | 14.07 | 15.63 | 17.19 | 18.76 | 20.33 | 21.91 | 23.50 | 25.09 | 26.69 | 28.30 |
| 11.5 | 11.57 | 13.17 | 14.80 | 16.43 | 18.08 | 19.73 | 21.38 | 23.04 | 24.71 | 26.39 | 28.07 | 29.76 |
| 12.0 | 12.21 | 13.89 | 15.61 | 17.33 | 19.06 | 20.80 | 22.55 | 24.30 | 26.06 | 27.83 | 29.61 | 31.39 |
| 12.5 | 12.91 | 14.69 | 16.51 | 18.34 | 20.17 | 22.01 | 23.85 | 25.71 | 27.57 | 29.44 | 31.32 | 33.21 |
| 13.0 | 13.71 | 15.60 | 17.53 | 19.46 | 21.41 | 23.36 | 25.32 | 27.29 | 29.27 | 31.26 | 33.25 | 35.25 |
| 13.5 | 14.61 | 16.62 | 18.68 | 20.74 | 22.82 | 24.90 | 26.99 | 29.09 | 31.19 | 33.31 | 35.43 | 37.57 |
| 14.0 | 15.64 | 17.80 | 20.00 | 22.20 | 24.42 | 26.65 | 28.89 | 31.14 | 33.39 | 35.66 | 37.93 | 40.22 |
| 14.5 | 16.83 | 19.15 | 21.51 | 23.89 | 26.28 | 28.68 | 31.08 | 33.50 | 35.93 | 38.37 | 40.81 | 43.27 |
| 15.0 | 18.21 | 20.72 | 23.29 | 25.86 | 28.44 | 31.04 | 33.64 | 36.26 | 38.89 | 41.53 | 44.17 | 46.83 |

Comment : Analyze by Rosin equation at ambient temperature ($35^{O}C$) and heating value 9,117.38 kcal/kg (38,174.47 kJ/kg)

### Figure 1.2-6 Percentage of flue gas loss from stack for Bituminous coal

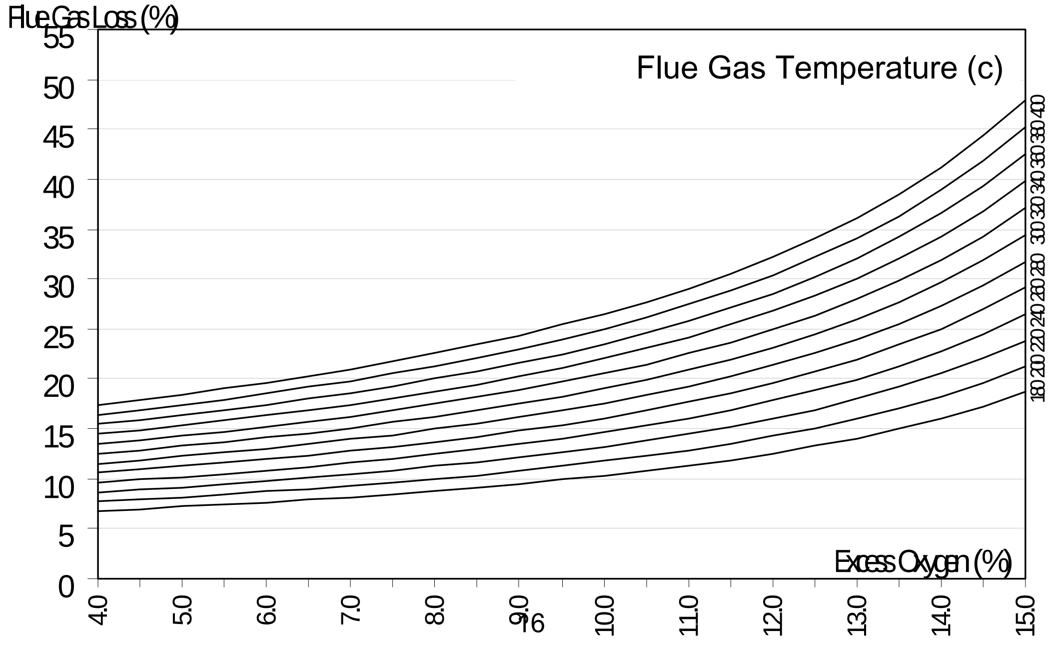


Table 1.2-3 Percentage of flue gas loss from stack for Bituminous coal

| Oxygen in exhaust air | exhaust air temperature from stack ($^{O}C$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (%) | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 4.0 | 6.78 | 7.71 | 8.67 | 9.63 | 10.59 | 11.55 | 12.52 | 13.50 | 14.48 | 15.46 | 16.44 | 17.43 |
| 4.5 | 6.98 | 7.94 | 8.92 | 9.90 | 10.89 | 11.89 | 12.89 | 13.89 | 14.89 | 15.91 | 16.92 | 17.94 |
| 5.0 | 7.18 | 8.18 | 9.19 | 10.20 | 11.22 | 12.24 | 13.27 | 14.30 | 15.34 | 16.38 | 17.43 | 18.47 |
| 5.5 | 7.41 | 8.43 | 9.47 | 10.52 | 11.57 | 12.62 | 13.68 | 14.75 | 15.81 | 16.89 | 17.96 | 19.05 |
| 6.0 | 7.64 | 8.70 | 9.77 | 10.85 | 11.94 | 13.03 | 14.12 | 15.22 | 16.32 | 17.43 | 18.54 | 19.65 |
| 6.5 | 7.90 | 8.99 | 10.10 | 11.21 | 12.33 | 13.46 | 14.59 | 15.72 | 16.86 | 18.00 | 19.15 | 20.31 |
| 7.0 | 8.17 | 9.29 | 10.44 | 11.60 | 12.76 | 13.92 | 15.09 | 16.26 | 17.44 | 18.62 | 19.81 | 21.00 |
| 7.5 | 8.46 | 9.63 | 10.82 | 12.01 | 13.21 | 14.42 | 15.63 | 16.84 | 18.06 | 19.29 | 20.52 | 21.75 |
| 8.0 | 8.77 | 9.98 | 11.22 | 12.46 | 13.70 | 14.95 | 16.21 | 17.47 | 18.73 | 20.00 | 21.28 | 22.56 |
| 8.5 | 9.11 | 10.37 | 11.65 | 12.94 | 14.23 | 15.53 | 16.83 | 18.14 | 19.46 | 20.77 | 22.10 | 23.43 |
| 9.0 | 9.48 | 10.79 | 12.12 | 13.46 | 14.80 | 16.15 | 17.51 | 18.87 | 20.24 | 21.61 | 22.99 | 24.37 |
| 9.5 | 9.88 | 11.24 | 12.63 | 14.03 | 15.43 | 16.83 | 18.25 | 19.67 | 21.09 | 22.52 | 23.96 | 25.40 |
| 10.0 | 10.31 | 11.74 | 13.19 | 14.64 | 16.11 | 17.58 | 19.05 | 20.53 | 22.02 | 23.51 | 25.01 | 26.52 |
| 10.5 | 10.79 | 12.28 | 13.80 | 15.32 | 16.85 | 18.39 | 19.93 | 21.48 | 23.04 | 24.60 | 26.17 | 27.75 |
| 11.0 | 11.31 | 12.87 | 14.47 | 16.06 | 17.67 | 19.28 | 20.90 | 22.53 | 24.16 | 25.80 | 27.44 | 29.09 |
| 11.5 | 11.89 | 13.53 | 15.21 | 16.89 | 18.58 | 20.27 | 21.97 | 23.68 | 25.40 | 27.12 | 28.85 | 30.59 |
| 12.0 | 12.54 | 14.27 | 16.03 | 17.80 | 19.58 | 21.37 | 23.16 | 24.96 | 26.77 | 28.59 | 30.41 | 32.24 |
| 12.5 | 13.26 | 15.09 | 16.95 | 18.82 | 20.70 | 22.59 | 24.49 | 26.39 | 28.31 | 30.23 | 32.16 | 34.09 |
| 13.0 | 14.07 | 16.01 | 17.99 | 19.97 | 21.97 | 23.97 | 25.99 | 28.01 | 30.04 | 32.07 | 34.12 | 36.17 |
| 13.5 | 14.98 | 17.05 | 19.16 | 21.28 | 23.40 | 25.54 | 27.68 | 29.83 | 32.00 | 34.17 | 36.35 | 38.53 |
| 14.0 | 16.03 | 18.25 | 20.50 | 22.77 | 25.04 | 27.33 | 29.62 | 31.92 | 34.24 | 36.56 | 38.89 | 41.23 |
| 14.5 | 17.24 | 19.63 | 22.05 | 24.48 | 26.93 | 29.39 | 31.85 | 34.33 | 36.82 | 39.32 | 41.83 | 44.34 |
| 15.0 | 18.66 | 21.23 | 23.85 | 26.49 | 29.14 | 31.79 | 34.46 | 37.14 | 39.83 | 42.54 | 45.25 | 47.97 |

Comment : Analyze by Rosin equation at ambient temperature ($35^{O}C$) and heating value 6,297.16 kcal/kg (26,366.21 kJ/kg)

Figure 1.2-7 Percentage of flue gas loss from stack for natural gas

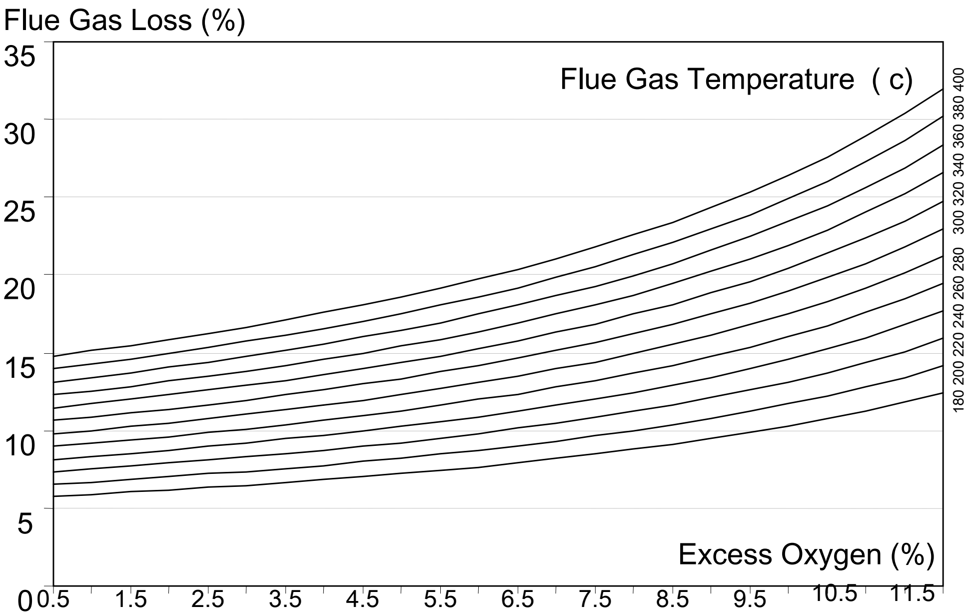


Table 1.2-4 Percentage of flue gas loss from stack for natural gas

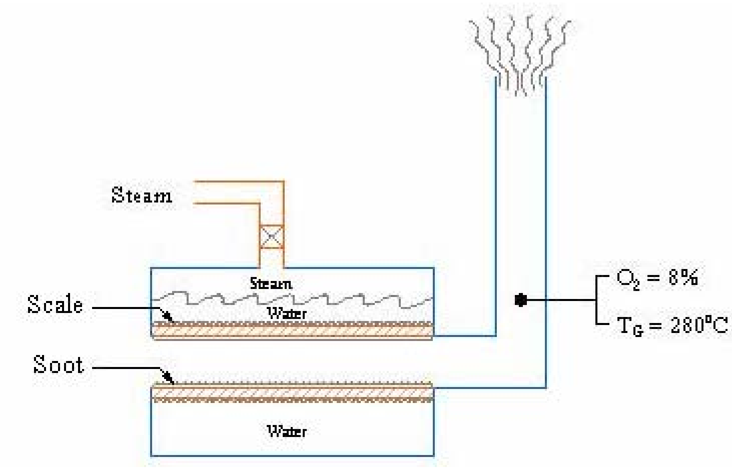
| Oxygen in exhaust air | exhaust air temperature from stack ($^oC$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (%) | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
| 0.5 | 5.75 | 6.54 | 7.35 | 8.16 | 8.98 | 9.80 | 10.62 | 11.45 | 12.28 | 13.11 | 13.95 | 14.79 |
| 1.0 | 5.88 | 6.69 | 7.52 | 8.35 | 9.18 | 10.02 | 10.86 | 11.71 | 12.56 | 13.41 | 14.26 | 15.12 |
| 1.5 | 6.02 | 6.85 | 7.69 | 8.54 | 9.40 | 10.26 | 11.12 | 11.98 | 12.85 | 13.72 | 14.6 | 15.48 |
| 2.0 | 6.16 | 7.01 | 7.88 | 8.75 | 9.62 | 10.50 | 11.38 | 12.27 | 13.16 | 14.05 | 14.95 | 15.85 |
| 2.5 | 6.32 | 7.19 | 8.08 | 8.97 | 9.86 | 10.76 | 11.67 | 12.57 | 13.48 | 14.4 | 15.32 | 16.24 |
| 3.0 | 6.48 | 7.37 | 8.28 | 9.20 | 10.11 | 11.04 | 11.96 | 12.89 | 13.83 | 14.77 | 15.71 | 16.65 |
| 3.5 | 6.65 | 7.56 | 8.50 | 9.44 | 10.38 | 11.33 | 12.28 | 13.23 | 14.19 | 15.16 | 16.12 | 17.09 |
| 4.0 | 6.83 | 7.77 | 8.73 | 9.69 | 10.66 | 11.64 | 12.61 | 13.59 | 14.58 | 15.57 | 16.56 | 17.56 |
| 4.5 | 7.02 | 7.99 | 8.97 | 9.97 | 10.96 | 11.96 | 12.97 | 13.97 | 14.99 | 16.00 | 17.02 | 18.05 |
| 5.0 | 7.22 | 8.22 | 9.23 | 10.25 | 11.28 | 12.31 | 13.34 | 14.38 | 15.42 | 16.47 | 17.52 | 18.57 |
| 5.5 | 7.44 | 8.46 | 9.51 | 10.56 | 11.62 | 12.68 | 13.74 | 14.81 | 15.88 | 16.96 | 18.04 | 19.13 |
| 6.0 | 7.67 | 8.73 | 9.81 | 10.89 | 11.98 | 13.07 | 14.17 | 15.27 | 16.37 | 17.49 | 18.60 | 19.72 |
| 6.5 | 7.92 | 9.01 | 10.12 | 11.24 | 12.36 | 13.49 | 14.62 | 15.76 | 16.90 | 18.05 | 19.20 | 20.36 |
| 7.0 | 8.18 | 9.31 | 10.46 | 11.61 | 12.77 | 13.94 | 15.11 | 16.29 | 17.47 | 18.65 | 19.84 | 21.03 |
| 7.5 | 8.46 | 9.63 | 10.82 | 12.02 | 13.22 | 14.42 | 15.63 | 16.85 | 18.07 | 19.30 | 20.53 | 21.76 |
| 8.0 | 8.77 | 9.98 | 11.21 | 12.45 | 13.70 | 14.95 | 16.20 | 17.46 | 18.72 | 19.99 | 21.27 | 22.55 |
| 8.5 | 9.10 | 10.35 | 11.63 | 12.92 | 14.21 | 15.51 | 16.81 | 18.12 | 19.43 | 20.75 | 22.07 | 23.40 |
| 9.0 | 9.46 | 10.76 | 12.09 | 13.43 | 14.77 | 16.12 | 17.47 | 18.83 | 20.19 | 21.56 | 22.94 | 24.32 |
| 9.5 | 9.85 | 11.20 | 12.59 | 13.98 | 15.38 | 16.78 | 18.19 | 19.60 | 21.02 | 22.45 | 23.88 | 25.32 |
| 10.0 | 10.27 | 11.69 | 13.13 | 14.58 | 16.04 | 17.50 | 18.97 | 20.45 | 21.93 | 23.42 | 24.91 | 26.41 |
| 10.5 | 10.73 | 12.22 | 13.73 | 15.24 | 16.76 | 18.29 | 19.83 | 21.37 | 22.92 | 24.48 | 26.04 | 27.60 |
| 11.0 | 11.25 | 12.80 | 14.38 | 15.97 | 17.56 | 19.17 | 20.77 | 22.39 | 24.01 | 25.64 | 27.28 | 28.92 |
| 11.5 | 11.81 | 13.44 | 15.10 | 16.77 | 18.44 | 20.13 | 21.82 | 23.51 | 25.22 | 26.93 | 28.65 | 30.37 |
| 12.0 | 12.44 | 14.15 | 15.90 | 17.66 | 19.42 | 21.20 | 22.98 | 24.76 | 26.56 | 28.36 | 30.17 | 31.98 |

Comment : Analyze by Rosin equation at ambient temperature ($35^OC$)
and heating value 8,763.96 kcal/$Nm^3$ (36,694.70 kJ/$Nm^3$)

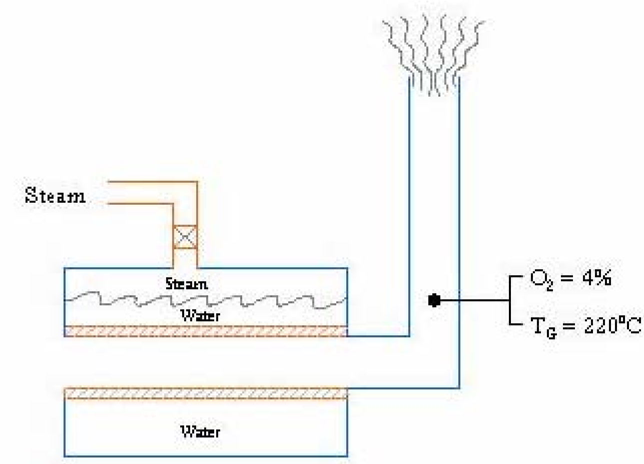
o **Example of boiler calculation**

ECON factory installed a fire tube steam boiler capacity 10 ton/hr, using bunker oil grade C 3,000,000 litres per year. As the factory checked exhaust gas from stack, it found 8% of excess oxygen, $280^oC$ of exhaust gas temperature and $35^oC$ of ambient temperature. After the factory reduced oxygen quantity to combustion chamber and clean heat exchange surface. This results in reduced flue gas temperature to $220^OC$ and excess oxygen reduced to 4%. How much heat loss from stack the factory can reduce?

From Table 1.2-2 or Figure 1.2-5, bunker oil grade C at 8% of excess oxygen, 280°C of exhaust gas temperature found that flue heat loss is 14.5%.




From Table 1.2-2 or Figure 1.2-5, bunker oil grade C at 4% of excess oxygen, 220°C of exhaust air temperature found that flue heat loss is 8.38%.




Percentage of heat loss reduction = 14.5 – 8.38

= 6.12%

Fuel reduction = (percentage of heat loss reduction/100) x annual fuel consumption

= (6.12/100) x 3,000,000

= 183,600 liters/year

### (3) Measures to Reduce Blowdown Loss

The exhaustion of water from a boiler or " blowdown" considered to be a heat loss of energy lesser than the exhaustion of flue gas. In general, the water discharged from the boiler should not be more than 5% of feed water.

- Why the boiler has to blow down

Essentially, the feed water contains certain amounts of water treatment chemicals. As the water boils into steam, the remaining water becomes more concentrated, in the forms of both solution and suspended solid. In order to maintain a proper condition of a boiler, the concentrated solutions inside the boiler water must be limited by regularly conducting a blowdown. Failure to perform, the residue will cause a damage to the boiler.

- How to blow down?

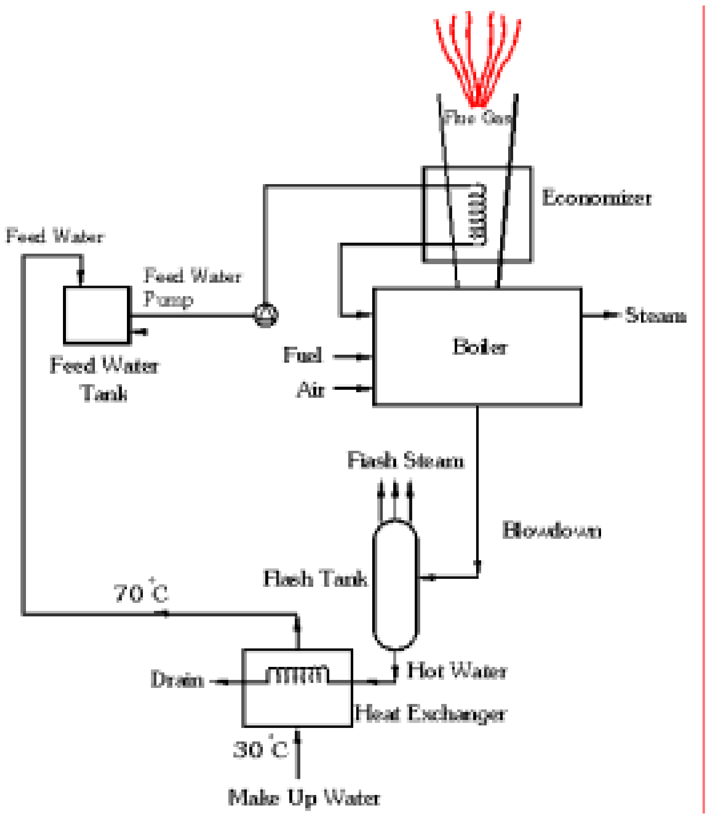



Figure 1.3-1 Boiler water discharge system (Blowdown)

There are two ways of conducting a blowdown.

1. Bottom blowdown

   A water discharge pipe is connected to the bottom of the boiler as to flush out all sediments. For a temporary blowdown, a worker has to turn on the discharge valve many times for a short period each time. The amount of water discharged can be seen through the sight glass.

2. Surface blowdown or continuous blowdown

   Basically, a surface blowdown is conducted continuously. A control valve of water discharge pipe is functioning corresponding to a program either on the timer or on the electrical conductivity basis.

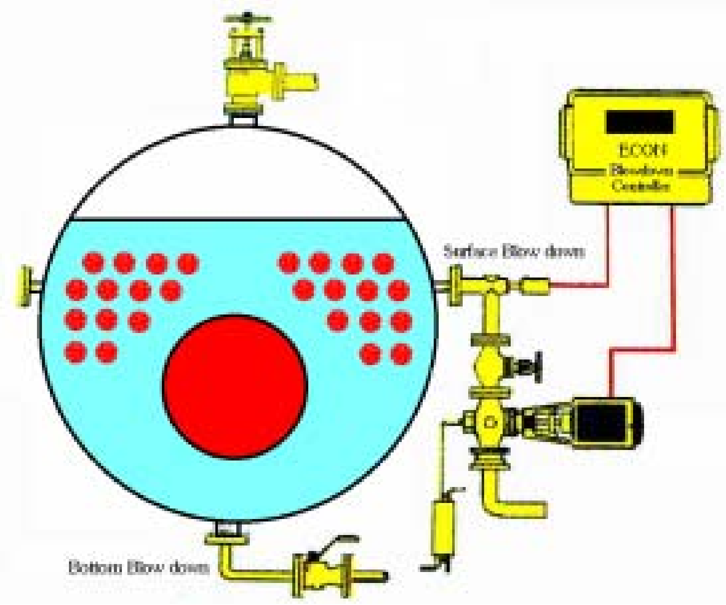



Figure 1.3-2 Blow down system

Small boilers usually utilized only the bottom blowdown, whereas large boilers may have both bottom and surface blowdown. Generally, the bottom blowdown largely discharges substances around the bottom of boiler.  While the surface blowdown is aimed to control the concentration of the substances .

o How to ensure the appropriateness of conducting the blowdown?

Too little water discharged will cause a steam generation problem, while too much water discharged will cause a loss of heat from the boiler. To indicate an appropriate amount of a blowdown, total dissolved solid or conductivity tests of boiler water samples can be conducted.

o What are the control standards of the boiler water?

Control standards of a boiler’ s discharge and feed water are as follows:

| Item | Feed water | Boiler water |
|---|---|---|
| Conductivity: µS /cm | <400 | 7,000 |
| pH | 8.5-9.5 | 10.5-12.0 |
| Phosphate: mg/kg | - | 30-60 |
| Silica : mg/kg | - | <150 |
| Hardness :PPM | <2 | - |

o How to control the blowdown ratio?

An operator should take a sample of boiler water for a conductivity test. If the test result showed a lower concentration than the standard, the operator would reduce the volume or frequency of water discharged from the boiler, or vice versa.

Since the change in steam usage also effects the change in solution concentration, the conductivity test should be done as often as every shift.

o How to reduce the blowdown loss?

One of critical factors affecting blowdown volume, which is ultimately effecting heat loss, is the quality of feed water. The more impurity of the feed water, the larger volume of water must be discharged. A proper control of feed water’ s quality is absolutely essential. In addition, an appropriate volume of water discharged from the boiler is also important.

o How to utilize the heat from the blowdown water?

The discharged water is still hot and has a lot of energy. In the boiler, the temperature of the water is usually higher than 100 $^{o}$C. When the water is discharged into the atmosphere at normal pressure, some part of it could boil into steam as “ flash steam.” Flash steam is so clean that its condensate can be reused as part of the feed water. On the other hand, the remaining discharge water, which is not so clean, will be utilized as a medium in a heat exchanger for the feed water or the production process. Figure 1.3-3 depicts the recovery process of the discharge water.

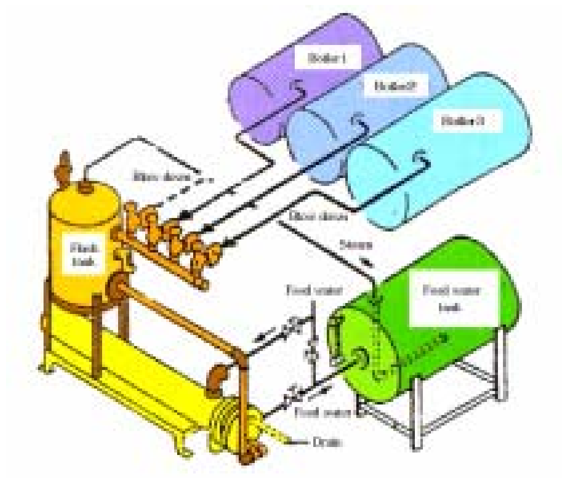


Figure 1.3-3 The recovery of discharge water

o **Procedure to calculate water loss and heat loss**

The assessments of heat loss value from a blowdown can be determined as graphs and tables below:

Figure 1.3-4 Percentage Discharge water from a blowdown

(µs/cm)

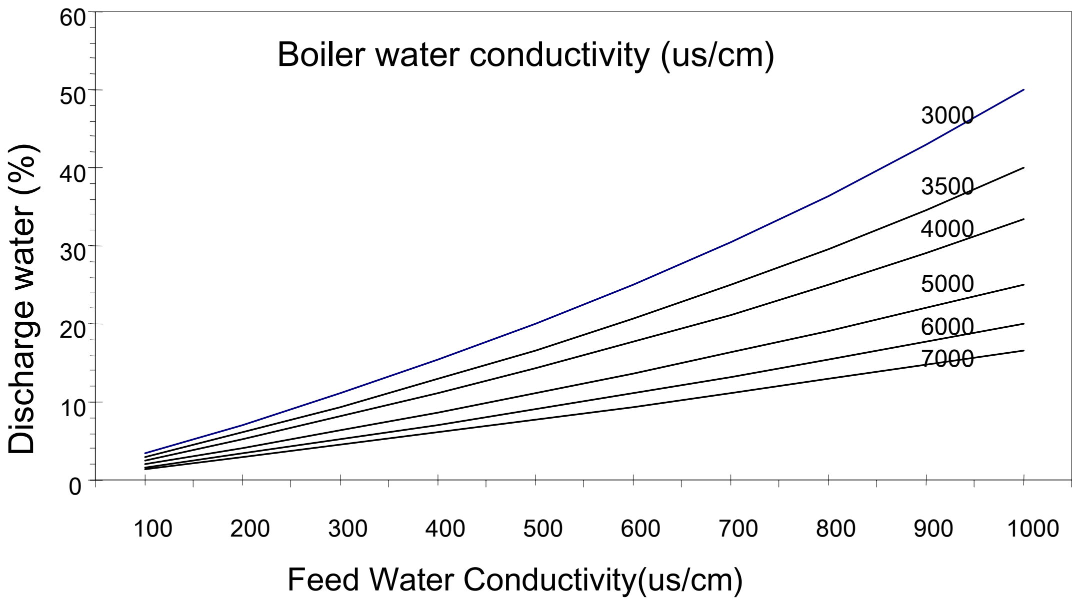


Figure 1.3-5 Percentage heat loss from a blowdown at feed water 30 °C (μs/cm)

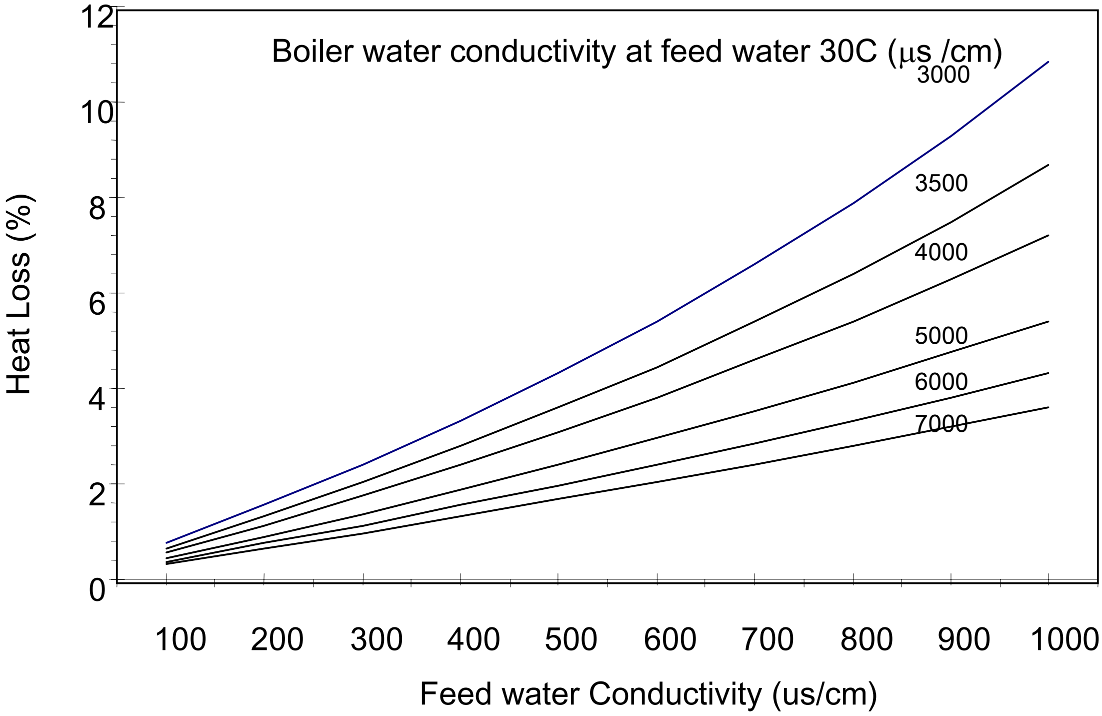



Figure 1.3-5 Percentage heat loss from a blowdown at feed water 70 °C

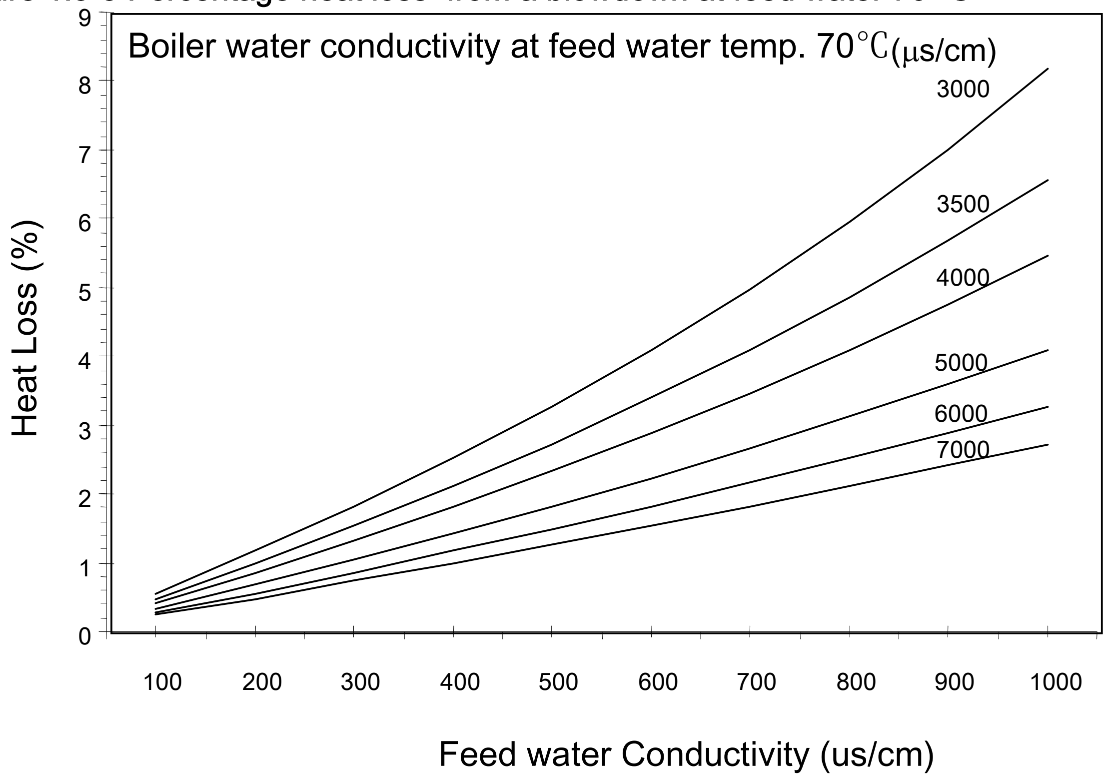


Table 1.3-1. Percentage of water and heat loss from a blowdown

| Feed water conductivity (µs /cm) | Feed water temperature at 30 °C | | | | | | Feed water temperature at 70 °C | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler water conductivity (µs/cm) | | | | | | Boiler water conductivity (µs /cm) | | | | | |
| | 3,000 | 3,500 | 4,000 | 5,000 | 6,000 | 7,000 | 3,000 | 3,500 | 4,000 | 5,000 | 6,000 | 7,000 |
| 100 | 3.45% | 2.94% | 2.56% | 2.04% | 1.69% | 1.45% | 3.45% | 2.94% | 2.56% | 2.04% | 1.69% | 1.45% |
| | 0.75% | 0.64% | 0.56% | 0.44% | 0.37% | 0.31% | 0.56% | 0.48% | 0.42% | 0.33% | 0.28% | 0.24% |
| 200 | 7.14% | 6.06% | 5.26% | 4.17% | 3.45% | 2.94% | 7.14% | 6.06% | 5.26% | 4.17% | 3.45% | 2.94% |
| | 1.55% | 1.31% | 1.14% | 0.90% | 0.75% | 0.64% | 1.17% | 0.99% | 0.86% | 0.68% | 0.56% | 0.48% |
| 300 | 11.11 % | 9.38% | 8.11% | 6.38% | 5.26% | 4.48% | 11.11 % | 9.38% | 8.11% | 6.38% | 5.26% | 4.48% |
| | 2.41% | 2.03% | 1.76% | 1.38% | 1.14% | 0.97% | 1.82% | 1.53% | 1.33% | 1.04% | 0.86% | 0.73% |
| 400 | 15.38 % | 12.90 % | 11.11 % | 8.70% | 7.14% | 6.06% | 15.38 % | 12.90 % | 11.11 % | 8.70% | 7.14% | 6.06% |
| | 3.33% | 2.80% | 2.41% | 1.88% | 1.55% | 1.31% | 2.52% | 2.11% | 1.82% | 1.42% | 1.17% | 0.99% |
| 500 | 20.00 % | 16.67 % | 14.29 % | 11.11 % | 9.09% | 7.69% | 20.00 % | 16.67 % | 14.29 % | 11.11 % | 9.09% | 7.69% |
| | 4.33% | 3.61% | 3.10% | 2.41% | 1.97% | 1.67% | 3.27% | 2.73% | 1.34% | 1.82% | 1.49% | 1.26% |
| 600 | 25.00 % | 20.69 % | 17.65 % | 13.64 % | 11.11 % | 9.38% | 25.00 % | 20.69 % | 17.65 % | 13.64 % | 11.11 % | 9.38% |
| | 5.42% | 4.48% | 3.82% | 2.95% | 2.41% | 2.03% | 4.09% | 3.39% | 2.89% | 2.23% | 1.82% | 1.53% |
| Feed water conductivity (µs /cm) | Feed water temperature at 30 °C | | | | | | Feed water temperature at 70 °C | | | | | |
| | Boiler water conductivity (µs /cm) | | | | | | Boiler water conductivity (µs /cm) | | | | | |
| | 3,000 | 3,500 | 4,000 | 5,000 | 6,000 | 7,000 | 3,000 | 3,500 | 4,000 | 5,000 | 6,000 | 7,000 |
| 700 | 30.43 % | 25.00 % | 21.21 % | 16.28 % | 13.21 % | 11.11 % | 30.43 % | 25.00 % | 21.21 % | 16.28 % | 13.21 % | 11.11 % |
| | 6.59% | 5.42% | 4.60% | 3.53% | 2.86% | 2.41% | 4.98% | 4.09% | 3.47% | 2.66% | 2.16% | 1.82% |
| 800 | 36.36 % | 29.63 % | 25.00 % | 19.05 % | 15.38 % | 12.90 % | 36.36 % | 29.63 % | 25.00 % | 19.05 % | 15.38 % | 12.90 % |
| | 7.88% | 6.42% | 5.42% | 4.13% | 3.33% | 2.80% | 5.95% | 4.85% | 4.09% | 3.12% | 2.52% | 2.11% |
| 900 | 42.86 % | 34.62 % | 29.03 % | 21.95 % | 17.65 % | 14.75 % | 42.86 % | 34.62 % | 29.03 % | 21.95 % | 17.65 % | 14.75 % |
| | 9.29% | 7.50% | 6.29% | 4.76% | 3.82% | 3.20% | 7.01% | 5.67% | 4.75% | 3.59% | 2.89% | 2.41% |
| 1000 | 50.00 % | 40.00 % | 33.33 % | 25.00 % | 20.00 % | 16.67 % | 50.00 % | 40.00 % | 33.33 % | 25.00 % | 20.00 % | 16.67 % |
| | 10.83 % | 8.67% | 7.22% | 5.42% | 4.33% | 3.61% | 8.18% | 6.55% | 5.46% | 4.09% | 3.27% | 2.73% |

Remarks: 1. The data showed in the table is base on a steam boiler generating 7 bar steam.

2. Top line is the percentage of volume of discharge water to boiler water, and the bottom line is the percentage of heat loss resulting from water discharged.

- Example of blowdown calculation

ECON factory runs a boiler with a capacity of 10 tons steam per hour. It uses bunker oil type C as the major fuel with a total consumption of 3 million liters annually. It produces steam at 7 $Bar_g$ with the usage of water and fuel as ratio of 14:1. The temperature of feed water is constantly at 30 $^oC$. As for the blowdown, hourly at 30 second each. The conductivity test shows that the feed water is at 200 μS/cm, and 4,000 μS/cm from water inside the boiler. Which of these results are unacceptable: therefore, the boiler will reduce the frequently of blowdown to every six hours. Thus, the result of conductivity tested again received at 6,500 μS/cm. How much the ECON will save from the latter procedure?

Usage of water annually = annual amount of fuel usage x ratio of usage of water and fuel

= 3,000,000 x 14

= 42,000,000 liter/year

For the feed water temperature of 30 C and conductivity of 200 μS /cm, and the boiler water conductivity of 4,000 μS /cm, according to Table 1.3-1, the boiler will basically discharge water at a ratio of 5.26% of its steam generation, representing heat loss ratio of 1.14%.

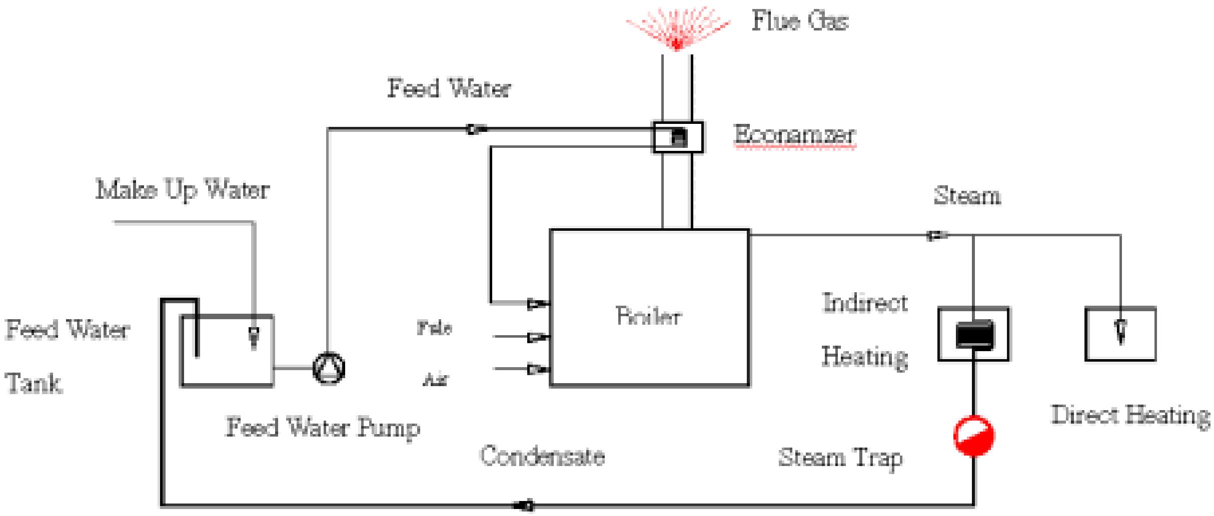
If the frequency of water discharge is reduced until the conductivity of the boiler water reaches 6,500 μS /cm, the boiler will then discharge water at a ratio of 3.20% of its steam generation, representing heat loss ratio of 0.7 %.

Percentage Blowdown saving = 5.26 – 3.20
= 2.06
Annual fuel saving (Blowdown) = (2.06/100) * 42,000,000
= 865,200 liter / year
Percentage Heat loss saving = 1.14 – 0.70
= 0.44
Annual fuel saving (Heat loss) = (0.44/100) * 3,000,000
= 13,200 liter / year

(4) Measures to Recover Condensate Water

O What is the condensate and How does it happen?

Steam is generated from boiler and transmits into piping system to steam utilizing equipment. When steam is fed into a steam servicing equipment, the quantity of energy in steam in form of sensible heat has been used. As a result, steam will transforms or condense into high temperature water. That is called " condensate" next from now on. This condensate needs to take out effectively from steam piping system to prevent or reduce any losses that will occur




O What is steam trap and its application?

Steam trap is automatic valve, which use to take water of condensation steam include any gaseous and air remove out from system. At the present time, many steam traps have been manufactured. There are classified into various types either by operating principles or by inside mechanism principles as shown in Table 1.4-2

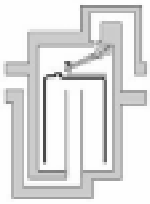
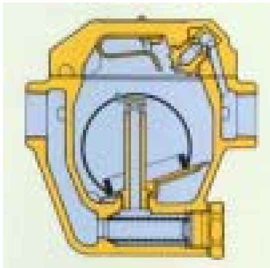
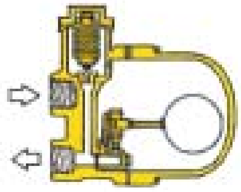
O How to select steam trap?

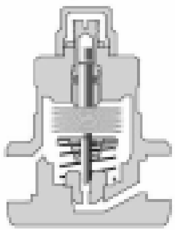
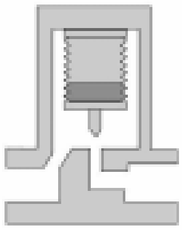
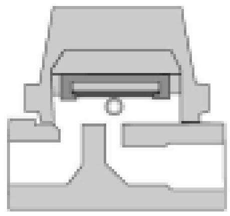
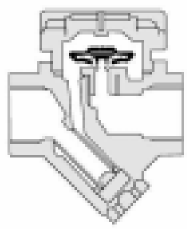
When realizes in each various types of steam trap characteristic and operating principles. subsequently have to consider how to select properly steam trap which has functional suitable for our purpose. That will encourage to maintain steam utilization at a maximum efficiency. Choosing steam trap base on operating condition characteristic as shown in table 1.4-1

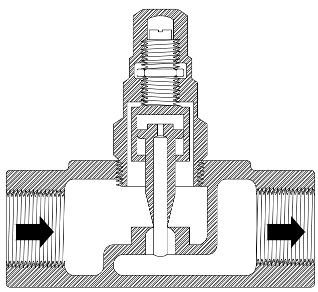
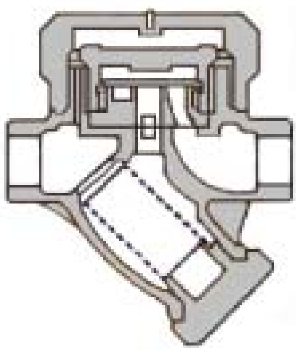
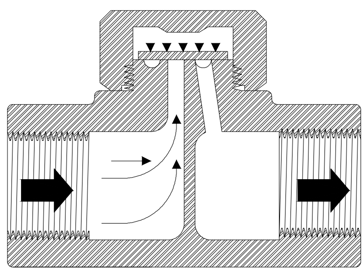
Table 1.4-1 Comparison of various types steam trap properties

| Working condition | Type of steam trap | | | | |
|---|---|---|---|---|---|
| | thermodynamic | float | bucket | Balance pressure | bimetal |
| Pressure range (Psi) | 10-600 | 0-300 | 10-2,700 | 0-600 | 0-3,000 |
| Maximum capacity (lb/hr) | 5,200 | 100,000 | 2,000 | 13,500 | 7,800 |
| Discharge condensate temperature | Below saturation point | saturation | saturation | Below saturation point | According to adjusting |
| Condensate releasing | Open/close | continuous | Open/close | Semi continuous | Semi continuous |
| Gaseous releasing | good | Very good | Fairly good | Very good | Very good |
| Dust removal | Fairly good | good | good | Fairly good | good |
| Superheat suitability | Very good | unsatisfied | Fairly good | Fairly good | Very good |
| Water hammer durability | Very good | Fairly good | Very good | Fairly good | Very good |
| Load variability | good | Very good | good | good | Fairly good |
| Pressure variability | good | Very good | Fairly good | Fairly good | Fairly good |
| Inconvenient blocked up condition | open | close | open | uncertainly | open |

Table 1.4-2 Classification and characteristic of steam trap

<table>
<tr><td colspan="4">Mechanical steam trap</td></tr>
<tr><td>Inverted bucket type</td><td>Free ball bucket type</td><td>Float with lever type</td><td>Free float type</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">principle : working by using differential of density between steam (gas phase) and hot condensate water(liquid phase) to be mechanism of open-close steam trap. The on-off element inside steam trap will float up in condensate and sink in steam</td></tr>
</table>

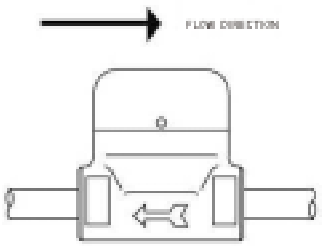
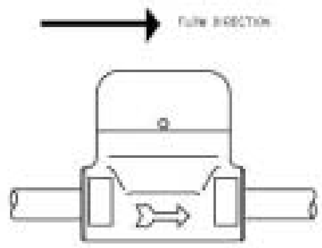
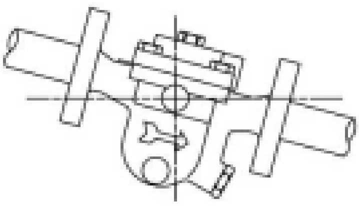
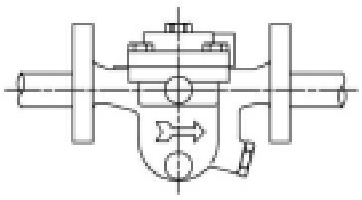
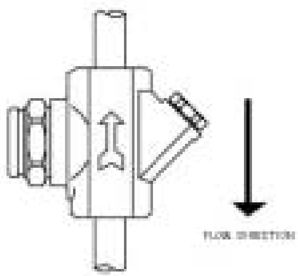
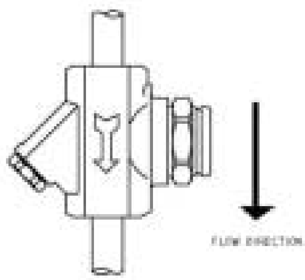
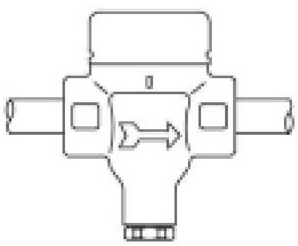
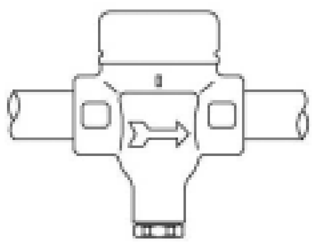
<table>
<tr><td colspan="4">Thermostat check steam trap</td></tr>
<tr><td>Bimetal type</td><td>Bellow type</td><td>Capsule type</td><td>X – Element type</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">principle : Working by using differential of temperature between steam and hot water to be mechanism of open-close steam trap. During condensation, condensate will have temperature equally same as steam. After that, condensate temperature will decrease below steam temperature due to they have losses in pipe</td></tr>
</table>

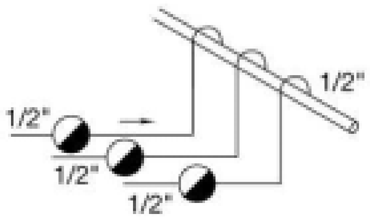
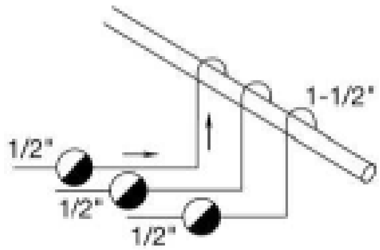
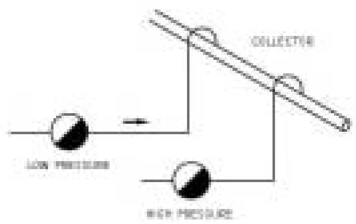
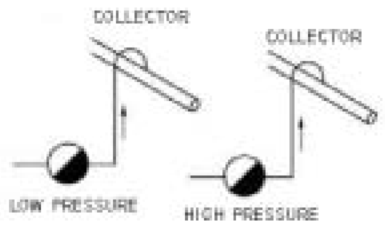
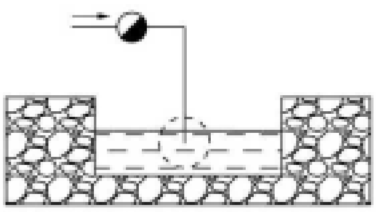
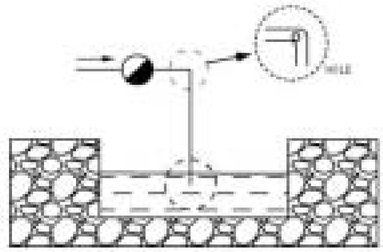
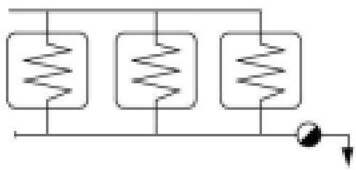
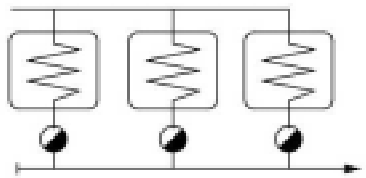
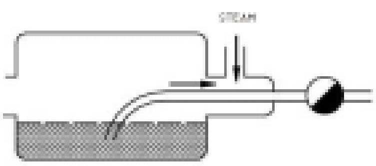
<table>
<tr><td colspan="3">Thermodynamic steam trap</td></tr>
<tr><td>Impulse type</td><td>Disc type Air vent</td><td>Disc type not Air vent</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">principle : working by using differential of property in dynamic flow between steam and condensate. Consequently , at same differentiate in pressure steam will flow through piping with higher velocity than condensate.</td></tr>
</table>

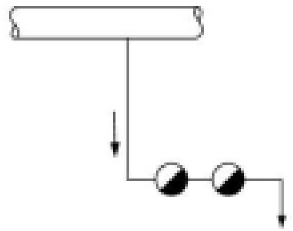
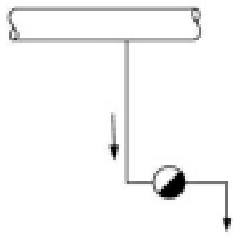
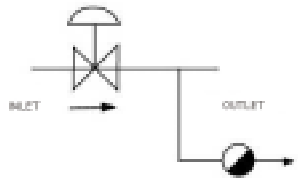
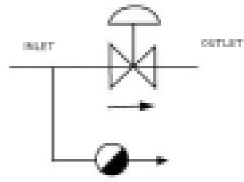
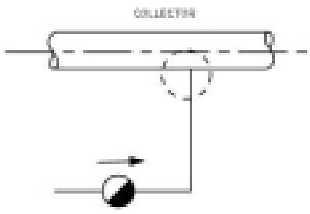
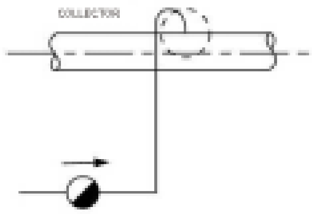
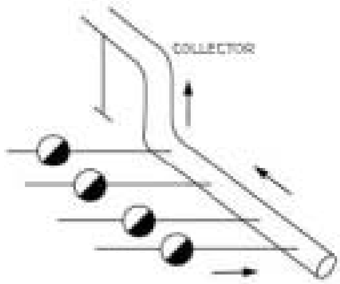
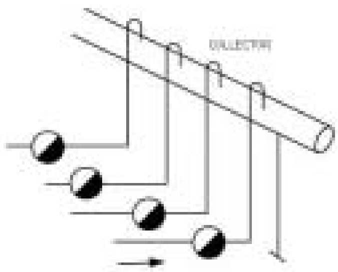
O How to install steam trap properly?

Having maximum efficiency in utilization not concerns only steam trap have chosen consistently with utilizing condition, but it should have to install in properly and correctly position. Consequently , condensate in equipment or piping system could be flow through steam trap as well to obtainable their real purpose.

Table 1.4-3 suggestion of installing steam trap

| Wrong installation | Description | Correct installation |
|---|---|---|
|  | Steam trap should be filled in the direction of flow .All steam trap bear on the body steam or make showing flow direction. |  |
|  | Free float type steam trap should be fitted horizontally. |  |
|  | Thermodynamic steam trap have no limitation as to position. It can be filled vertical. |  |
|  | Never use an inlet pipe smaller than trap size. Steam locking and air binding are apt to occur when inlet pipe is too small. |  |

| Wrong installation | Description | Correct installation |
|---|---|---|
|   | Size of collector must be larger than trap size. The collector should have a sectional area above sum of those for all traps connected to it. |   |
|  | Condensate discharged through two traps which operate at different pressure should not be collected to a common collector. |   |
|  | Outlet pipe should not be submerged into trenches. Provide small hole to break vacuum. |  |
|  | Each steam unit should always have individual steam trap. To fit one trap to several steam equipment is a bad practice. |  |
|  | In siphon type cylinder, steam locking is liable to occur. | |

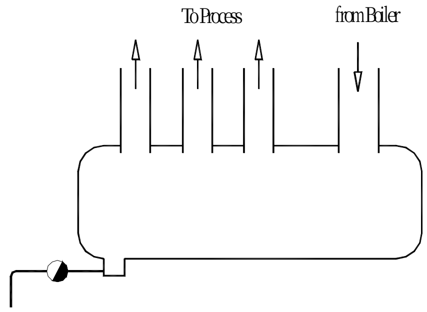
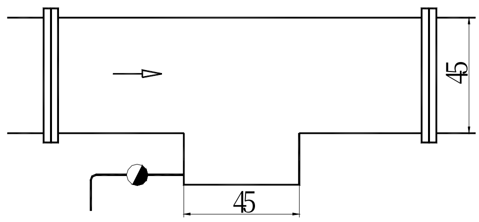
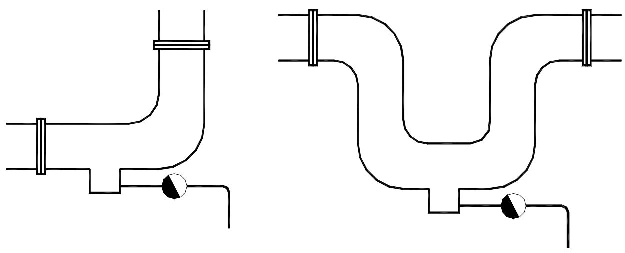
| Wrong installation | Description | Correct installation |
|---|---|---|
|  | Double trapping is a bad practice. As efficient one trap is enough. |  |
|  | Steam trap must be fitted at the inlet side to discharge condensate before the regulating valve. |  |
|  | To collect condensate, the trap outlet pipe must not be connected to the bottom of collector. |  |
|  | Collector should not have a riser. The head of condensate in the collector exerts on the traps as back pressure. |  |

O Steam trap installation in piping system

Subsequently, selection of steam trap and how to installation in properly has been mentioned. It would be good to know which position steam usually condense in piping system. It could be helps for examine to increase efficiency of steam utilization. Appropriately steam trap installing position are as following.

1) At Header after exiting boiler.
2) At inlet of reducing valve and automatic valve.
3) At inlet of extension valve.
4) At elbow pipe.
5) At lower of vertical piping.
6) Inlet of steam utilization.

Table 1.4-4 Properly position of steam trap installation to trap condensate

| Position | Installation characteristic |
|---|---|
| Header |  |
| Main pipe |  |
| Elbow pipe |  |

O How to install steam trap with piping for easy inspection and maintenance

For easily inspection , maintenance and be able to get maximum operating efficiency , it has principles to install steam trap with piping as following :

| At inlet piping |
|---|
| - Install at lowest positioning area of steam utilizing equipment but should not have condensate accumulate occurred.<br>- Inlet piping should be as short as possible and inclined.<br>- Do not install insulation at inlet piping area.<br>- Avoid using vertical piping to be inlet pipe. If it could not, need to have additional lift filling be install. |

| At discharge piping |
|---|
| - Preventing for backward pressure, discharge piping should have big size shortage, less bend and less in life-up<br>- In case piping was inclined up, it need to modify with check valve by installed after steam trap.<br>- Should not install discharge pipe in series with water tank in position that steam trap was lower level than of water. |
| Bypass piping |
| - Should have to install bypass piping of draining water and vent air during period of start up steam utilization. Also easily for maintenance or replace steam trap. |

O How to inspect Steam trap

When steam trap has been used for a period of time, it should be inspect occasionally to maintain a maximum efficiency. As in case an inside-element of steam trap was damaged, it may cause to exceed steam losses in piping or troublesome effect with utilizing equipment. Steam trap inspection could be done in various methods, each method have differently accurate in results. Inspection can be done as following:

1) By spilling water on steam trap.
2) By using temperature measuring equipment to examine.
3) By checking frequent timing of condensate released.
4) By using ultrasonic measuring equipment.
5) By using steam trap testing equipment.

O How condensate recovery beneficial?

As every one have been known that high temperature water or condensate water has energy inside. Whether higher temperature and pressure, internal energy in condensate will accordingly higher extreme. Anyhow we can be find how much energy of condensate according to temperature and pressure from steam table. At this stage, we show some examples in table below.

Table 1.4-5 Energy of condensate steam at various temperature/pressure levels.

| Pressure (barg) | enthalpy ; $h_f$ (kJ/kg) | enthalpy ; $h_{fg}$ (kJ/kg) | Pressure (barg) | enthalpy ; $h_f$ (kJ/kg) | enthalpy ; $h_{fg}$ (kJ/kg) |
|---|---|---|---|---|---|
| 0.25 | 444.32 | 2241.0 | 5.50 | 684.28 | 2076.0 |
| 0.50 | 467.11 | 2226.5 | 6.00 | 697.22 | 2066.3 |
| 0.75 | 486.99 | 2213.6 | 6.50 | 709.47 | 2057.0 |
| 1.00 | 504.70 | 2201.9 | 7.00 | 721.11 | 2048.0 |
| 1.25 | 520.72 | 2191.3 | 7.50 | 732.22 | 2039.4 |
| 1.50 | 535.37 | 2181.5 | 8.00 | 742.83 | 2031.1 |
| 1.75 | 548.89 | 2172.4 | 8.50 | 753.02 | 2023.1 |
| 2.00 | 561.47 | 2163.8 | 9.00 | 762.81 | 2015.3 |
| 2.25 | 573.25 | 2155.88 | 10.00 | 781.34 | 2000.4 |
| 2.50 | 584.33 | 2148.1 | 11.00 | 798.65 | 1986.2 |
| 2.75 | 594.81 | 2140.8 | 12.00 | 814.93 | 1972.7 |
| 3.00 | 604.74 | 2133.8 | 13.00 | 830.30 | 1959.7 |
| 3.50 | 623.25 | 2120.7 | 14.00 | 844.89 | 1947.3 |
| 4.00 | 640.23 | 2108.5 | 16.50 | 878.50 | 1917.9 |
| 4.50 | 655.93 | 2097.0 | 19.00 | 908.79 | 1890.7 |
| 5.00 | 670.56 | 2086.3 | 20.50 | 936.49 | 1865.2 |

Due to high temperature condensate having energy inside as we had seen in table above, If we could be recovery that condensate to use or able feed into boiler as feed water, it will have beneficially as:

1. Save fuel that use for producing steam. Calculation for saving potential will show in next other session.
2. Save water, according to ground water had been abolished to use in many area of Thailand, Therefore water will be ones of important producing cost. Then many factories is pay attention to reduce in water consumption. Considering in recovery condensate use to mixed as boiler feed water, will deduct in water consuming, decrease waste water treatment load, and reduce in water-treated chemicals. Furthermore, it will save electricity consume for water pumping, etc too.

3. Increase in boiler capacity. Means-if we wants to heat 30 degree of water to be steam, it needs time for boiling. How long does it is depend on amount of water to be boiler, area of heat exchange surface and how much heat is input. At the same time, if we used 80 degree water to boil instead of 30 degree with same conditions, it will boil to be steam fast than as it was. Then it likely to have increasing boiler capacity.

O Benefits of condensate recovery

Condensate is clean water that suitable for boiler feed water as it has appropriately heat content and chemical properties. As well as higher in temperature of feed water, boiler will receive big amount of heat too. More condensate recovery then amount of recovery heat is higher. However, it was some remarkably that in case recovery condensate was not available to use:

1. Far away in distance between boiler and condensation area. It will cause big losses during send back recovery condensate, even if insulation have been installed. Some factory might not have economically situation to recovery condensate. But some mill is available whether condensate was cool down. Accordingly condensate is clean water, suitably to use as boiler feed water, and also highly in soft-water treatment cost. If not difficult to get water and not a big cost for soft treatment, condensate will be utilize in other area as use for processing as a hot water.
2. Condensate that might be contaminate also can be recovery by using heat exchanger to recovery heat. However, it should think about economically possibility, by compare with benefits from an amount of heat recover and investment in heat exchanger equipment.

Caution

To send back condensate, it should think about pipe sizing and necessity to have electrical power pumping it or can be by their natural pressure force.

Three important issues need to be careful when think about send back recover condensate in pipe.

1. Released air on start up period of steam utilizing process that had been gone in to condensate pipe.

2. At beginning phase, machine is cool therefore it will cause to have 2-3 times of condensate more than normally. It also cause to have a few amount of flash steam or hardly, and reduce in differential pressure of inlet of steam trap. Exiting or terminal pressure is very important because it related with backward pressure in condensate piping system.

During running, machine was heat up then it has impact on steam condensation. Results in reduce an amount of condensate to normally condition. However condensate that have temperature equally to steam temperature, will change to be flash steam when it was trapped out from steam trap.

Table 1.4-6 Selection of condensate recovery piping size depend on amount of condensate per hour

| diameter (m.m.) ; in | Maximum volume (kilogram/hour) |
|---|---|
| (15) ;1/2 | 160 |
| (20) ;3/4 | 370 |
| (25) ;1 | 700 |
| (32) ;1-1/4 | 1,500 |
| (40) ;1-1/2 | 2,300 |
| (50) ;2 | 4,500 |
| (65) ;2-1/2 | 9,000 |
| (80) ;3 | 14,000 |
| (100) ;4 | 29,000 |

Due to high temperature in condensate , cavitation problems might be take place at pump incase overall condensated was recovered. This problems could be solve by using pump that have adequately positive pressure at entrance. Entrnace pressure of pump is very with temperature, or water head pressure of pump at inlet pipe is in equivalent dipending on type of pump being used. It could not get an information of pump from manufacture, it should be betler to selective with positive displacement type. 1.4-1

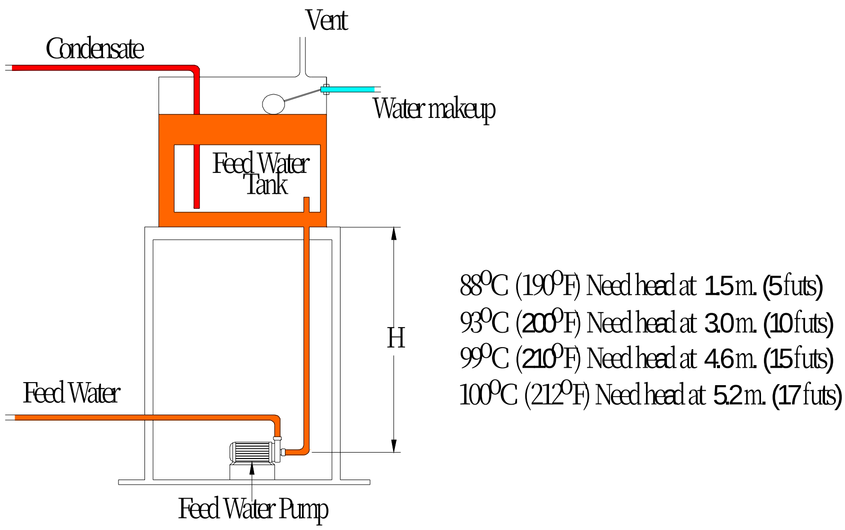
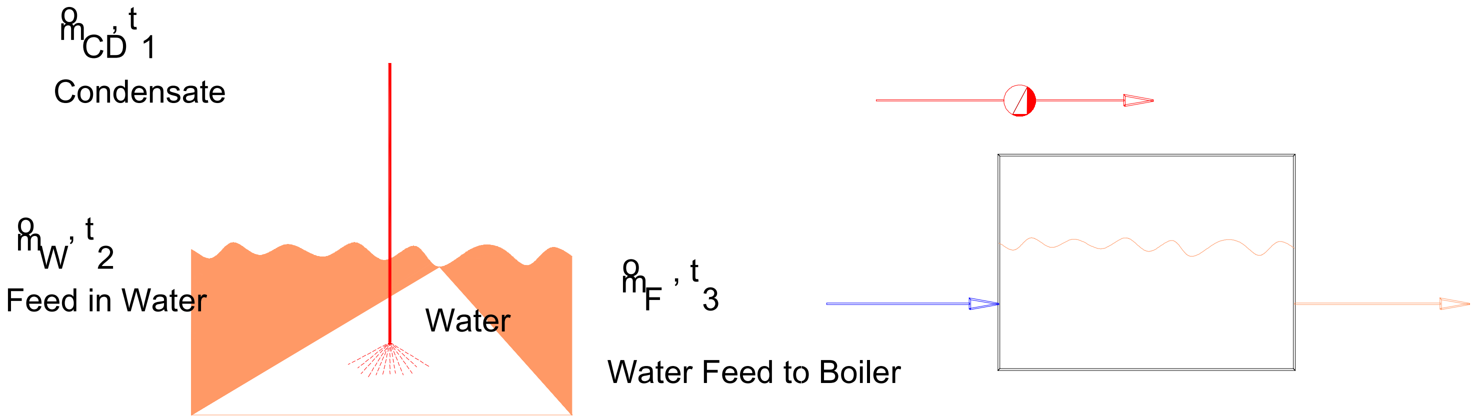



Figure 1.4-1 Caution in pumping recovery condensate at high temperature level

O Fuel saving from recovery of the condensate




Mass balance

$$\dot{m}_F = \dot{m}_{CD} + \dot{m}_W \quad (1.4\text{-}1)$$

Heat balance

$$\dot{m}_F C_p t_3 = \dot{m}_{CD} C_p t_1 + \dot{m}_W C_p t_2 \quad (1.4\text{-}2)$$

Temperature after mixed ($t_3$)

$$\dot{m}_F C_p t_3 = \dot{m}_{CD} C_p t_1 + \dot{m}_W C_p t_2 \quad (1.4\text{-}3)$$

Fuel saving

$$\text{Fuel save} = (\dot{m}_F C_p (t_3 - t_2)) / HI \times \eta_B \quad (1.4\text{-}4)$$

When

$\dot{m}_{CL}$ = flow rate of condensate ; kg/y

$\dot{m}_{W}$ = flow rate of feed in water ; kg/y

$\dot{m}_{F}$ = flow rate of water after mixed (Boiler feed water); kg/y

$t_1$ = condensate temperature ; $^oC$

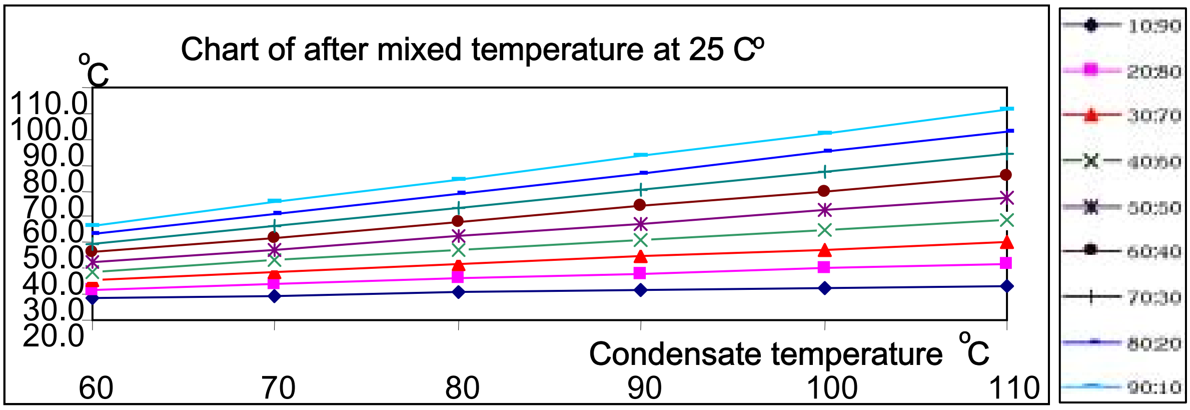
$t_2$ = temperature of feed in water ; $^oC$

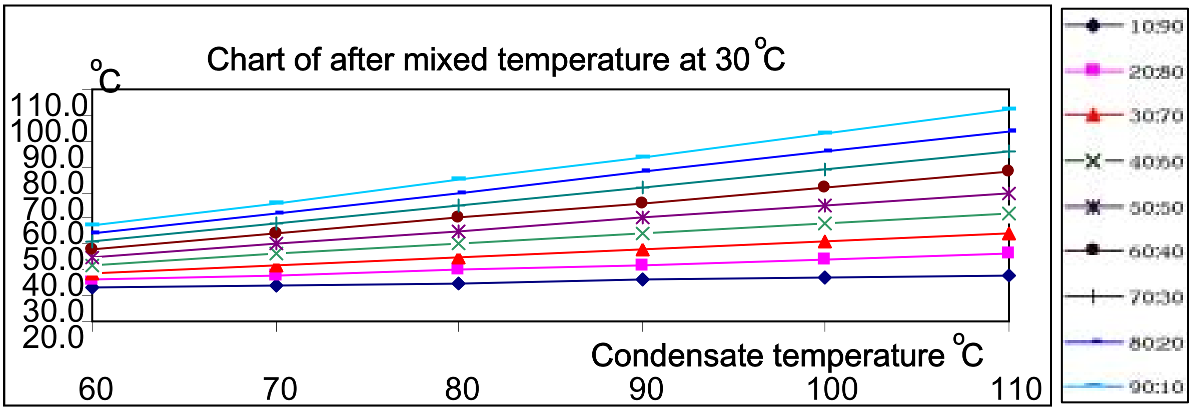
$t_3$ = temperature of mixed water ; $^oC$

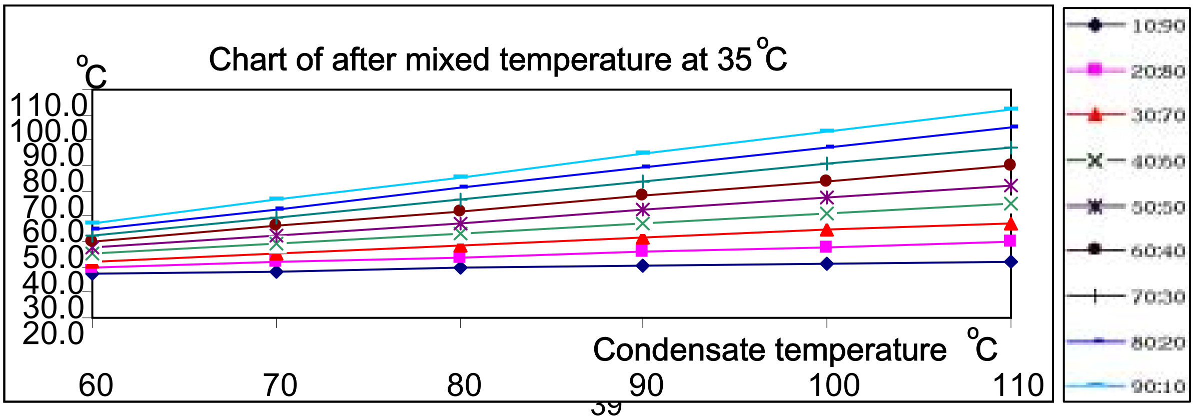
HL = low heating of fuel ; kJ/Unit

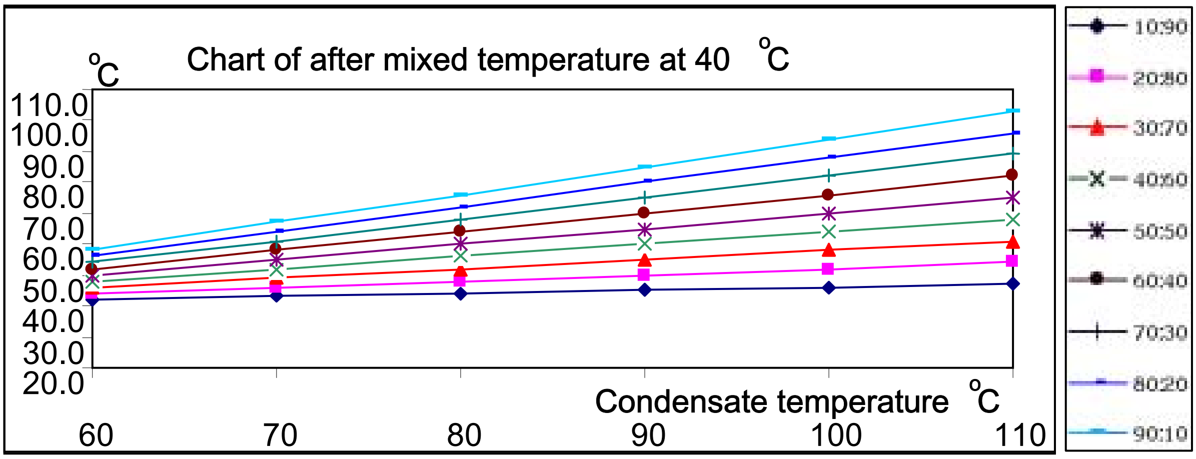
$\eta_B$ = Boiler efficiency ;

Cp = specific heat of water ; 4.187 kJ/kg






**Calculation steps**

1) For easy calculation, use table that has been prepared.
2) Please fill in basic information completely.
3) Analyze data by using basic information data to place in an equation accordance with code that have suggested in data soupe topic calculation.
4) Continuous to calculation until finish.

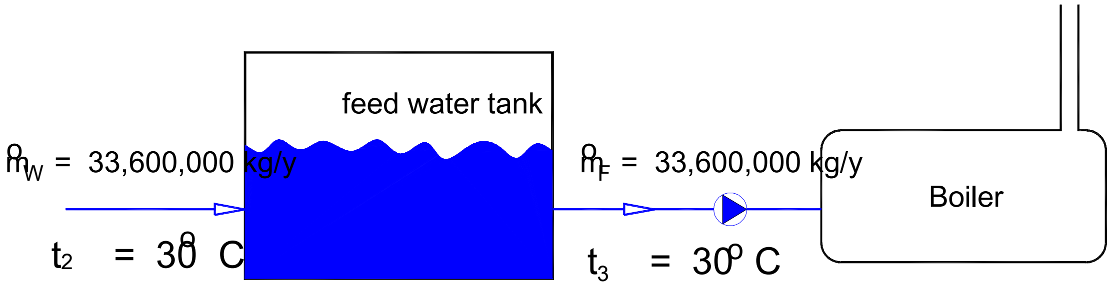
Table 1.4-7 Temperature of water after mixed ($t_3$ ; °C)

| Feed in water temperature (°C) | Condensate temperature (°C) | Ratio of condensate to water (condensate : water) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 10:90 | 20:80 | 30:70 | 40:60 | 50:50 | 60:40 | 70:30 | 80:20 | 90:10 |
| 25 | 60 | 28.5 | 32.0 | 35.5 | 39.0 | 42.5 | 46.0 | 49.5 | 53.0 | 56.5 |
| | 70 | 29.5 | 34.0 | 38.5 | 43.0 | 47.5 | 52.0 | 56.5 | 61.0 | 65.5 |
| | 80 | 30.5 | 36.0 | 41.5 | 47.0 | 52.5 | 58.0 | 63.5 | 69.0 | 74.5 |
| | 90 | 31.5 | 38.0 | 44.5 | 51.0 | 57.5 | 64.0 | 70.5 | 77.0 | 83.5 |
| | 100 | 32.5 | 40.0 | 47.5 | 55.0 | 62.5 | 70.0 | 77.5 | 85.0 | 92.5 |
| | 110 | 33.5 | 42.0 | 50.5 | 59.0 | 67.5 | 76.0 | 84.5 | 93.0 | 101.5 |
| 30 | 60 | 33.0 | 36.0 | 39.0 | 42.0 | 45.0 | 48.0 | 51.0 | 54.0 | 57.0 |
| | 70 | 34.0 | 38.0 | 42.0 | 46.0 | 50.0 | 54.0 | 58.0 | 62.0 | 66.0 |
| | 80 | 35.0 | 40.0 | 45.0 | 50.0 | 55.0 | 60.0 | 65.0 | 70.0 | 75.0 |
| | 90 | 36.0 | 42.0 | 48.0 | 54.0 | 60.0 | 66.0 | 72.0 | 78.0 | 84.0 |
| | 100 | 37.0 | 44.0 | 51.0 | 58.0 | 65.0 | 72.0 | 79.0 | 86.0 | 93.0 |
| | 110 | 38.0 | 46.0 | 54.0 | 62.0 | 70.0 | 78.0 | 86.0 | 94.0 | 102.0 |
| 35 | 60 | 37.5 | 40.0 | 42.5 | 45.0 | 47.5 | 50.0 | 52.5 | 55.0 | 57.5 |
| | 70 | 38.5 | 42.0 | 45.5 | 49.0 | 52.5 | 56.0 | 59.5 | 63.0 | 66.5 |
| | 80 | 39.5 | 44.0 | 48.5 | 53.0 | 57.5 | 62.0 | 66.5 | 71.0 | 75.5 |
| | 90 | 40.5 | 46.0 | 51.5 | 57.0 | 62.5 | 68.0 | 73.5 | 79.0 | 84.5 |

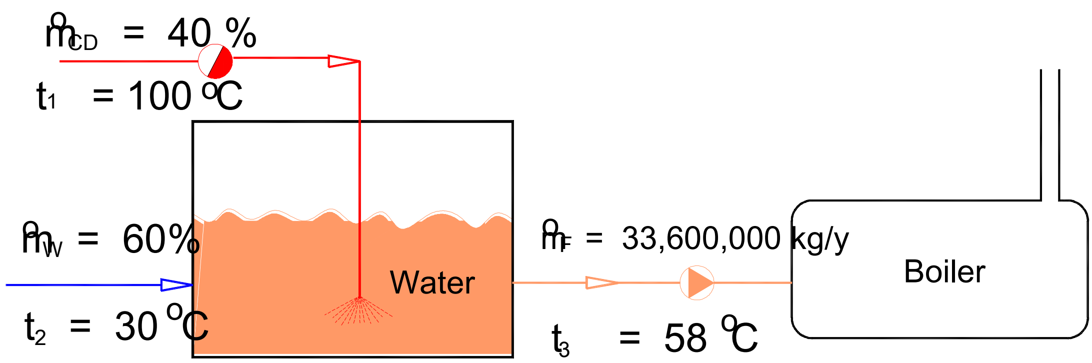
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 41.5 | 48.0 | 54.5 | 61.0 | 67.5 | 74.0 | 80.5 | 87.0 | 93.5 |
| | 110 | 42.5 | 50.0 | 57.5 | 65.0 | 72.5 | 80.0 | 87.5 | 95.0 | 102.5 |
| | 60 | 42.0 | 44.0 | 46.0 | 48.0 | 50.0 | 52.0 | 54.0 | 56.0 | 58.0 |
| | 70 | 43.0 | 46.0 | 49.0 | 52.0 | 55.0 | 58.0 | 61.0 | 64.0 | 67.0 |
| 40 | 80 | 44.0 | 48.0 | 52.0 | 56.0 | 60.0 | 64.0 | 68.0 | 72.0 | 76.0 |
| | 90 | 45.0 | 50.0 | 55.0 | 60.0 | 65.0 | 70.0 | 75.0 | 80.0 | 85.0 |
| | 100 | 46.0 | 52.0 | 58.0 | 64.0 | 70.0 | 76.0 | 82.0 | 88.0 | 94.0 |
| | 110 | 47.0 | 54.0 | 61.0 | 68.0 | 75.0 | 82.0 | 89.0 | 96.0 | 103.0 |

Example - 1

ECON factory used bunker C fuel with 10 ton/hr of boiler produce steam 33,600,000 kg/y. Released condensate at 100 °C without used and boiler feed water is 30 °C. This mill wants to recover condensate to mix with water before feed into boiler, around 40 % of amount of existing boiler feed water. en, ratio of condensate to water is 40 :lease calculate how much fuel saving potential in this implementation measure.




Before recovery condensate




After recovery condensate

| Item | Symbol | Unit | data | Data source |
|---|---|---|---|---|
| 1) Basic information | | | | |
| A Fuel type | - | - | Bunker C | From actual used |
| B Low heating value | | | | From table 2.1-5 |
| C Liquid | HL | MJ/kg | 38.17 | |
| D Solid | HL | MJ/kg | - | |
| E Gas | HL | MJ/kg | - | |
| F Boiler efficiency | | %/100 | 0.7 | 70 % from measuring equipment |
| G condensate temperature | $t_1$ | $^oC$ | 100 | From measuring equipment |
| H Temperature of feeding water | $t_2$ | $^oC$ | 30 | From measuring equipment |
| I mixed water flow rate (or feed water) | $m_F$ | kg/y | 33,600,000 | From actual used |
| J Ratio between condensate and water ($\overset{o}{m}_{CD}:\overset{o}{m}_{W}$) | R | - | 40:60 | From propose how much condensate mill recovery |
| K Specific heat of water | $C_P$ | $kJ/kg^oC$ | 4.187 | From water propertics 4.187 $kJ/kg^oC$ |
| 2) Calculation | | | | |
| 2.1 Temperature mixed water or (Boiler feed water) | $t_3$ | $^oC$ | 58 | Used item J,G and H to See in table 1.4-7 |
| 2.2 Fuel saving per year | | | | |
| $= m_F x C_P x(t_3-t_2)x10^{-3}/(HLx\ \eta_B)$ | | | | |
| 2.2.1 Liquid | kg/y | | 147,428.03 | I x K x2.1-H x $10^{-3}$/(C x F) |
| 2.2.2 Solid | kg/y | | | I x K x2.1-H x $10^{-3}$/(D x F) |
| 2.2.3 Gas | kg/y | | | I x K x2.1-H x $10^{-3}$/(E x F) |

O How to recovery the heat from flash steam?

Flash steam is usefully steam that has dryness fraction mare than normally steam from boiler. In many situation, could be use recovery flash steam with some simple equipment. During steam condensate is in the pipe or vessel, condensate temperature was equally same as steam temperature. Big differences between initial pressure and flash steam pressure, it will cause large amount of flash steam.

Normally, standardization to recovery flash steam is, collection condensate which discharged from steam trap and pipe into flash tank. Therefore, it will have high temperature condensate and flash steam. This flash steam could be bring to use as low pressure steam at some equipment machine which does not need high pressure steam. Equipment use for recovery flash steam Table 1.4-8.

Table 1.4-8 Appropriate Flash tank volume

| Flash tank volume | | | Condensate volume kg/h |
|---|---|---|---|
| diameter mm | in | hight mm | |
| 150 | 6 | 940 | 900 |
| 200 | 8 | 940 | 2,250 |
| 300 | 12 | 1,000 | 4,500 |
| 380 | 15 | 1,100 | 9,000 |
| 460 | 18 | 1,200 | 13,000 |
| 500 | 20 | 1,400 | 16,000 |
| 600 | 24 | 1,400 | 20,000 |
| 760 | 30 | 1,400 | 34,000 |
| 920 | 36 | 1,500 | 50,000 |

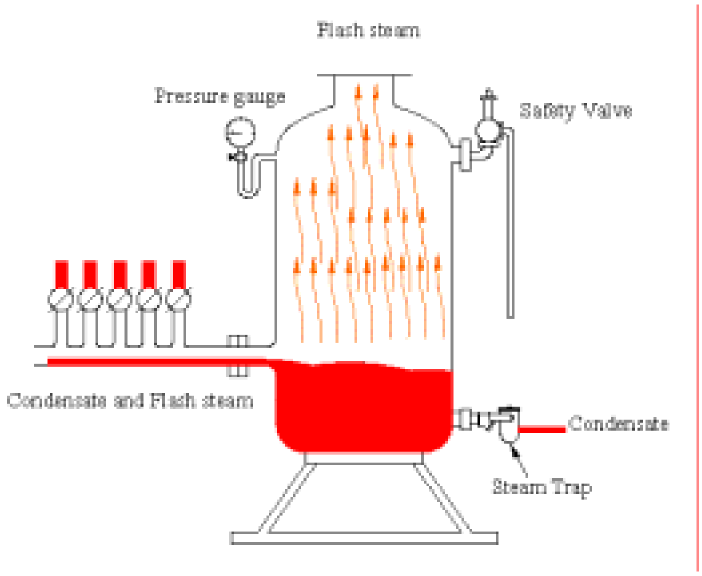



Figure 1.4-2 Equipment use recovery flash steam

At atmosphere pressure, if flash steam was thrown away then results either in vapor and will cause to damage surrounding building or environment. To solve this, flash steam should have to collect , pass through pipe and spray water to condense flash steam by using an shower as shown in Figure 1.4-3. There fore, it will have hot water that can be recovery to use in any prousses that need hot water or use as boiler feed water. If condensate steam was contaminated, heat exchanger units will bring to exchange heat instead of directly using.

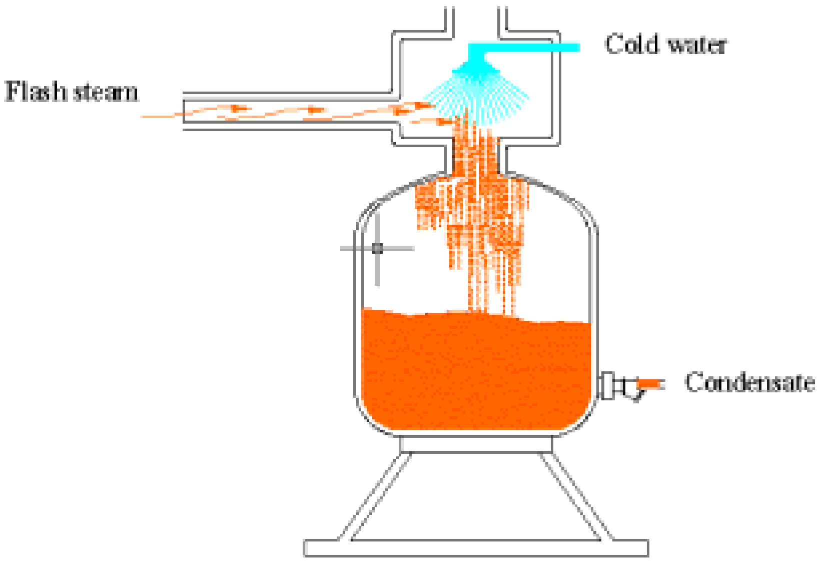
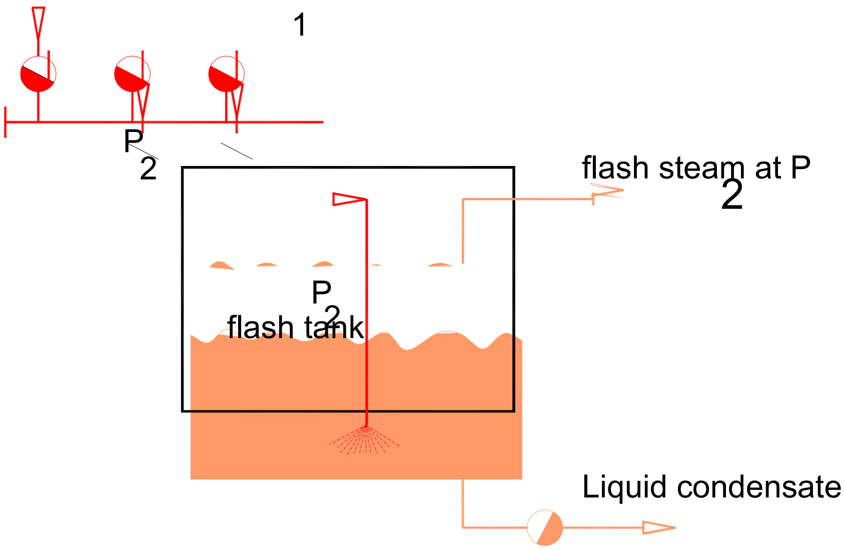



Figure 1.4-3 technical use to recovery flash steam

O How many loss in flash steam?

Condensate from equipment at $P_1$




Percentage of flash steam happened. ($R_{flash}$)

$$= \frac{\dot{m}_{FS}}{\dot{m}_{CD}} x100 = \frac{(h_{P1} - h_{P2})}{h_{fg(P2)}} x100 \qquad 1.4\text{-}5$$

amount of heat loss flash steam ; $Q_{flash}$

$$= \dot{m}_{CD} x\ h_{fg(P2)} x (R_{flash}) / 100 \qquad 1.4\text{-}6$$

volume of fuel loss from flash steam ; Fuel Loss

$$= Q_{flash} \times 10^{-3} / (HL \times \eta_B) \qquad 1.4\text{-}7$$

When $\dot{m}_{FS}$ = Amount of flash steam ;(kg/y)

$\overset{o}{m}_{CD}$ = Amount of condensate water ;(kg/y)

$h_{P1}$ = Enthalpy for condensate at pressure ; $P_1$ (kJ/kg)

$h_{P2}$ = Enthalpy for condensate at pressure ; $P_2$ (kJ/kg)

$h_{fg\ (P2)}$ = Latent heat of steam at pressure ; $P_2$ (kJ/kg)

HL = Low heating value of fuel ; MJ/kg

$\eta_B$ = Boiler efficiency

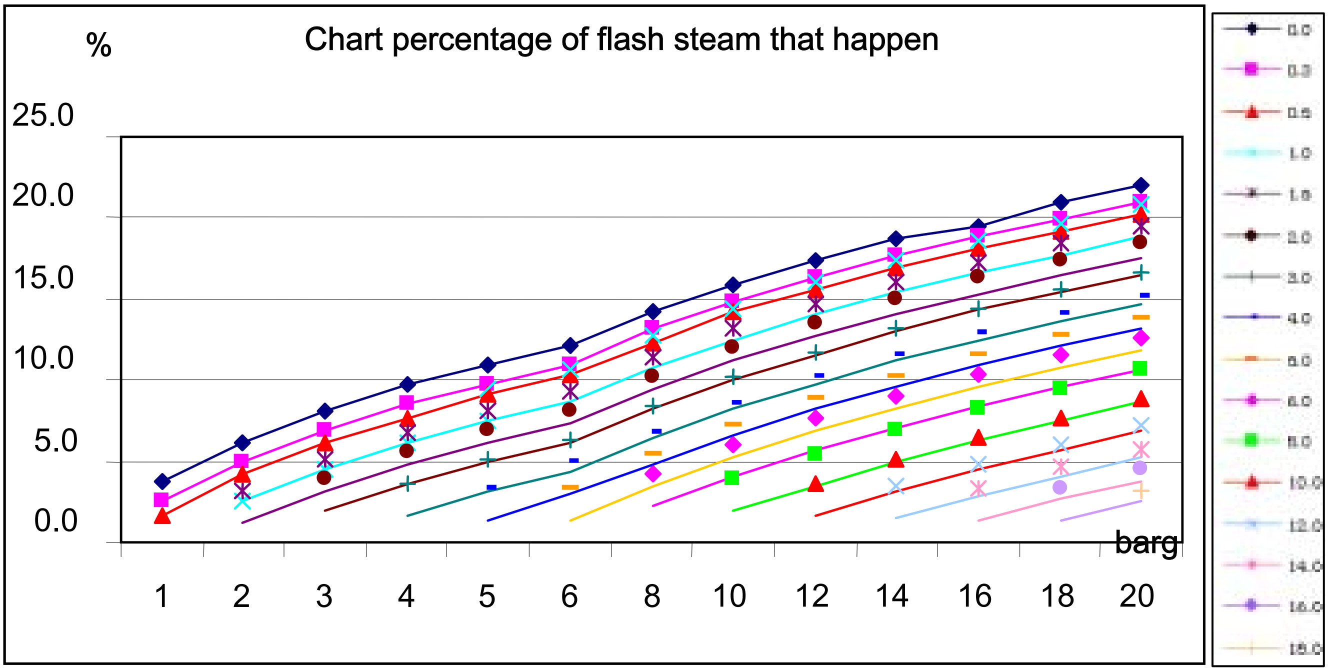


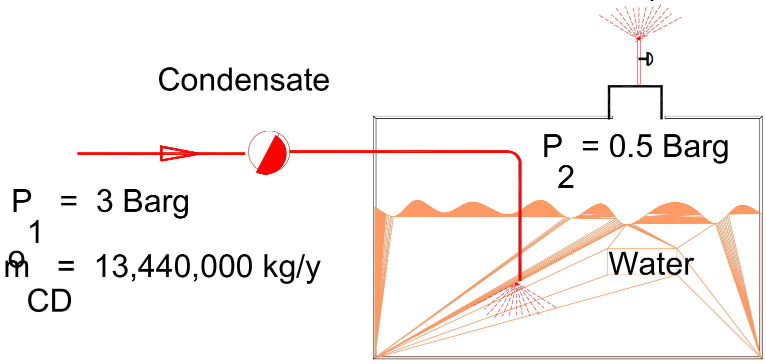
Table 1.4-9 Percentage of flash steam that happen

| Pressure in high pressure side (barg) | Low pressure side (barg) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | 0.3 | 0.5 | 1.0 | 1.5 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 |
| 1 | 3.7 | 2.5 | 1.7 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | 6.2 | 5.0 | 4.2 | 2.6 | 1.2 | - | - | - | - | - | - | - | - | - | - | - |
| 3 | 8.1 | 6.9 | 6.1 | 4.5 | 3.2 | 2.0 | - | - | - | - | - | - | - | - | - | - |
| 4 | 9.7 | 8.5 | 7.7 | 6.1 | 4.8 | 3.6 | 1.6 | - | - | - | - | - | - | - | - | - |
| 5 | 11.0 | 9.8 | 9.1 | 7.5 | 6.2 | 5.0 | 3.1 | 1.4 | - | - | - | - | - | - | - | - |
| 6 | 12.2 | 11.0 | 10.3 | 8.7 | 7.4 | 6.2 | 4.3 | 3.0 | 1.3 | - | - | - | - | - | - | - |
| 8 | 14.2 | 13.1 | 12.3 | 10.8 | 9.5 | 8.3 | 6.4 | 4.8 | 3.4 | 2.2 | - | - | - | - | - | - |
| 10 | 15.9 | 14.8 | 14.2 | 12.5 | 11.2 | 10.1 | 8.2 | 6.6 | 5.3 | 4.0 | 1.9 | - | - | - | - | - |
| 12 | 17.4 | 16.3 | 15.5 | 14.0 | 12.7 | 11.6 | 9.8 | 8.2 | 6.9 | 5.7 | 3.5 | 1.7 | - | - | - | - |
| 14 | 18.7 | 17.6 | 16.9 | 15.4 | 14.1 | 13.0 | 11.2 | 9.6 | 8.3 | 7.1 | 5.0 | 3.2 | 1.5 | - | - | - |
| 16 | 19.0 | 18.8 | 18.1 | 16.6 | 15.3 | 14.3 | 12.4 | 10.9 | 9.6 | 8.4 | 6.3 | 4.5 | 2.9 | 1.4 | - | - |
| 18 | 21.0 | 19.9 | 19.2 | 17.7 | 16.5 | 15.4 | 13.6 | 12.1 | 10.8 | 9.6 | 7.5 | 5.7 | 4.1 | 2.7 | 1.3 | - |
| 20 | 22.0 | 20.9 | 20.2 | 18.8 | 17.5 | 16.5 | 14.7 | 13.2 | 11.9 | 10.7 | 8.7 | 6.9 | 8.3 | 3.8 | 2.5 | 1.2 |

Example-2

ECON factory used bunker C fuel with 10 ton/hr of boiler to produce steam 33,600,000 kg/y. Efficiency of steam is 70 %, Around 40 % or 13,440,000 kg/y of condensate was recovered into flash tank. Condensate before fuel into flash tank has 3.0 Barg pressure, 0.5 Barg pressure in flash tank. Please calculate how much thermal energy has been loss from this flash tank.

heat loss from flash steam = kJ (from calculation)




| Item | Symbol | Unit | data | Data source |
|---|---|---|---|---|
| 1) Basic information | | | | |
| Ⓐ Fuel type | - | - | Bunker C | From actual used |
| Ⓑ Low heating value | | | | From table 2.1-5 |
| Ⓒ Liquid | HL | MJ/kg | 38.17 | |
| Ⓓ Solid | HL | MJ/kg | - | |

| | | | | |
|---|---|---|---|---|
| E Gas | HL | MJ/kg | - | |
| F Boiler efficiency | | %/100 | 0.7 | 70 % from measuring equipment |
| G Pressure of recovery condensate | $P_1$ | Barg | 3.0 | From measuring equipment |
| H Pressure of condensate in flash tank | $P_2$ | Barg | 0.5 | From measuring equipment |
| I Amount of recovery condensate per year | $\overset{o}{m}_F$ | kg/y | 13,440,000 | From actual used |
| J Latent heat of steam at flash tank pressure($P_2$) | $H_{fg}(P_2)$ | kJ/kg | 2,226.5 | See $P_2$ in Table 1.4-5 |
| 2) Calculation | | | | |
| 2.1 Percentage of flash steam that occured | $R_{flash}$ | %/100 | 0.061 | Used item G and H to see Table 1.4-7 then divide by 100 |
| 2.2 Amount of heat loss from flash steam $Q_{flah}$ = $m_{CD} x h_{fg\ (P2)} x (R_{flash}) x 10^{-3}/(HL x \eta_B)$ | $Q_{flah}$ | MJ/y | 1,825,373.76 | I x J x 2.1 x $10^{-3}$ |
| 2.3 Through flash steam per year = $Q_{flah}/(HL x \eta_B)$ | | | | |
| 2.2.1 Liquid | kg/y | | 68,317.44 | 2.2/(C x F) |
| 2.2.2 Solid | kg/y | | | 2.2/(D x F) |
| 2.2.3 Gas | kg/y | | | 2.2/(E x F) |

(5) Measures to Reduce Surface Loss

O What Surface heat loss is?

Surface heat loss is energy loss through hot surface or cold surface of an object. If surface temperature is higher than ambient Temperature, heat will transfer from the object to ambient, called ‘ heat loss’ . And if surface temperature is lower than ambient temperature, heat will transfer from ambient to the object, called ‘ heat gain’

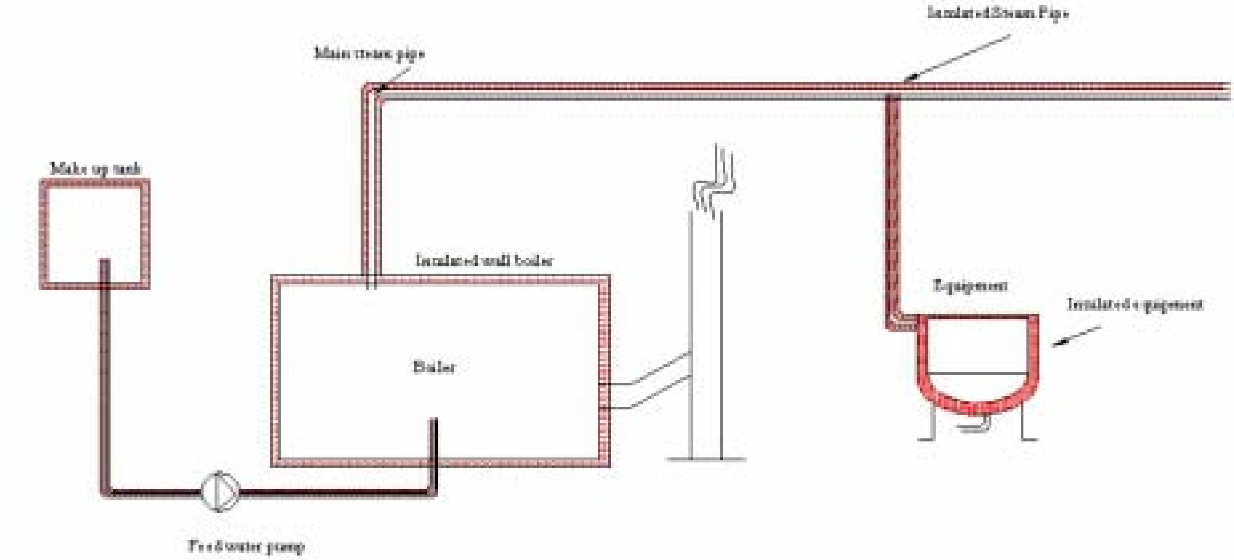
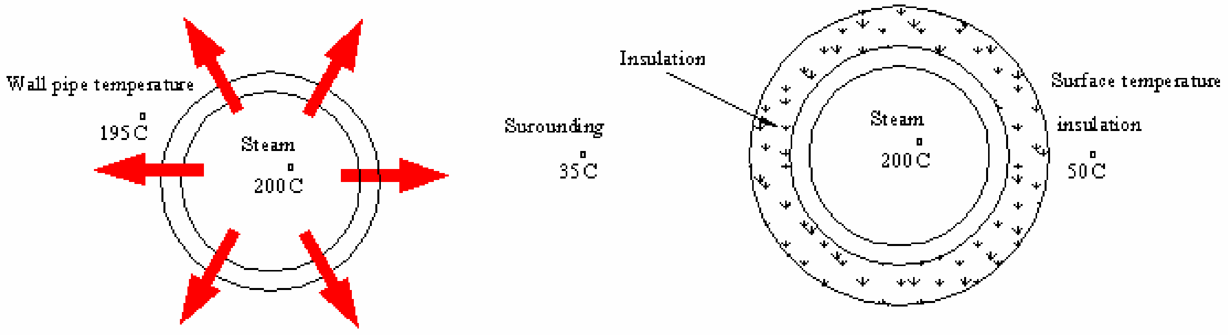



Fig 1.5-1 Position of Insulation

O How to prevent surface heat loss?

We can prevent surface heat loss by insulating the hot surface with insulating materials.




Before Insulating After Insulating

Fig 1.5-2 Surface loss prevention

O What is insulation?

Insulation is material which does not conduct heat. After insulating, the object can be touch safely. An example of insulation is leather globe for handling hot Iron bars.

O How to choose appropriate insulation?

Insulation has many types and materials such as board type, roll type etc. In insulation selection we should consider surface temperature and operating temperature of the insulation. Table 2.5-1 and 2.5-3 shows Insulation selection.

Table 1.5-1 Physical properties of Insulation

| Name of insulation | Classification | Thermal conductivity (W/m. K) | Specific heat (kJ/kg. K) | Density ($kg/m^3$) |
|---|---|---|---|---|
| Calcium Silicate | Heat insulating mould No.1 – 13 | 0.0407 | 0.84 | 135 |
| Glass Wool | Heat insulating mould | 0.0324 | 0.84 | 45 |
| Rock Wool | at insulating mould | 0.0314 | 1.13 | 100 |

Table 1.5-2 Insulation Selection

| Materials | Types | Operating Temperature | Heat conductivity | Advantages |
|---|---|---|---|---|
| Asbestos | Cylinder No.1<br>Plane No.2 | 550<br>350 | < 0.046 - 0.048<br>< 0.041 - 0.046 | convenience installation<br>Applicable in vibration |
| | Blanket<br>Rope | 400 | < 0.047 - 0.056 | convenience installation<br>suit to valve and flange |
| Rock Wool | Plane<br>Cylinder<br>Band | 400 – 600 | < 0.034 - 0.041 | High operating temperature |
| Glass Wool | Plane<br>No.1 8 K – 24 K<br>No.2 10 K – 96 K<br>No.3 96 K<br>Cylinder No.1<br>Band | 300 – 350 | < 0.046 - 0.034<br>< 0.049 - 0.031<br>< 0.034<br>< 0.032<br>< 0.039 | Most popular insulation<br>Low thermal conductivity |
| Calcium silicate | Plane No. 1<br>1,000 ◦ C<br>Cylinder No. 2<br>650 ◦ C | 650 | < 0.050<br><br>< 0.046 | High strength |

Table 1.5-3 Thickness Of Insulation Selection

| System Pipe | Fluid Temperature | | Normal Pipe | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | F | <1" (33 mm.) | 1 1"/2 - 2" (42-60mm.) | 2 1"/2 - 4" (73-114mm.) | 5" - 6" (140-168mm.) | 8" - 12" (219-324mm.) | 14" - 20" (350-500mm.) |
| High Temperature | Insulation Thickness Optimum | | | | | | | |
| - Super heated | 239-320 | 462-608 | 2.0" (50 mm.) | 2.0" (50 mm.) | 2.5" (63 mm.) | 3"(63 mm.) | 3.5" (88 mm.) | 3.5" (88 mm.) |
| - Steam, Hot water | 238-152 | 450-306 | 1.5" (38 mm.) | 1.5" (38 mm.) | 2.0" (50 mm.) | 2.5" (63 mm.) | 3.0" (75 mm.) | 3.5" (88 mm.) |
| High Pressure | 151-122 | 305-251 | 1.5" (38 mm.) | 1.5" (38 mm.) | 2.0" (50 mm.) | 2.0" (50 mm.) | 2.5" (63 mm.) | 3.0" (75 mm.) |
| Medium Pressure | 121-94 | 250-201 | 1.0" (25 mm.) | 1.5" (38 mm.) | 1.5" (38 mm.) | 2.0" (50 mm.) | 2.0" (50 mm.) | 2.5" (63 mm.) |
| Low Pressure | 93-49 | 200-120 | 1.0" (25 mm.) | 1.0" (25 mm.) | 1.5" (38 mm.) | 1.5" (38 mm.) | 1.5" (38 mm.) | 2.0" (50 mm.) |
| Condensate | 50-30 | 148-110 | 1.0" (25 mm.) | 1.0" (25 mm.) | 1.0" (25 mm.) | 1.5" (38 mm.) | 1.5" (38 mm.) | 2.0" (50 mm.) |

O Life-time of Insulation

Insulation has 5-15 year life time depending on types and installation. Inappropriate Insulation also shortens insulation life such as installing in very humid area or installing outdoor without insulation jackets.

O How to inspect insulation failure?

- Failure insulation can be determined by its surface temperature. It should be lower than 60 ◦ C or not be higher than that of new installation more than 20 C
- Components of failure or deteriorate insulation do not bond to each other and become powder.

O How to prevent insulation failure?

Insulation jackets can prevent insulation from failure. they are usually Aluminum foils, zinc-irons or thin aluminum sheets. After wrapping with insulation jackets, the edges of the jackets should be sealed with Silicone to prevent moisture and diffusion of failure insulation.

O How long is Insulation Investment payback?

Insulation can reduce surface heat loss up to 70-95% depending on insulation types and thickness. In general case Insulation investment will pay back within 2 years depending on surface temperature, operating hours and energy cost.

O How can we estimate Energy saving by Insulation?

The energy saving of Insulation works can be estimated as follows.

Energy saving for Heat Loss= Heat loss before isolate – Heat loss after isolate

Or $$Q_S = Q_{UNIN} - Q_{IN} \qquad 1.5\text{-}1$$

Heat loss before isolate ($Q_{UNIN}$)

$$Q_{UNIN} = Q_{CV} + Q_R \qquad 1.5\text{-}2$$

$$Q_{CV} = 1.32 \times \left[\frac{(T_w - T_a)}{D_2}\right]^{1/4} \times A \times (T_w - T_a)$$

$$Q_R = 5.6697 \times 10^{-8} \times \varepsilon \times A \times ((T_w+273)^4 - (T_a+273)^4)$$

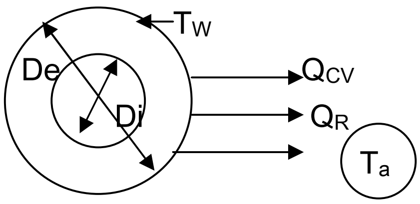


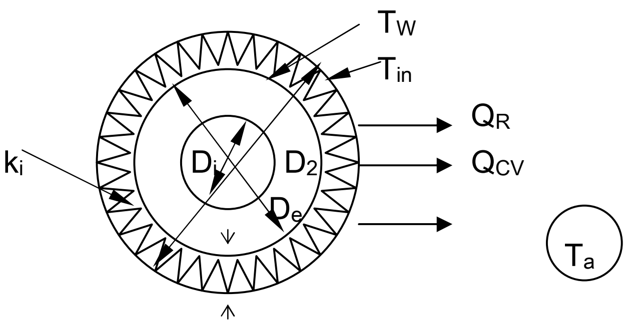

Fig 1.5-3 Surface loss of pipe non-isolate

$$QIN = Q_{CD(INS)} = Q_{CV} + Q_R$$

$$= \frac{T_w - T_a}{\frac{1}{2\pi \cdot L \cdot k_i}\ln\frac{(0.5 \cdot D_e)}{(0.5 \cdot D_2)} + \frac{1}{2\pi \cdot D_e \cdot L \cdot h}} \qquad 1.5.3$$

$$T_{in} = Q_{cd} \times \frac{1}{2 \cdot \pi \cdot D_e \cdot L \cdot h} + T_a \qquad 1.5\text{-}4$$

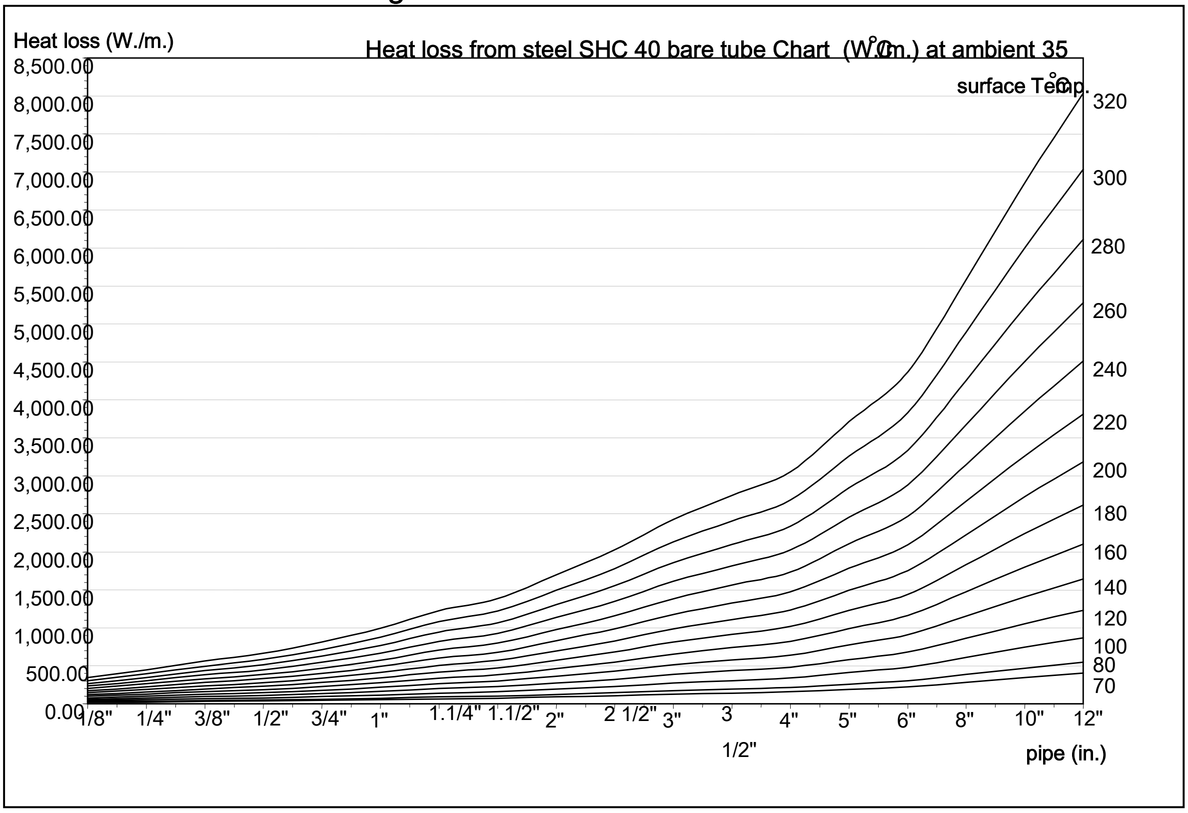
$$D_e = D_2 + (2 \times t_i) \qquad 1.5\text{-}5$$




ti Fig 1.5-4 Surface loss of pipe isolate

| | | | |
|---|---|---|---|
| When | $L$ | = | Pipe length (m.) |
| | $T_W$ | = | Surface pipe temperature ($\circ$ C) |
| | $T_a$ | = | Ambient temperature ($\circ$ C) |
| | $T_{in}$ | = | Surface insulation temperature ($\circ$ C) |
| | $A$ | = | Pipe area ($m^2$) |
| | $\varepsilon$ | = | Emissivity (Used 0.9) |
| | $t_i$ | = | Insulation thickness (m.) |
| | $k_i$ | = | Insulation conductivity ($W/m^2 \circ C$) |
| | $h$ | = | Heat transfer coefficient of air ($W/m^2 \circ C$) = $4.0 + 0.09 \times (T_w - T_a)$ |
| | $D_i$ | = | Inside diameter pipe (m.) |
| | $D_e$ | = | Outside diameter pipe (m.) |
| | $D_2$ | = | Outside diameter include insulation (m.) |
| | $Q_{CV}$ | = | Heat loss from convection (W/m) |
| | $Q_{CD}$ | = | Heat loss from conduction (W/m) |
| | $Q_R$ | = | Heat loss from radiation (W/m) |

## Fig 1.5-5 Heat loss from bare tube




## Fig 1.5-6 Heat loss from wall and Slab

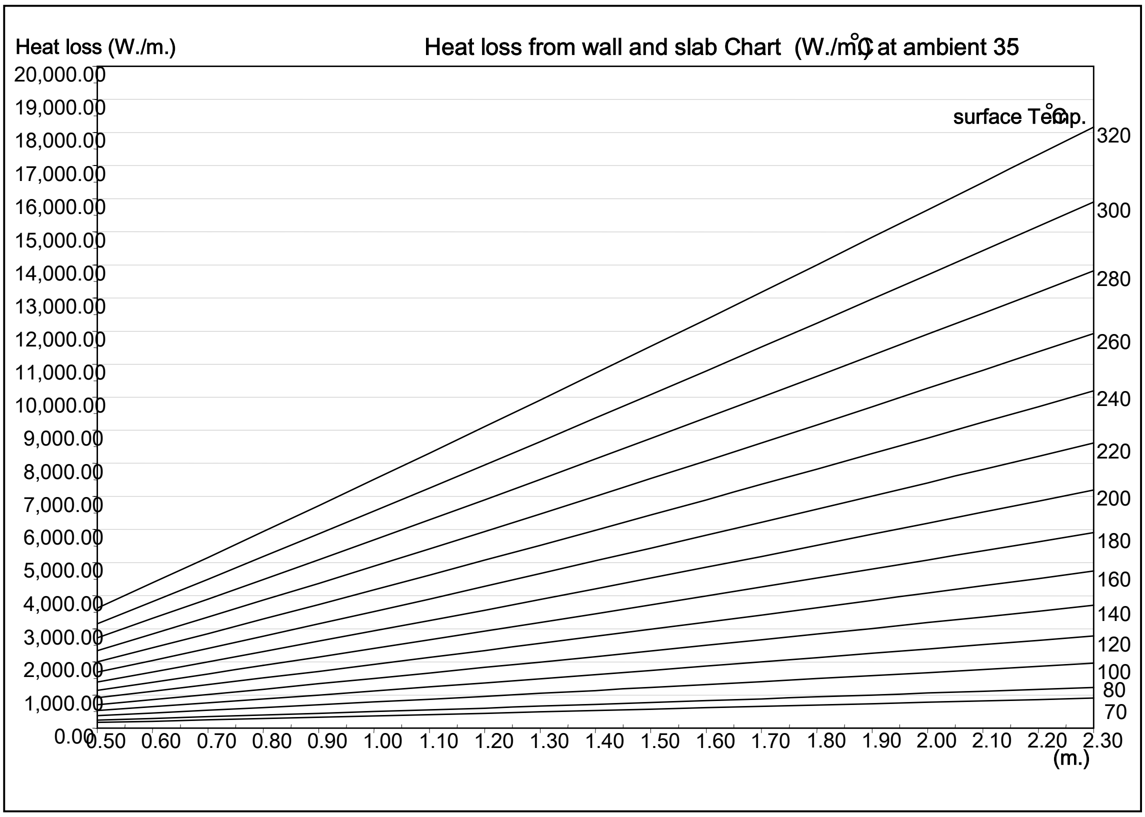


Fig 1.5-7 Heat loss from insulation tube (Glass Wool)

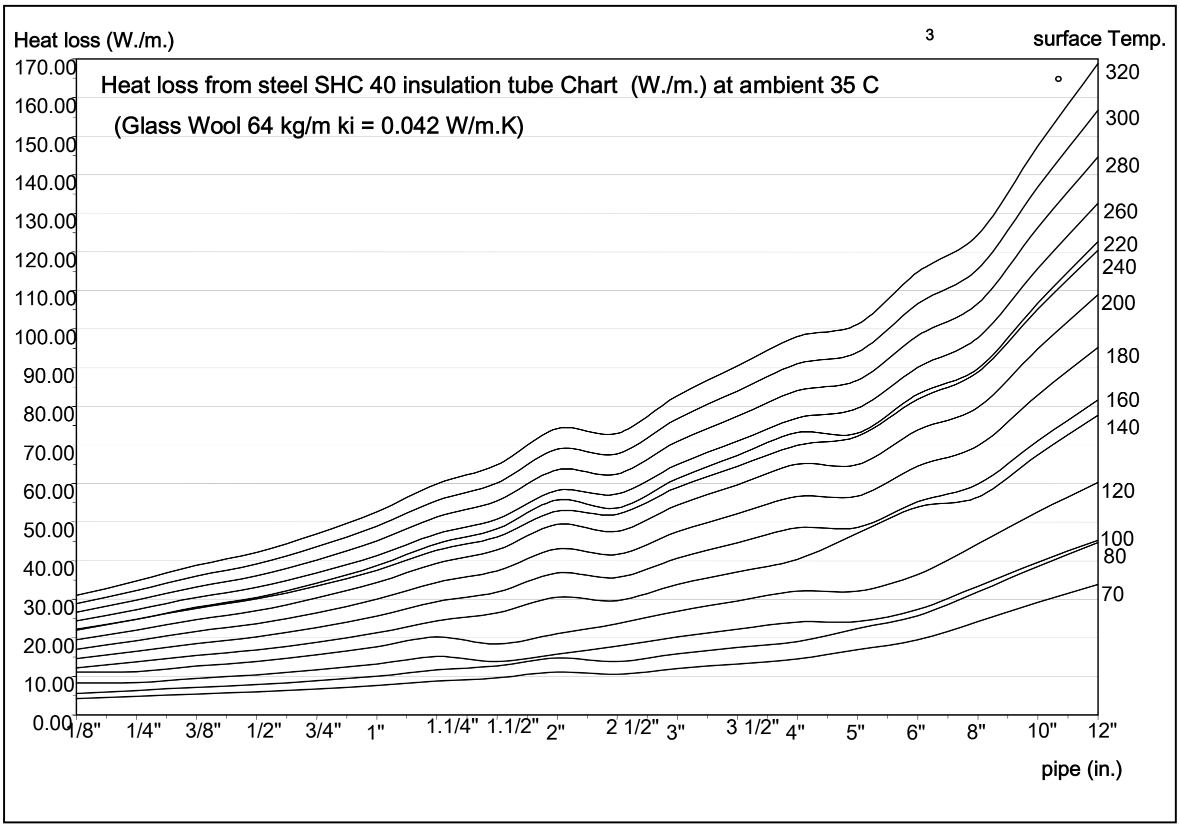



Fig 1.5-8 Heat loss from insulation tube (Calcium silicate)

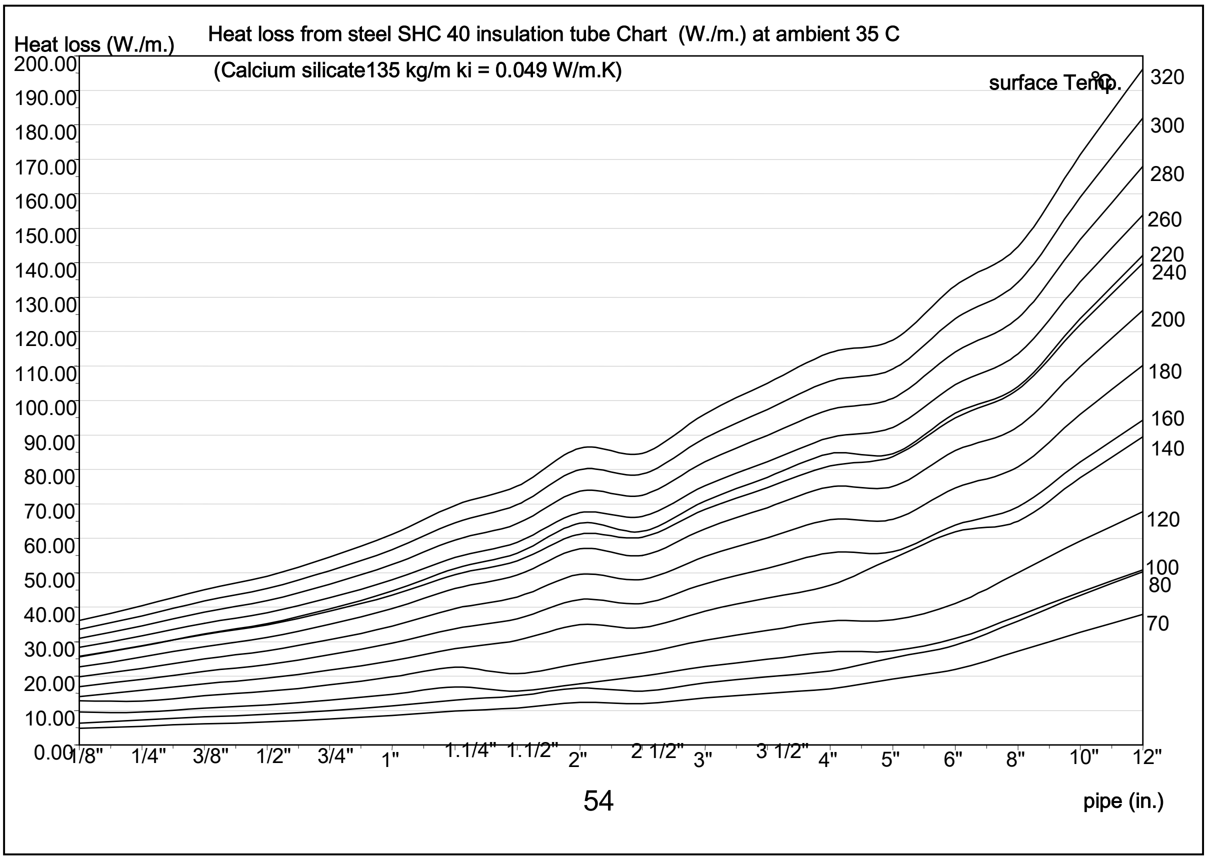


Fig 1.5-9 Heat loss from insulation tube (Rock Wool)

Fig 1.5-10 Heat loss from insulation wall (Glass Wool)

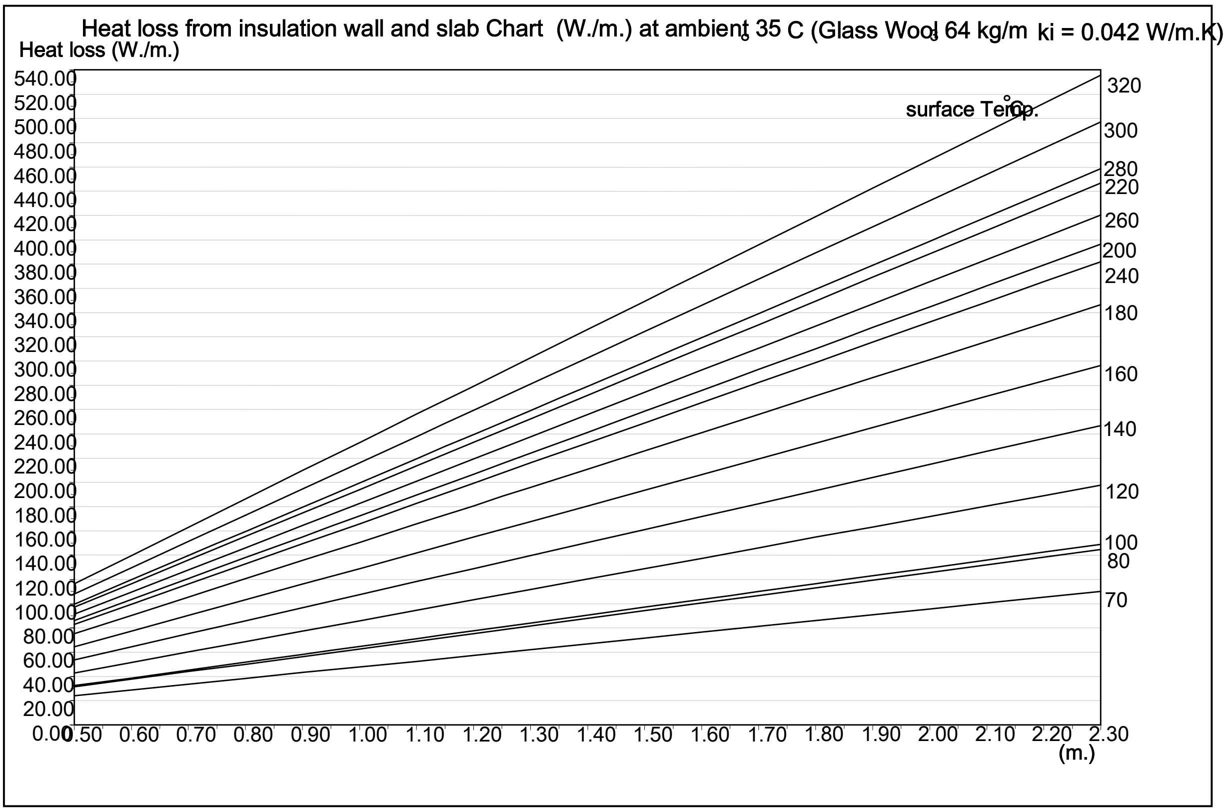



Fig 1.5-11 Heat loss from insulation wall (Rock Wool)

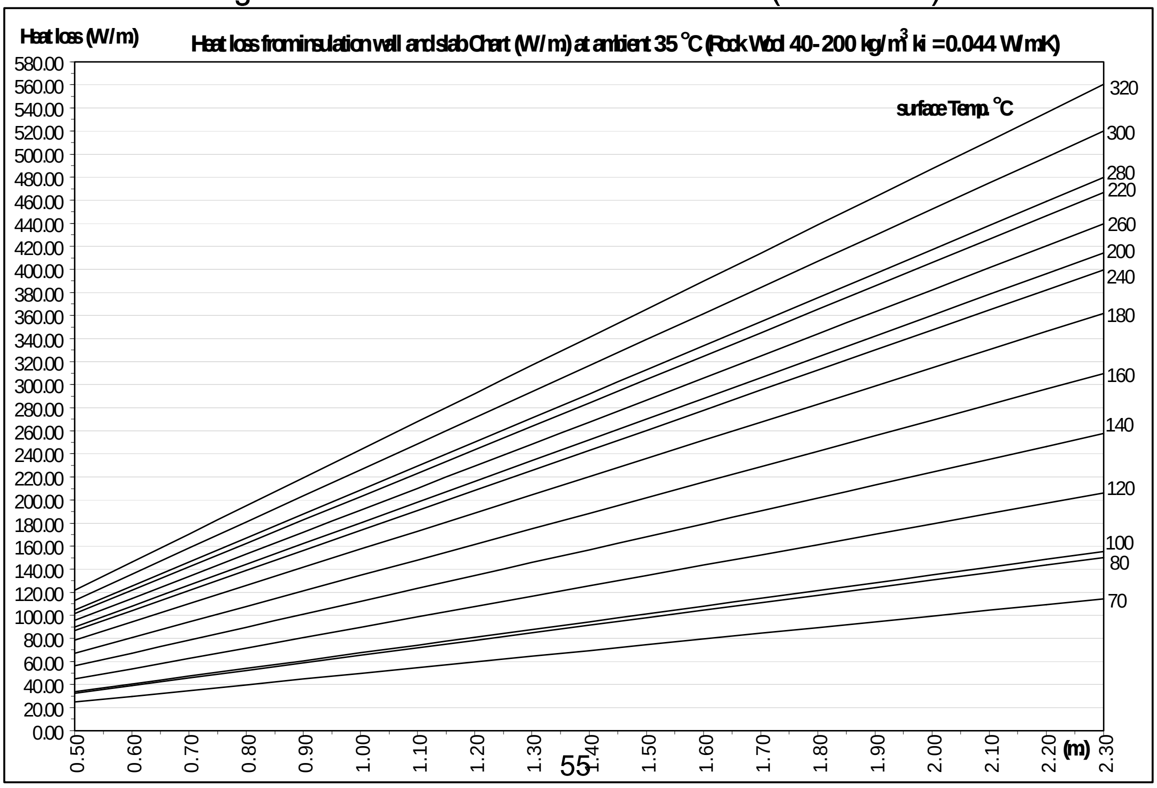


Fig 1.5-12Heat loss from insulation wall (Calcium silicate)

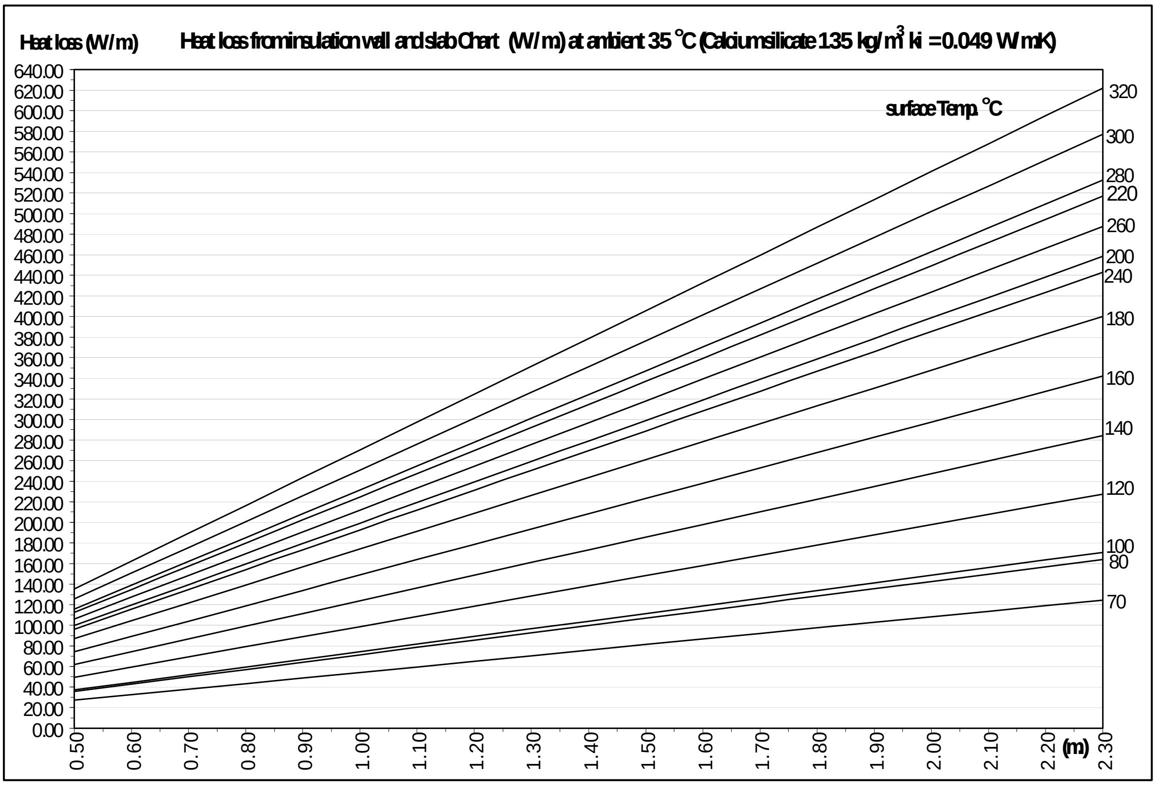


Table 1.5-4 Heat loss from bare tube SCH 40 (W/m) at ambient 35 C

| Pipe Diameter | | | Surface Temperature ( C ) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in. | De | Di | 70 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| 1/8" | 10.29 | 6.83 | 19.39 | 26.38 | 41.81 | 59.08 | 78.18 | 99.14 | 122.03 | 146.95 | 174.01 | 203.33 | 235.04 | 269.29 | 306.23 | 346.02 |
| 1/4" | 13.72 | 9.25 | 24.80 | 33.73 | 53.46 | 75.58 | 100.07 | 127.00 | 156.47 | 188.61 | 223.56 | 261.49 | 302.58 | 347.03 | 395.05 | 446.85 |
| 3/8" | 17.75 | 12.52 | 30.95 | 42.08 | 66.69 | 94.32 | 124.96 | 158.70 | 195.69 | 236.08 | 280.07 | 327.89 | 379.77 | 435.97 | 496.75 | 562.40 |
| 1/2" | 21.34 | 15.80 | 36.28 | 49.32 | 78.17 | 110.58 | 146.57 | 186.24 | 229.77 | 277.37 | 329.27 | 385.74 | 447.07 | 513.57 | 585.55 | 663.37 |
| 3/4" | 26.67 | 20.93 | 44.00 | 59.81 | 94.79 | 134.15 | 177.90 | 226.20 | 279.27 | 337.37 | 400.81 | 469.92 | 545.07 | 626.63 | 715.03 | 810.68 |
| 1" | 33.40 | 26.64 | 53.51 | 72.72 | 115.25 | 163.16 | 216.49 | 275.45 | 340.31 | 411.42 | 489.16 | 573.96 | 666.27 | 766.59 | 875.41 | 993.30 |
| 1.1/4" | 42.16 | 35.05 | 65.57 | 89.09 | 141.21 | 199.98 | 265.49 | 338.02 | 417.92 | 505.64 | 601.67 | 706.55 | 820.86 | 945.22 | 1,080.28 | 1,226.73 |
| 1.1/2" | 48.26 | 40.89 | 73.81 | 100.27 | 158.94 | 225.13 | 298.98 | 380.79 | 471.01 | 570.13 | 678.72 | 797.40 | 926.84 | 1,067.76 | 1,220.90 | 1,387.04 |
| 2" | 60.33 | 52.50 | 89.80 | 121.97 | 193.34 | 273.96 | 364.01 | 463.92 | 574.23 | 695.58 | 828.70 | 974.36 | 1,133.40 | 1,306.73 | 1,495.27 | 1,700.02 |
| 2 1/2" | 73.03 | 62.71 | 106.28 | 144.33 | 228.78 | 324.27 | 431.06 | 549.67 | 680.77 | 825.16 | 983.70 | 1,157.36 | 1,347.16 | 1,554.18 | 1,779.57 | 2,024.52 |
| 3" | 88.90 | 77.93 | 126.48 | 171.72 | 272.22 | 385.96 | 513.30 | 654.90 | 811.59 | 984.35 | 1,174.26 | 1,382.48 | 1,610.26 | 1,858.94 | 2,129.91 | 2,424.62 |
| 3 1/2" | 101.60 | 90.12 | 142.39 | 193.30 | 306.43 | 434.56 | 578.12 | 737.87 | 914.79 | 1,109.99 | 1,324.72 | 1,560.32 | 1,818.22 | 2,099.95 | 2,407.09 | 2,741.33 |
| 4" | 114.30 | 102.26 | 158.12 | 214.63 | 340.24 | 482.59 | 642.19 | 819.92 | 1,016.88 | 1,234.34 | 1,473.69 | 1,736.47 | 2,024.27 | 2,338.83 | 2,681.93 | 3,055.47 |
| 5" | 141.30 | 128.19 | 191.04 | 259.26 | 411.01 | 583.16 | 776.40 | 991.86 | 1,230.91 | 1,495.14 | 1,786.31 | 2,106.29 | 2,457.11 | 2,840.87 | 3,259.82 | 3,716.30 |
| 6" | 168.27 | 154.05 | 223.37 | 303.08 | 480.48 | 681.91 | 908.25 | 1,160.84 | 1,441.38 | 1,751.76 | 2,094.08 | 2,470.60 | 2,883.71 | 3,335.97 | 3,830.03 | 4,368.69 |
| 8" | 219.08 | 202.72 | 283.10 | 384.04 | 608.85 | 864.45 | 1,152.06 | 1,473.52 | 1,831.05 | 2,227.16 | 2,664.61 | 3,146.36 | 3,675.56 | 4,255.51 | 4,889.71 | 5,581.80 |
| 10" | 273.05 | 254.51 | 345.30 | 468.32 | 742.47 | 1,054.52 | 1,406.07 | 1,799.46 | 2,237.52 | 2,723.39 | 3,260.55 | 3,852.70 | 4,503.77 | 5,217.91 | 5,999.49 | 6,853.05 |
| 12" | 323.85 | 304.80 | 402.93 | 546.41 | 866.29 | 1,230.69 | 1,641.59 | 2,101.82 | 2,614.76 | 3,184.19 | 3,814.23 | 4,509.30 | 5,274.07 | 6,113.49 | 7,032.72 | 8,037.18 |

$T_a = 35$ C, $q_{c1} = (1.32 \times ((T_w - T_a)/De)^{0.25}) \times (T_w - T_a)$, $q_{r1} = 5.6697 \times 10^{-8} \times {}_i \times ((T_w + 273)^4 - (T_a + 273)^4)$, ${}_i = 0.9$

$Q = (q_{r1} + q_{c1}) \times \times De$

Table 1.5-5 **Heat loss from wall and Slab** (W/m.) at ambient 35 C

| Heat loss from wall and Slab (W/m.) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wall Temp. ( C) | 70 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| Wall High (m.) | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 0.50 | 174.37 | 236.14 | 374.45 | 533.10 | 713.36 | 916.80 | 1,145.20 | 1,400.54 | 1,684.91 | 2,000.54 | 2,349.79 | 2,735.12 | 3,159.12 | 3,624.47 |
| 0.60 | 212.08 | 287.27 | 455.51 | 648.35 | 867.26 | 1,114.12 | 1,391.06 | 1,700.41 | 2,044.69 | 2,426.57 | 2,848.86 | 3,314.53 | 3,826.66 | 4,388.49 |
| 0.70 | 250.36 | 339.15 | 537.77 | 765.28 | 1,023.36 | 1,314.17 | 1,640.19 | 2,004.14 | 2,408.92 | 2,857.66 | 3,353.62 | 3,900.27 | 4,501.19 | 5,160.15 |
| 0.80 | 289.12 | 391.71 | 621.11 | 883.71 | 1,181.41 | 1,516.65 | 1,892.26 | 2,311.30 | 2,777.12 | 3,293.25 | 3,863.45 | 4,491.64 | 5,181.93 | 5,938.62 |
| 0.90 | 328.34 | 444.89 | 705.41 | 1,003.49 | 1,341.22 | 1,721.33 | 2,146.96 | 2,621.57 | 3,148.90 | 3,732.93 | 4,377.86 | 5,088.10 | 5,868.29 | 6,723.24 |
| 1.00 | 367.97 | 498.62 | 790.60 | 1,124.52 | 1,502.66 | 1,928.02 | 2,404.09 | 2,934.69 | 3,523.96 | 4,176.33 | 4,896.45 | 5,689.23 | 6,559.79 | 7,513.50 |
| 1.10 | 407.97 | 552.87 | 876.62 | 1,246.69 | 1,665.58 | 2,136.57 | 2,663.45 | 3,250.43 | 3,902.06 | 4,623.18 | 5,418.92 | 6,294.66 | 7,256.05 | 8,308.95 |
| 1.20 | 448.32 | 607.61 | 963.39 | 1,369.93 | 1,829.90 | 2,346.84 | 2,924.89 | 3,568.62 | 4,282.98 | 5,073.24 | 5,944.99 | 6,904.10 | 7,956.72 | 9,109.25 |
| 1.30 | 489.01 | 662.79 | 1,050.88 | 1,494.17 | 1,995.51 | 2,558.73 | 3,188.28 | 3,889.10 | 4,666.54 | 5,526.30 | 6,474.44 | 7,517.30 | 8,661.53 | 9,914.08 |
| 1.40 | 530.00 | 718.40 | 1,139.04 | 1,619.35 | 2,162.36 | 2,772.15 | 3,453.50 | 4,211.73 | 5,052.58 | 5,982.19 | 7,007.06 | 8,134.03 | 9,370.25 | 10,723.19 |
| 1.50 | 571.29 | 774.41 | 1,227.84 | 1,745.42 | 2,330.36 | 2,987.01 | 3,720.47 | 4,536.41 | 5,440.98 | 6,440.76 | 7,542.69 | 8,754.10 | 10,082.65 | 11,536.33 |
| 1.60 | 612.86 | 830.81 | 1,317.25 | 1,872.34 | 2,499.46 | 3,203.23 | 3,989.07 | 4,863.02 | 5,831.62 | 6,901.87 | 8,081.18 | 9,377.35 | 10,798.55 | 12,353.31 |
| 1.70 | 654.69 | 887.57 | 1,407.23 | 2,000.06 | 2,669.62 | 3,420.77 | 4,259.25 | 5,191.48 | 6,224.39 | 7,365.40 | 8,622.38 | 10,003.62 | 11,517.79 | 13,173.95 |
| 1.80 | 696.78 | 944.67 | 1,497.76 | 2,128.55 | 2,840.77 | 3,639.54 | 4,530.93 | 5,521.70 | 6,619.18 | 7,831.24 | 9,166.19 | 10,632.79 | 12,240.22 | 13,998.07 |
| 1.90 | 739.11 | 1,002.11 | 1,588.82 | 2,257.78 | 3,012.88 | 3,859.52 | 4,804.05 | 5,853.61 | 7,015.93 | 8,299.30 | 9,712.48 | 11,264.72 | 12,965.70 | 14,825.54 |
| 2.00 | 781.67 | 1,059.87 | 1,680.38 | 2,387.72 | 3,185.92 | 4,080.63 | 5,078.55 | 6,187.14 | 7,414.55 | 8,769.48 | 10,261.16 | 11,899.31 | 13,694.12 | 15,656.23 |
| 2.10 | 824.46 | 1,117.93 | 1,772.43 | 2,518.34 | 3,359.84 | 4,302.86 | 5,354.37 | 6,522.24 | 7,814.97 | 9,241.71 | 10,812.14 | 12,536.46 | 14,425.36 | 16,490.00 |
| 2.20 | 867.47 | 1,176.30 | 1,864.95 | 2,649.61 | 3,534.62 | 4,526.14 | 5,631.48 | 6,858.83 | 8,217.13 | 9,715.92 | 11,365.34 | 13,176.08 | 15,159.31 | 17,326.75 |
| 2.30 | 910.68 | 1,234.94 | 1,957.93 | 2,781.52 | 3,710.23 | 4,750.45 | 5,909.82 | 7,196.89 | 8,620.96 | 10,192.03 | 11,920.68 | 13,818.07 | 15,895.90 | 18,166.38 |

$T_a = 35$ C, $q_{c1} = (1.42 \text{ x } ((T_w-T_a)/H)^{0.25}) \text{ x } (T_w-T_a)$, $q_{r1} = 5.6697 \text{ x} 10^{-8} \text{x } {}_i \text{ x } ((T_w + 273)^4 - (T_a + 273)^4)$, ${}_i = 0.9$

$Q = (q_{r1}+q_{c1}) \text{ x } H$

Table 1.5-6 **Heat loss from optimum insulation tube** SCH 40 (**Glass Wool density** 64 kg/$m^3$ ($k_i$ = 0.042 W/m.K)) at ambient 35 C

| Pipe Diameter | | | Heat loss from optimum insulation tube (W/m.) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| De | Di | Temp. before Insulate | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| | | Temp. after Insulate | 40.19 | 41.34 | 42.43 | 42.51 | 44.28 | 43.55 | 44.23 | 45.36 | 46.45 | 47.51 | 45.69 | 46.49 | 47.26 | 48.02 | 48.77 |
| mm. | mm. | in. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 10.29 | 6.83 | 1/8" | 4.27 | 5.60 | 6.96 | 8.35 | 11.16 | 12.20 | 14.63 | 17.07 | 19.52 | 21.98 | 22.17 | 24.39 | 26.60 | 28.82 | 31.04 |
| 13.72 | 9.25 | 1/4" | 4.83 | 6.35 | 7.91 | 8.46 | 11.25 | 13.73 | 16.48 | 19.25 | 22.02 | 24.80 | 24.81 | 27.29 | 29.77 | 32.26 | 34.74 |
| 17.75 | 12.52 | 3/8" | 5.44 | 7.17 | 8.94 | 9.51 | 12.67 | 15.41 | 18.51 | 21.62 | 24.74 | 27.87 | 27.66 | 30.43 | 33.21 | 35.98 | 38.76 |
| 21.34 | 15.8 | 1/2" | 5.97 | 7.87 | 9.83 | 10.40 | 13.86 | 16.82 | 20.22 | 23.63 | 27.05 | 30.48 | 30.06 | 33.07 | 36.09 | 39.12 | 42.14 |
| 26.67 | 20.93 | 3/4" | 6.72 | 8.88 | 11.09 | 11.67 | 15.56 | 18.84 | 22.65 | 26.49 | 30.33 | 34.19 | 33.45 | 36.81 | 40.18 | 43.55 | 46.92 |
| 33.4 | 26.64 | 1" | 7.64 | 10.10 | 12.64 | 13.20 | 17.63 | 21.28 | 25.61 | 29.96 | 34.32 | 38.70 | 37.54 | 41.32 | 45.11 | 48.90 | 52.69 |
| 42.16 | 35.05 | 1.1/4" | 8.80 | 11.65 | 14.60 | 15.11 | 20.21 | 24.35 | 29.32 | 34.32 | 39.34 | 44.38 | 42.65 | 46.96 | 51.27 | 55.59 | 59.90 |
| 48.26 | 40.89 | 1.1/2" | 9.59 | 12.72 | 15.94 | 13.85 | 18.38 | 26.44 | 31.85 | 37.29 | 42.76 | 48.25 | 46.11 | 50.78 | 55.45 | 60.12 | 64.79 |
| 60.33 | 52.5 | 2" | 11.13 | 14.78 | 18.55 | 15.81 | 21.00 | 30.50 | 36.76 | 43.06 | 49.40 | 55.76 | 52.81 | 58.16 | 63.52 | 68.88 | 74.25 |
| 73.03 | 62.71 | 2 1/2" | 10.54 | 13.84 | 17.22 | 17.81 | 23.68 | 29.61 | 35.59 | 41.59 | 47.61 | 53.65 | 52.00 | 57.23 | 62.46 | 67.70 | 72.94 |
| 88.90 | 77.93 | 3" | 12.06 | 15.86 | 19.74 | 20.25 | 26.95 | 33.76 | 40.59 | 47.45 | 54.34 | 61.24 | 58.95 | 64.89 | 70.83 | 76.78 | 82.73 |
| 101.60 | 90.12 | 3 1/2" | 13.26 | 17.45 | 21.73 | 22.17 | 29.52 | 37.04 | 44.54 | 52.08 | 59.65 | 67.25 | 64.43 | 70.93 | 77.43 | 83.93 | 90.44 |
| 114.30 | 102.3 | 4" | 14.46 | 19.04 | 23.72 | 24.06 | 32.05 | 40.29 | 48.46 | 56.68 | 64.93 | 73.20 | 69.86 | 76.90 | 83.96 | 91.02 | 98.09 |
| 141.30 | 128.2 | 5" | 16.98 | 22.38 | 27.90 | 24.18 | 32.09 | 47.14 | 48.57 | 56.71 | 64.88 | 73.07 | 72.20 | 79.45 | 86.70 | 93.96 | 101.22 |
| 168.27 | 154.1 | 6" | 19.49 | 25.70 | 32.06 | 27.41 | 36.39 | 53.92 | 55.27 | 64.55 | 73.86 | 83.19 | 81.84 | 90.07 | 98.30 | 106.54 | 114.79 |
| 219.08 | 202.7 | 8" | 24.18 | 31.91 | 39.84 | 33.37 | 44.35 | 56.42 | 59.79 | 69.76 | 79.76 | 89.78 | 88.87 | 97.77 | 106.68 | 115.59 | 124.51 |
| 273.05 | 254.5 | 10" | 29.15 | 38.49 | 48.07 | 39.57 | 52.63 | 67.38 | 71.06 | 82.94 | 94.84 | 106.77 | 105.20 | 115.74 | 126.30 | 136.86 | 147.42 |
| 323.85 | 304.80 | 12" | 33.81 | 44.66 | 55.81 | 45.32 | 60.30 | 77.64 | 81.62 | 95.27 | 108.96 | 122.68 | 120.46 | 132.54 | 144.64 | 156.74 | 168.85 |

h = 4.0 + 0.09 x (Tw-Ta)  ki = 0.042  De2 = D2 + 2 $t_i$  Ta = 35 C  Q = p.(Tw-Tin) / (((1 / (2 x ki)) x ln(De/D2)) + (1/(h x De)))

Tin = Ta + ((1 / (h x De))/(((1 / (2 x ki)) x ln(De/D2)) + (1 / (h x De)))) x (Tw-Ta)

Table 1.5-7 **Heat loss from optimum insulation tube** SCH 40 **(Calcium Silicate density** 135 kg/m$^3$ ($k_i$ = 0.049 W/m.K)**)** at ambient 35 C

| Pipe Diameter | | | **Heat loss from optimum insulation tube** (W/m.) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| De | Di | Temp. before Insulate | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| | | Temp. after Insulate | 40.86 | 42.17 | 43.42 | 43.54 | 45.57 | 44.79 | 45.59 | 46.88 | 48.14 | 49.36 | 47.32 | 48.24 | 49.14 | 50.02 | 50.88 |
| mm. | mm. | in. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 10.29 | 6.83 | 1/8" | 4.83 | 6.35 | 7.92 | 9.51 | 12.76 | 14.08 | 16.91 | 19.75 | 22.60 | 25.46 | 25.75 | 28.33 | 30.91 | 33.49 | 36.08 |
| 13.72 | 9.25 | 1/4" | 5.45 | 7.19 | 8.97 | 9.54 | 12.71 | 15.84 | 19.03 | 22.25 | 25.47 | 28.71 | 28.80 | 31.69 | 34.58 | 37.48 | 40.38 |
| 17.75 | 12.52 | 3/8" | 6.13 | 8.10 | 10.13 | 10.70 | 14.27 | 17.75 | 21.35 | 24.97 | 28.61 | 32.25 | 32.09 | 35.32 | 38.56 | 41.79 | 45.03 |
| 21.34 | 15.8 | 1/2" | 6.71 | 8.88 | 11.11 | 11.68 | 15.60 | 19.37 | 23.31 | 27.28 | 31.26 | 35.25 | 34.87 | 38.38 | 41.90 | 45.42 | 48.95 |
| 26.67 | 20.93 | 3/4" | 7.54 | 9.99 | 12.52 | 13.07 | 17.48 | 21.67 | 26.10 | 30.56 | 35.03 | 39.52 | 38.79 | 42.71 | 46.63 | 50.56 | 54.49 |
| 33.4 | 26.64 | 1" | 8.55 | 11.35 | 14.24 | 14.74 | 19.75 | 24.46 | 29.48 | 34.53 | 39.61 | 44.71 | 43.51 | 47.92 | 52.33 | 56.75 | 61.17 |
| 42.16 | 35.05 | 1.1/4" | 9.82 | 13.07 | 16.42 | 16.84 | 22.59 | 27.97 | 33.73 | 39.54 | 45.37 | 51.23 | 49.41 | 54.43 | 59.45 | 64.48 | 69.52 |
| 48.26 | 40.89 | 1.1/2" | 10.69 | 14.24 | 17.91 | 15.62 | 20.79 | 30.35 | 36.62 | 42.94 | 49.29 | 55.67 | 53.41 | 58.84 | 64.28 | 69.73 | 75.18 |
| 60.33 | 52.5 | 2" | 12.39 | 16.52 | 20.81 | 17.80 | 23.71 | 34.97 | 42.23 | 49.55 | 56.91 | 64.30 | 61.14 | 67.37 | 73.61 | 79.86 | 86.12 |
| 73.03 | 62.71 | 2 1/2" | 11.91 | 15.69 | 19.57 | 20.02 | 26.69 | 34.10 | 41.04 | 48.01 | 55.02 | 62.05 | 60.30 | 66.39 | 72.49 | 78.59 | 84.70 |
| 88.90 | 77.93 | 3" | 13.61 | 17.95 | 22.41 | 22.73 | 30.32 | 38.85 | 46.78 | 54.75 | 62.76 | 70.80 | 68.34 | 75.25 | 82.18 | 89.11 | 96.04 |
| 101.60 | 90.12 | 3 1/2" | 14.96 | 19.74 | 24.66 | 24.85 | 33.18 | 42.60 | 51.31 | 60.08 | 68.88 | 77.72 | 74.67 | 82.24 | 89.82 | 97.40 | 104.99 |
| 114.30 | 102.3 | 4" | 16.29 | 21.52 | 26.89 | 26.95 | 35.99 | 46.32 | 55.81 | 65.36 | 74.96 | 84.58 | 80.95 | 89.16 | 97.38 | 105.61 | 113.85 |
| 141.30 | 128.2 | 5" | 19.11 | 25.28 | 31.60 | 27.25 | 36.25 | 54.17 | 56.08 | 65.55 | 75.06 | 84.59 | 83.75 | 92.19 | 100.65 | 109.11 | 117.58 |
| 168.27 | 154.1 | 6" | 21.91 | 29.00 | 36.28 | 30.85 | 41.06 | 61.93 | 63.80 | 74.59 | 85.42 | 96.29 | 94.91 | 104.50 | 114.09 | 123.70 | 133.31 |
| 219.08 | 202.7 | 8" | 27.16 | 35.97 | 45.04 | 37.49 | 49.93 | 65.00 | 69.11 | 80.72 | 92.36 | 104.03 | 103.15 | 113.52 | 123.90 | 134.29 | 144.68 |
| 273.05 | 254.5 | 10" | 32.70 | 43.35 | 54.31 | 44.39 | 59.16 | 77.59 | 82.12 | 95.93 | 109.79 | 123.69 | 122.06 | 134.35 | 146.65 | 158.96 | 171.28 |
| 323.85 | 304.80 | 12" | 37.90 | 50.27 | 63.01 | 50.77 | 67.70 | 89.38 | 94.30 | 110.18 | 126.11 | 142.09 | 139.75 | 153.83 | 167.93 | 182.03 | 196.15 |

$h = 4.0 + 0.09 \times (T_w - T_a)$, $k_i = 0.049$, $De_2 = D_2 + 2\,t_I$, $T_a = 35$ C, $Q = .(T_w - T_{in}) / (((1 / (2 \times k_i)) \times \ln(De/D_2)) + (1/(h \times De)))$

$T_{in} = T_a + ((1 / (h \times De))/(((1 / (2 \times k_i)) \times \ln(De/D_2)) + (1 / (h \times De)))) \times (T_w - T_a)$

Table 1.5-8 **Heat loss from optimum insulation tube** SCH 40 **(Rock Wool density** 40 - 200 kg/m$^3$ ($k_i$ = 0.044 W/m.K)**)** at ambient 35 C

| Pipe Diameter | | | **Heat loss from optimum insulation tube** (W/m.) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| De | Di | Temp. before Insulate | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| | | Temp. after Insulate | 40.38 | 41.58 | 42.72 | 42.81 | 44.65 | 43.91 | 44.62 | 45.80 | 46.94 | 48.04 | 46.16 | 46.99 | 47.80 | 48.60 | 49.38 |
| mm. | mm. | in. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 10.29 | 6.83 | 1/8" | 4.43 | 5.82 | 7.24 | 8.69 | 11.62 | 12.74 | 15.29 | 17.84 | 20.41 | 22.98 | 23.20 | 25.52 | 27.84 | 30.16 | 32.48 |
| 13.72 | 9.25 | 1/4" | 5.01 | 6.59 | 8.22 | 8.78 | 11.68 | 14.34 | 17.22 | 20.11 | 23.01 | 25.92 | 25.95 | 28.55 | 31.15 | 33.75 | 36.36 |
| 17.75 | 12.52 | 3/8" | 5.65 | 7.44 | 9.29 | 9.86 | 13.14 | 16.08 | 19.33 | 22.58 | 25.85 | 29.13 | 28.93 | 31.83 | 34.74 | 37.65 | 40.56 |
| 21.34 | 15.8 | 1/2" | 6.19 | 8.17 | 10.20 | 10.78 | 14.37 | 17.56 | 21.11 | 24.68 | 28.26 | 31.85 | 31.44 | 34.60 | 37.76 | 40.92 | 44.09 |
| 26.67 | 20.93 | 3/4" | 6.96 | 9.20 | 11.51 | 12.08 | 16.13 | 19.66 | 23.65 | 27.66 | 31.69 | 35.73 | 34.98 | 38.50 | 42.03 | 45.56 | 49.09 |
| 33.4 | 26.64 | 1" | 7.90 | 10.47 | 13.11 | 13.65 | 18.25 | 22.20 | 26.72 | 31.28 | 35.85 | 40.43 | 39.25 | 43.21 | 47.18 | 51.15 | 55.12 |
| 42.16 | 35.05 | 1.1/4" | 9.10 | 12.07 | 15.13 | 15.62 | 20.91 | 25.40 | 30.60 | 35.83 | 41.08 | 46.35 | 44.59 | 49.10 | 53.62 | 58.14 | 62.66 |
| 48.26 | 40.89 | 1.1/2" | 9.91 | 13.16 | 16.52 | 14.37 | 19.09 | 27.57 | 33.23 | 38.92 | 44.64 | 50.38 | 48.21 | 53.09 | 57.98 | 62.88 | 67.77 |
| 60.33 | 52.5 | 2" | 11.50 | 15.30 | 19.22 | 16.39 | 21.79 | 31.79 | 38.34 | 44.94 | 51.56 | 58.22 | 55.20 | 60.81 | 66.42 | 72.03 | 77.66 |
| 73.03 | 62.71 | 2 1/2" | 10.94 | 14.38 | 17.90 | 18.46 | 24.56 | 30.91 | 37.16 | 43.44 | 49.74 | 56.06 | 54.38 | 59.86 | 65.34 | 70.82 | 76.31 |
| 88.90 | 77.93 | 3" | 12.51 | 16.47 | 20.52 | 20.98 | 27.94 | 35.23 | 42.37 | 49.55 | 56.76 | 63.99 | 61.64 | 67.86 | 74.08 | 80.31 | 86.54 |
| 101.60 | 90.12 | 3 1/2" | 13.76 | 18.12 | 22.59 | 22.96 | 30.59 | 38.64 | 46.49 | 54.38 | 62.31 | 70.26 | 67.37 | 74.17 | 80.98 | 87.80 | 94.61 |
| 114.30 | 102.3 | 4" | 15.00 | 19.76 | 24.64 | 24.91 | 33.21 | 42.03 | 50.58 | 59.18 | 67.82 | 76.48 | 73.04 | 80.42 | 87.81 | 95.21 | 102.61 |
| 141.30 | 128.2 | 5" | 17.61 | 23.23 | 28.98 | 25.08 | 33.30 | 49.17 | 50.73 | 59.25 | 67.81 | 76.38 | 75.51 | 83.10 | 90.70 | 98.30 | 105.91 |
| 168.27 | 154.1 | 6" | 20.20 | 26.66 | 33.29 | 28.42 | 37.76 | 56.24 | 57.73 | 67.44 | 77.19 | 86.96 | 85.59 | 94.21 | 102.83 | 111.46 | 120.09 |
| 219.08 | 202.7 | 8" | 25.06 | 33.10 | 41.36 | 34.58 | 45.98 | 58.90 | 62.47 | 72.91 | 83.38 | 93.87 | 92.97 | 102.29 | 111.62 | 120.95 | 130.29 |
| 273.05 | 254.5 | 10" | 30.19 | 39.91 | 49.90 | 40.99 | 54.54 | 70.32 | 74.25 | 86.67 | 99.14 | 111.63 | 110.04 | 121.08 | 132.13 | 143.19 | 154.26 |
| 323.85 | 304.80 | 12" | 35.01 | 46.31 | 57.92 | 46.92 | 62.47 | 81.03 | 85.27 | 99.56 | 113.89 | 128.26 | 125.99 | 138.65 | 151.32 | 163.99 | 176.67 |

$h = 4.0 + 0.09 \times (T_w - T_a)$, $k_i = 0.044$, $De_2 = D_2 + 2\,t_I$, $T_a = 35$ C, $Q = .(T_w - T_{in}) / (((1 / (2 \times ki)) \times \ln(De/D_2)) + (1/(h \times De)))$

$T_{in} = T_a + ((1 / (h \times De))/(((1 / (2 \times k_i)) \times \ln(De/D_2)) + (1 / (h \times De)))) \times (T_w - T_a)$

Table 1.5-9 Heat loss from optimum insulation Wall (Glass Wool density 64 kg/m$^3$ ($k_i$ = 0.042 W/m.K)) at ambient 35 C

| Optimum Insulation Thickness | | | | | | | | | | Heat loss optimum insulation wall (W/m.) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Wall Temp. ( C) | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| 49 - 93 C | | 94 - 121 C | | 122 – 151 C | | 152 – 238 C | | 239 – 320 C | | Temp. after Insulate | 40.98 | 40.48 | 44.76 | 43.09 | 45.74 | 48.42 | 51.12 | 53.83 | 56.55 | 59.27 | 55.76 | 57.84 | 59.93 | 62.02 | 64.11 |
| in. | mm. | in. | mm. | in. | mm. | in. | mm. | in. | mm. | Wall High (m.) | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.50 | 23.93 | 31.40 | 39.03 | 32.36 | 42.97 | 53.68 | 64.47 | 75.31 | 86.18 | 97.09 | 83.02 | 91.36 | 99.71 | 108.06 | 116.42 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.60 | 28.72 | 37.69 | 46.84 | 38.83 | 51.56 | 64.42 | 77.36 | 90.37 | 103.42 | 116.51 | 99.63 | 109.63 | 119.65 | 129.68 | 139.71 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.70 | 33.50 | 43.97 | 54.65 | 45.31 | 60.15 | 75.15 | 90.25 | 105.43 | 120.66 | 135.93 | 116.23 | 127.91 | 139.59 | 151.29 | 162.99 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.80 | 38.29 | 50.25 | 62.45 | 51.78 | 68.75 | 85.89 | 103.15 | 120.49 | 137.89 | 155.34 | 132.83 | 146.18 | 159.53 | 172.90 | 186.28 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.90 | 43.07 | 56.53 | 70.26 | 58.25 | 77.34 | 96.62 | 116.04 | 135.55 | 155.13 | 174.76 | 149.44 | 164.45 | 179.48 | 194.51 | 209.56 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.00 | 47.86 | 62.81 | 78.07 | 64.72 | 85.93 | 107.36 | 128.93 | 150.61 | 172.37 | 194.18 | 166.04 | 182.72 | 199.42 | 216.13 | 232.85 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.10 | 52.65 | 69.09 | 85.87 | 71.20 | 94.53 | 118.10 | 141.83 | 165.67 | 189.60 | 213.60 | 182.65 | 200.99 | 219.36 | 237.74 | 256.13 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.20 | 57.43 | 75.37 | 93.68 | 77.67 | 103.12 | 128.83 | 154.72 | 180.74 | 206.84 | 233.02 | 199.25 | 219.27 | 239.30 | 259.35 | 279.42 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.30 | 62.22 | 81.65 | 101.49 | 84.14 | 111.71 | 139.57 | 167.61 | 195.80 | 224.08 | 252.43 | 215.85 | 237.54 | 259.24 | 280.97 | 302.70 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.40 | 67.00 | 87.93 | 109.29 | 90.61 | 120.31 | 150.30 | 180.51 | 210.86 | 241.31 | 271.85 | 232.46 | 255.81 | 279.19 | 302.58 | 325.99 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.50 | 71.79 | 94.21 | 117.10 | 97.09 | 128.90 | 161.04 | 193.40 | 225.92 | 258.55 | 291.27 | 249.06 | 274.08 | 299.13 | 324.19 | 349.27 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.60 | 76.58 | 100.50 | 124.91 | 103.56 | 137.49 | 171.78 | 206.29 | 240.98 | 275.79 | 310.69 | 265.67 | 292.36 | 319.07 | 345.80 | 372.56 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.70 | 81.36 | 106.78 | 132.71 | 110.03 | 146.09 | 182.51 | 219.19 | 256.04 | 293.03 | 330.11 | 282.27 | 310.63 | 339.01 | 367.42 | 395.84 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.80 | 86.15 | 113.06 | 140.52 | 116.50 | 154.68 | 193.25 | 232.08 | 271.10 | 310.26 | 349.52 | 298.88 | 328.90 | 358.95 | 389.03 | 419.13 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.90 | 90.93 | 119.34 | 148.33 | 122.98 | 163.27 | 203.98 | 244.97 | 286.16 | 327.50 | 368.94 | 315.48 | 347.17 | 378.90 | 410.64 | 442.41 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.00 | 95.72 | 125.62 | 156.13 | 129.45 | 171.86 | 214.72 | 257.87 | 301.23 | 344.74 | 388.36 | 332.08 | 365.44 | 398.84 | 432.26 | 465.70 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.10 | 100.51 | 131.90 | 163.94 | 135.92 | 180.46 | 225.46 | 270.76 | 316.29 | 361.97 | 407.78 | 348.69 | 383.72 | 418.78 | 453.87 | 488.98 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.20 | 105.29 | 138.18 | 171.75 | 142.39 | 189.05 | 236.19 | 283.66 | 331.35 | 379.21 | 427.20 | 365.29 | 401.99 | 438.72 | 475.48 | 512.26 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.30 | 110.08 | 144.46 | 179.55 | 148.87 | 197.64 | 246.93 | 296.55 | 346.41 | 396.45 | 446.61 | 381.90 | 420.26 | 458.66 | 497.09 | 535.55 |

$T_a$ = 35 C, h = 4.2 + 0.09 x ($T_w$ - $T_a$) W/m$^2$. C, Q = ($T_w$ - $T_a$) / [($t_i$ / ($k_i$ x H)) + (1 / (H x h))] W/m. $T_{in}$ = [Q x (1/( H x h))] + $T_a$ C

Table 1.5-10 Heat loss from optimum insulation Wall (Rock Wool density 40 – 200 kg/m$^3$ ($k_i$ = 0.044 W/m.K)) at ambient 35 C

| Optimum Insulation Thickness | | | | | | | | | | Heat loss optimum insulation wall (W/m.) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Wall Temp ( C) | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| 49 – 93 C | | 94 – 121 C | | 122 – 151 C | | 152 – 238 C | | 239 – 320 C | | Temp. after Insulate | 41.21 | 40.76 | 45.15 | 43.44 | 46.21 | 49.01 | 51.83 | 54.67 | 57.51 | 60.37 | 56.71 | 58.89 | 61.08 | 63.26 | 65.45 |
| in. | mm. | in. | mm. | in. | mm. | in. | mm. | in. | mm. | Wall High (m.) | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.50 | 24.85 | 32.64 | 40.59 | 33.74 | 44.83 | 56.04 | 67.32 | 78.67 | 90.05 | 101.47 | 86.83 | 95.56 | 104.30 | 113.05 | 121.81 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.60 | 29.82 | 39.16 | 48.71 | 40.49 | 53.80 | 67.24 | 80.79 | 94.40 | 108.06 | 121.76 | 104.19 | 114.67 | 125.16 | 135.66 | 146.17 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.70 | 34.79 | 45.69 | 56.83 | 47.24 | 62.76 | 78.45 | 94.25 | 110.13 | 126.07 | 142.06 | 121.56 | 133.78 | 146.02 | 158.27 | 170.53 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.80 | 39.76 | 52.22 | 64.95 | 53.99 | 71.73 | 89.66 | 107.72 | 125.87 | 144.08 | 162.35 | 138.92 | 152.90 | 166.89 | 180.89 | 194.89 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.90 | 44.73 | 58.75 | 73.07 | 60.74 | 80.69 | 100.86 | 121.18 | 141.60 | 162.09 | 182.65 | 156.29 | 172.01 | 187.75 | 203.50 | 219.26 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.00 | 49.70 | 65.27 | 81.18 | 67.49 | 89.66 | 112.07 | 134.65 | 157.33 | 180.11 | 202.94 | 173.65 | 191.12 | 208.61 | 226.11 | 243.62 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.10 | 54.67 | 71.80 | 89.30 | 74.24 | 98.63 | 123.28 | 148.11 | 173.07 | 198.12 | 223.23 | 191.02 | 210.23 | 229.47 | 248.72 | 267.98 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.20 | 59.64 | 78.33 | 97.42 | 80.99 | 107.59 | 134.49 | 161.58 | 188.80 | 216.13 | 243.53 | 208.38 | 229.35 | 250.33 | 271.33 | 292.34 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.30 | 64.61 | 84.86 | 105.54 | 87.73 | 116.56 | 145.69 | 175.04 | 204.53 | 234.14 | 263.82 | 225.75 | 248.46 | 271.19 | 293.94 | 316.70 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.40 | 69.58 | 91.38 | 113.66 | 94.48 | 125.52 | 156.90 | 188.50 | 220.27 | 252.15 | 284.12 | 243.11 | 267.57 | 292.05 | 316.55 | 341.07 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.50 | 74.55 | 97.91 | 121.78 | 101.23 | 134.49 | 168.11 | 201.97 | 236.00 | 270.16 | 304.41 | 260.48 | 286.68 | 312.91 | 339.16 | 365.43 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.60 | 79.52 | 104.44 | 129.89 | 107.98 | 143.46 | 179.32 | 215.43 | 251.73 | 288.17 | 324.70 | 277.85 | 305.79 | 333.77 | 361.77 | 389.79 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.70 | 84.49 | 110.97 | 138.01 | 114.73 | 152.42 | 190.52 | 228.90 | 267.47 | 306.18 | 345.00 | 295.21 | 324.91 | 354.63 | 384.38 | 414.15 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.80 | 89.46 | 117.49 | 146.13 | 121.48 | 161.39 | 201.73 | 242.36 | 283.20 | 324.19 | 365.29 | 312.58 | 344.02 | 375.49 | 406.99 | 438.51 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.90 | 94.43 | 124.02 | 154.25 | 128.23 | 170.35 | 212.94 | 255.83 | 298.93 | 342.20 | 385.59 | 329.94 | 363.13 | 396.35 | 429.60 | 462.87 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.00 | 99.40 | 130.55 | 162.37 | 134.98 | 179.32 | 224.14 | 269.29 | 314.67 | 360.21 | 405.88 | 347.31 | 382.24 | 417.21 | 452.21 | 487.24 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.10 | 104.37 | 137.08 | 170.49 | 141.72 | 188.29 | 235.35 | 282.76 | 330.40 | 378.22 | 426.17 | 364.67 | 401.35 | 438.07 | 474.82 | 511.60 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.20 | 109.34 | 143.60 | 178.61 | 148.47 | 197.25 | 246.56 | 296.22 | 346.13 | 396.23 | 446.47 | 382.04 | 420.47 | 458.93 | 497.43 | 535.96 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.30 | 114.31 | 150.13 | 186.72 | 155.22 | 206.22 | 257.77 | 309.69 | 361.87 | 414.24 | 466.76 | 399.40 | 439.58 | 479.80 | 520.04 | 560.32 |

$T_a$ = 35 C, h = 4.2 + 0.09 x ($T_w$ - $T_a$) W/m$^2$. C , Q = ($T_w$ - $T_a$) / [($t_i$ / ($k_i$ x H)) + (1 / (H x h))] W/m. $T_{in}$ = [Q x (1/( H x h))] + $T_a$ C

Table 1.5-11 Heat loss from optimum insulation wall (Calcium Silicate density 135 kg/m$^3$ ($k_i$ = 0.049 W/m.K)) at ambient 35 C

| Optimum Insulation Thickness | | | | | | | | | | Heat loss optimum insulation wall (W/m.) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Wall Temp ( C) | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| 49 - 93 C | | 94 – 121 C | | 122 – 151 C | | 152 – 238 C | | 239 – 320 C | | Temp. after Insulate | 41.77 | 41.44 | 46.10 | 44.29 | 47.36 | 50.46 | 53.60 | 56.75 | 59.91 | 63.08 | 59.07 | 61.50 | 63.93 | 66.37 | 68.80 |
| in. | mm. | in. | mm. | in. | mm. | in. | mm. | in. | mm. | Wall High (m.) | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. | W/m. |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.50 | 27.08 | 35.63 | 44.39 | 37.14 | 49.42 | 61.85 | 74.38 | 86.98 | 99.64 | 112.33 | 96.28 | 106.00 | 115.73 | 125.47 | 135.21 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.60 | 32.49 | 42.76 | 53.27 | 44.57 | 59.31 | 74.23 | 89.26 | 104.38 | 119.56 | 134.80 | 115.54 | 127.20 | 138.88 | 150.56 | 162.25 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.70 | 37.91 | 49.89 | 62.15 | 52.00 | 69.19 | 86.60 | 104.14 | 121.78 | 139.49 | 157.26 | 134.80 | 148.40 | 162.02 | 175.65 | 189.30 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.80 | 43.33 | 57.01 | 71.03 | 59.43 | 79.08 | 98.97 | 119.01 | 139.18 | 159.42 | 179.73 | 154.05 | 169.60 | 185.17 | 200.75 | 216.34 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 0.90 | 48.74 | 64.14 | 79.90 | 66.86 | 88.96 | 111.34 | 133.89 | 156.57 | 179.35 | 202.19 | 173.31 | 190.80 | 208.31 | 225.84 | 243.38 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.00 | 54.16 | 71.27 | 88.78 | 74.28 | 98.85 | 123.71 | 148.77 | 173.97 | 199.27 | 224.66 | 192.57 | 212.00 | 231.46 | 250.93 | 270.42 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.10 | 59.57 | 78.40 | 97.66 | 81.71 | 108.73 | 136.08 | 163.64 | 191.37 | 219.20 | 247.12 | 211.82 | 233.20 | 254.60 | 276.03 | 297.46 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.20 | 64.99 | 85.52 | 106.54 | 89.14 | 118.62 | 148.45 | 178.52 | 208.76 | 239.13 | 269.59 | 231.08 | 254.40 | 277.75 | 301.12 | 324.51 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.30 | 70.41 | 92.65 | 115.42 | 96.57 | 128.50 | 160.82 | 193.40 | 226.16 | 259.06 | 292.06 | 250.34 | 275.60 | 300.90 | 326.21 | 351.55 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.40 | 75.82 | 99.78 | 124.30 | 104.00 | 138.39 | 173.19 | 208.28 | 243.56 | 278.98 | 314.52 | 269.60 | 296.80 | 324.04 | 351.31 | 378.59 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.50 | 81.24 | 106.90 | 133.17 | 111.43 | 148.27 | 185.56 | 223.15 | 260.95 | 298.91 | 336.99 | 288.85 | 318.00 | 347.19 | 376.40 | 405.63 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.60 | 86.65 | 114.03 | 142.05 | 118.86 | 158.16 | 197.93 | 238.03 | 278.35 | 318.84 | 359.45 | 308.11 | 339.20 | 370.33 | 401.49 | 432.67 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.70 | 92.07 | 121.16 | 150.93 | 126.28 | 168.04 | 210.30 | 252.91 | 295.75 | 338.77 | 381.92 | 327.37 | 360.40 | 393.48 | 426.59 | 459.72 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.80 | 97.48 | 128.28 | 159.81 | 133.71 | 177.93 | 222.68 | 267.78 | 313.14 | 358.69 | 404.39 | 346.62 | 381.60 | 416.63 | 451.68 | 486.76 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 1.90 | 102.90 | 135.41 | 168.69 | 141.14 | 187.81 | 235.05 | 282.66 | 330.54 | 378.62 | 426.85 | 365.88 | 402.80 | 439.77 | 476.77 | 513.80 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.00 | 108.32 | 142.54 | 177.56 | 148.57 | 197.70 | 247.42 | 297.54 | 347.94 | 398.55 | 449.32 | 385.14 | 424.01 | 462.92 | 501.87 | 540.84 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.10 | 113.73 | 149.66 | 186.44 | 156.00 | 207.58 | 259.79 | 312.41 | 365.34 | 418.48 | 471.78 | 404.39 | 445.21 | 486.06 | 526.96 | 567.89 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.20 | 119.15 | 156.79 | 195.32 | 163.43 | 217.47 | 272.16 | 327.29 | 382.73 | 438.40 | 494.25 | 423.65 | 466.41 | 509.21 | 552.05 | 594.93 |
| 1" | 25 | 1.5" | 38 | 1.5" | 38 | 1.5" | 38 | 2" | 50 | 2.30 | 124.56 | 163.92 | 204.20 | 170.85 | 227.35 | 284.53 | 342.17 | 400.13 | 458.33 | 516.71 | 442.91 | 487.61 | 532.36 | 577.15 | 621.97 |

$T_a = 35$ C, $h = 4.2 + 0.09 \times (T_w - T_a)$ W/m$^2$. C , $Q = (T_w - T_a) / [(t_i / (k_i \times H)) + (1 / (H \times h))]$ W/m. $T_{in} = [Q \times (1/( H \times h))] + T_a$ C

From these equations, we can generate Table 1.5-4 to 1.5-11 presenting energy loss before and after insulating the pipe with an economic thickness.

Surface heat loss analysis by Tables

Surface heat loss of Bare pipe

1. Measure surface temperature of the pipe. Let say 110 $^{O}$C
2. Measure the length and size of bare pipes for example pipe of 2' ' diameter and 10 meters.
3. Count the number of bare valves and flank and convert them to their equivalent length.

| Parts | Equivalent length (meters/Pcs.) |
|---|---|
| Valve | 0.4 |
| Flank | 1.2 |

For example, for 1 valve and 1 flank, the equivalent length is 0.4x1+1.2x1 =1.6

4. look at table 1.5-4 the surface heat loss of 110 C bare pipe is 232.49 $W_{th}$/m.
5. operating hours are 3000 hr./year
6. So the loss is = 232.49 W/m. x 11.6 m. x 3,000 hr/year x $10^{-3}$
   = 8,090.65 $kW_{th}$/y

Surface heat loss of Insulated pipe

1. Choose insulation materials-rock wool, glass wool or calcium silicate
2. Look up table 1.1-5 for surface temperature and loss of insulated pipe. In this case the loss is 18.40 $W_{th}$/m and 43.41 ◦ C surface temperature.
3. Look up table 1.1-3 for insulation thickness. That is 38 mm.
7. Operating hours are 3000 hr./year
8. So the loss is = 18.40 $W_{th}$/m. x 11.6 m. x 3,000 hr/year x $10^{-3}$ = 640.32 $kW_{th}$/y

The energy saving is = 8,090.65 – 640.32= 7,450.33$kW_{th}$/y

O Are there any example?

Example ECON factory uses Heavy oil to produce 7 $bar_g$ steam and distribute it by 2 inch pipes. From survey, 57 meters of bare pipe, 2 Pcs of non insulated valves and 3 Pcs of non insulated flank were found. The factory operator 312 day per year and 16 hrs per day. Ambient temperature is 35 ◦ C. Determine Fuel saving after insulated pipe.

Using Tables to analyze the project.

1. From Table 1.5-4, Surface heat loss of 150 ◦ C pipe = 412.71 $W_{th}$/m.

2. Choose insulation thickness from Table 1.5-3 = 38 mm. Or 1.5”
3. Use glass wool as insulation, Surface heat loss of insulating pipe from Table 1.5-6
   = 33.62 $W_{th}$/m.
4. Total length = 57 + (1.2 x 2) + (0.4 x3) = 60.6 m.
5. Saving of heat loss = (412.71-33.62) x 60.6 x 312 x16 / 1000
   = 114,680.49 $kW_{th}$/Y. = 114,680.49 x 3.6 = 412,849.76 MJ/Y.
6. Fuel saving = 412,849.76 / 38.18 = 10,813.25 L./Y.

** Heating value of Heavy Oil = 38.18 MJ/L.

## (6) STEAM MANAGEMENT

- How to produce and utilize steam in energy efficient manner

For a better boiler performance, the system should be produce dry saturated steam, and steam traps should be installed in steam distribution to maintain the dryness of the steam until it reaches the steam appliances. Also, an efficient steam management should be aware of the total performance of the system, starting from the steam boiler, steam distribution system and steam appliances. Every part of the steam system should be performed at the highest efficiency to be kept at the lowest cost of the system.

| *Steam boiler* | *Steam distribution* | *Steam equipment* |
|---|---|---|
| -High efficiency of the combustion process<br>-High efficiency of the heat exchange<br>-Good qualities of feed water and steam<br>-Small amount of heat loss | -Precise pipe installation and sizes<br>-No steam leaking<br>-Pipes and steam equipment insulated<br>-Good quality of steam in the distribution system | -Operating the equipment with similar load limiting<br>-Operating with control equipment with a good function<br>-Steam pressure used matching the requirement<br>-Small amount of heat loss |

Figure 1.6-1 Characteristics of high efficient steam production and utilization

Table 1.6-1 Comparison of the properties of saturated steam and super heat steam

| Saturated steam | Super heat steam |
|---|---|
| -High heat transfer coefficient (5,000-100,000 kcal / $m^2 \cdot {}^oC$)<br>-Suitable for heating equipment<br>-Temperature of equipment is controlled by steam pressure<br>-Substantial latent heat released when condensation at constant temperature | -Low heat transfer coefficient (20-100 kcal / $m^2 \cdot {}^oC$)<br>-Not suitable for heating equipment but suitable for high power equipment such as a steam turbine<br>-Unstable temperature at heating equipment<br>-Substantial heat loss occurred when applying to heating equipment<br>-High thermal stress occurred at the equipment |

- A steam boiler must be in high efficiency.

| Steam and Fuel consumption index; S/F | = $\dfrac{FeedWater(kg)}{FuelConsumption(fuelunit)}$ |
|---|---|

(1.6-1)

| Steam Generation Cost; $C_s$ | = $\dfrac{CostofFuelConsumption}{FeedWater}$ |
|---|---|

(1.6-2)

<u>Setting</u> - Water 1 litre equals 1 kg of weight (density of 1000 kg/$m^3$)

- The fuel unit depends on fuel type
- Cost of Fuel = Fuel Consumption x Price of fuel per Litre

The two devices, fuel consumption meter and feed water flow meter, are necessary for determining the index value. These two figures are normally recorded in the log sheet.

Table 1.6-2 Standard of steam and fuel consumption index for boiler

| Type of fuel | steam and fuel consumption index |
|---|---|
| Liquid | 14 $kg_{stream}/kg_{fuel}$ |
| Solid | 8 $kg_{stream}/kg_{fuel}$ |
| Gas | 13 $kg_{stream}/Nm^3_{fuel}$ |

If the real index value from the operation is lower than the standard, this means the decrease of boiler efficiency and the increase of steam investment cost. Practically, we can take the S/F value derived after the commissioning or annual cleaning of the boiler as the boiler standard. Herein, for every 1 $kg_{steam}$/1unit of fuel decrease, the boiler efficiency reduces about 7%.

### Example

The factory has 10 ton/hr boiler using heavy oil. From data collection, The boiler consume 9,600 L/d and Feed water is about 130,000 L/d. Blowdown rate is 10,000 L/d. Oil price is 13 Baht/L.

$$\text{Steam Fuel Ratio} = \frac{(130,000 - 10,000)}{9,600} = 12.50 \text{ kg/L}$$

$$\text{Steam Cost} = \frac{9{,}600 \times 13}{(130{,}000 - 10{,}000)} = 1{,}040 \text{ Baht/ton}$$

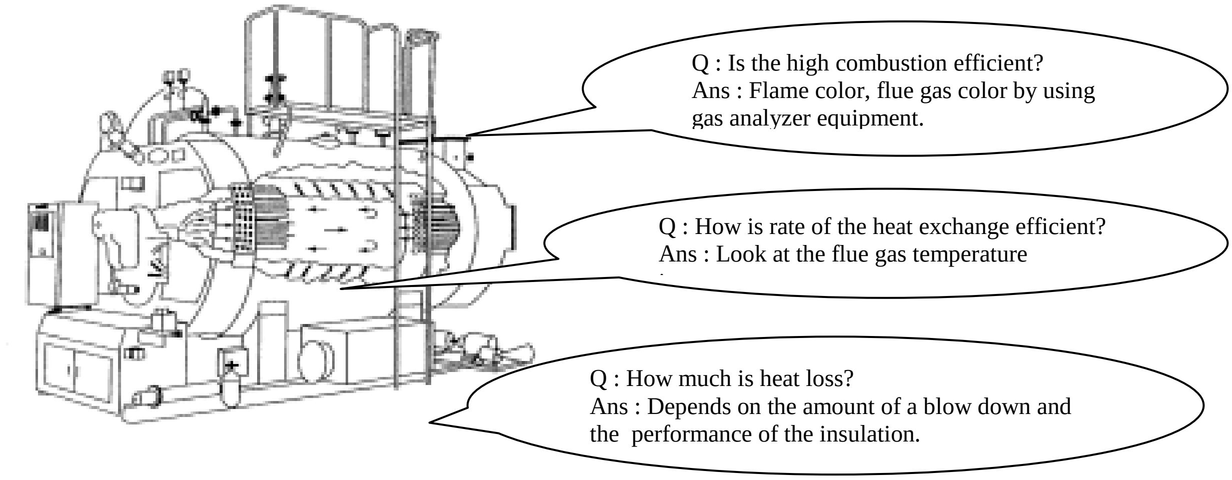



Figure 1.6-2 Guidelines for boiler improvement justification

O How to match boiler operation and steam demand?

When boilers operate at low load, The steam cost will rise because some losses such as surface loss blowdown loss are fixed. Therefore sizes and number of boiler should be well matched with steam demand. Generally boiler load should be higher than 80%.

Example

The factory has 2 boilers of 5t/h and 10 ton/hr. The plant runs 24 hrs a day and 365 d/y. At 01:00 – 13:00 steam demand is very low (3-4 t/h) and 13:00 – 01:00 steam demand rises to 7-8 t/h. Normally 10 t/h boiler operates all the time. The factory has a plan to run small boiler at low load.

Present, Running 10 t/h boiler from 13:00 to 01:00

From Measurement,

| | | | |
|---|---|---|---|
| Fuel Consumption | = 270 | L/h | |
| Feed Water | = 3,500 | L/h | |
| Steam to Fuel Ratio | = | 12.96 | kg/L |

After Implement, Running 5 t/h boiler from 13:00 to 01:00

From Measurement,

| | | | |
|---|---|---|---|
| Fuel Consumption | = 260 | L/h | |
| Feed Water | = 3,500 | L/h | |
| Steam to Fuel Ratio | = | 13.46 | kg/L |

- **Reduce Pressure drop in the steam system.**

The steam in boiler will be transfer through the steam distribution system. The incorrect size of steam pipes in the system , the effects in the system are following :

**Table 1.6-3 Comparison of the effects resulting from under sized and over sized steam pipes**

| Under sized steam pipe | Over sized steam pipe |
|---|---|
| - High pressure drop in the system.<br>- Difficult to supply the steam in system.<br>- Noise occurred in the steam pipe. | - Low pressure drop in the system.<br>- High investment costs.<br>- High heat loss in steam distribution system. |

The factors to be taken into consideration for the steam piping design include pressure drop, heat loss, and maintenance and installation costs.

Table 1.6-4 Flow rate capacity of steam in different pipe sizes

| Pressure | Density | Velocity | Diameter of Pipe (mm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (barg) | ($kg/m^3$) | (m/s) | 15 | 20 | 25 | 32 | 40 | 50 | 65 | 80 | 100 | 125 | 150 | 200 | 250 |
| 1 | 1.135 | 25 | 18 | 32 | 50 | 82 | 128 | 201 | 339 | 514 | 803 | 1,254 | 1,806 | 3,210 | 5,016 |
| | 1.135 | 40 | 29 | 51 | 80 | 131 | 205 | 321 | 543 | 822 | 1,284 | 2,007 | 2,889 | 5,137 | 8,026 |
| 2 | 1.658 | 25 | 26 | 47 | 73 | 120 | 188 | 293 | 495 | 750 | 1,172 | 1,832 | 2,638 | 4,690 | 7,328 |
| | 1.658 | 40 | 42 | 75 | 117 | 192 | 300 | 469 | 793 | 1,201 | 1,876 | 2,931 | 4,221 | 7,504 | 11,724 |
| 3 | 2.169 | 25 | 35 | 61 | 96 | 157 | 245 | 383 | 648 | 982 | 1,534 | 2,397 | 3,451 | 6,135 | 9,586 |
| | 2.169 | 40 | 55 | 98 | 153 | 251 | 393 | 614 | 1,037 | 1,571 | 2,454 | 3,834 | 5,522 | 9,816 | 15,338 |
| 4 | 2.674 | 25 | 43 | 76 | 118 | 194 | 303 | 473 | 799 | 1,210 | 1,891 | 2,955 | 4,255 | 7,564 | 11,818 |
| | 2.674 | 40 | 68 | 121 | 189 | 310 | 484 | 756 | 1,278 | 1,936 | 3,025 | 4,727 | 6,807 | 12,102 | 18,909 |
| 5 | 3.175 | 25 | 51 | 90 | 140 | 230 | 359 | 561 | 949 | 1,437 | 2,245 | 3,508 | 5,052 | 8,981 | 14,032 |
| | 3.175 | 40 | 81 | 144 | 225 | 368 | 575 | 898 | 1,518 | 2,299 | 3,592 | 5,613 | 8,083 | 14,369 | 22,452 |
| 6 | 3.676 | 25 | 58 | 104 | 162 | 266 | 416 | 650 | 1,098 | 1,664 | 2,599 | 4,062 | 5,849 | 10,398 | 16,247 |
| | 3.676 | 40 | 94 | 166 | 260 | 426 | 665 | 1,040 | 1,757 | 2,662 | 4,159 | 6,499 | 9,358 | 16,637 | 25,995 |
| 7 | 4.167 | 25 | 66 | 118 | 184 | 302 | 471 | 737 | 1,245 | 1,886 | 2,947 | 4,604 | 6,630 | 11,787 | 18,417 |
| | 4.167 | 40 | 106 | 189 | 295 | 483 | 754 | 1,179 | 1,992 | 3,017 | 4,715 | 7,367 | 10,608 | 18,859 | 29,467 |
| 8 | 4.651 | 25 | 74 | 132 | 206 | 337 | 526 | 822 | 1,390 | 2,105 | 3,289 | 5,139 | 7,400 | 13,156 | 20,556 |
| | 4.651 | 40 | 118 | 210 | 329 | 539 | 842 | 1,316 | 2,223 | 3,368 | 5,262 | 8,222 | 11,840 | 21,049 | 32,889 |
| 9 | 5.155 | 25 | 82 | 146 | 228 | 373 | 583 | 911 | 1,540 | 2,333 | 3,645 | 5,696 | 8,202 | 14,581 | 22,783 |
| | 5.155 | 40 | 131 | 233 | 365 | 597 | 933 | 1,458 | 2,464 | 3,733 | 5,833 | 9,113 | 13,123 | 23,330 | 36,453 |
| 10 | 5.650 | 25 | 90 | 160 | 250 | 409 | 639 | 999 | 1,688 | 2,557 | 3,995 | 6,243 | 8,990 | 15,981 | 24,971 |
| | 5.650 | 40 | 144 | 256 | 400 | 655 | 1,023 | 1,598 | 2,701 | 4,091 | 6,393 | 9,988 | 14,383 | 25,570 | 39,954 |

Steam Piping Sizeing (Capacity in kg/h)

The flow rate of steam : $\overset{o}{m}_s$ = $900 \times \pi \times \rho \times d^2 \times V$ (1.6-3)

Where $\overset{o}{m}_s$ : Steam flow rate (kg/h)

$\rho$ : Steam density ($kg/m^3$)

$d$ : Pipe inner-diameter (m)

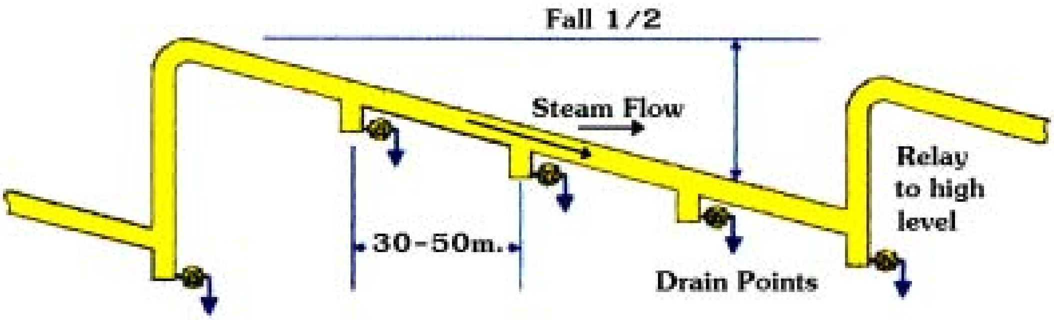
$V$ : Steam velocity (m/s)

If designed of steam flow rate is a maximum load, steam velocity in pipe is 40 m/s. This condition to reduce steam pipe size. But if it is an average load, steam velocity should be 25 m/s, for system equipment operation at start-up point or maximum load.

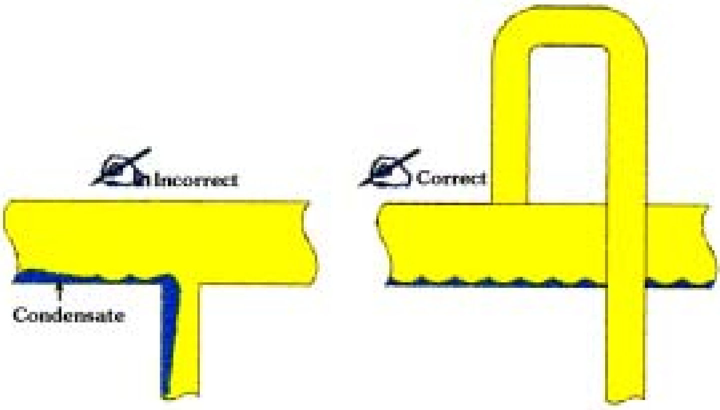
## Steam Piping installation techniques

- Steam pipes should be as short as possible.
- Connect pipes with welding rather than threaded pipe connection to avoid the leaking problem.
- Choose flange valves, and avoid thread valves.
- Select bend piping instead of elbow to avoid high pressure drop

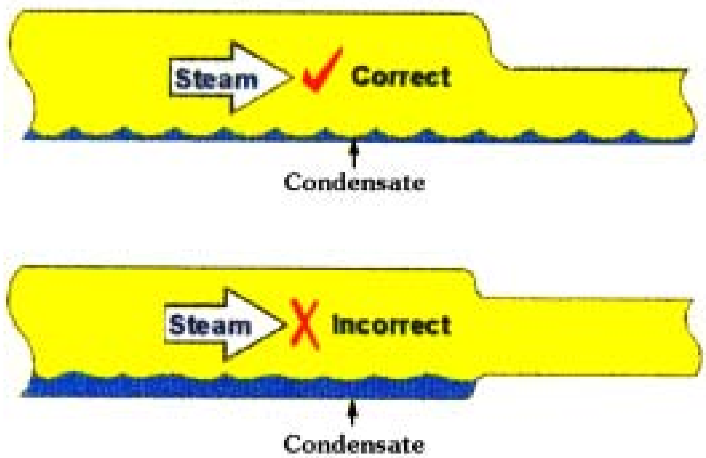
- Steam pipe should have a slope of 1:250, declining parallel to the steam direction. Steam traps should be installed for every 30-50 meters along with the pipe.




- Always choose the open bucket traps or thermodynamics traps types for discharging condensate from the main steam pipe.
- Install expansion loops within the steam pipe to prevent the crack and damage of steam pipes and steam equipment
- Branch steam pipes, excluding condensate discharge pipes, should be connected at the upper side of the main pipe not including drain pipe.




- Reduction of pipe should be free of condensate.



o **Avoid steam leakage**

Valve and joint is basic equipment in the steam distribution system. The steam leakage of such equipment is often while the system operated. The steam leakage will become larger hole and give more seriousness if the repair is not done immediately. The expansion rate of the leakage depends on the leakage hole size and the steam pressure in the system. Therefore, immediate repair of the steam leakage is essential.

Figure 1.6-3 Steam leaking rate at different steam pressures and leakage sizes (kg/h)

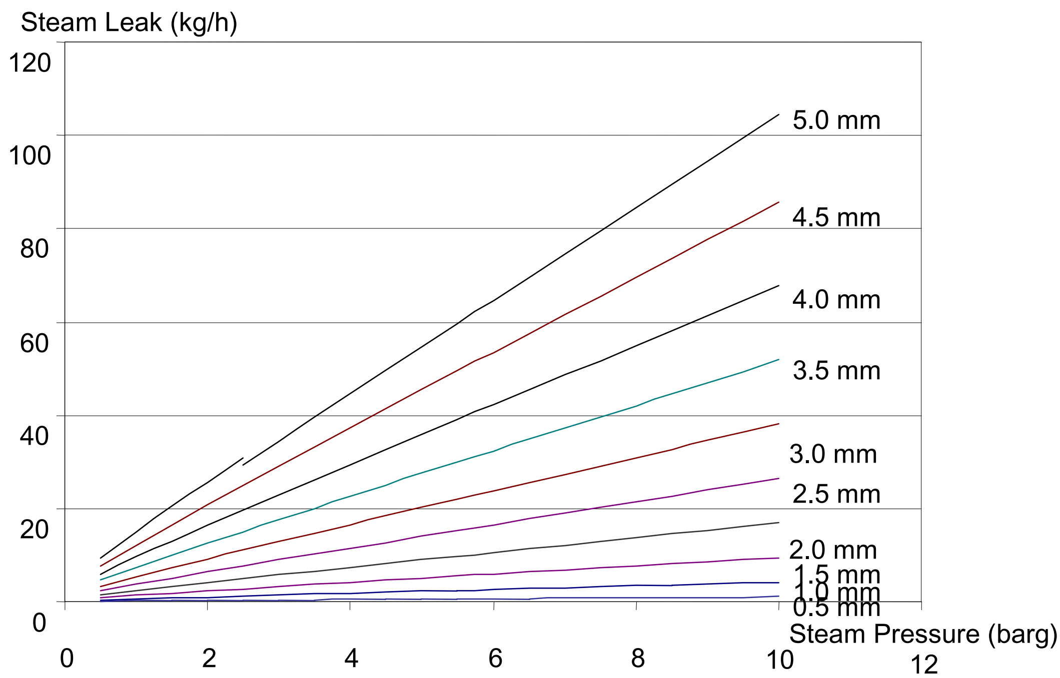



Table 1.6-5 Steam leaking rate at different steam pressures and leakage sizes (kg/h)

| Pressure (barg) | Specific Volume ($m^3$/kg) | Density (kg/$m^3$) | Diameter of Leak (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| 1.0 | 0.881 | 1.135 | 0.15 | 0.60 | 1.35 | 2.40 | 3.75 | 5.40 | 7.35 | 9.60 | 12.14 | 14.99 |
| 1.5 | 0.714 | 1.135 | 0.20 | 0.82 | 1.84 | 3.26 | 5.10 | 7.34 | 9.99 | 13.05 | 16.52 | 20.40 |
| 2.0 | 0.603 | 1.658 | 0.26 | 1.03 | 2.31 | 4.10 | 6.41 | 9.23 | 12.56 | 16.40 | 20.76 | 25.63 |
| 2.5 | 0.522 | 1.658 | 0.31 | 1.23 | 2.77 | 4.93 | 7.70 | 11.09 | 15.09 | 19.71 | 24.94 | 30.80 |
| 3.0 | 0.461 | 2.169 | 0.36 | 1.44 | 3.23 | 5.74 | 8.97 | 12.92 | 17.59 | 22.97 | 29.08 | 35.90 |
| 3.5 | 0.413 | 2.169 | 0.41 | 1.64 | 3.69 | 6.55 | 10.24 | 14.75 | 20.07 | 26.22 | 33.18 | 40.97 |
| 4.0 | 0.374 | 2.674 | 0.46 | 1.84 | 4.14 | 7.36 | 11.51 | 16.57 | 22.55 | 29.45 | 37.28 | 46.02 |
| 4.5 | 0.342 | 2.674 | 0.51 | 2.04 | 4.59 | 8.17 | 12.76 | 18.38 | 25.01 | 32.67 | 41.35 | 51.05 |
| 5.0 | 0.315 | 3.175 | 0.56 | 2.24 | 5.05 | 8.97 | 14.02 | 20.18 | 27.47 | 35.88 | 45.41 | 56.06 |
| 5.5 | 0.292 | 3.175 | 0.61 | 2.44 | 5.50 | 9.77 | 15.27 | 21.99 | 29.93 | 39.09 | 49.47 | 61.07 |
| 6.0 | 0.272 | 3.676 | 0.66 | 2.64 | 5.95 | 10.57 | 16.52 | 23.79 | 32.39 | 42.30 | 53.53 | 66.09 |
| 6.5 | 0.255 | 3.676 | 0.71 | 2.84 | 6.39 | 11.37 | 17.76 | 25.58 | 34.81 | 45.47 | 57.55 | 71.05 |
| 7.0 | 0.240 | 4.167 | 0.76 | 3.04 | 6.84 | 12.16 | 19.00 | 27.36 | 37.24 | 48.64 | 61.56 | 76.00 |
| 7.5 | 0.227 | 4.167 | 0.81 | 3.24 | 7.28 | 12.94 | 20.22 | 29.12 | 39.63 | 51.77 | 65.52 | 80.89 |
| 8.0 | 0.215 | 4.651 | 0.86 | 3.43 | 7.73 | 13.73 | 21.46 | 30.90 | 42.06 | 54.94 | 69.53 | 85.84 |
| 8.5 | 0.204 | 4.651 | 0.91 | 3.63 | 8.18 | 14.53 | 22.71 | 32.70 | 44.51 | 58.13 | 73.58 | 90.84 |
| 9.0 | 0.194 | 5.155 | 0.96 | 3.83 | 8.63 | 15.34 | 23.96 | 34.51 | 46.97 | 61.34 | 77.64 | 95.85 |
| 9.5 | 0.185 | 5.155 | 1.01 | 4.03 | 9.08 | 16.13 | 25.21 | 36.30 | 49.41 | 64.54 | 81.68 | 100.84 |
| 10.0 | 0.177 | 5.650 | 1.06 | 4.23 | 9.52 | 16.92 | 26.44 | 38.08 | 51.83 | 67.69 | 85.68 | 105.77 |

$$\overset{o}{m}_L = 199 \times A \times \sqrt{\frac{P}{v}} \times 3{,}600 \times n \qquad (1.6\text{-}4)$$

Where $\overset{o}{m}_L$ = steam leaking rate (kg/h)A = cross sectional area of the leakage ($m^2$)

P = steam pressure (barg) v = specific volume of steam ($m^3$/kg)

n = number of the leakage (hole)

o **Procedure to calculate steam loss by the steam leakage**

$$FL\ (L/h) = \frac{\overset{o}{m}_L}{S/F} \qquad (1.6\text{-}5)$$

WhereFL = fuel loss (L/h)

$\overset{o}{m}_L$ = steam leaking rate

S/F = steam and fuel consumption index (from the Equation 1.6-1)

**Example** ECON Factory using a steam boiler with a capacity of 10 ton/h, grade C of bunker oil at 3,000,000 liters per year. The feed water to boiler is 40,500,000 liters/year. The boiler operated 16 h/d and 312 d/y, and generate steam pressure at 7 barg. From the inspection of the steam pipe, it is found that there are 20 points of leakage with cross sectional area of 1 mm each point. How much are the steam and fuel lost from the leaking?

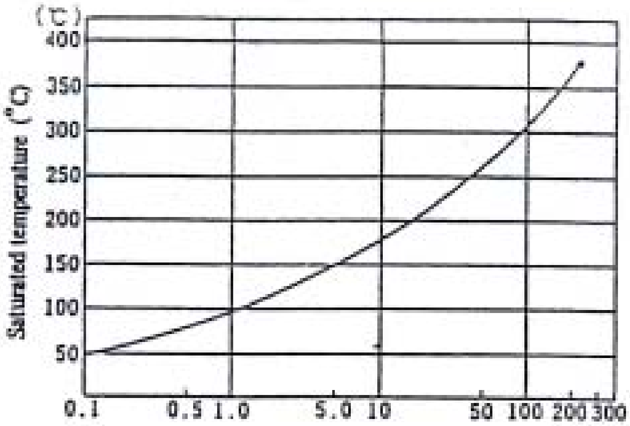
From Table 1.6-5, for steam pressure of 7 barg and leakage of 1 mm. in size, the steam leaking rate will be 3.04 kg/h per point. For 30 points of leakage, the total steam leaking will be 91.2 kg/h..

From (1.6-1), the S/F ratio will be = $\frac{40{,}500{,}000}{3{,}000{,}000}$ = 13.5 kg/L

From (1.6-3), the loss of fuel will be = $\frac{91.2}{13.5}$ = 6.76 L/h

The annual fuel loss will be = 6.76x16x312 = 33,745.92 L/Y o Appropriate Steam pressure

Too high steam pressure generated will result in too much energy consumption. In general, the steam pressure will be recommends by heating processes, and no used high steam pressure. However the characteristic of steam, the temperature will relate the pressure as presented in the figure below.




Saturated steam

Figure 1.6-4 The relation between temperature and pressure of steam

| Steam pressure = Maximum pressure required + pressure drop in the system | (1.6-6) |
|---|---|

The reduction of steam pressure to a proper level will give the following benefits:

1. Latent heat ($h_{fg}$) for condensing steam will increase.
2. Steam dryness ratio will increase, resulting in the increase of energy from the steam, as showed in 1.6-5.
3. It helps reduce the steam loss from pipe leaking
4. It helps reduce the heat loss at the boiler surface and steam distribution system.
5. It helps reduce the steam loss from the blow down and the steam system.
6. It reduces fuel consumption for the same amount of steam generation.

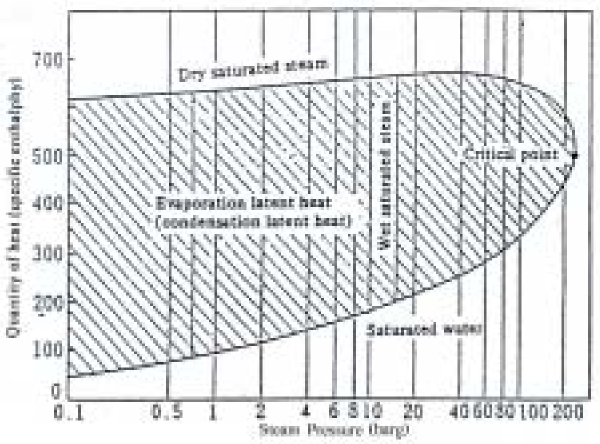



Figure 1.6-5 The relation between steam pressure and latent heat

Table 1.6-6 Percentage of energy saved from steam pressure reduction

| Item | Before Pressure Reduced (barg) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| After Pressure Reduced (barg) | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | |
| Feed Water Temperature($^{o}$C) | 5.5 | 5.0 | 4.5 | 6.5 | 6.0 | 5.5 | 7.5 | 7.0 | 6.5 | 8.5 | 8.0 | 7.5 | 9.5 | 9.0 | 8.5 |
| 30 | 0.123 | 0.247 | 0.398 | 0.104 | 0.208 | 0.331 | 0.087 | 0.174 | 0.278 | 0.077 | 0.155 | 0.241 | 0.066 | 0.132 | 0.209 |
| 35 | 0.124 | 0.249 | 0.401 | 0.105 | 0.210 | 0.334 | 0.088 | 0.175 | 0.280 | 0.078 | 0.156 | 0.243 | 0.066 | 0.133 | 0.211 |
| 40 | 0.125 | 0.251 | 0.405 | 0.106 | 0.212 | 0.337 | 0.088 | 0.177 | 0.282 | 0.079 | 0.157 | 0.245 | 0.067 | 0.134 | 0.212 |
| 45 | 0.126 | 0.253 | 0.408 | 0.107 | 0.213 | 0.339 | 0.089 | 0.178 | 0.284 | 0.079 | 0.158 | 0.247 | 0.068 | 0.135 | 0.214 |
| 50 | 0.127 | 0.255 | 0.411 | 0.107 | 0.215 | 0.342 | 0.090 | 0.179 | 0.287 | 0.080 | 0.160 | 0.249 | 0.068 | 0.136 | 0.216 |
| 55 | 0.128 | 0.257 | 0.415 | 0.108 | 0.217 | 0.345 | 0.090 | 0.181 | 0.289 | 0.081 | 0.161 | 0.251 | 0.069 | 0.137 | 0.218 |
| 60 | 0.129 | 0.259 | 0.418 | 0.109 | 0.219 | 0.348 | 0.091 | 0.182 | 0.292 | 0.081 | 0.162 | 0.253 | 0.069 | 0.138 | 0.219 |
| 65 | 0.131 | 0.261 | 0.422 | 0.110 | 0.220 | 0.351 | 0.092 | 0.184 | 0.294 | 0.082 | 0.164 | 0.256 | 0.070 | 0.140 | 0.221 |
| 70 | 0.132 | 0.263 | 0.425 | 0.111 | 0.222 | 0.354 | 0.093 | 0.186 | 0.296 | 0.083 | 0.165 | 0.258 | 0.070 | 0.141 | 0.223 |
| 75 | 0.133 | 0.266 | 0.429 | 0.112 | 0.224 | 0.357 | 0.094 | 0.187 | 0.299 | 0.083 | 0.167 | 0.260 | 0.071 | 0.142 | 0.225 |
| 80 | 0.134 | 0.268 | 0.433 | 0.113 | 0.226 | 0.360 | 0.094 | 0.189 | 0.302 | 0.084 | 0.168 | 0.262 | 0.072 | 0.143 | 0.227 |
| 85 | 0.135 | 0.270 | 0.436 | 0.114 | 0.228 | 0.363 | 0.095 | 0.190 | 0.304 | 0.085 | 0.169 | 0.264 | 0.072 | 0.144 | 0.229 |
| 90 | 0.136 | 0.273 | 0.440 | 0.115 | 0.230 | 0.366 | 0.096 | 0.192 | 0.307 | 0.085 | 0.171 | 0.267 | 0.073 | 0.146 | 0.231 |
| 95 | 0.137 | 0.275 | 0.444 | 0.116 | 0.232 | 0.369 | 0.097 | 0.194 | 0.310 | 0.086 | 0.172 | 0.269 | 0.073 | 0.147 | 0.233 |
| 100 | 0.139 | 0.277 | 0.448 | 0.117 | 0.234 | 0.373 | 0.098 | 0.195 | 0.312 | 0.087 | 0.174 | 0.272 | 0.074 | 0.148 | 0.235 |
| 105 | 0.140 | 0.280 | 0.452 | 0.118 | 0.236 | 0.376 | 0.099 | 0.197 | 0.315 | 0.088 | 0.176 | 0.274 | 0.075 | 0.150 | 0.237 |
| 110 | 0.141 | 0.283 | 0.456 | 0.119 | 0.238 | 0.379 | 0.100 | 0.199 | 0.318 | 0.089 | 0.177 | 0.276 | 0.075 | 0.151 | 0.239 |

% Saving for Exclude leaking , Surface loss and Blowdown loss

## How to optimize steam pressure for fuel saving?

ECON Factory operates a steam boiler with a capacity of 10 t/h, using grade C of bunker oil at a volume of 3,000,000 liters per year. The feed water intake is 40,500,000 liters/y. The boiler generates steam pressure at 7 barg, and its feed water temperature is 80 $^{o}$C. It is found that the required steam pressure is maximum at 5 barg, and the pressure drop in steam distributing is 0.5 barg. As a result, the factory is able to reduce the pressure of steam generation.

From (1.6-6)

The new pressure of steam generated =5.0 + 0.5= 5.5 barg

From Table 1.6-6, at the temperature of 80 $^{o}$C, the initial steam pressure of 7.0 barg and the new steam pressure of 5.5 barg, the energy that can be saved will be 0.360%.

And the fuel that can be saved will be =3,000,000 x (0.360/100) =10,800 L/Y

1.3 I Measures to inspect and maintain boilers

A boiler operator should have appropriate skills of inspection, analysis and maintenance of the equipment, in order to maintain its efficiency long life of steam boiler and operation safety. A guideline for inspection, analysis and maintenance is as follows:

(1) Inspection and analysis of the steam boiler and steam distribution system

| Checklists | | Analysis Guideline |
|---|---|---|
| Items | How often | |
| 1. Soot removal | every…month | 1. To remove the soot from heat exchange surface (fire side) regularly maintains the heat exchange efficiency. This is because the soot acts as heat resistance and more heat lost through the stack. In general, the soot removal should be done after the flue gas temperature is 20 °C higher than that after newly cleaned. |
| 2. Scale removal | every….month | 2. The scale depositing on the waterside of heat exchanger surface to decreases the heat exchange efficiency. In general, the scale removal should be done once a year. |
| 3. Burner cleaning (liquid fuel) | Every day | 3. A burner is important equipment for completion combustion. Therefore, cleaning the burner once a week is necessarily recommended. |
| 4. Flue gas temperature | ………..°C | 4. Too high flue gas temperature means too much heat loss from the boiler system. It is important that the air-fuel ratio adjustment and cleaning of heat exchange surfaces should be regularly practiced. |
| 5. Flame color | ……………… ……… | 5. Normally, the flame color from liquid fuel should be orange, while that from gaseous fuel should be blue with orange end. |
| 6. Flue gas color | ……………… ……… | 6. For a complete combustion, the flue gas color from stack should be gray. White smoke indicates too much air content in the combustion. |
| 7. Brightness of combustion chamber | ……………… ……… | 7. Too bright combustion chamber indicates too much air content in the combustion. In the contrary, too dark combustion chamber means too low air content. |

| | | |
|---|---|---|
| 8. Liquid fuel temperature | ……………$^{O}$C | 8. The lower fuel temperature, the result to higher viscosity of liquid fuel, will hamper the blending process of fuel droplets and the air, and in completion of combustion. In general, the A-grade and C-grade bunker oil should be preheated to the temperatures of 90 and 110 °C, respectively. |
| 9. Liquid fuel pressure | ………$Bar_g$ | 9. Liquid fuel pressure should meet the standard of each type of burner. Lower fuel pressure means lower efficiency of the combustion. |
| 10. Feed water temperature | …………$^{O}$C | 10. The feed water temperature should be as high as possible, for this will shorten the time required for steam generation, and the dissolved gases will be easier removed. Dissolved oxygen causes erosion on water/steam piping system. The feed water temperature should not be lower than 90 °C. |
| 11. Blow down | every….hour | 11. The effect of the higher amount of water blow down to increase the heat loss and fuel consumption. Generally, the conductivity of boiler water should be controlled in the range of 6000-7000 μS/cm. Value adjustment should be using from the feed water. |
| 12. Feed water quality | ………μS/cm | 12. The feed water should be well treated—suspended and dissolved solid removed, otherwise the scale problem will occur. In general, the feed water conductivity should be maintained at lower than 800 μS/cm. |
| 13. Boiler surface temperature | …………$^{O}$C | 13. The insulated wall of a boiler should have a temperature of lower than 60 C, or be touchable. |
| 14. Fuel reheat process. | ……………. | 14. The fuel preheat by electricity only more will cost more than using both the electricity and the steam. |
| 15. Generated Steam pressure (minimum-maximum) | …………$Bar_g$ | 15. High pressure generation used energy than the lower one. This is because represents more heat loss in its generation process, and received latent heat less than at low steam pressure. |
| 16. Maximum steam pressure required by steam equipment' s | ……$Bar_g$ | 16. All steam equipment' s pressure requirements should be set to meet those equipment' s standards. Then, the steam pressure will also be reduced to be slightly higher than the maximum requirements of those equipment' s. Pressure drop in the steam piping system should be less than 0.5 $bar_g$. |

| | | |
|---|---|---|
| 17. Percentage of high pressure steam required for all steam equipment' s | …………% | 17. High pressure steam equipment' s used to a small amount of steam white compared to the factory' s total steam demand. Classification of steam equipment' s into low and high pressure steam requirements is recommended. |
| 18. Condition of insulation pipes valves and flank | ………… | 18. Insulation of pipes, valves and flanges will help reduce the heat loss, and maintain the steam quality (the dryness), providing efficient performance of steam equipment' s. |
| 19. Steam leakage | ……….point | 19. Steam leakage should be avoided for it causes the loss of heat from steam. |
| 20. Steam generation per fuel consumption | ……………….. | 20. The liquid-fuel steam boiler should be used steam generation and fuel consumption ratio of 14:1. |
| 21. Steam boiler operation at low loading | ……………. | 21. The boiler operation at lower load, the boiler efficiency to decrease the total loss is stable. |
| 22. Start-stop frequency of the burner | ……………. | 22. Before each start up, the burner needs to be purged for 2 minutes for safety reason. Too often start-stop of the burner can cause substantial heat loss, due to the cold air supplied to combustion chamber. Hence, if larger boiler caused higher frequency of start-stop of the burner, the burner size should be reduced or shorter purging should be practiced. |
| 23. Selection of the highest efficiency boiler | ………… | 23. Each set of boilers operated with different efficiency from others. In order, the ratio of steam generated and fuel consumed of the set should be recorded. The highest ratio means the highest boiler efficiency. Thus, we should plan to operate the highest boiler efficiency set as the first priority. |
| 24. Have pressure drop problem? | …………… | 24. Pressure drop may result from too small and long pipe, too many joints of the pipe, too much steam consumption at the same time, or malfunctioning of a pressure reducing valve. Hence, this should be checked the condition of the problem. An installation of a steam accumulator in the local area of high steam consumption is recommended. |
| 25. Steam equipment' s delay to become hot. | ………… | 25. This problem can be resulted from the wet steam. It is necessary that the steam input should be dried by water separation. The problem can also be resulted from the malfunction of a control valve or dirty of heat exchange surface. |

| | | |
|---|---|---|
| 26. Steam trap check-up | every…month | 26. The steam trap should neither leak nor clog, and its by-pass valve should not leak either. Leaking will cause heat loss, while clogging will cause the delay to be hot of steam equipment' s due to the condensate accumulation in the system. |
| 27. Suitable size of steam trap for proper function | ………… | 27. If the steam trap in the system is not corrected, will increase the damage and clog frequency. Too small steam trap will hamper the condensate draining and head drop in the steam equipment' s. |
| 28. Percentage of condensate recovery | …………….% | 28. Condensate is clean and hot water. Without corrosion problems, it should be recovered to preheat feed water or to use as a heat source for that area. |
| 29. Flue gas recovery | ……………… …... | 29. The application of flue gas. It can be recovered to use in heat exchanger such as economizer and air preheator. However, be aware of erosion if the fuel contains sulfur. |
| 30. Blow down recovery | ……………… …. | 30. In case of a large amount of blow down, the recovery of the blow down should be applied, for example, to preheat the feed water by using heat exchanger, and applying continuous blow down in the system. |

(2) The maintenance of a steam boiler

| Implementation | Appropriate period |
|---|---|
| 1. Adjustment of the fuel/air ratio regarding to the standard of each fuel type | Every 3 months |
| 2. Inspection of the feed water and boiler water qualities regarding to the international standard | Every week (feed water) |
| 3. Cleaning burners and accessories | Every month (boiler water) |
| 4. Inspection of the boiler' s fire-resistant bricks, walls and insulation | Every week (liquid fuel) |
| 5. Cleaning heat exchange surface both water side and fire side | Every month (gaseous fuel) |
| 6. Observation of the shape and color of the flame | Every year |

| | |
|---|---|
| 7. Cleaning the strainers of both feed water and fuel oil | Every year |
| 8. Inspection of the air entrance to the boiler, and cleaning the blower's' suction side as well as air strainers (if any) | Every day<br>Every month |
| 9. Cleaning the flue gas stack | Every month |
| 10. Cleaning the feed water tank, chemical storage tanks and fuel oil tanks | Every 3 years |
| 11. Inspection of the insulation of the steam distribution system and the steam equipment's | Every year |
| 12. Inspection and repairing the steam leakage's (if any) | Every month<br>Every day |
| 13. Inspection of the conditions of the following equipment<br>- Measuring devices such as flow meter, pressure gauge,<br>thermocouple, flue gas analyzer<br>- Water and fuel pumps<br>- Valves and automatic valves<br>- Blower motors<br>- Burners and fuel oil preheator's<br><br><br>- Steam traps | <br>3 months<br><br><br>Every year<br>Every year<br>Every year<br>Every month<br>Every 6 months (liquid fuel)<br>Every week (gaseous fuel)<br>Every month |
| 14. Inspection and record of these items<br>- Water and fuel consumption rates<br>- Pressure and temperature of fuel oil before the in to the burner<br>- Pressure and/or temperature of steam<br>- Feed water and boiler water qualities<br>- Oxygen or carbon dioxide contents in the flue gas<br>- Flue gas temperature after the combustion chamber<br>- Appearance and colors of the flue gas<br>- Boiler's surface temperature, steam pipe insulation's surface temperature and steam appliances' surface temperature | <br>Every day<br>Every day<br>Every day<br><br>After each water sample test<br>After each adjustment<br>Every day<br>Every day<br>Every month |

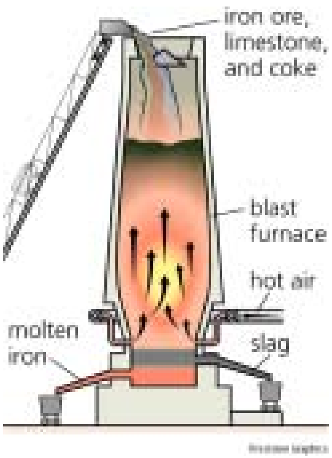
Chapter 2

# Industrial Furnaces

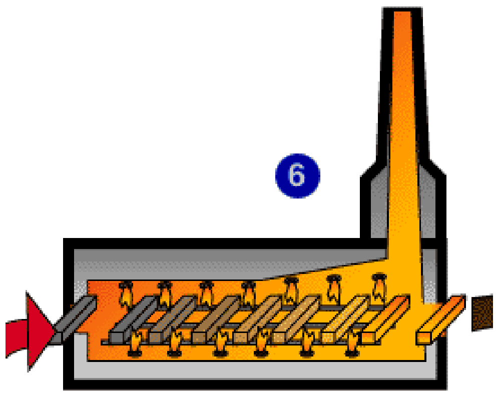
## 2.1 Furnace Application

Furnaces are one of the largest energy-use equipment in industry like those of foundry, Steel , Glass , Ceramic, Cement or Chemical plants etc.

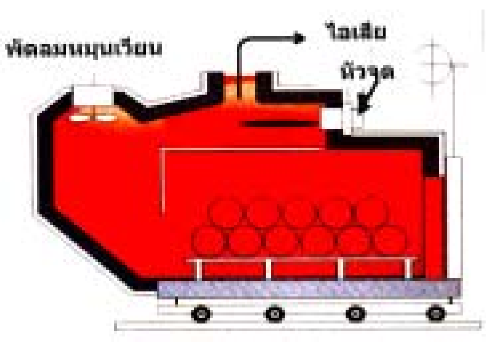
Furnaces have many types different in physical structures and operations for example, Blast Furnaces which iron ore and coke are fed from the top and combustion air enters at the middle and molten iron drops to the lower trays, Reheat Furnaces which iron bars are conveyed through the combustion chamber with or without pushers, Ceramic furnaces which pottery is contained in trolleys or cement furnaces which are rotating cylinders as shown in Figure 2-1




a. Blast Furnaces




b. Reheat Furnaces




c. Melting Furnace

d. Cement kilns

Figure 2-1 Industrial Furnaces

O Furnace Structure

Though furnaces have many structures and operations , they have the same basic components which are Bases, Frames for insulation holding , thermal Insulation , Combustion chambers which is heating zones, Product handlers , Control systems which controls temperature and pressure in furnace and Heat recovery parts.

O What is the furnace efficiency?

Industrial furnaces generally operate at high temperature as shown in Table 2.1-2.

| Furnace types | Furnace temperature ($^{O}$C) |
|---|---|
| Annealing furnaces | 600-1,100 |
| Glass furnaces | 1,000-1,300 |
| Ceramic furnaces | 700-1,100 |
| Cement furnaces | 650-700 |
| incinarators | 650-1,000 |

The higher operating temperature, the higher flue gas temperature and losses. Basically furnaces efficiency is about 20-40 % that means at most only 4 units of energy products can receive from 10 units of input energy. Figure 2.1-2 shows energy balance of reheating furnaces. The product energy is about 20-25% and the flue gas and moisture loss is as high as 51-54%. The loss from openings takes parts 9% and the surface heat loss 3% .

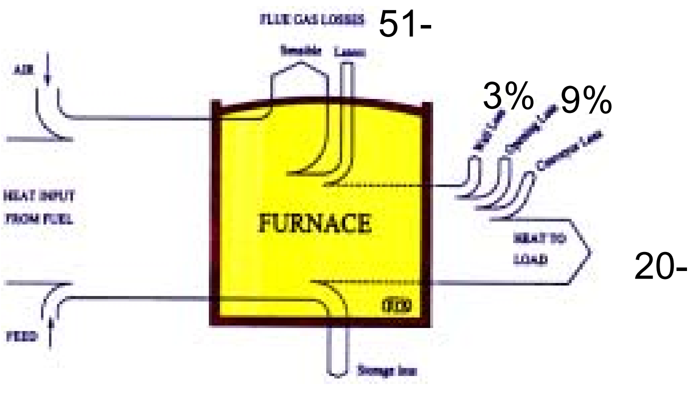



Figure 2-2 Energy balance of reheating furnaces

Fuels + air -> product energy + flue gas loss + opening loss + surface heat loss

The key measures to improve furnace efficiency will be described in the next section.

## 2.2 Measures to improve the furnace efficiency

The furnace efficiency can be improved by means of

(1) Measures to improve combustion efficiency

(2) Measures to reduce stack loss

(3) Measures to reduce leakage loss

(4) Measures to surface heat loss

(5) Measures to reduce loss in cooling system

(6) Measures of inspection and maintenance

### (1) Measures to improve combustion efficiency

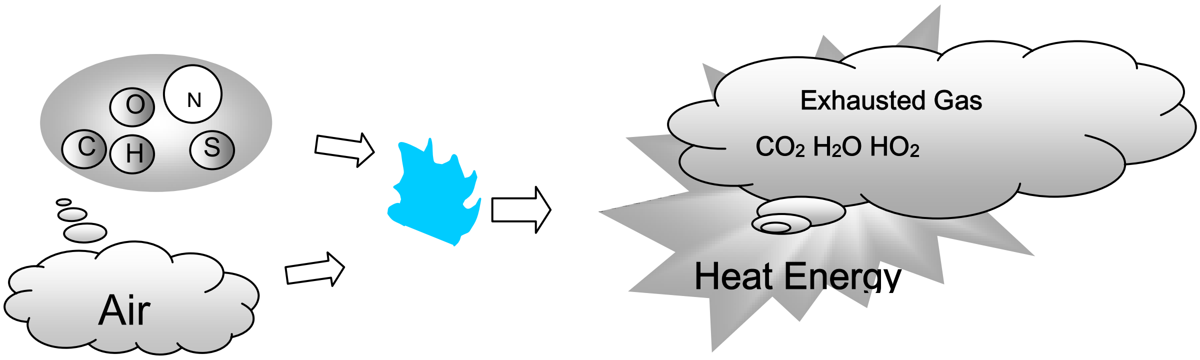
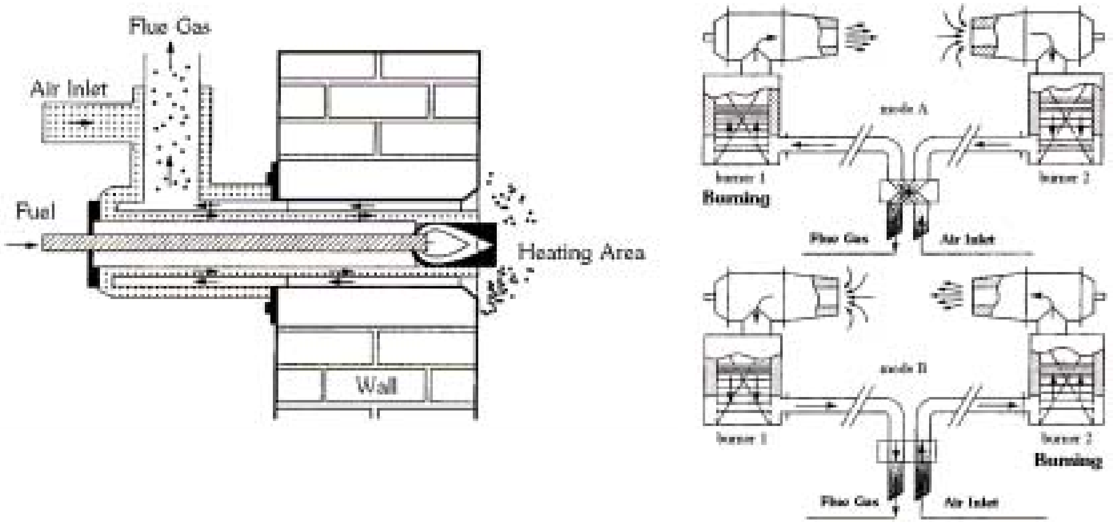



Figure 2.2-1 Combustion

Furnaces have the same combustion principles as those of boilers that combustion efficiency depends on fuel types , excess air and combustion characteristics.

O High Efficiency Burners

Now the efficiency of burners has been improved, particularly in high temperature combustion , by recovering flue gas heat to preheat combustion air. These burners have 2 types-Recuperative burners and Regenerative burners. Self-Recuperative burner takes hot gas from its combustion to exchange with intake combustion air. It can easily replace the existing burners and can save up to 30% of fuels. (see Figure 2.2-2a) A regenerative burner set has 2 burners, operating alternately. While one burner is operating, the other burner which turns off will intake flue gas to preheat heating media for heating up its combustion air in the next turn . (see Figure 2.2-2b) this type can save up to 50% of fuels.



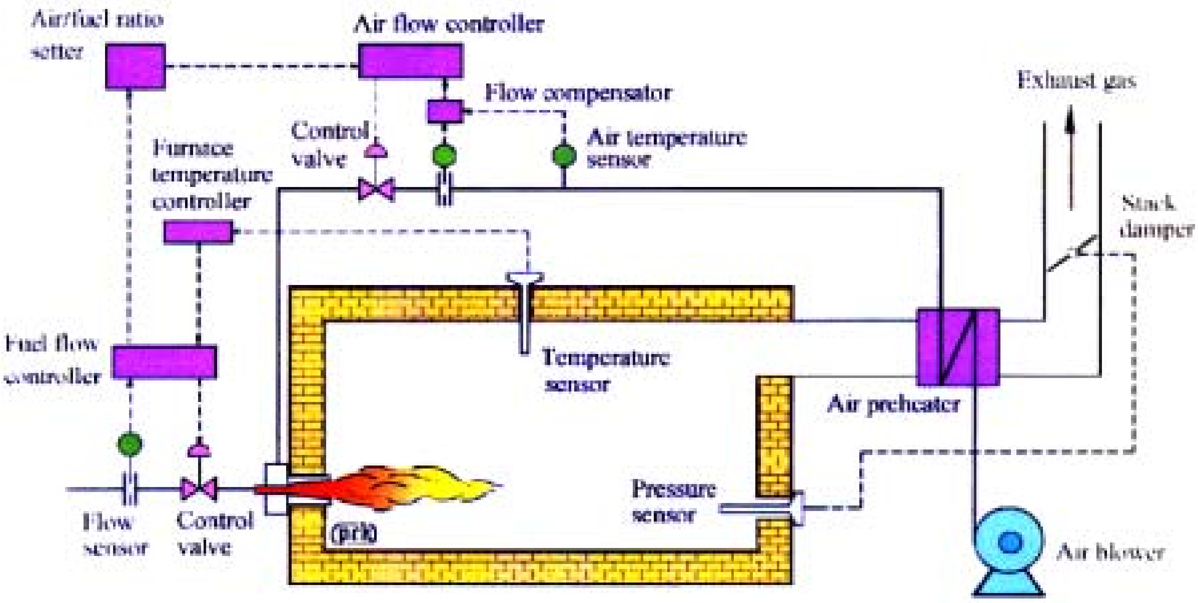

a. recuperative burners b. regenerative burners

Figure. 2.2-2 high efficiency burners

O How Industrial furnaces control combustion?

Most Furnaces have control systems which measure furnace Temperature and throttle fuel valves to keep furnace temperature at the setpoint. At the same time the controllers will adjust air dampers to achieve preset air to fuel ratio.

Besides combustion, the controllers also control Furnace Pressures by sensing the pressure and manipulating exhaust air dampers




Furnace control

O Combustion Improvement

We can improve combustion efficiency by means of

1 Cleaning burners every week. Dirt and soots obstruct air and fuel flow.
2 Controlling combustion air ratio to the standard in table 2.2-1
3 Monitoring Oil Pressure regularly and Control it to commissioning figure .
4 Monitoring Heavy Oil Temperature regularly and control at recommended value in Table 2-3

Table 2-3 Recommended oil temperature

| Fuels | Appropriate Temperature |
|---|---|
| Heavy Oil type A | 90-100 |
| Heavy Oil type C | 110-120 |

5 Draining and removing deposits and water in Oil tank every year
6 Using appropriate burner size if your burners always operating at low load
7 Reducing moisture and size of Solid fuel before burning
8 Replace ordinary burners with recuperative burners or regenerative burners.
9 Adjust flame direction and do not allow direct product firing

O Calculation

How much of heat energy fuels can give us?

Heat energy from fuel = Quantity of fuels x heating value

Heating values of different fuels shown in Table 1.1.5

Example The factory uses heavy oil Type C of 12,000 litres per month.

Heat energy Consumed = 12,000 x 9117.38 Kcal/L

= 109,408,560 Kcal/month

O What air ratio is?

Air ratio is a value that indicates how much intake air is more than theoretical air, for example, at 30% excess air the air ratio is 130/100 = 1.3

Air ratio can be calculated from percentage of oxygen content in flue gas

$$m = O_2 / (21-O_2)$$

Where $m$ = air ratio

$O_2$ = percentage of oxygen content in flue gas

(2) Measures to Reduce Flue Gas Loss

o How does flue gas loss occur?

Thermal energy from fuel combustion in furnace is used to heat up or melting specimens. It can use direct contact with specimens or indirect contact by using heat exchanger to transfer heat to the specimens. The thermal energy cannot completely used,the remnant heat will be lose through flue gas stack. In general, flue gas loss from furnace approximately 20-40%.

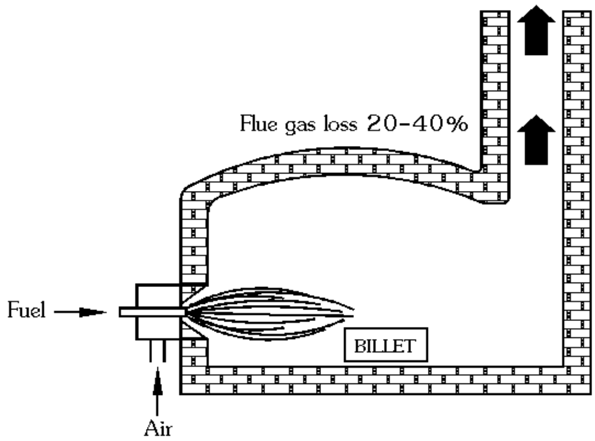



Figure 2.2-3 Heat loss from flue gas of furnace

o What are effects of the flue gas loss?

1. Inappropriate air for combustion: If use more excess air, the uncombustion air will conduct more heat from combustion chamber to the stack which can notice by higher flue gas temperature. If use insufficient air, the fuel cannot combustion completely cause the toxic gas ( carbon monoxide ) and unburn fuel which can notice by higher flue gas temperature, more soot and smoke at the stack. Therefore, we need to adjust the appropriate air:fuel ratio to each type of fuel.

Table 2.2-1 The standard air fuel ratio of industrial furnace
(Except for solid fuel furnace or the furnace of below 500 Mcal/h)

| Classification | Continuous type | Intermittent type |
|---|---|---|
| Metal melting furnace for casting | 1.30 | 1.40 |
| Continuous billet heating furnace | 1.25 | |
| Other metal heating furnace | 1.25 | 1.35 |

| | | |
|---|---|---|
| Metal heat treating furnace<br>Petroleum heating furnace<br>Thermal cracking furnace and reforming furnace<br>Cement kiln<br>Lime baking furnace<br>Drying oven (only the burner section) | 1.25<br>1.25<br>1.25<br>1.30<br>1.30<br>1.30 | 1.3<br><br><br><br>1.35<br>1.50 |

Air Fuel Ratio = $1 + \frac{\%O_2}{21 - \%O_2}$ where % O2 = percentage of oxygen in flue gas

2. The pressure of hot air in the furnace ( draught pressure ) is not equilibrium with atmospheric pressure. If the draught pressure is lower than atmospheric pressure, the cool air from ambient will flow into furnace through the opening or the crack, reduce the hot air temperature in furnace and has more flue gas loss. Therefore, the draught pressure should be controlled slightly higher than atmospheric pressure by installing the damper. In general, the draught pressure will be adjusted higher than atmospheric pressure about 1 $mmH_2O$.

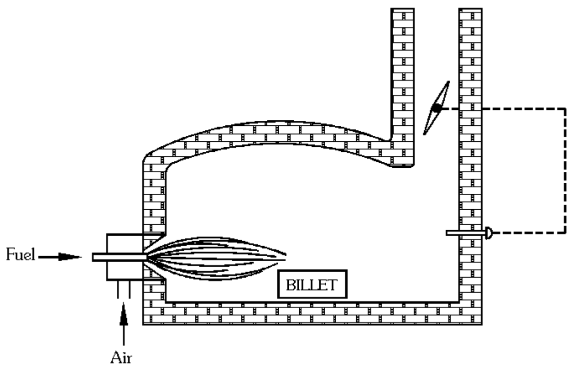
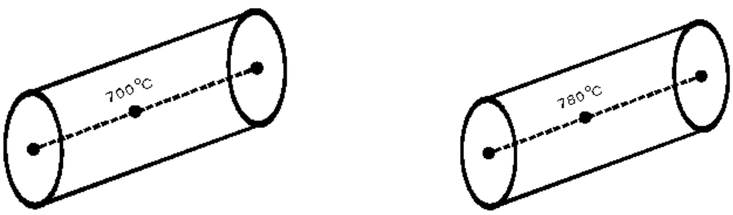



Figure 2.2-4 The draught pressure control in furnace

3. The temperature of furnace must setting to the standard. In general , the standard temperature of furnace will be controlled at the core temperature of specimen. Therefore, if operate at higher temperature than standard cause more flue gas loss and reduce quality of specimen due to the higher flue gas temperature.

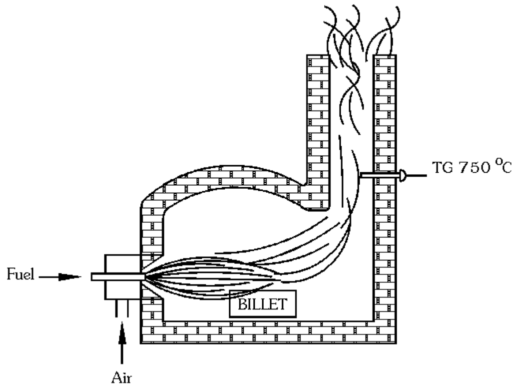



standard $700^0C$ actually $780^0C$

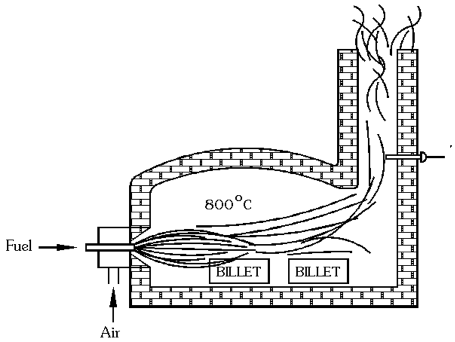
Figure 2.2-5 The core temperature of raw materials or products

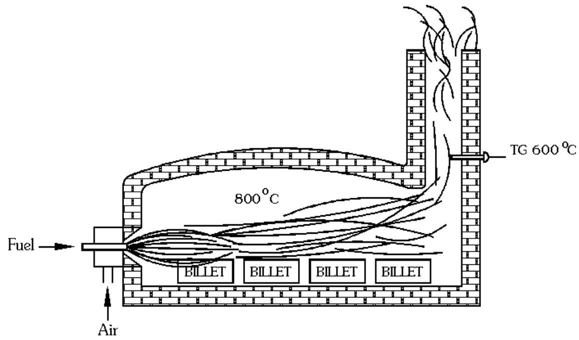
4. The combustion chamber design and burner is installed not appropriate and right in position cause the higher flue gas loss.

4.1 The combustion chamber or heat exchange area too small cause the shorter time for heat exchange.

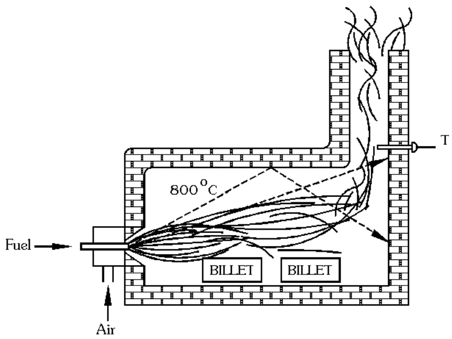


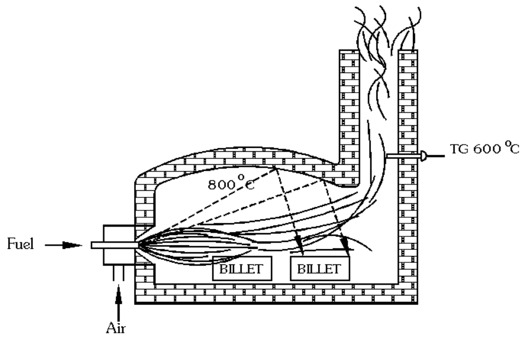

4.2 The short furnace design cause the shorter time for heat in the combustion chamber.



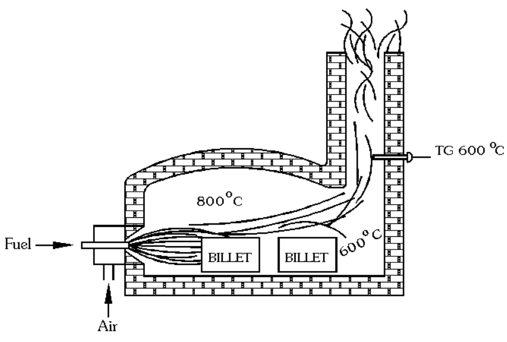



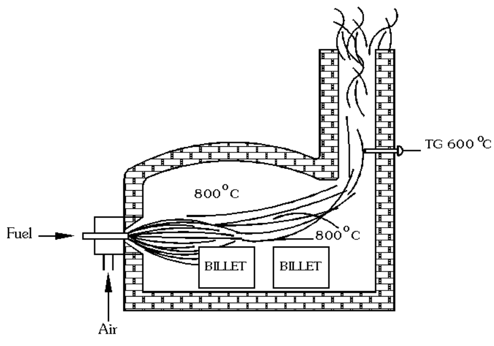

4.3 The top of furnace’ s wall is not in a curve shape in addition to reflect heat to the specimen.




4.4 The burner is not in the right position to distribute heat thoroughly the specimen.



o **How to calculate heat loss?**

The heat loss quantity from flue gas through the stack each set of furnace is quite different. The heat loss quantity from flue gas can be calculated by using table 2.2-2, 2.2-3 and 2.2-4, which are presented for 3 types of fuel : bunker oil, bituminous coal and natural gas. Using these tables, the users must be known all information as following:

1. Type of fuel and fuel consumption per year
2. The oxygen content in the flue gas
3. The temperature of flue gas at the stack

Finding the heat loss from flue gas, the users must use the right tables. For example, bunker oil with flue gas temperature of 700 °C and oxygen content in flue gas of 8%. From table 2.2-2, heat loss from flue gas is 41.56% .This value can convert to find the fuel loss. The fuel loss is equal to heat loss in percent divided by 100 then multiply with the fuel consumption per year.

**Figure 2.2-4 Percentage of flue gas loss from stack for bunker oil Grade C**

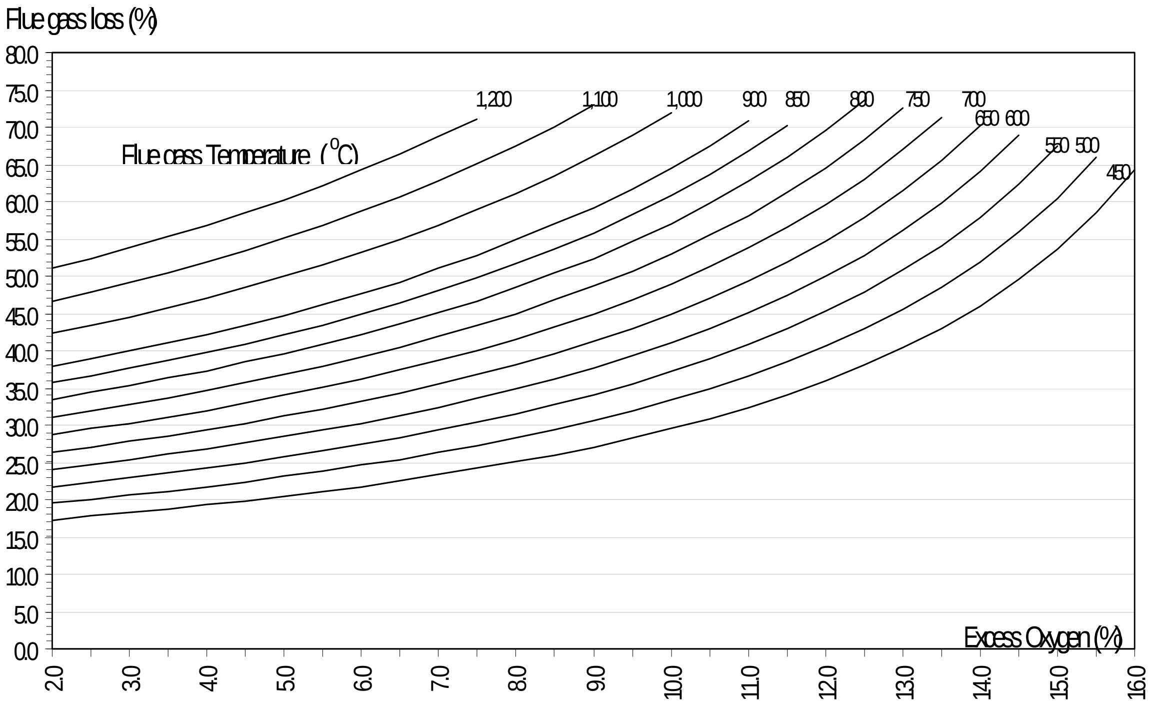
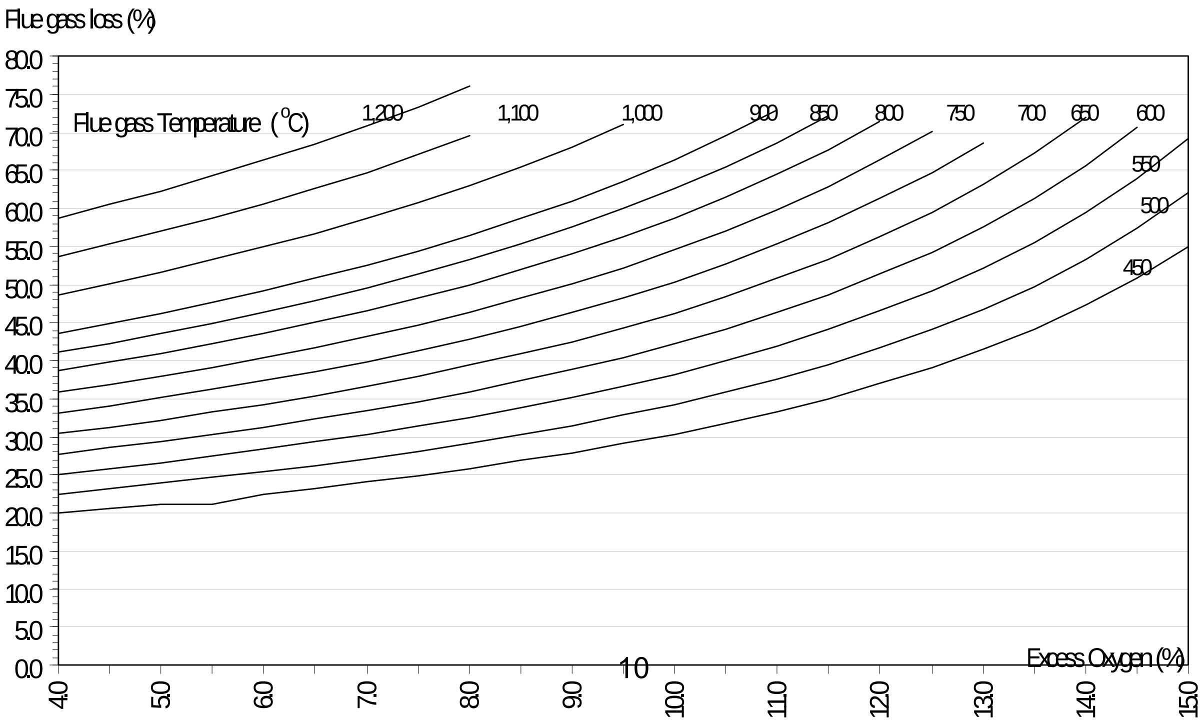


Table 2.2-2 Percentage of flue gas loss from stack for bunker oil Grade C

| Oxigen content in flue gas (%) | flue gas temperature from stack ($^{O}C$) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 1,000 | 1,100 | 1,200 |
| 2.0 | 17.33 | 19.55 | 21.80 | 24.09 | 26.40 | 28.74 | 31.11 | 33.51 | 35.70 | 37.89 | 42.27 | 46.65 | 51.03 |
| 2.5 | 17.78 | 20.06 | 22.37 | 24.72 | 27.09 | 29.49 | 31.92 | 34.38 | 36.63 | 38.88 | 43.37 | 47.86 | 52.36 |
| 3.0 | 18.26 | 20.60 | 22.98 | 25.38 | 27.82 | 30.28 | 32.78 | 35.31 | 37.61 | 39.92 | 44.54 | 49.15 | 53.77 |
| 3.5 | 18.76 | 21.17 | 23.61 | 26.08 | 28.58 | 31.12 | 33.68 | 36.28 | 38.65 | 41.03 | 45.77 | 50.51 | 55.25 |
| 4.0 | 19.30 | 21.78 | 24.28 | 26.83 | 29.40 | 32.01 | 34.65 | 37.32 | 39.76 | 42.19 | 47.07 | 51.95 | 56.83 |
| 4.5 | 19.87 | 22.41 | 25.00 | 27.61 | 30.26 | 32.95 | 35.66 | 38.41 | 40.92 | 43.44 | 48.46 | 53.48 | 58.50 |
| 5.0 | 20.47 | 23.10 | 25.76 | 28.45 | 31.18 | 33.95 | 36.75 | 39.58 | 42.17 | 44.75 | 49.93 | 55.10 | 60.27 |
| 5.5 | 21.11 | 23.82 | 26.56 | 29.34 | 32.16 | 35.01 | 37.90 | 40.82 | 43.49 | 46.16 | 51.49 | 56.83 | 62.16 |
| 6.0 | 21.80 | 24.59 | 27.43 | 30.30 | 33.20 | 36.15 | 39.13 | 42.14 | 44.90 | 47.65 | 53.16 | 58.67 | 64.18 |
| 6.5 | 22.53 | 25.42 | 28.35 | 31.31 | 34.32 | 37.36 | 40.44 | 43.56 | 46.41 | 49.25 | 54.95 | 60.64 | 66.33 |
| 7.0 | 23.31 | 26.3 | 29.33 | 32.40 | 35.51 | 38.66 | 41.85 | 45.07 | 48.02 | 50.97 | 56.86 | 62.75 | 68.64 |
| 7.5 | 24.15 | 27.25 | 30.39 | 33.57 | 36.79 | 40.06 | 43.36 | 46.70 | 49.76 | 52.81 | 58.91 | 65.02 | 71.12 |
| 8.0 | 25.06 | 28.28 | 31.53 | 34.83 | 38.18 | 41.56 | 44.99 | 48.46 | 51.62 | 54.79 | 61.12 | 67.46 | - |
| 8.5 | 26.04 | 29.38 | 32.77 | 36.19 | 39.67 | 43.18 | 46.75 | 50.35 | 53.64 | 56.93 | 63.51 | 70.09 | - |
| 9.0 | 27.10 | 30.58 | 34.10 | 37.67 | 41.28 | 44.94 | 48.65 | 52.40 | 55.83 | 59.25 | 66.10 | 72.95 | - |
| 9.5 | 28.25 | 31.88 | 35.55 | 39.27 | 43.04 | 46.86 | 50.72 | 54.63 | 58.20 | 61.77 | 68.91 | - | - |
| 10.0 | 29.51 | 33.30 | 37.14 | 41.02 | 44.96 | 48.94 | 52.98 | 57.06 | 60.79 | 64.52 | 71.98 | - | - |
| 10.5 | 30.89 | 34.85 | 38.87 | 42.94 | 47.06 | 51.23 | 55.45 | 59.73 | 63.63 | 67.54 | - | - | - |
| 11.0 | 32.41 | 36.56 | 40.77 | 45.04 | 49.37 | 53.74 | 58.17 | 62.66 | 66.75 | 70.85 | - | - | - |
| 11.5 | 34.08 | 38.45 | 42.88 | 47.37 | 51.92 | 56.52 | 61.18 | 65.90 | 70.21 | - | - | - | - |
| 12.0 | 35.94 | 40.55 | 45.23 | 49.96 | 54.75 | 59.61 | 64.52 | 69.50 | - | - | - | - | - |
| 12.5 | 38.02 | 42.90 | 47.84 | 52.85 | 57.92 | 63.06 | 68.26 | 73.52 | - | - | - | - | - |
| 13.0 | 40.36 | 45.54 | 50.79 | 56.10 | 61.49 | 66.94 | 72.46 | - | - | - | - | - | - |
| 13.5 | 43.01 | 48.53 | 54.13 | 59.79 | 65.53 | 71.34 | - | - | - | - | - | - | - |
| 14.0 | 46.05 | 51.95 | 57.94 | 64.00 | 70.15 | - | - | - | - | - | - | - | - |
| 14.5 | 49.54 | 55.90 | 62.34 | 68.87 | - | - | - | - | - | - | - | - | - |
| 15.0 | 53.62 | 60.51 | 67.48 | - | - | - | - | - | - | - | - | - | - |
| 15.5 | 58.45 | 65.95 | - | - | - | - | - | - | - | - | - | - | - |
| 16.0 | 64.23 | - | - | - | - | - | - | - | - | - | - | - | - |

Comment : Analyze by Rosin equation at ambient temperature (35$^{O}$C) and heating value 9,117.38 kcal/kg (38,174.47 kJ/kg)

Figure 2.2-6 Percentage of flue gas loss from stack for Bituminous coal



## Table 2.2-3 Percentage of flue gas loss from stack for Bituminous coal

| Oxigen content in flue gas(%) | flue gas temperature from stack (c) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 1,000 | 1,100 | 1,200 |
| 4.0 | 19.96 | 22.52 | 25.12 | 27.75 | 30.41 | 33.10 | 35.83 | 38.6 | 41.12 | 43.64 | 48.69 | 53.73 | 58.78 |
| 4.5 | 20.54 | 23.18 | 25.85 | 28.55 | 31.29 | 34.06 | 36.87 | 39.72 | 42.31 | 44.90 | 50.10 | 55.29 | 60.48 |
| 5.0 | 21.15 | 23.87 | 26.62 | 29.40 | 32.22 | 35.08 | 37.97 | 40.9 | 43.58 | 46.25 | 51.60 | 56.94 | 62.29 |
| 5.5 | 21.18 | 24.61 | 27.44 | 30.31 | 33.22 | 36.17 | 39.15 | 42.17 | 44.92 | 47.68 | 53.19 | 58.70 | 64.21 |
| 6.0 | 22.50 | 25.39 | 28.32 | 31.28 | 34.28 | 37.32 | 40.40 | 43.52 | 46.36 | 49.2 | 54.89 | 60.58 | 66.27 |
| 6.5 | 23.25 | 26.23 | 29.26 | 32.32 | 35.42 | 38.56 | 41.74 | 44.96 | 47.89 | 50.83 | 56.71 | 62.59 | 68.46 |
| 7.0 | 24.05 | 27.13 | 30.26 | 33.43 | 36.64 | 39.88 | 43.17 | 46.50 | 49.54 | 52.58 | 58.66 | 64.74 | 70.81 |
| 7.5 | 24.91 | 28.10 | 31.34 | 34.62 | 37.94 | 41.31 | 44.71 | 48.16 | 51.31 | 54.45 | 60.75 | 67.05 | 73.34 |
| 8.0 | 25.83 | 29.14 | 32.50 | 35.90 | 39.35 | 42.84 | 46.37 | 49.95 | 53.21 | 56.48 | 63.00 | 69.53 | 76.06 |
| 8.5 | 26.83 | 30.27 | 33.76 | 37.29 | 40.87 | 44.49 | 48.16 | 51.87 | 55.27 | 58.66 | 65.44 | - | - |
| 9.0 | 27.91 | 31.49 | 35.12 | 38.79 | 42.52 | 46.29 | 50.10 | 53.96 | 57.49 | 61.02 | 68.07 | - | - |
| 9.5 | 29.08 | 32.82 | 36.60 | 40.43 | 44.31 | 48.23 | 52.21 | 56.24 | 59.91 | 63.59 | 70.94 | - | - |
| 10.0 | 30.37 | 34.26 | 38.21 | 42.21 | 46.26 | 50.36 | 54.51 | 58.71 | 62.55 | 66.39 | - | - | - |
| 10.5 | 31.77 | 35.85 | 39.98 | 44.16 | 48.40 | 52.69 | 57.03 | 61.43 | 65.44 | 69.46 | - | - | - |
| 11.0 | 33.31 | 37.59 | 41.92 | 46.31 | 50.75 | 55.25 | 59.80 | 64.41 | 68.62 | 72.83 | - | - | - |
| 11.5 | 35.02 | 39.51 | 44.07 | 48.68 | 53.35 | 58.08 | 62.87 | 67.71 | 72.14 | - | - | - | - |
| 12.0 | 36.92 | 41.65 | 46.45 | 51.31 | 56.24 | 61.22 | 66.27 | 71.38 | - | - | - | - | - |
| 12.5 | 39.04 | 44.04 | 49.12 | 54.26 | 59.47 | 64.74 | 70.08 | - | - | - | - | - | - |
| 13.0 | 41.42 | 46.73 | 52.12 | 57.57 | 63.10 | 68.69 | - | - | - | - | - | - | - |
| 13.5 | 44.12 | 49.78 | 55.52 | 61.33 | 67.21 | - | - | - | - | - | - | - | - |
| 14.0 | 47.21 | 53.27 | 59.41 | 65.62 | 71.92 | - | - | - | - | - | - | - | - |
| 14.5 | 50.77 | 57.29 | 63.89 | 70.58 | - | - | - | - | - | - | - | - | - |
| 15.0 | 54.93 | 61.98 | 69.12 | - | - | - | - | - | - | - | - | - | - |

Comment : Analyze by Rosin equation at ambient temperature (35$^{O}$C) and heating value 6,297.16 kcal/kg (26,366.21 kJ/kg)

Figure 2.2-7 Percentage of flue gas loss from stack for natural gas

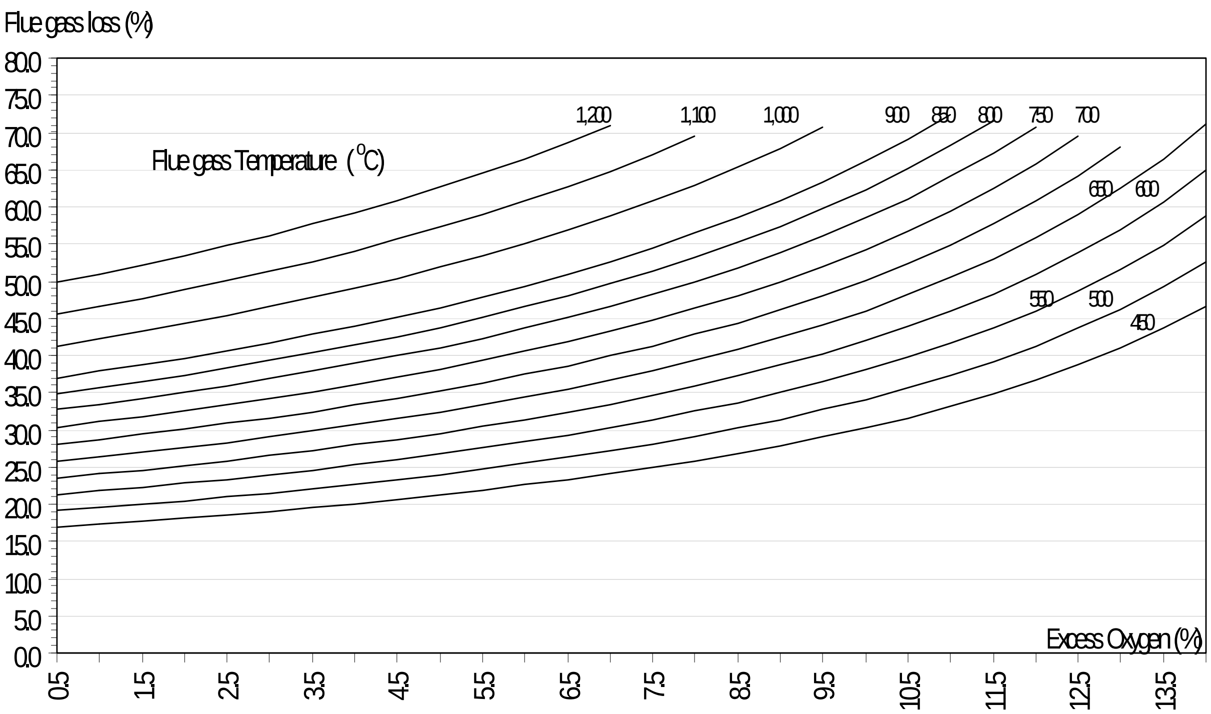


Table 2.2-4 Percentage of flue gas loss from stack for natural gas

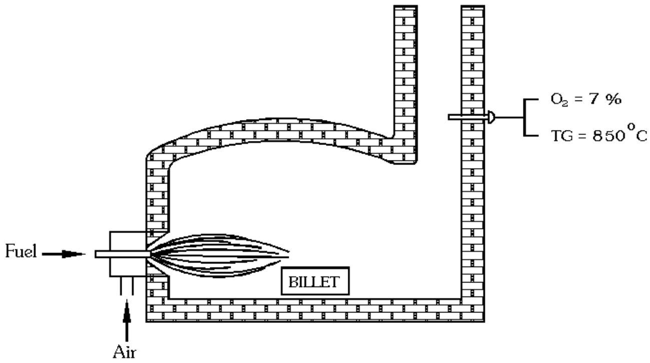
| Oxigen content in flue gas(%) | fuel gas temperature from stack (C) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 1,000 | 1,100 | 1,200 |
| 0.5 | 16.93 | 19.10 | 21.30 | 23.53 | 25.79 | 28.08 | 30.39 | 32.73 | 34.87 | 37.01 | 41.29 | 45.57 | 49.85 |
| 1.0 | 17.31 | 19.54 | 21.79 | 24.07 | 26.38 | 28.72 | 31.08 | 33.48 | 35.67 | 37.86 | 42.23 | 46.61 | 50.99 |
| 1.5 | 17.72 | 19.99 | 22.3 | 24.63 | 27.00 | 29.39 | 31.81 | 34.26 | 36.5 | 38.74 | 43.22 | 47.70 | 52.18 |
| 2.0 | 18.15 | 20.47 | 22.83 | 25.22 | 27.64 | 30.09 | 32.58 | 35.09 | 37.38 | 39.67 | 44.26 | 48.85 | 53.43 |
| 2.5 | 18.60 | 20.98 | 23.40 | 25.85 | 28.33 | 30.84 | 33.38 | 35.96 | 38.31 | 40.66 | 45.36 | 50.06 | 54.76 |
| 3.0 | 19.07 | 21.52 | 24.00 | 26.51 | 29.05 | 31.63 | 34.23 | 36.87 | 39.28 | 41.69 | 46.51 | 51.33 | 56.15 |
| 3.5 | 19.57 | 22.08 | 24.63 | 27.20 | 29.81 | 32.46 | 35.13 | 37.84 | 40.32 | 42.79 | 47.74 | 52.68 | 57.63 |
| 4.0 | 20.10 | 22.68 | 25.30 | 27.94 | 30.62 | 33.34 | 36.09 | 38.87 | 41.41 | 43.95 | 49.03 | 54.11 | 59.19 |
| 4.5 | 20.67 | 23.32 | 26.00 | 28.73 | 31.48 | 34.27 | 37.10 | 39.96 | 42.57 | 45.18 | 50.41 | 55.63 | 60.85 |
| 5.0 | 21.26 | 23.99 | 26.76 | 29.56 | 32.39 | 35.26 | 38.17 | 41.12 | 43.80 | 46.49 | 51.87 | 57.24 | 62.61 |
| 5.5 | 21.90 | 24.71 | 27.56 | 30.44 | 33.36 | 36.32 | 39.32 | 42.35 | 45.12 | 47.88 | 53.42 | 58.95 | 64.49 |
| 6.0 | 22.58 | 25.48 | 28.41 | 31.39 | 34.40 | 37.45 | 40.54 | 43.66 | 46.52 | 49.37 | 55.08 | 60.78 | 66.49 |
| 6.5 | 23.31 | 26.30 | 29.33 | 32.40 | 35.50 | 38.65 | 41.84 | 45.07 | 48.01 | 50.96 | 56.85 | 62.74 | 68.63 |
| 7.0 | 24.08 | 27.18 | 30.31 | 33.48 | 36.69 | 39.94 | 43.24 | 46.57 | 49.61 | 52.66 | 58.75 | 64.83 | 70.92 |
| 7.5 | 24.92 | 28.12 | 31.36 | 34.64 | 37.96 | 41.33 | 44.74 | 48.19 | 51.34 | 54.49 | 60.78 | 67.08 | - |
| 8.0 | 25.82 | 29.13 | 32.49 | 35.89 | 39.33 | 42.82 | 46.35 | 49.93 | 53.19 | 56.45 | 62.98 | 69.51 | - |
| 8.5 | 26.79 | 30.23 | 33.71 | 37.24 | 40.82 | 44.43 | 48.10 | 51.81 | 55.19 | 58.58 | 65.35 | - | - |
| 9.0 | 27.85 | 31.42 | 35.04 | 38.71 | 42.42 | 46.18 | 49.99 | 53.84 | 57.36 | 60.88 | 67.92 | - | - |
| 9.5 | 28.99 | 32.71 | 36.48 | 40.30 | 44.16 | 48.08 | 52.04 | 56.06 | 59.72 | 63.38 | 70.71 | - | - |
| 10.0 | 30.24 | 34.12 | 38.05 | 42.03 | 46.07 | 50.15 | 54.29 | 58.47 | 62.29 | 66.11 | - | - | - |
| 10.5 | 31.61 | 35.66 | 39.77 | 43.93 | 48.15 | 52.42 | 56.74 | 61.12 | 65.11 | 69.10 | - | - | - |
| 11.0 | 33.11 | 37.36 | 41.67 | 46.03 | 50.44 | 54.91 | 59.44 | 64.03 | 68.21 | 72.39 | - | - | - |
| 11.5 | 34.77 | 39.24 | 43.76 | 48.34 | 52.97 | 57.67 | 62.43 | 67.24 | 71.64 | - | - | - | - |
| 12.0 | 36.62 | 41.32 | 46.08 | 50.91 | 55.79 | 60.74 | 65.74 | 70.81 | - | - | - | - | - |
| 12.5 | 38.69 | 43.65 | 48.68 | 53.78 | 58.94 | 64.16 | 69.45 | - | - | - | - | - | - |
| 13.0 | 41.01 | 46.27 | 51.60 | 57.00 | 62.47 | 68.01 | - | - | - | - | - | - | - |
| 13.5 | 43.64 | 49.24 | 54.92 | 60.66 | 66.49 | - | - | - | - | - | - | - | - |
| 14.0 | 46.65 | 52.64 | 58.70 | 64.85 | 71.07 | - | - | - | - | - | - | - | - |

Comment : Analyze by Rosin equation at ambient temperature ($35^{O}C$)
and heating value 8,763.96 kcal/$Nm^3$ (36,694.70 kJ/$Nm^3$)

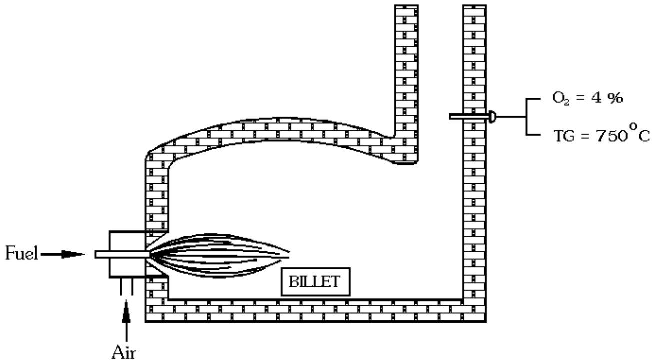
ο **Example (furnace calculation)**

ENCON factory installed a metal forming furnace capacity of 15 Gcal/h, using bunker oil grade C 8,000,000 liter/year. The measurement data from the flue gas : oxygen content 7% , temperature 8500C and the ambient temperature 350C. After adjust air fuel ration, improve combustion chamber and control draught pressure the oxygen content and flue gas temperature at stack reduce to 4% and 7500C respectively. How much heat loss can be reduced?

From table 2.2-2 or figure 2.2-4, bunker oil grade C at oxygen content of flue gas 7% and temperature of flue gas 8500C. The heat loss is 48.02%.




From table 2.2-2 or figure 2.2-4, bunker oil grade C at oxygen content of flue gas 4% and temperature of flue gas 7500C. The heat loss is 34.65%.




Heat loss reduction = 48.02 – 34.65 = 13.37%

Fuel reduction =

( Heat loss reduction in percent / 100) x Fuel consumption per year

= (13.37 / 100) x 8,000,000

= 1,069,600 liter/year

(3) Measures to Reduce Surface heat loss

O What is Surface heat loss?

Surface heat loss is energy loss through hot surface or cold surface of an object. If surface temperature is higher than ambient Temperature, heat will transfer from the object to ambient, called ‘heat loss’. And if surface temperature is lower than ambient temperature, heat will transfer from ambient to the object, called ‘heat gain ’ .

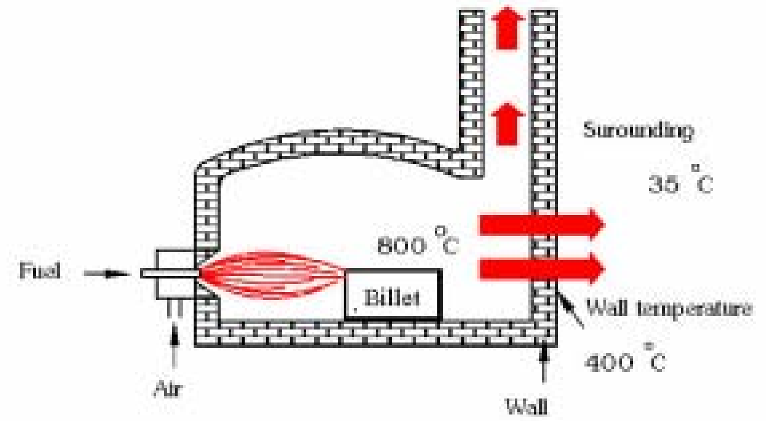
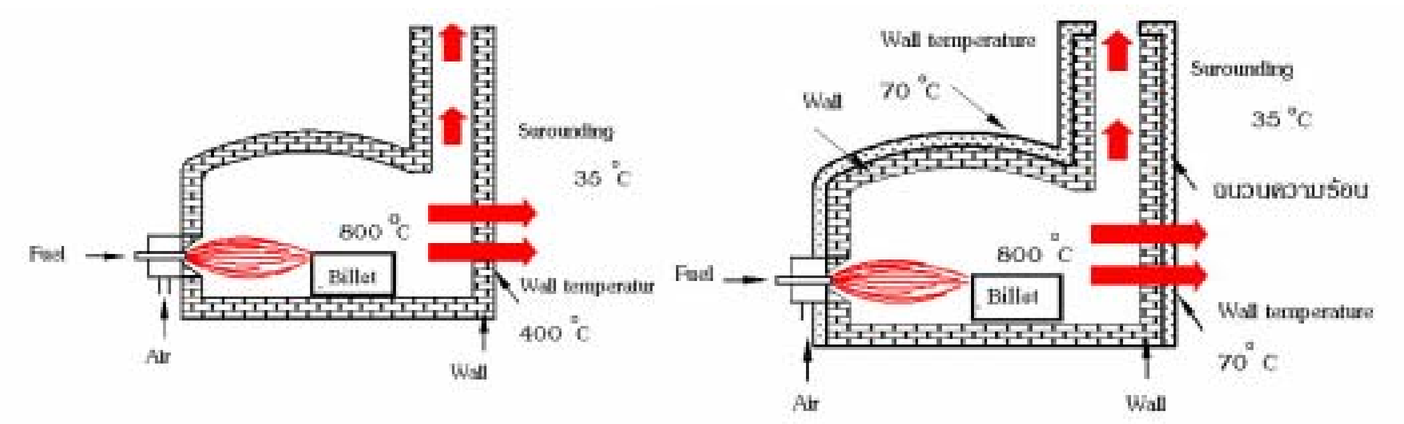



Fig 2.3-1 Heat Transfer

O How to prevent surface heat loss

We can prevent surface heat loss by insulating the hot surface with insulating materials.




Before Insulating After Insulating

Fig 2.3-2 Surface loss prevention

O What is insulation?

Insulation is material which does not conduct heat. After insulating, the object can be touch safely. An example of insulation is leather globe for handling hot Iron bars.

O How to choose appropriate insulation?

Insulation has many types and materials such as board type, roll type etc. In insulation selection we should consider surface temperature and operating temperature of the insulation. Table 2.3-1 and 2.3-2 shows Insulation selection.

Table 2.3-1 Physical properties of Insulation

| Name of insulation | Classification | Thermal conductivity (W/m. K) | Specific heat (kJ/kg.K) | Density (kg/m$^3$) |
|---|---|---|---|---|
| Calcium Silicate | Heat insulating mould No.1 – 13 | 0.0407 | 0.84 | 135 |
| Glass Wool | Heat insulating mould | 0.0324 | 0.84 | 45 |
| Rock Wool | at insulating mould | 0.0314 | 1.13 | 100 |

Table 2.3-2 Insulation Selection

| Materials | Types | Operating Temperature (◦ C) | Heat conductivity (W/m. K) | Advantages |
|---|---|---|---|---|
| Asbestos | Cylinder No.1<br>Blanket No.2 | 550<br>350 | < 0.046 - 0.048<br>< 0.041 - 0.046 | convenience installation<br>Applicable in vibration |
| | Blanket<br>Rope | 400 | < 0.047 - 0.056 | convenience installation<br>suit to valve and flange |
| Rock wool | Blanket<br>Cylinder<br>Rope | 400 – 600 | < 0.034 - 0.041 | High operating temperature |
| Glass wool | Blanket<br>No.1 8 K – 24 K<br>No.2 10 K – 96 K<br>No.3 96 K<br>Cylinder No.1<br>Rope | 300 – 350 | < 0.046 - 0.034<br>< 0.049 - 0.031<br>< 0.034<br>< 0.032<br>< 0.039 | Most popular insulation<br>Low thermal conductivity |
| Calcium silicate | Blanket No.1<br>1,000 ◦ C<br>Cylinder No.2 | 650 | < 0.050<br>< 0.046 | High strength |

| | | | | |
|---|---|---|---|---|
| | 650 ◦ C | | | |
| Ceramic fiber | Rope<br>Blanket<br>Rigid Board | 1,260<br>1,400<br>1,260 | 0.085 – 0.185<br>0.132 – 0.220<br>0.085 – 0.185 | High strength<br>High Temperature |

O Life-time of Insulation

Insulation has 5-15 year life time depending on types and installation. Inappropriate Insulation also shortens insulation life such as installing in very humid area or installing outdoor without insulation jackets.

O How to inspect insulation failure?

- Failure insulation can be determined by its surface temperature. It should be lower than Table 2.3-3 or not be higher than that of new installation more than 20 C
- Components of failure or deteriorate insulation do not bond to each other and become powder.

**Table 2.3-3 Standard Outside Temperature of Furnace Wall**

| Temperature inside the furnace (◦ C) | Temperature outside the furnace wall (◦ C) | | |
|---|---|---|---|
| | Ceiling | Side wall | Bottom in contact with the outer air |
| >1,300 | 148 | 128 | 180 |
| 1,100 – 1,300 | 133 | 118 | 145 |
| 900 – 1,100 | 118 | 103 | 120 |
| 700 - 900 | 98 | 88 | 100 |
| 500 - 700 | 71 | 66 | 80 |

O How to prevent insulation failure?

Insulation jackets can prevent insulation from failure. they are usually Aluminum foils , zinc-irons or thin aluminum sheets. After wrapping with insulation jackets, the edges of the jackets should be sealed with Silicone to prevent moisture and diffusion of failure insulation.

O How long Insulation Investment pays back?

Insulation can reduce surface heat loss up to 70-95% depending on insulation types and thickness. In general case Insulation investment will pay back within 2 years depending on surface temperature, operating hours and energy cost.

O How to estimate Energy saving by Insulation installation?

The energy saving of Insulation works can be estimated as follows.

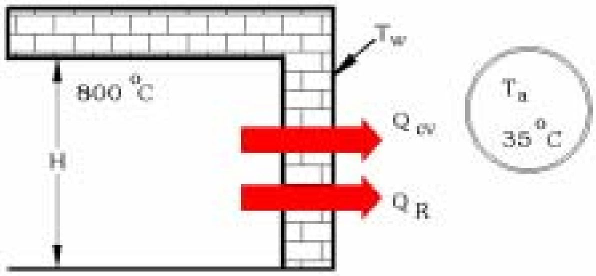
Energy saving for Heat Loss = Heat loss before isolate – Heat loss after isolate Or $Q_S = Q_{UNIN} - Q_{IN}$ 2.3-1

Heat loss before isolate ($Q_{UNIN}$)

$$Q_{UNIN} = Q_{CV} + Q_R \qquad 2.3\text{-}2$$

$$= 1.42 \times [(T_w-T_a)/H]^{0.25} \times (T_w-T_a) \times A + 5.6697\times10^{-8} \times [(T_w+273)^4-(T_a+273)^4] \times \varepsilon \times A$$

Fig 2.3-3 Wall non-isolate




Heat loss after isolate ($Q_{IN}$)

$$Q_{IN} = Q_{CD(INS)} = Q_{CV} + Q_R$$

$$= \frac{\frac{T_w - T_{in}}{t_i}}{A \cdot k_i} = \frac{T_{in} - T_a}{\frac{1}{A \cdot h}} = \frac{T_w - T_a}{\frac{t_i}{A \cdot k_i} + \frac{1}{A \cdot h}} \qquad 2.3\text{-}3$$

$$T_{in} = Q_{cd} \times \frac{1}{A \cdot h} + T_a \qquad 2.3\text{-}4$$

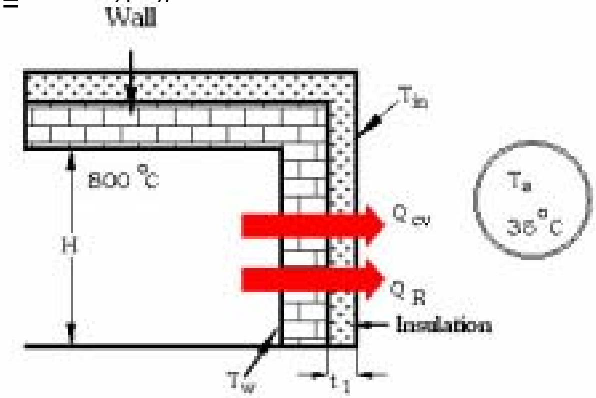



Fig 2.3-4 Wall isolate

เมื่อ A = Wall area (L x H) m.
L = Length of Wall m.
H = High of Wall m.
$T_w$ = Wall Temperature ◦ C
ε = Emissivtiy of Materials (Used 0.9)
$t_i$ = Insulation Thickness m.
$k_i$ = Conductivity of Insulation $W/m^2$ ◦ C
h = heat transfer coefficient of air $W/m^2$ ◦ C = 4.2 + 0.09 x ($T_w$-$T_a$)
$Q_{CV}$ = Heat loss from convection W/m
$Q_{CD}$ = Heat loss from conduction W/m
$Q_R$ = Heat loss from radiation W/m

From these equations , we can generate Table 2.3-4 to 2.3-8 or Figure 2.3-5 to 2.3-9 presenting energy loss before and after insulating the Wall with an economic thickness at surrounding temperature 35◦ C.

Fig 2.3-5 Heat loss from wall non-isolate (kW/m)

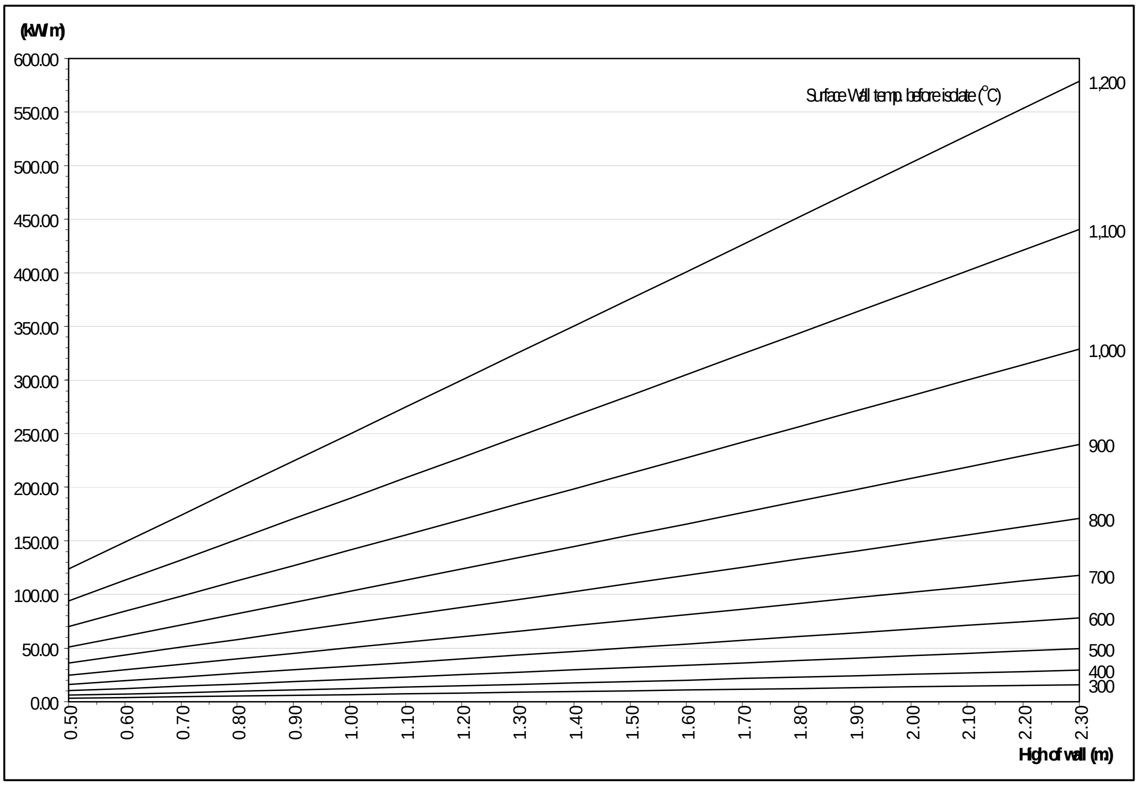


Table 2.3-4 Heat loss from wall non-isolate (kW/m)

| Surface Temp. ( C) | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 |
|---|---|---|---|---|---|---|---|---|---|---|
| High of wall (m.) | Heat loss from wall non-isolate (kW/m) | | | | | | | | | |
| 0.50 | 3.16 | 5.96 | 10.17 | 16.23 | 24.65 | 35.99 | 50.87 | 69.98 | 94.07 | 123.95 |
| 0.60 | 3.83 | 7.20 | 12.27 | 19.57 | 29.70 | 43.33 | 61.20 | 84.16 | 113.09 | 148.96 |
| 0.70 | 4.50 | 8.46 | 14.39 | 22.93 | 34.76 | 50.68 | 71.57 | 98.37 | 132.15 | 174.02 |
| 0.80 | 5.18 | 9.72 | 16.53 | 26.30 | 39.85 | 58.07 | 81.96 | 112.61 | 151.24 | 199.12 |
| 0.90 | 5.87 | 10.99 | 18.67 | 29.69 | 44.95 | 65.47 | 92.37 | 126.88 | 170.36 | 224.26 |
| 1.00 | 6.56 | 12.27 | 20.83 | 33.09 | 50.07 | 72.89 | 102.81 | 141.18 | 189.52 | 249.43 |
| 1.10 | 7.26 | 13.56 | 22.99 | 36.50 | 55.21 | 80.33 | 113.26 | 155.50 | 208.70 | 274.63 |
| 1.20 | 7.96 | 14.86 | 25.16 | 39.93 | 60.35 | 87.79 | 123.74 | 169.85 | 227.90 | 299.85 |
| 1.30 | 8.66 | 16.16 | 27.34 | 43.36 | 65.52 | 95.26 | 134.23 | 184.21 | 247.13 | 325.11 |
| 1.40 | 9.37 | 17.46 | 29.53 | 46.81 | 70.69 | 102.75 | 144.75 | 198.59 | 266.38 | 350.39 |
| 1.50 | 10.08 | 18.77 | 31.73 | 50.26 | 75.87 | 110.25 | 155.27 | 212.99 | 285.66 | 375.69 |
| 1.60 | 10.80 | 20.09 | 33.93 | 53.73 | 81.07 | 117.77 | 165.82 | 227.41 | 304.95 | 401.01 |
| 1.70 | 11.52 | 21.41 | 36.14 | 57.20 | 86.28 | 125.30 | 176.38 | 241.85 | 324.26 | 426.36 |
| 1.80 | 12.24 | 22.74 | 38.36 | 60.68 | 91.50 | 132.84 | 186.95 | 256.30 | 343.59 | 451.72 |
| 1.90 | 12.97 | 24.07 | 40.58 | 64.17 | 96.72 | 140.39 | 197.53 | 270.77 | 362.94 | 477.11 |
| 2.00 | 13.69 | 25.41 | 42.81 | 67.66 | 101.96 | 147.95 | 208.13 | 285.25 | 382.30 | 502.51 |
| 2.10 | 14.43 | 26.75 | 45.05 | 71.17 | 107.20 | 155.52 | 218.74 | 299.75 | 401.68 | 527.94 |
| 2.20 | 15.16 | 28.09 | 47.29 | 74.68 | 112.46 | 163.10 | 229.37 | 314.26 | 421.08 | 553.37 |
| 2.30 | 15.90 | 29.44 | 49.53 | 78.19 | 117.72 | 170.70 | 240.00 | 328.78 | 440.49 | 578.83 |

Fig 2.3-6 Heat loss from insulation wall with an economic thickness (Glass Wool, kW/m)

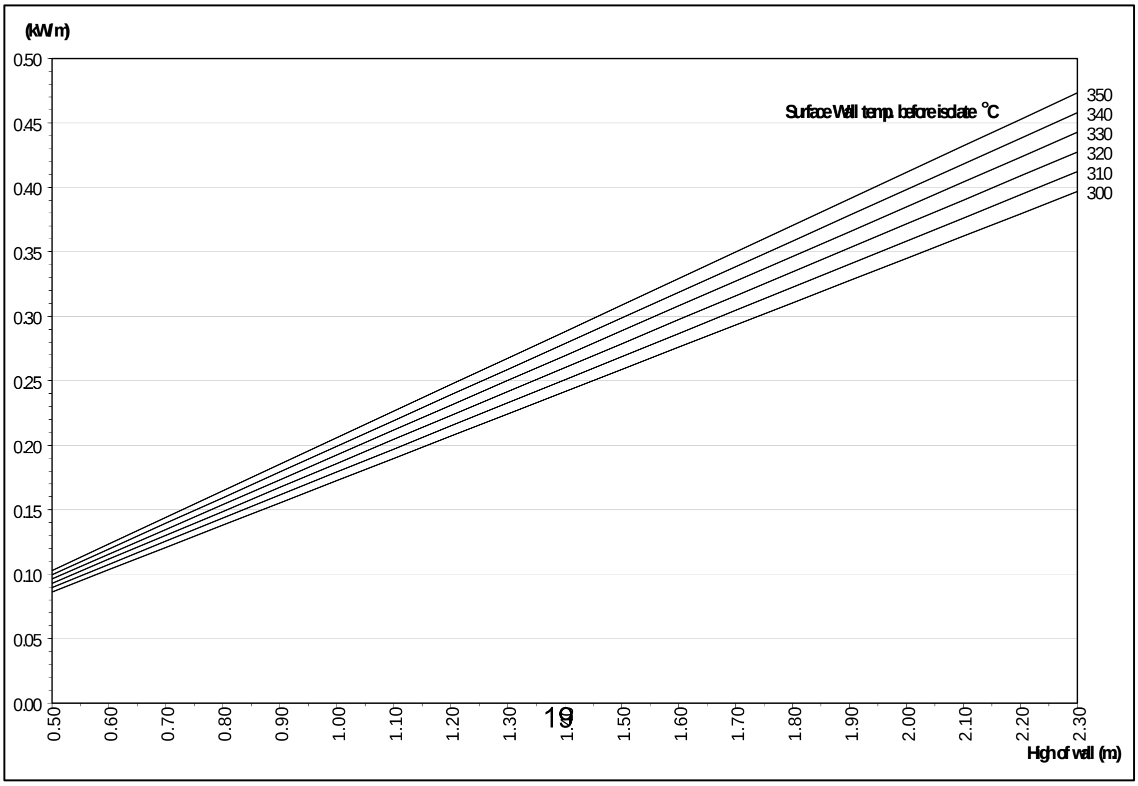


Table 2.3-5 Heat loss from insulation wall with an economic thickness (Glass Wool, kW/m)

| Insulation thickness | | | | Surface Temp. ( C) | 300 | 305 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 –320 C | | 321 – 400 C | | After isolate temp.( C) | 56.57 | 56.99 | 57.40 | 57.82 | 58.23 | 58.65 | 59.06 | 59.48 | 59.89 | 60.31 | 60.72 |
| in. | mm. | in. | mm. | High of wall (m.) | Heat loss from insulation wall with an economic thickness (Glass Wool, kW/m) | | | | | | | | | | |
| 2.5" | 63 | 2.5" | 63 | 0.50 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 2.5" | 63 | 2.5" | 63 | 0.60 | 0.10 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |
| 2.5" | 63 | 2.5" | 63 | 0.70 | 0.12 | 0.12 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 |
| 2.5" | 63 | 2.5" | 63 | 0.80 | 0.14 | 0.14 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 | 0.16 | 0.16 | 0.16 |
| 2.5" | 63 | 2.5" | 63 | 0.90 | 0.16 | 0.16 | 0.16 | 0.16 | 0.17 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 | 0.19 |
| 2.5" | 63 | 2.5" | 63 | 1.00 | 0.17 | 0.18 | 0.18 | 0.18 | 0.19 | 0.19 | 0.19 | 0.20 | 0.20 | 0.20 | 0.21 |
| 2.5" | 63 | 2.5" | 63 | 1.10 | 0.19 | 0.19 | 0.20 | 0.20 | 0.20 | 0.21 | 0.21 | 0.22 | 0.22 | 0.22 | 0.23 |
| 2.5" | 63 | 2.5" | 63 | 1.20 | 0.21 | 0.21 | 0.22 | 0.22 | 0.22 | 0.23 | 0.23 | 0.23 | 0.24 | 0.24 | 0.25 |
| 2.5" | 63 | 2.5" | 63 | 1.30 | 0.22 | 0.23 | 0.23 | 0.24 | 0.24 | 0.25 | 0.25 | 0.25 | 0.26 | 0.26 | 0.27 |
| 2.5" | 63 | 2.5" | 63 | 1.40 | 0.24 | 0.25 | 0.25 | 0.26 | 0.26 | 0.26 | 0.27 | 0.27 | 0.28 | 0.28 | 0.29 |
| 2.5" | 63 | 2.5" | 63 | 1.50 | 0.26 | 0.26 | 0.27 | 0.27 | 0.28 | 0.28 | 0.29 | 0.29 | 0.30 | 0.30 | 0.31 |
| 2.5" | 63 | 2.5" | 63 | 1.60 | 0.28 | 0.28 | 0.29 | 0.29 | 0.30 | 0.30 | 0.31 | 0.31 | 0.32 | 0.32 | 0.33 |
| 2.5" | 63 | 2.5" | 63 | 1.70 | 0.29 | 0.30 | 0.30 | 0.31 | 0.32 | 0.32 | 0.33 | 0.33 | 0.34 | 0.34 | 0.35 |
| 2.5" | 63 | 2.5" | 63 | 1.80 | 0.31 | 0.32 | 0.32 | 0.33 | 0.33 | 0.34 | 0.35 | 0.35 | 0.36 | 0.36 | 0.37 |
| 2.5" | 63 | 2.5" | 63 | 1.90 | 0.33 | 0.33 | 0.34 | 0.35 | 0.35 | 0.36 | 0.37 | 0.37 | 0.38 | 0.38 | 0.39 |
| 2.5" | 63 | 2.5" | 63 | 2.00 | 0.35 | 0.35 | 0.36 | 0.37 | 0.37 | 0.38 | 0.38 | 0.39 | 0.40 | 0.40 | 0.41 |
| 2.5" | 63 | 2.5" | 63 | 2.10 | 0.36 | 0.37 | 0.38 | 0.38 | 0.39 | 0.40 | 0.40 | 0.41 | 0.42 | 0.43 | 0.43 |
| 2.5" | 63 | 2.5" | 63 | 2.20 | 0.38 | 0.39 | 0.39 | 0.40 | 0.41 | 0.42 | 0.42 | 0.43 | 0.44 | 0.45 | 0.45 |
| 2.5" | 63 | 2.5" | 63 | 2.30 | 0.40 | 0.40 | 0.41 | 0.42 | 0.43 | 0.44 | 0.44 | 0.45 | 0.46 | 0.47 | 0.47 |

Fig 2.3-7 Heat loss from insulation wall with an economic thickness (Rock Wool, kW/m)

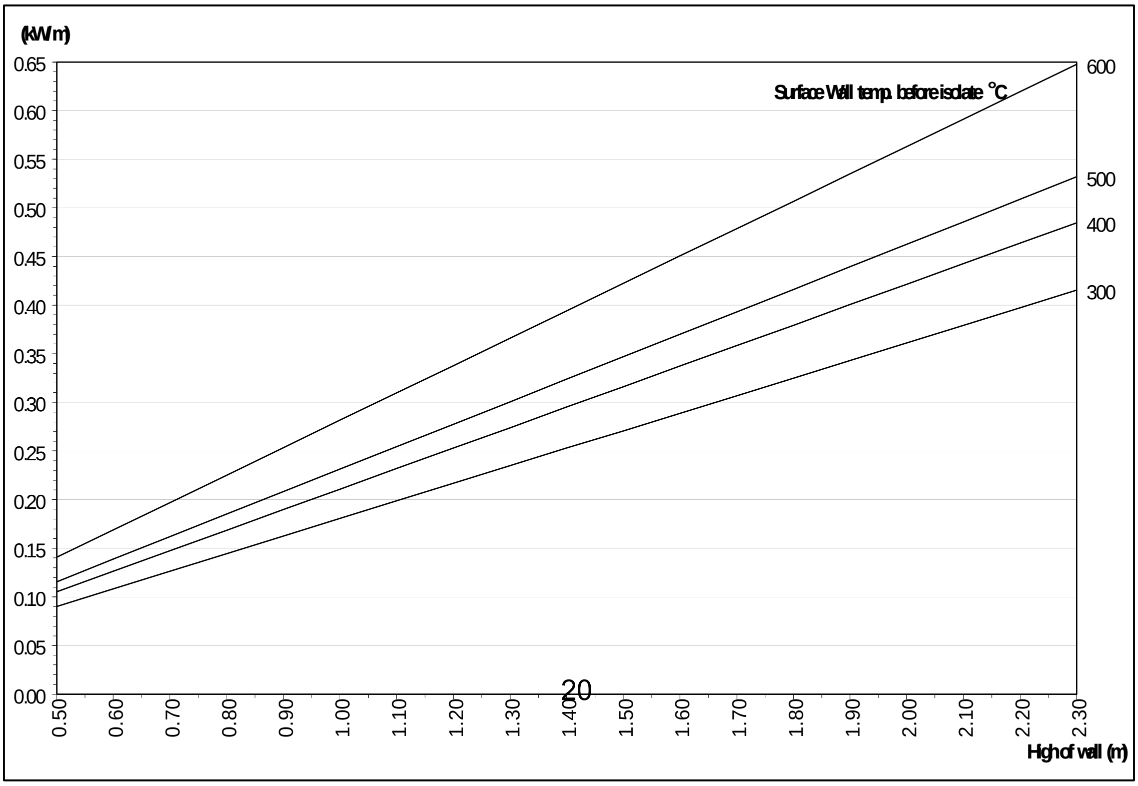


Table 2.3-6 Heat loss from insulation wall with an economic thickness (Rock Wool, kW/m)

| Insulation thickness | | | | | | Surface Temp. ( C) | 300 | 360 | 380 | 400 | 420 | 440 | 460 | 480 | 500 | 520 | 540 | 560 | 580 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300-399 C | | 400-499 C | | 500-600 C | | After isolate temp. ( C) | 57.57 | 62.79 | 64.53 | 61.35 | 62.81 | 64.28 | 65.74 | 67.21 | 63.91 | 65.17 | 66.42 | 67.68 | 68.94 | 70.19 |
| in. | mm. | in. | mm | in. | mm. | High of wall (m.) | Heat loss from insulation wall with an economic thickness (Rock Wool, kW/m) | | | | | | | | | | | | | |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 0.50 | 0.09 | 0.11 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.14 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 0.60 | 0.11 | 0.13 | 0.14 | 0.13 | 0.13 | 0.14 | 0.15 | 0.15 | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.17 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 0.70 | 0.13 | 0.16 | 0.17 | 0.15 | 0.16 | 0.16 | 0.17 | 0.18 | 0.16 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 0.80 | 0.14 | 0.18 | 0.19 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.19 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 0.90 | 0.16 | 0.20 | 0.21 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.21 | 0.22 | 0.23 | 0.24 | 0.24 | 0.25 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.00 | 0.18 | 0.22 | 0.24 | 0.21 | 0.22 | 0.23 | 0.25 | 0.26 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.10 | 0.20 | 0.24 | 0.26 | 0.23 | 0.24 | 0.26 | 0.27 | 0.28 | 0.25 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.20 | 0.22 | 0.27 | 0.28 | 0.25 | 0.27 | 0.28 | 0.30 | 0.31 | 0.28 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.30 | 0.23 | 0.29 | 0.31 | 0.27 | 0.29 | 0.30 | 0.32 | 0.33 | 0.30 | 0.31 | 0.33 | 0.34 | 0.35 | 0.37 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.40 | 0.25 | 0.31 | 0.33 | 0.30 | 0.31 | 0.33 | 0.34 | 0.36 | 0.32 | 0.34 | 0.35 | 0.37 | 0.38 | 0.39 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.50 | 0.27 | 0.33 | 0.35 | 0.32 | 0.33 | 0.35 | 0.37 | 0.39 | 0.35 | 0.36 | 0.38 | 0.39 | 0.41 | 0.42 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.60 | 0.29 | 0.36 | 0.38 | 0.34 | 0.36 | 0.37 | 0.39 | 0.41 | 0.37 | 0.39 | 0.40 | 0.42 | 0.43 | 0.45 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.70 | 0.31 | 0.38 | 0.40 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.39 | 0.41 | 0.43 | 0.44 | 0.46 | 0.48 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.80 | 0.33 | 0.40 | 0.43 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 | 0.42 | 0.43 | 0.45 | 0.47 | 0.49 | 0.51 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 1.90 | 0.34 | 0.42 | 0.45 | 0.40 | 0.42 | 0.45 | 0.47 | 0.49 | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0.53 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 2.00 | 0.36 | 0.44 | 0.47 | 0.42 | 0.45 | 0.47 | 0.49 | 0.52 | 0.46 | 0.48 | 0.50 | 0.52 | 0.54 | 0.56 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 2.10 | 0.38 | 0.47 | 0.50 | 0.44 | 0.47 | 0.49 | 0.52 | 0.54 | 0.49 | 0.51 | 0.53 | 0.55 | 0.57 | 0.59 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 2.20 | 0.40 | 0.49 | 0.52 | 0.46 | 0.49 | 0.52 | 0.54 | 0.57 | 0.51 | 0.53 | 0.55 | 0.58 | 0.60 | 0.62 |
| 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 2.30 | 0.42 | 0.51 | 0.54 | 0.48 | 0.51 | 0.54 | 0.57 | 0.59 | 0.53 | 0.56 | 0.58 | 0.60 | 0.62 | 0.65 |

Fig 2.3-8 Heat loss from insulation wall with an economic thickness (Calcium silicate, kW/m)

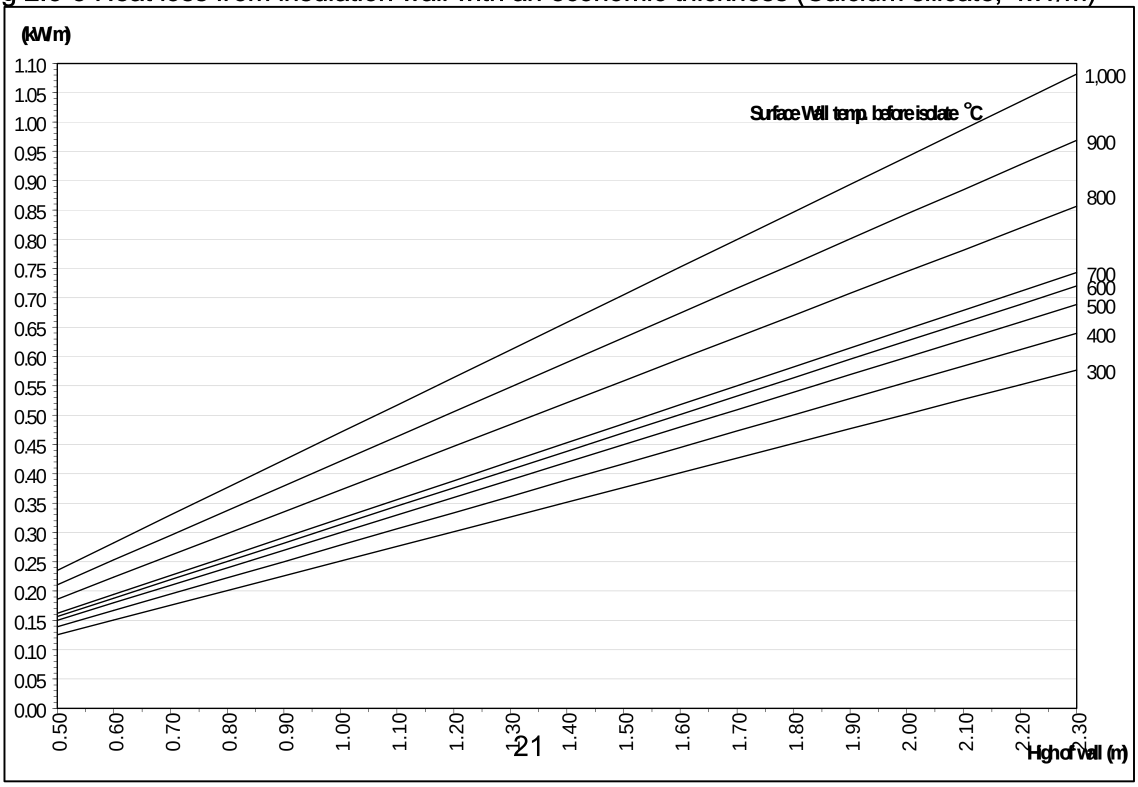


Table 2.3-7 Heat loss from insulation wall with an economic thickness (Calcium silicate, kW/m)

| Insulation thickness | | | | | | | | | | Surface Temp( C) | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 C | | 400 C | | 500 - 599 C | | 600 - 699 C | | 700 - 1000 C | | After isolate temp ( C) | 66.37 | 69.76 | 72.44 | 74.15 | 75.42 | 81.54 | 87.67 | 93.79 |
| in. | mm | in. | mm | in. | mm. | in. | mm. | in. | mm. | High of wall (m.) | Heat loss from insulation wall with an economic thickness (Calcium silicate, kW/m) | | | | | | | |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 0.50 | 0.13 | 0.14 | 0.15 | 0.16 | 0.16 | 0.19 | 0.21 | 0.24 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 0.60 | 0.15 | 0.17 | 0.18 | 0.19 | 0.19 | 0.22 | 0.25 | 0.28 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 0.70 | 0.18 | 0.19 | 0.21 | 0.22 | 0.23 | 0.26 | 0.29 | 0.33 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 0.80 | 0.20 | 0.22 | 0.24 | 0.25 | 0.26 | 0.30 | 0.34 | 0.38 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 0.90 | 0.23 | 0.25 | 0.27 | 0.28 | 0.29 | 0.34 | 0.38 | 0.42 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.00 | 0.25 | 0.28 | 0.30 | 0.31 | 0.32 | 0.37 | 0.42 | 0.47 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.10 | 0.28 | 0.31 | 0.33 | 0.34 | 0.36 | 0.41 | 0.46 | 0.52 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.20 | 0.30 | 0.33 | 0.36 | 0.38 | 0.39 | 0.45 | 0.51 | 0.56 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.30 | 0.33 | 0.36 | 0.39 | 0.41 | 0.42 | 0.48 | 0.55 | 0.61 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.40 | 0.35 | 0.39 | 0.42 | 0.44 | 0.45 | 0.52 | 0.59 | 0.66 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.50 | 0.38 | 0.42 | 0.45 | 0.47 | 0.49 | 0.56 | 0.63 | 0.71 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.60 | 0.40 | 0.44 | 0.48 | 0.50 | 0.52 | 0.60 | 0.67 | 0.75 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.70 | 0.43 | 0.47 | 0.51 | 0.53 | 0.55 | 0.63 | 0.72 | 0.80 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.80 | 0.45 | 0.50 | 0.54 | 0.56 | 0.58 | 0.67 | 0.76 | 0.85 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 1.90 | 0.48 | 0.53 | 0.57 | 0.60 | 0.61 | 0.71 | 0.80 | 0.89 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 2.00 | 0.50 | 0.56 | 0.60 | 0.63 | 0.65 | 0.74 | 0.84 | 0.94 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 2.10 | 0.53 | 0.58 | 0.63 | 0.66 | 0.68 | 0.78 | 0.88 | 0.99 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 2.20 | 0.55 | 0.61 | 0.66 | 0.69 | 0.71 | 0.82 | 0.93 | 1.03 |
| 2" | 50 | 2.5" | 63 | 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 2.30 | 0.58 | 0.64 | 0.69 | 0.72 | 0.74 | 0.86 | 0.97 | 1.08 |

Fig 2.3-9 Heat loss from insulation wall with an economic thickness (Ceramic Fiber, kW/m)

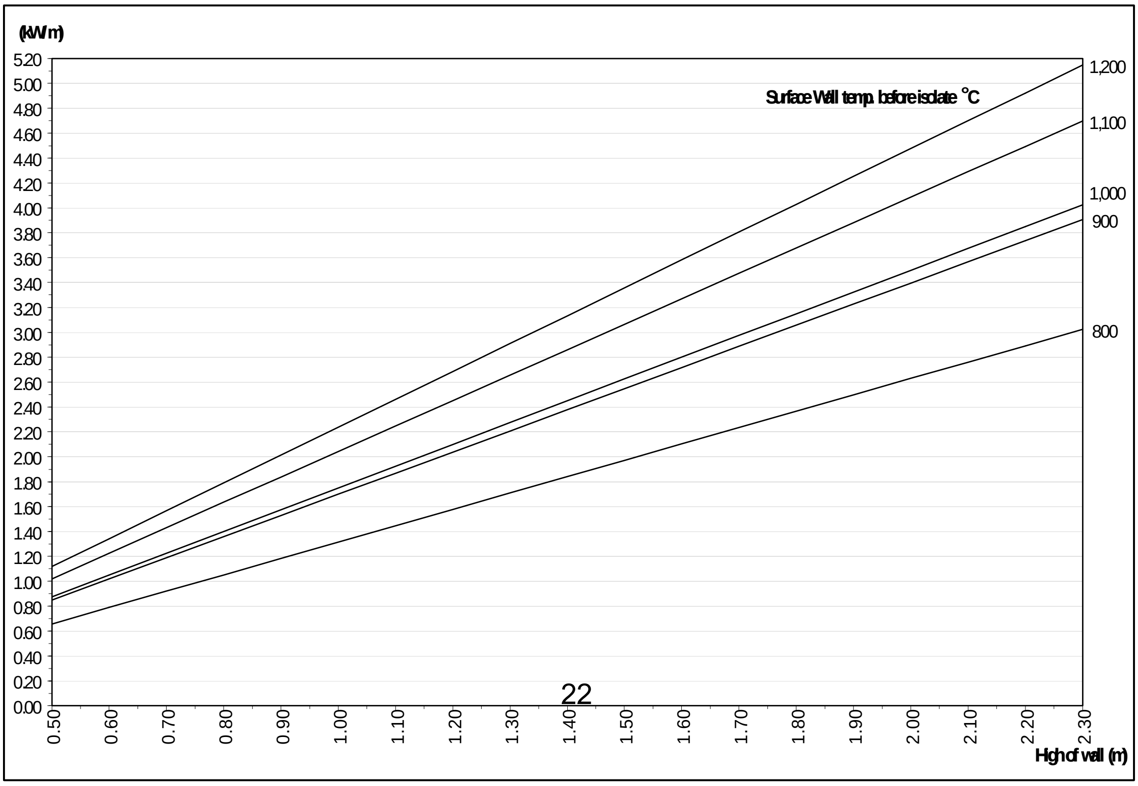


Table 2.3-8 Heat loss from insulation wall with an economic thickness (Ceramic Fiber, kW/m)

| Insulation thickness | | | | | | | | Surface Temp. ( C) | 800 | 900 | 1000 | 1020 | 1040 | 1060 | 1080 | 1100 | 1120 | 1140 | 1160 | 1180 | 1200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 800 C | | 900 C | | 1000 C | | 1100-1200 C | | Surface Temp. ( C) | 199.34 | 247.28 | 253.71 | 258.33 | 262.95 | 267.57 | 272.19 | 290.34 | 295.23 | 300.11 | 304.99 | 309.88 | 314.76 |
| in. | mm | in. | mm. | in. | mm. | in. | mm. | High of wall (m.) | Heat loss from insulation wall with an economic thickness (Ceramic Fiber, kW/m) | | | | | | | | | | | | |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 0.50 | 0.66 | 0.85 | 0.87 | 0.89 | 0.91 | 0.93 | 0.95 | 1.02 | 1.04 | 1.06 | 1.08 | 1.10 | 1.12 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 0.60 | 0.79 | 1.02 | 1.05 | 1.07 | 1.09 | 1.12 | 1.14 | 1.23 | 1.25 | 1.27 | 1.30 | 1.32 | 1.34 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 0.70 | 0.92 | 1.19 | 1.22 | 1.25 | 1.28 | 1.30 | 1.33 | 1.43 | 1.46 | 1.48 | 1.51 | 1.54 | 1.57 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 0.80 | 1.05 | 1.36 | 1.40 | 1.43 | 1.46 | 1.49 | 1.52 | 1.63 | 1.67 | 1.70 | 1.73 | 1.76 | 1.79 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 0.90 | 1.18 | 1.53 | 1.57 | 1.61 | 1.64 | 1.67 | 1.71 | 1.84 | 1.87 | 1.91 | 1.94 | 1.98 | 2.01 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.00 | 1.31 | 1.70 | 1.75 | 1.79 | 1.82 | 1.86 | 1.90 | 2.04 | 2.08 | 2.12 | 2.16 | 2.20 | 2.24 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.10 | 1.45 | 1.87 | 1.92 | 1.97 | 2.01 | 2.05 | 2.09 | 2.25 | 2.29 | 2.33 | 2.38 | 2.42 | 2.46 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.20 | 1.58 | 2.04 | 2.10 | 2.14 | 2.19 | 2.23 | 2.28 | 2.45 | 2.50 | 2.55 | 2.59 | 2.64 | 2.69 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.30 | 1.71 | 2.21 | 2.27 | 2.32 | 2.37 | 2.42 | 2.47 | 2.66 | 2.71 | 2.76 | 2.81 | 2.86 | 2.91 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.40 | 1.84 | 2.38 | 2.45 | 2.50 | 2.55 | 2.60 | 2.66 | 2.86 | 2.91 | 2.97 | 3.02 | 3.08 | 3.13 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.50 | 1.97 | 2.55 | 2.62 | 2.68 | 2.74 | 2.79 | 2.85 | 3.06 | 3.12 | 3.18 | 3.24 | 3.30 | 3.36 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.60 | 2.10 | 2.72 | 2.80 | 2.86 | 2.92 | 2.98 | 3.04 | 3.27 | 3.33 | 3.39 | 3.46 | 3.52 | 3.58 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.70 | 2.24 | 2.89 | 2.97 | 3.04 | 3.10 | 3.16 | 3.23 | 3.47 | 3.54 | 3.61 | 3.67 | 3.74 | 3.80 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.80 | 2.37 | 3.06 | 3.15 | 3.22 | 3.28 | 3.35 | 3.42 | 3.68 | 3.75 | 3.82 | 3.89 | 3.96 | 4.03 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 1.90 | 2.50 | 3.23 | 3.32 | 3.39 | 3.46 | 3.54 | 3.61 | 3.88 | 3.96 | 4.03 | 4.10 | 4.18 | 4.25 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 2.00 | 2.63 | 3.40 | 3.50 | 3.57 | 3.65 | 3.72 | 3.80 | 4.09 | 4.16 | 4.24 | 4.32 | 4.40 | 4.48 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 2.10 | 2.76 | 3.57 | 3.67 | 3.75 | 3.83 | 3.91 | 3.98 | 4.29 | 4.37 | 4.45 | 4.54 | 4.62 | 4.70 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 2.20 | 2.89 | 3.74 | 3.85 | 3.93 | 4.01 | 4.09 | 4.17 | 4.49 | 4.58 | 4.67 | 4.75 | 4.84 | 4.92 |
| 3" | 75 | 3.1/2" | 87.5 | 4" | 100 | 4.1/2" | 112.5 | 2.30 | 3.02 | 3.91 | 4.02 | 4.11 | 4.19 | 4.28 | 4.36 | 4.70 | 4.79 | 4.88 | 4.97 | 5.06 | 5.15 |

***Surface heat loss analysis by Tables***

**Surface heat loss of Wall non-isolate**

1. Measure surface temperature of the Wall. Let say 500 $^{O}$C
2. Measure the length and size of Wall for example high of wall 1.3 meter and length 2.5 meters.
3. look at table 2.3-4 the surface heat loss of 500 C wall is 27.34 kW/m.
4. operating hours are 3000 hr./year
5. So the loss is = 27.34 kW/m. x 2.5 m. x 3,000 hr/year

   = 205,050.00 kW/y

Surface heat loss of Insulated Wall

1. Choose insulation materials-rock wool, glass wool or calcium silicate
2. Look up table 2.3-6 for surface temperature and loss of insulated wall. In this case the loss is 0.30 kW/m and 63.91◦ C surface temperature.
3. Look up table 2.3-6 for insulation thickness. That is 3.1/2" or 87.5 mm.
6. Operating hours are 3000 hr./year
7. So the loss is = 0.30 kW/m. x 2.5 m. x 3,000 hr/year =2,250.00 kW/y

   The energy saving is = 205,050 – 2,250 = 202,800.00 kW/y

O Example

ECON factory uses Heavy oil to produce hot gases for furnace. From survey, 4.5 meters of Length wall and 2 meters of high wall. The wall no insulated was found. The factory operates 312 day per year and 16 hrs per day. Ambient temperature is 35 ◦ C. Determine Fuel saving after insulated Wall.

Using Tables to analyze the project.

1. From Table 2.3-4, Surface heat loss of 700 ◦ C pipe = 101.96 kW/m.
2. Use Calcium silicate as insulation, Surface heat loss of insulating wall from Table 2.3-7

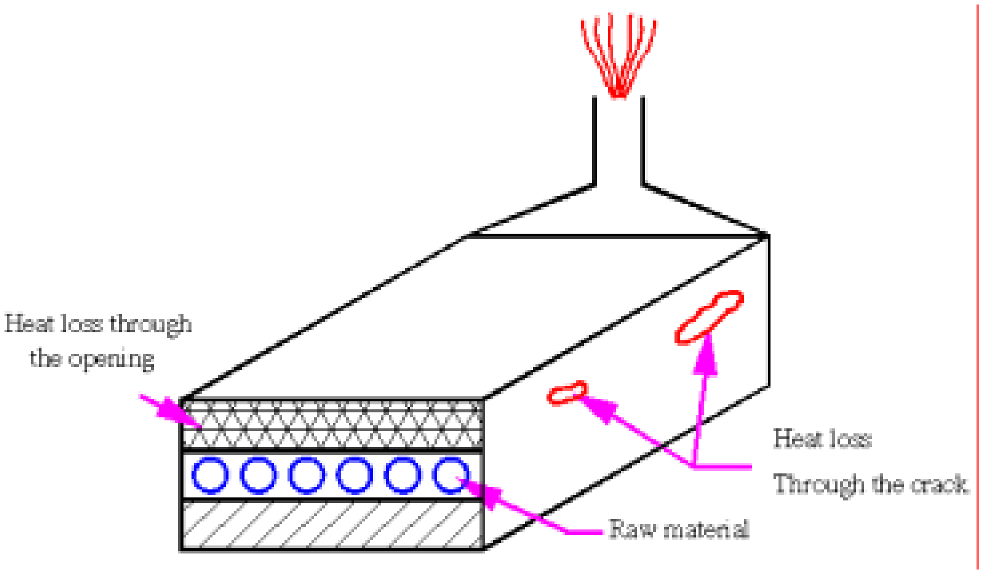
   = 0.65 kW/m.
3. Choose insulation thickness from Table 2.3-7 = 100 mm. Or 4"
4. Temperature after insulation from Table 2.3-7 = 75.42 C
5. Saving of heat loss = (101.96-0.65) x 2 x 312 x16

   = 1,011,479.04 kW/Y. = 1,011,479.04 x 3.6 = 3,641,324.54 MJ/Y.
6. Fuel saving = 3,641,324.54/ 38.18 = 95,372.57 L./Y.

** Heating value of Heavy Oil = 38.18 MJ/L.

(4) Measures to reduce heat loss from leakage and openings

The thermal energy from fuel combustion besides transfer to specimen, it still loss by many ways such as flue gas loss, furnace wall, cooling water including with heat loss through the opening or the crack of furnace. Therefore, the users should tighten the crack and reduce the opening of furnace as possible. Furthermore, the draught pressure must control to be nearly atmospheric pressure.




o What are factors to affect heat loss?

1. The size of the opening and crack: The more size, the more loss. Therefore, the users should be reduced the opening size as much as possible and tighten the crack of furnace.
2. The temperature of hot gas in furnace: The more temperature, the more loss. Therefore, should be adjusted temperature to the standard.
3. The draught pressure: If the draught pressure is higher than atmospheric pressure, the hot gas inside furnace will flow through the opening or crack to the ambient. On the other hand, the cool air from ambient will flow into the furnace cause the temperature of hot gas in furnace unstable and may be reduce the quality of specimen. Therefore, should be controlled the draught pressure nearly atmospheric pressure.
4. The ambient temperature: The lower ambient temperature, the more heat loss.

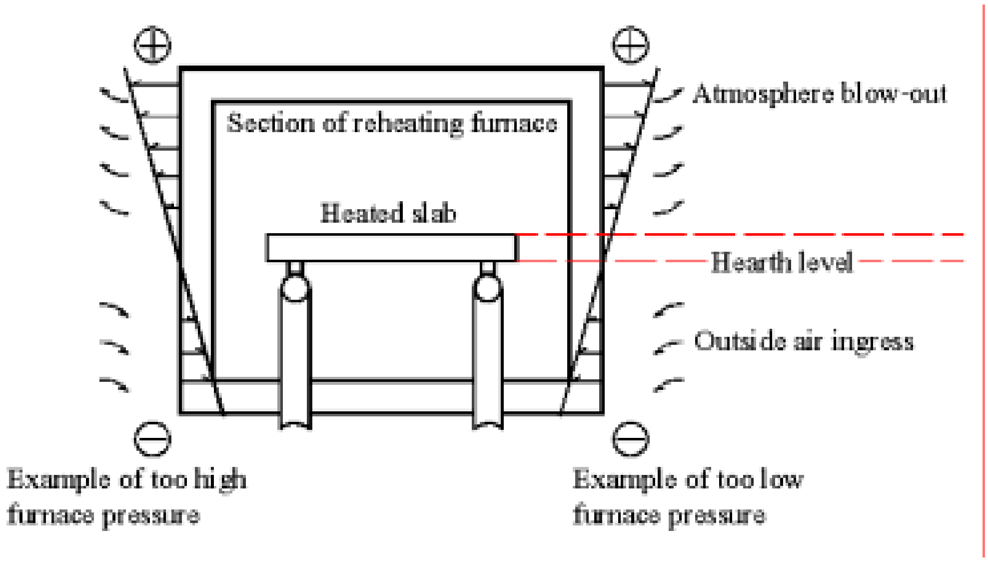



Figure 2.4-1 Effect of draught pressure

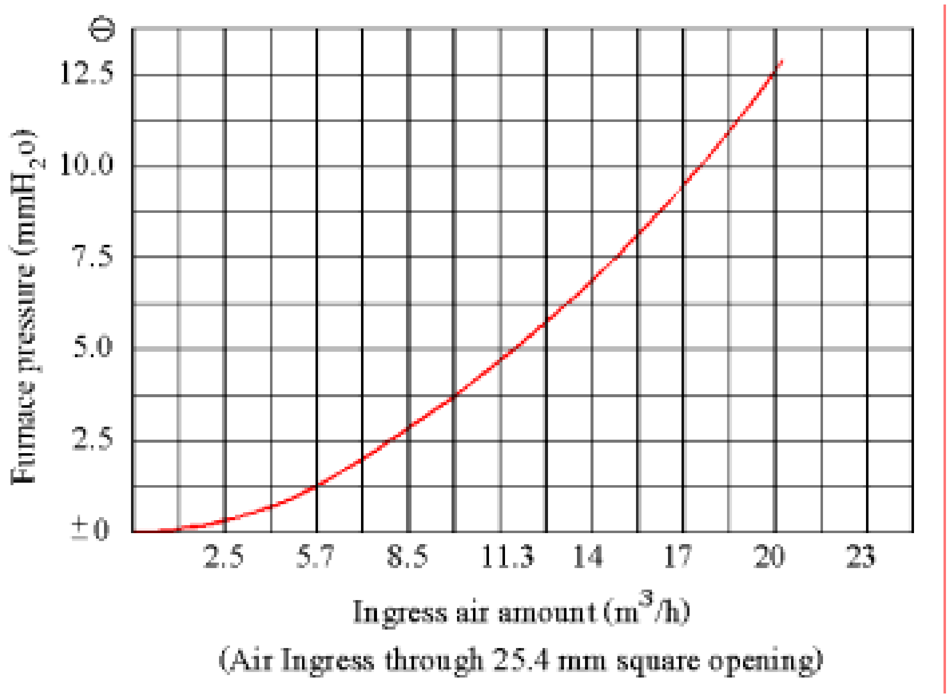


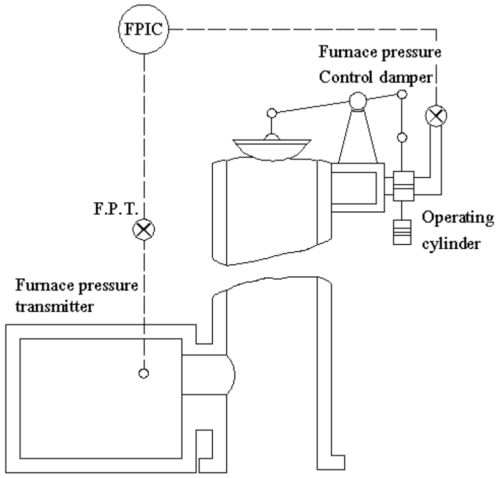

Figure 2.4-2 Relationship between draught pressure and gas flow rate through the opening

o How to control furnace pressure?

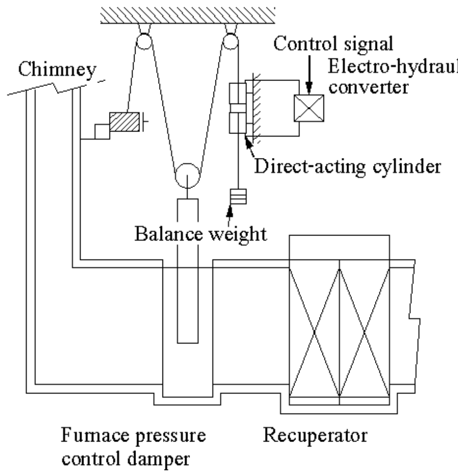
The draught pressure should control to be nearly atmospheric pressure. In general, the draught pressure is slightly higher than atmospheric pressure which approximately 0.5-1.0 mmH2O. The pressure control is done by decreasing or increasing of flue gas from the stack. If decrease flue gas, the draught pressure will increase while increase flue gas, the draught pressure will decrease. The draught pressure control methods are:

1. Mechanical Control: by using some devices against the flow of flue gas.
   1.1 Using slide damper
   1.2 Using rotary (butterfly) damper
   1.3 Using poppet valve
2. Air Curtain Control: by using air curtain against the flow of flue gas.

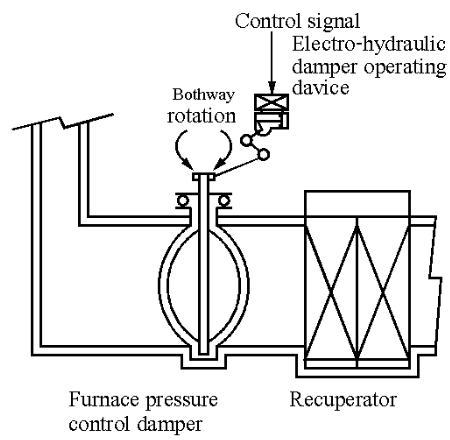
In general, all methods should be installed the pressure sensor to measure the draught pressure ( Furnace Pressure Transmitter: FPT).This sensor will send the signal to the pressure control device ( Furnace Pressure Control) for controlling damper or air curtain in addition to increase or decrease flue gas from the stack.



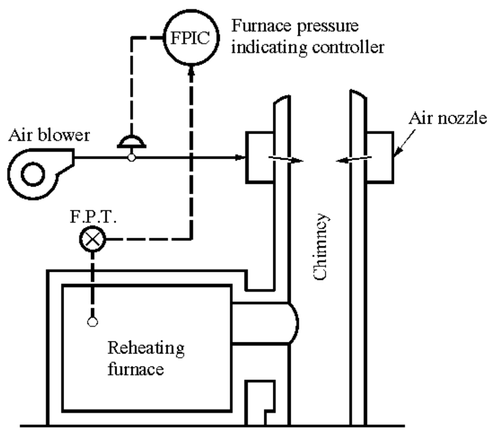

(a) Poppet valve type




(b) Suspended slide damper




(c) Rotary (butterfly) type damper




(d) Air curtain type

Figure 2.4-3 Draught pressure control

- **How to calculate heat loss?**

The heat which leaks from furnace to ambient or leaks from ambient to furnace both cause heat loss in furnace. This heat loss can calculate as the following:

The air velocity flow through the opening of furnace; m/Sec

$$VL = -0.0263 \times h2 + 0.9402 \times h + 1.0638 \quad \text{——— (2.4-1)}$$

The mass flow rate of air through the opening; kg/Sec

$$\mathring{m}_L = \rho \times A \times VL \quad \text{——— (2.4-2)}$$

The heat loss rate through the opening; kJ/Sec

$$QL = \mathring{m}_L \times Cp \times (t2-t1) \quad \text{——— (2.4-3)}$$

where

| | | |
|---|---|---|
| h | = | draught pressure: mm $H^2O$ |
| $\rho$ | = | density of air at mean temperature; kg/m$^3$ |
| A | = | cross-section area of the opening; m$^2$ |
| Cp | = | specific heat of air at mean temperature; kJ/kg $^OC$ |
| t2 | = | temperature of hot gas in furnace; $^OC$ |
| t1 | = | ambient temperature; $^OC$ |

- **How to check heat loss?**

The heat loss from the opening or the crack of furnace can find in 2 cases:

Case 1: known draught pressure

1.1 Using table 2.4-1or figure 2.4-4, from the temperature and draught pressure of furnace can find heat loss rate in term of MJ/h/m2

1.2 Compute the opening or the crack area then multiply with heat loss rate obtain from 1.1 gives heat loss rate in term of MJ/h

1.3 Use heat loss rate obtain from 1.2 divided by calorific heating value of fuel then multiply with operating hours in a year, the result is the fuel loss in a year.

Case 2: Unknown draught pressure

2.1 Using table 2.4-2 or figure 2.4-5, from the temperature of hot gas in the furnace gives heat loss rate through the opening of furnace in term of kJ/h/m$^3$

2.2 Find the air flow rate by measure the mean air velocity flow through the opening then multiply with cross-sectional area of air flow.

2.3 Using air flow rate obtain from 2.2 multiply with heat loss rate obtain from 2.1 gives heat loss in term of kJ/h

2.4 Using heat loss rate obtain from 2.3 divided by low calorific heating value of fuel then multiply with operating hours in a year, the result is fuel loss in a year.

Figure 2.4-4 Heat loss rate through the opening per square metre (MJ/h/m$^2$)

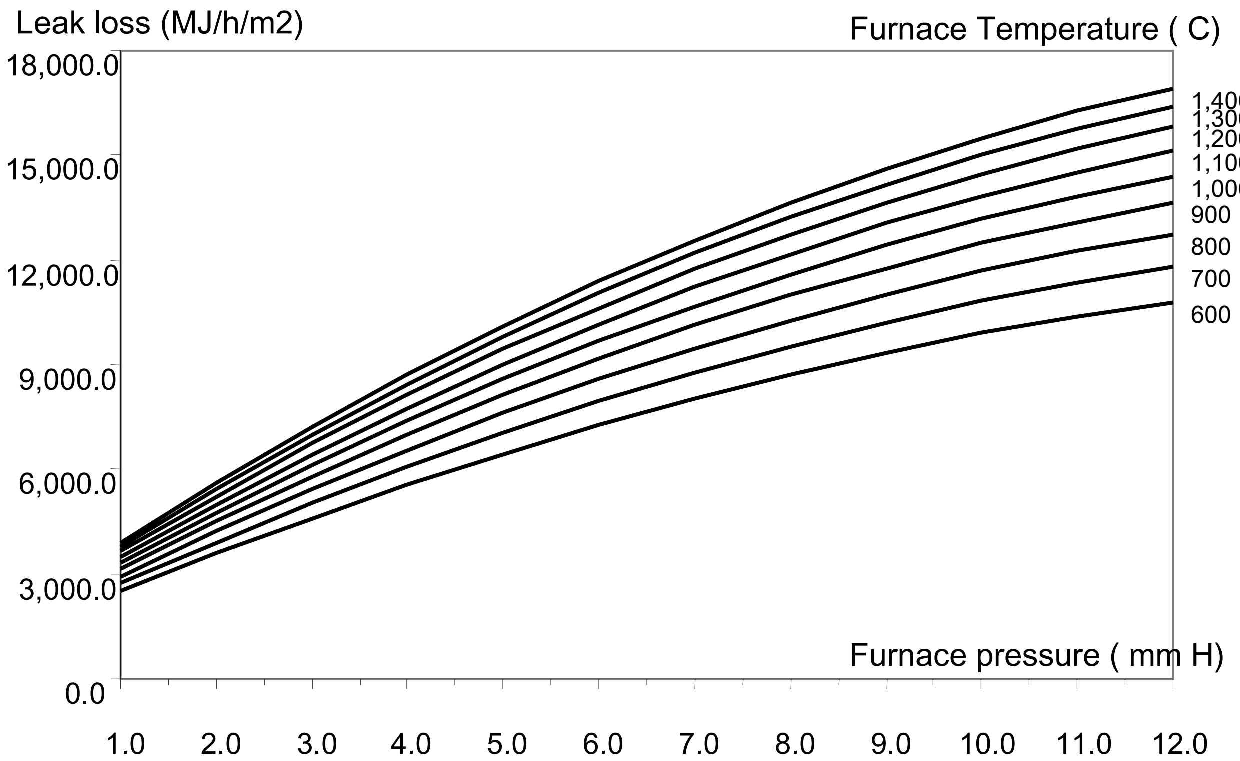


Table 2.4-1 Heat loss rate through the opening per square metre (MJ/h/$m^2$)

| Draught gauge pressure (mm H2O) | Temperature of hot air in furnace (c) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 |
| 0.5 | 1,930.4 | 2,115.2 | 2,278.8 | 2,435.6 | 2,570.3 | 2,700.3 | 2,823.9 | 2,931.2 | 3,024.9 |
| 1.0 | 2,498.1 | 2,737.3 | 2,949.1 | 3,152.0 | 3,326.3 | 3,494.5 | 3,654.4 | 3,793.3 | 3,914.6 |
| 1.5 | 3,040.6 | 3,331.8 | 3,589.5 | 3,836.5 | 4,048.7 | 4,253.4 | 4,448.0 | 4,617.1 | 4,764.7 |
| 2.0 | 3,583.2 | 3,926.3 | 4,230.0 | 4,521.0 | 4,771.1 | 5,012.3 | 5,241.7 | 5,440.9 | 5,614.9 |
| 2.5 | 4,100.4 | 4,493.1 | 4,840.7 | 5,173.7 | 5,459.9 | 5,736.0 | 5,998.4 | 6,226.4 | 6,425.5 |
| 3.0 | 4,605.1 | 5,046.1 | 5,436.4 | 5,810.5 | 6,131.9 | 6,441.9 | 6,736.7 | 6,992.7 | 7,216.3 |
| 3.5 | 5,084.6 | 5,571.4 | 6,002.4 | 6,415.4 | 6,770.2 | 7,112.6 | 7,438.0 | 7,720.7 | 7,967.6 |
| 4.0 | 5,551.4 | 6,082.9 | 6,553.5 | 7,004.4 | 7,391.8 | 7,765.6 | 8,120.9 | 8,429.6 | 8,699.1 |
| 4.5 | 6,005.6 | 6,580.6 | 7,089.7 | 7,577.5 | 7,996.6 | 8,401.0 | 8,785.3 | 9,119.3 | 9,410.9 |
| 5.0 | 6,447.2 | 7,064.5 | 7,611.0 | 8,134.6 | 8,584.6 | 9,018.7 | 9,431.3 | 9,789.8 | 10,102.9 |
| 5.5 | 6,863.5 | 7,520.7 | 8,102.5 | 8,660.0 | 9,139.0 | 9,601.1 | 10,040.4 | 10,422.0 | 10,755.3 |
| 6.0 | 7,267.3 | 7,963.1 | 8,579.1 | 9,169.4 | 9,676.6 | 10,165.9 | 10,631.0 | 11,035.1 | 11,387.9 |
| 7.0 | 8,024.3 | 8,792.6 | 9,472.8 | 10,124.5 | 10,684.5 | 11,224.8 | 11,738.4 | 12,184.6 | 12,574.2 |
| 8.0 | 8,705.6 | 9,539.2 | 10,277.1 | 10,984.1 | 11,591.7 | 12,177.9 | 12,735.0 | 13,219.1 | 13,641.8 |
| 9.0 | 9,336.4 | 10,230.4 | 11,021.8 | 11,780.1 | 12,431.7 | 13,060.3 | 13,657.9 | 14,177.0 | 14,630.4 |
| 10.0 | 9,891.5 | 10,838.7 | 11,677.2 | 12,480.5 | 13,170.9 | 13,836.9 | 14,470.0 | 15,020.0 | 15,500.3 |
| 11.0 | 10,371.0 | 11,364.1 | 12,243.1 | 13,085.5 | 13,809.3 | 14,507.6 | 15,171.3 | 15,748.0 | 16,251.6 |
| 12.0 | 10,800.0 | 11,834.1 | 12,749.6 | 13,626.7 | 14,380.5 | 15,107.6 | 15,798.8 | 16,399.4 | 16,923.8 |

Figure 2.4-5 Heat loss rate through the opening per cubic metre (kJ/h/$m^3$)

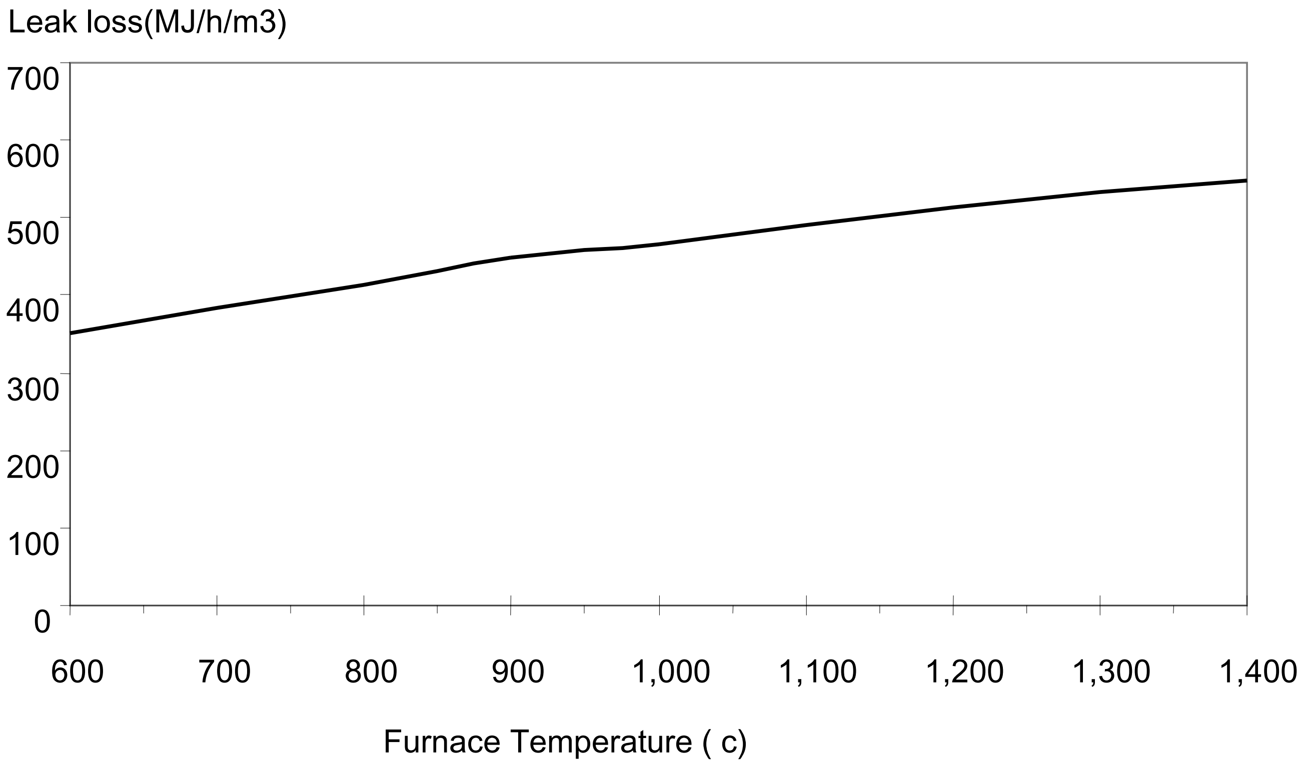


Table 2.4-2 Heat loss rate through the opening per cubic metre (kJ/h/$m^3$)

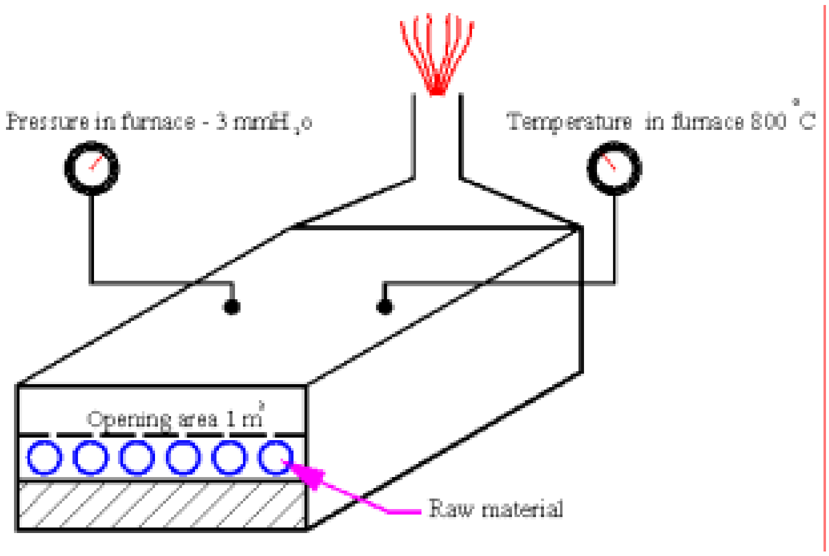
| Temperature of hot air in furnace or through the opening (C) | 600 | 700 | 800 | 900 | 1,000 | 1,100 | 1,200 | 1,300 | 1,400 |
|---|---|---|---|---|---|---|---|---|---|
| Heat loss rate (kJ/h/$m^3$) | 350.5 | 384.0 | 413.7 | 447.2 | 466.7 | 490.3 | 512.7 | 532.2 | 549.2 |
| Fuel consumption rate bunker oil grade C (L/h/$m^3$) | 0.0092 | 0.0102 | 0.0108 | 0.01171 | 0.0122 | 0.0128 | 0.0134 | 0.0139 | 0.0144 |
| Bituminous coal (kg/h/m3) | 0.0133 | 0.0146 | 0.0157 | 0.0170 | 0.0177 | 0.0186 | 0.0194 | 0.0202 | 0.0208 |
| Natural gas ($Nm^3$/h/$m^3$) | 0.0096 | 0.0105 | 0.0113 | 0.0122 | 0.0127 | 0.0134 | 0.0140 | 0.0145 | 0.0150 |

Note : air flow rate through the opening 1 $m^3$/h , ambient temperature 35°C ,using mean air temperature properties

o Examples for more understanding

Example 1 : In case of known draught pressure

ECON steel factory installed a hot roll mill furnace, which the hot gas temperature inside furnace is 800°C. This factory operates 24 hours a day and 300 days a year. The bunker oil grade C is used as the fuel in furnace, the opening of furnace is 0.1 $m^2$. The draught pressure is lower than outside ( -3 $mmH_2O$) and the ambient temperature is 35°C. If reduce the opening size and adjust draught pressure to be 0 $mmH_2O$, how much fuel saving in a year?



From table 2.4-1, at temperature of 800 $^{O}C$ and draught pressure of 3 mmH2O gives

| | | |
|---|---|---|
| the heat loss rate | = | 5,436.4 MJ/h/$m^2$ |
| Area of the opening | = | 0.1 m2 |
| Heat loss through the opening | = | 5,436.4 x 0.1 |
| | = | 543.64 MJ/h |
| Fuel loss | = | 543.64/38.17 |
| | = | 14.24 Liter/h |
| | = | 14.24 x 24 x 300 |
| | = | 102,528 Liter/yr |

Thus, for adjust the draught pressure will save fuel for 102,528 liter/yr.
Where : Calorific heating value of bunker oil grade C is 38.17 MJ/Liter

**Example 2 : In case of unknown draught pressure**

ECON steel factory installed a hot roll mill furnace, which the hot gas temperature inside furnace is 800$^{0}$C. This factory operates 24 hours a day and 300 days a year. The bunker oil grade C is used as the fuel in furnace, the opening of furnace is 0.1 $m^2$. The air velocity through the opening is 3.5 m/s. The ambient temperature is 35$^{0}$C. If reduce the opening size and adjust draught pressure to be 0 $mmH_20$, How much fuel saving in a year?

| | | |
|---|---|---|
| The air flow rate through the opening | = | A x VL |
| | = | 0.1 x 3.5 |
| | = | 0.35 $m^3$/Sec |
| | = | 1,260 $m^3$/h |

From table 2.4-2, at temperature of hot gas in furnace 800 OC :

| | | |
|---|---|---|
| The heat loss rate | = | 413.7 kJ/h/m3 |
| Heat loss per hour | = | 1,260 x 413.7 |
| | = | 521,260 kJ/h |
| Fuel loss | = | 521,260/38,170 |
| | = | 13.66 Liter/h |
| | = | 13.66 x 24 x 300 |
| | = | 98,352 Liter/y |

Thus, for adjust the draught pressure will save fuel for 98,352 liter/yr.
Where: Calorific heating value of bunker oil grade C is 38,170 kJ/Liter

(5) Measures to reduce loss in cooling system

Some furnaces need cooling water for furnace structures. Cooling system should be proper. Over-cooling results in high heat loss and more electricity consumption.

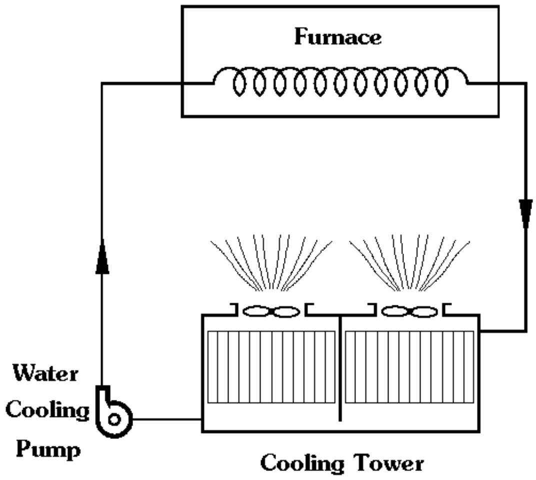



Figure 2.5-1 Cooling System for Furnaces

O How to reduce energy consumption in cooling system

1) Reduce water flow rate by
   - Valve throttle
   - Reduce blade size
   - Vary speed drive
   - Reduce pump size
2) Improve CT efficiency. Poor maintenance results in higher water temperature and more CT operating.

O How to Calculate heat loss

We can calculate heat in cooling water by the following equation.

$Q = m^o \times Cp \times \Delta t$

| | | | |
|---|---|---|---|
| Where | $Q$ | = | Cooling Rate (kJ/h) |
| | $m^o$ | = | Water Flow Rate (kg/h) |
| | $Cp$ | = | Specific Heat of Water (kJ/kg.$^o$C) |
| | $\Delta t$ | = | Temperature Difference ($^o$C) |

O Procedure to evaluate heat loss

1) Use table 2.5-1 or Figure 2.5-2 to find cooling rate (MJ/h) at water flow rate 1 $m^3/h$.
2) Find water flow rate by measurement or pump curves.
3) Multiply cooling rate and water flow rate.
4) Divide the result by low heating value of fuel to get fuel saving per hour.

Table 2.5-1 Heat loss from cooling water (MJ/h) at 1 $m^3/h$ flow rate

| Water Temperature Difference (°C) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|
| Heat Loss at 1 $m^3/h$ (MJ/h) | 42 | 84 | 126 | 168 | 210 | 252 | 294 | 336 | 378 |
| Fuel Consumption at 1$m^3/h$ | | | | | | | | | |
| - Heavy Oil (L/h) | 1.10 | 2.20 | 3.30 | 4.40 | 5.50 | 6.60 | 7.70 | 8.80 | 9.90 |
| - Coal (kg/h) | 1.59 | 3.19 | 4.78 | 6.37 | 7.96 | 9.56 | 11.15 | 12.74 | 14.34 |
| - Natus ($Nm^3/h$) | 1.14 | 2.29 | 3.43 | 4.58 | 5.72 | 6.87 | 8.01 | 9.16 | 10.30 |

**Note** Heating Value according to Table 1.1-5

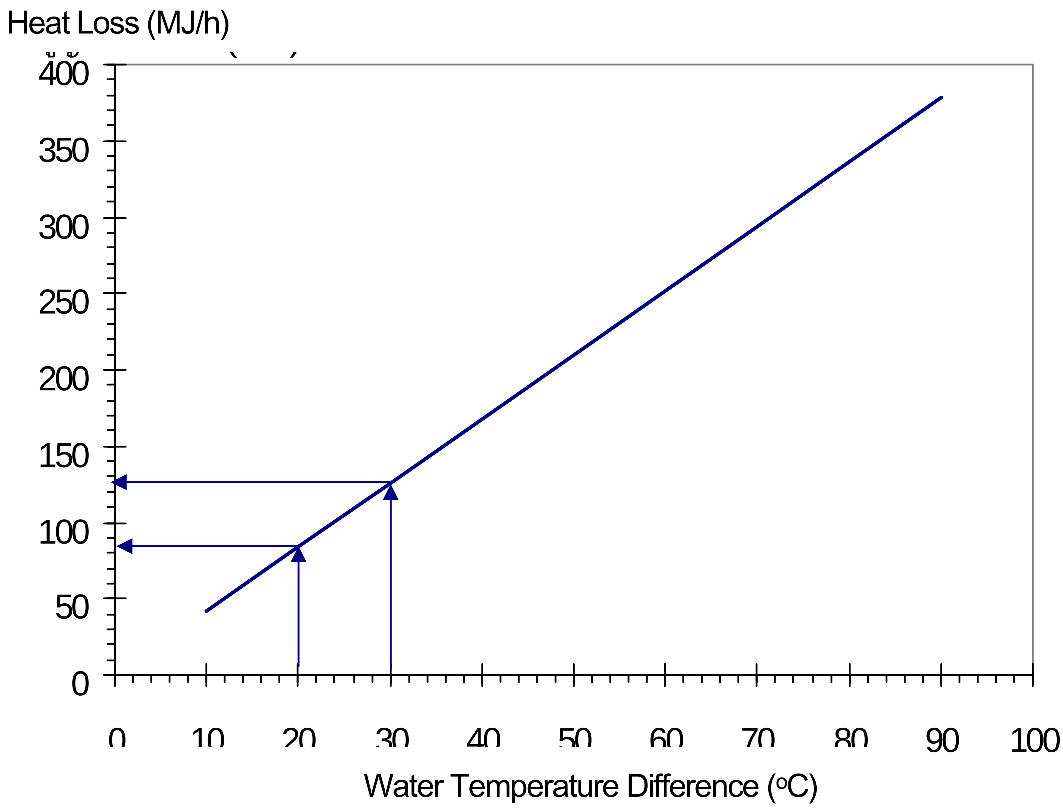



**Figure 2.5-2 Heat loss from cooling water (MJ/h) at 1 $m^3/h$ flow rate**

O Example

The factory operates the furnace 24 hour a day and 300 days per year. The cooling water flow rate is 10 $m^3/h$ instead of 5 $m^3/h$ according to the specification. Inlet temperature is 30 $^oC$ and outlet temperature is 50 $^oC$. So

| | | |
|---|---|---|
| Temperature Difference | = 50 – 30 | $^oC$ |
| | = 20 | $^oC$ |
| From table 2.5-1 heat loss | = 84 x 10 x 24 x 300 | |
| | = 6,048,000 | MJ/y |

After reducing water flow rate to 5 $m^3/h$, the temperature difference becomes 30 $^oC$

| | | |
|---|---|---|
| From table 2.5-1 New heat loss | = 126 x 5 x 24 x 300 | |
| | = 4,536,000 | MJ/y |
| Heat Loss Saving | = 6,048,000 – 4,536,000 | |
| | = 1,512,000 | MJ/y |
| | = 39,600 | L/y |

## 2.3 How to inspect and maintain Industrial Furnace

The furnace controller should have skills in the inspection, analysis and maintenance of the furnace in order to maintain the efficiency, maximize the life time and keep the safe condition of the furnace. The guidelines for inspecting, analyzing, and maintaining the furnace are as the following.

- How to inspect and analyze an industrial furnace?

| Inspection checklists | | Analysis guidelines |
|---|---|---|
| Items | Results | |
| 1. Burner cleaning (liquid fuel) | Every…day(s) | 1. A burner is important equipment for its quality results in the completion of combustion. Therefore, cleaning the burner once a week is necessarily recommended. |
| 2. Flue gas temperature | …………°C | 2. Too high flue gas temperature will cause more heat loss through the stack. The control of flue gas temperature within the standard by adjusting the air/fuel ratio is important. |
| 3. Flame color | ……………… …………… | 3. Normally, the flame color from liquid fuel should be orange, while that from gaseous fuel should be blue with orange end. |
| 4. Stack smoke color | ……………… …………… | 4. For a complete combustion, the smoke color from stack should be grey. White smoke indicates too much air content in the combustion. |
| 5. Brightness of combustion chamber | ……………… ……………… | 5. Too bright combustion chamber indicates too much air content in the combustion. In the contrary, too dark combustion chamber means too low air content. |
| 6. Liquid fuel temperature | ………°C | 6. The lower temperature, the higher viscosity of liquid fuel. A liquid fuel with high viscosity will hamper the blending process of fuel droplets and the air, and undermine the completion of combustion. In general, the A-grade and C-grade bunker oil should be preheated to the temperatures of 90 an 110 C, respectively. |
| 7. Liquid fuel pressure | ………Barg | 7. Liquid fuel pressure should meet the standard of each type of burner. Lower fuel pressure means lower efficiency of the combustion. |
| 8. Energy sources for fuel preheating | ……………… ……. | 8. To use electricity only for fuel preheating will cost more money than using both the electricity and heat from the steam. |

| Inspection checklists | | Analysis guidelines |
|---|---|---|
| Items | Results | |
| 9. Furnace' s surface temperature | ………$^{O}$C | 9. The temperature of each side of furnace surface should not exceed the standard level which is determined by the furnace temperature. If the surface temperature appears too high, the operator should decrease the furnace temperature or replacing the fire-resistant brick or installing ceramic fiber insulation on the inner wall. |
| 10. Controlled furnace temperature | ………$^{O}$C | 10. The controlled furnace temperature should be within the standard level. Too high temperature will result in wasting the fuel consumption. |
| 11. Start-stop frequency of the burner | ……. | 11. Before each start up, the burner needs to be purged for 2 minutes for safety reason. Too often start-stop of the burner can cause substantial heat loss, due to the cold air supplied to combustion chamber for each purging. |
| 12. Furnace pressure | Higher/lower ambient pressure | 12. The furnace pressure should be a little higher than ambient pressure (about 1 mm $H_2O$) in order to minimize the heat loss through the stack and the suction of cold air through leakages. |
| 13. Appropriateness of the burner position | Yes/no | 13. The burner should be placed at the position where the heat dispersion can cover the largest area and the flame does not affect the raw materials as well as the products. |
| 14. Heat loss through openings or leakages | Large/small | 14. The furnace wall should have the smallest opening and leakage areas. |
| 15. Conditions of insulation and fire-resistant bricks | Good/not good | 15. The decay of insulation and fire-resistant bricks will result in heat loss through the furnace walls. |
| 16. Full capacity for raw material feeding to the furnace | Full/ not full | 16. Feeding of raw materials with lower capacity will result in the higher consumption of energy use per unit of product. This is because the heat loss from the system is relatively constant whether the furnace operation is in the full capacity or not. |
| 17. Furnace doors and stack dampers shut after the use of the furnace | Shut/open | 17. Furnace doors and stack dampers should be shut after the use the furnace in order to avoid heat loss from the system, as well as reducing the heat required for the next start up. |
| 18. Proper arrangement of the objects in the furnace | Proper/ improper | 18. Placing the objects to block the heat direction will cause lengthened burning time and low product quality. |

| | | |
|---|---|---|
| 19. Leaving the furnace to go cold before the next operation | Yes/no | 19. The furnace should be in operation continuously without leaving the furnace to go cold. |
| 20. Recovering the flue gas for reheating the inlet air | Yes/no | 20. Recovering the flue gas for reheating the inlet air to the furnace (Recuperator) will help increase the combustion efficiency and reduce the heat loss through the stack. |
| 21. Recovering the flue gas for reheating the raw materials before entering the furnace | Yes/no | 21. Recovering the flue gas for reheating the raw materials before entering the furnace will help reduce the heat loss through the stack as well as the time consumption for the burning process. |
| 22. The use of automatic burning system | Yes/no | 22. An automatic burning system will help maintain the high efficiency of burning process as well as controlling the furnace temperature within the standard. |
| 23. Existence of stack damper | Yes/no | 23. A stack damper will help stabilize the furnace pressure in order to minimize the heat loss through the stack and after the use of the furnace. |
| 24. Selection of high efficient burners | Yes/no | 24. It is recommended to use high efficient burners such as recuperative burner and regenerative burner. |
| 25. Selection of a high efficient furnace | Yes/no | 25. It is recommended to use a modern and high efficient furnace. |
| 26. Calibration of temperature measuring devices | Every…… | 26. Calibration of temperature measuring devices should be regularly practiced so that the temperature control will be always within the standard. |
| 27. Heat released from the furnace | High/ appropriate | 27. Appropriate amount of heat released from the furnace will help reduce the heat loss from the system. |

- How to maintain industrial furnace

| Implementation | Appropriate period |
|---|---|
| 1. Adjusting the fuel/air ratio regarding to the standard of each fuel type<br>2. Inspecting the heat pattern setting to be optimum for the production<br>3. Cleaning burners and accessories<br>4. Inspecting the furnace' s fire-resistant bricks and wall insulation<br>5. Cleaning the suction duct of the blower and its strainers(if any)<br>6. Inspecting the fuel pressure<br>7. Inspecting the conditions of the following equipment: | Every 3 months<br>Every day<br>Every week (liquid fuel)<br>Every month (gaseous fuel)<br>Every year<br>Every month<br>Every day |

| | |
|---|---|
| • Measuring devices such as pressure gauge, temperature measuring devices, flue gas analyzers and measuring devices, etc.<br>• Fuel pumps<br>• Blower motors<br>• Burner system and fuel preheating system<br><br>8. Measuring and recording the following items:<br>• Fuel consumption rates and production rates<br>• Fuel oil pressure and temperature before the burner<br>• Oxygen or carbon dioxide contents in the flue gas<br>• Appearance and color of the flue gas<br>• Furnace surface temperature | Every 3 months<br><br><br>Every year<br>Every year<br>Every month (liquid fuel)<br>Every 6 months (gaseous fuel)<br>Every day<br>Every day<br>Every time of adjustment<br>Every day<br>Every 6 months |

## Chapter 3
## Waste Heat Recovery

### 3.1 What is Waste Heat?

Waste heat is the energy associated with the waste stream of air, exhaust gases, water, or liquids that is rejected from a process at a higher temperature above ambient temperature. All waste heat should be recovered as much as possible for the reason of heat loss reduction.

- **What difference in quality of waste heat?**

The quality of waste heat can be characterized in terms of the temperature of the waste stream into 3 classes,

1. High quality waste heat

The temperature range of this class is 600 – 1600 °C. This waste heat is from the exhaust gas of the furnace and used for power generation, cogeneration or re-used in the process.

2. Medium quality waste heat

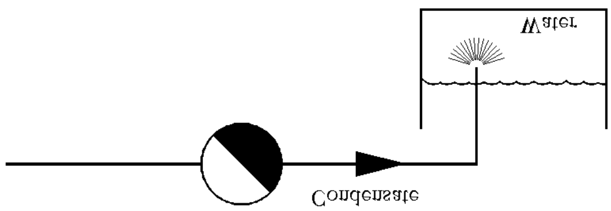
This class has the temperature range of 200 – 600 °C. The source of this waste heat is the exhaust gas from boiler, gas turbine, engine, or furnace. The recovered heat is used for waste heat boiler, or re-used in the process.

3. Low quality waste heat

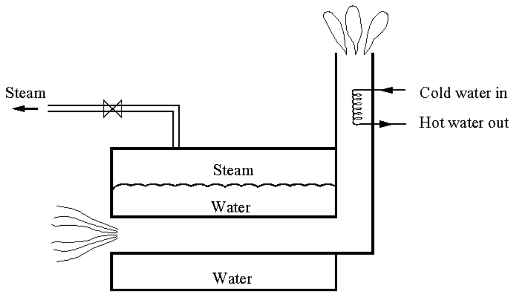
The low quality waste heat has the temperature range of 35 – 200 °C and is used for preheating, or re-used in the process. The sources of this waste heat are steam condensate, cooling water, or cooling air.

- **How to utilize waste**

1. Direct contact or mix with substances that need to be heated. In this way, the purity of hot stream is much concerned.



2. Indirect contact through heat exchanger. The available quantity of waste heat depends on heat exchanger efficiency.




### 3.2 Measures to improve heat recovery

This section will describe measures to improve heat recovery as follows

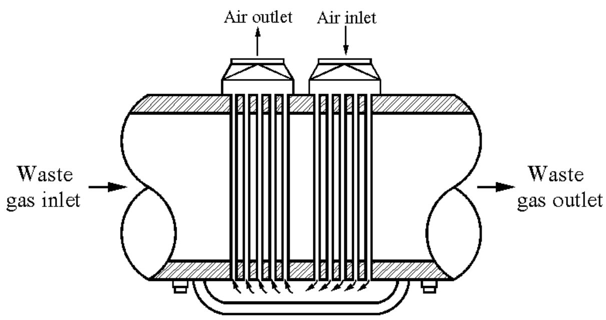
(1) How can the Exhaust Gas be Utilized?

(2) How can the Hot Water or Hot Liquid be Utilized?

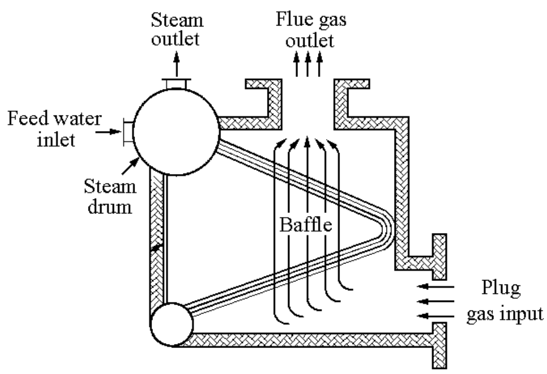
(3) How can the Hot Air be Utilized?

### (1) How to recover flue gas heat

The heat loss from exhaust gas of boiler or furnace is around 10 – 40 % and can be recovered for (a) preheating combustion air by recuperator, (b) generating steam by a waste heat boiler, (c) preheating combustion air by recuperative burner, (d) preheating combustion air by regenerator, (e) preheating combustion air by an air preheater, (f) preheating boiler feed water by an economizer, (g) preheating materials by add preheating zone, and (h) using in processes such as drying process or hot liquid generating process.

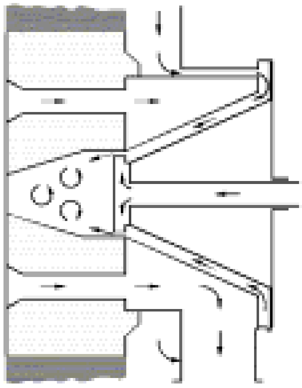



(a) Recuperator

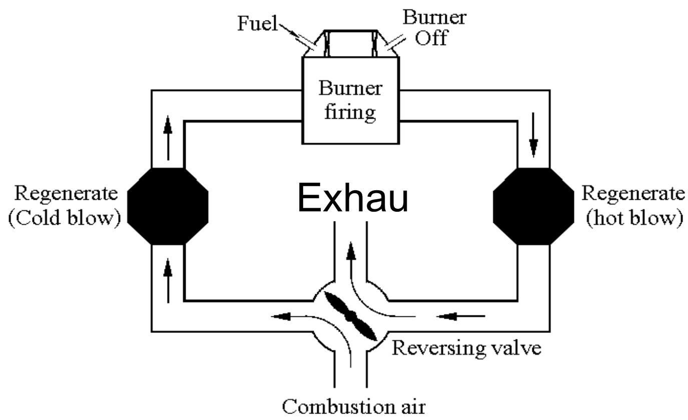



(b) Waste Heat

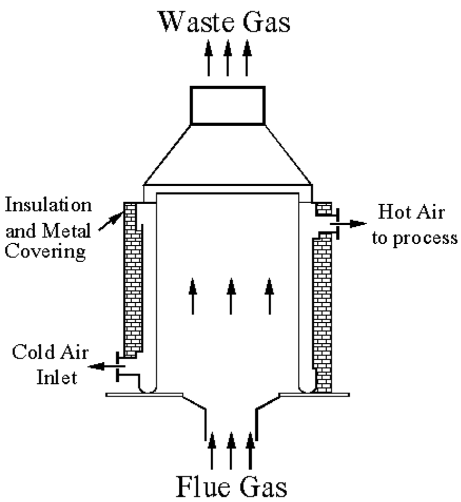
Boiler



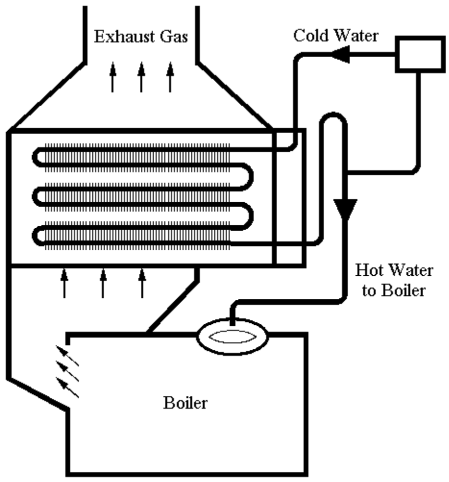
(c) Recuperative Burner



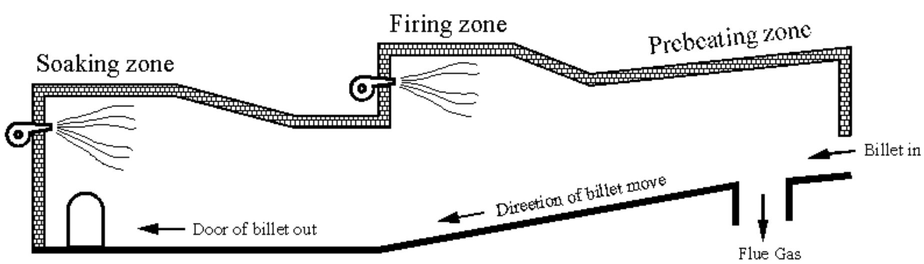

(d) Regenerator



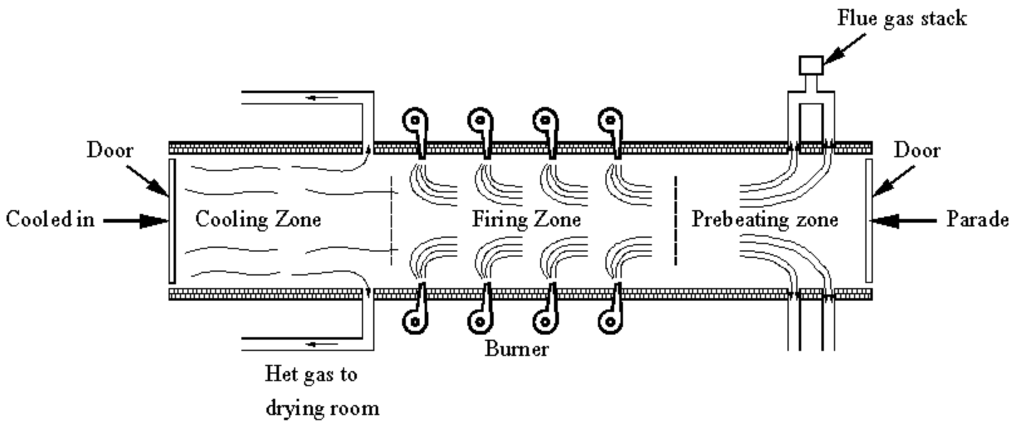

(e) Air Preheater




(f) Economizer




(g) Adding Preheating Zone for Materials Preheating




(h) Bringing Hot Air from Cooling Zone to Drying Process

**Figure 3.2-1 Utilization of waste heat from exhaust gas**

Mostly, the heat exchanger is used for recovering waste heat. It is commonly constructed of steel but in case of high temperature exhaust gas ceramic is more proper but the cost is much expensive.

One factor that should be concerned in recovering waste heat from exhaust gas is the dew point temperature of sulfuric acid ($H_2SO_4$) if the fuel composes of sulfur. So the temperature of exhaust gas at the exit of the heat exchanger that used for calculating available recovering heat must beyond 180 °C and the heat exchanger efficiency is 70%.

**Table 3.2-1 Standard of exhaust gas heat recovery**

| Flue gas temperature ($^0$C) | Percentage of exhaust gas heat recovery (%) | | |
|---|---|---|---|
| | 84 GJ/h | 21-84 GJ/h | 4.2-21 GJ/h |
| < 600 | 25 | 25 | - |
| 600-800 | 35 | 30 | 25 |
| 800-900 | 40 | 30 | 25 |
| > 900 | 45 | 35 | 30 |

- **Data Calculation**
    1. Fuel type
    2. Annual fuel consumption (litres/year)
    3. $O_2$ quantity in exhaust gas (%)
    4. Exhaust gas temperature (°C)

- How to calculate fuel saving by heat recovery
    1. See table 1.2-2 and 2.2-2 for bunker oil grade C, table 1.2-3 and 2.2-3 for bituminous coal, and table 1.2-4 and 2.2-4 for natural gas.
    2. Calculate existing percentage of flue gas loss from stack, using $\%O_2$ and exhaust gas temperature.
    3. Calculate new percentage of flue gas loss, using same $\%O_2$ but new exhaust gas temperature.
    4. Calculate available recovering heat rate by subtract the result from2. by the one from 3. and then multiply by the heat exchanger efficiency (70%)
    5. Calculate annual fuel saving by multiply the result from 4. by annual fuel consumption.

- Examples

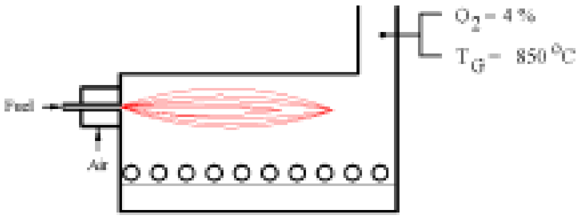
Example1

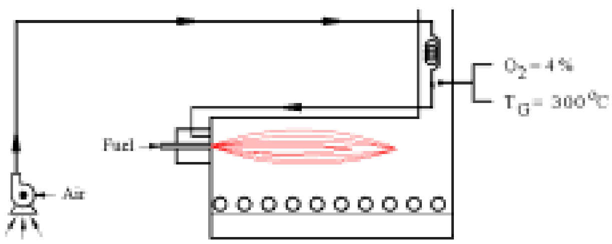
The ECON factory has a furnace that consumes 10,000,000 liters/year of bunker oil grade C. The excess oxygen in exhaust gas is 4%. The exhaust gas temperature and ambient temperature are 850 °C and 35 °C, respectively. In order to save energy, installation of a recuperator to preheat combustion air is proposed. Assuming that the recuperator efficiency is 70 % and the exhaust gas temperature at the exit of the recuperator is 300 °C. Determine the rate of heat recovery and annual fuel saving.

*Analysis:*

From table 1.2-2; Bunker oil grade C, 4% excess $O_2$ and exhaust gas temperature 850 °C, flue gas loss = 39.76 %

From table 1.2 -2; Bunker oil grade C, 4% excess $O_2$ and exhaust gas temperature 300 °C, flue gas loss = 12.11 %



Rate of heat recovery = (39.76-12.11)x(recuperator efficiency, 70%)

= 19.36%

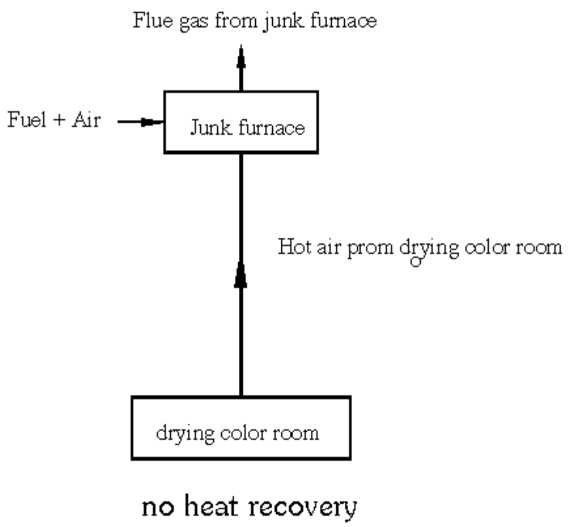
Fuel saving = (rate of heat recovery/100)x(annual fuel consumption)

= (19.36/100) x 10,000,000

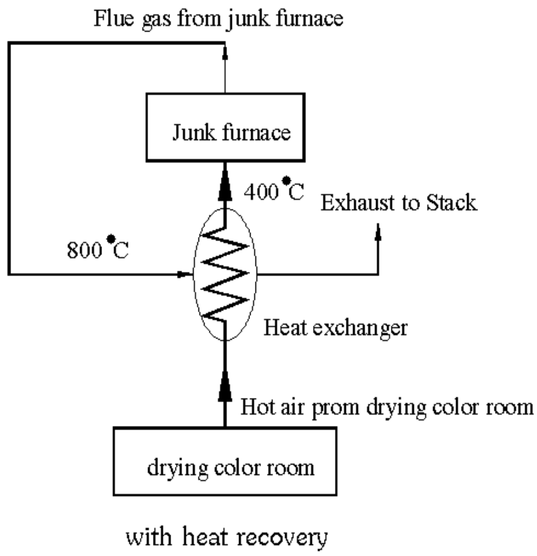
= 1,936,000 liters/year

Example 2

The ECON factory has an oven that rejects hot air at 180 °C. The hot air is burnt in the incinerator to dispose odor and flammable solution. The exhaust gas temperature of the incinerator is 800 °C. In order to save energy, installation of a heat exchanger to heat oven exhaust gas by incinerator exhaust gas is proposed. Assuming that the temperature of oven exhaust gas temperature at the exit of the heat exchanger raise to 400 °C. Determine the annual fuel saving of this factory.




no heat recovery




with heat recovery

*Analysis:*

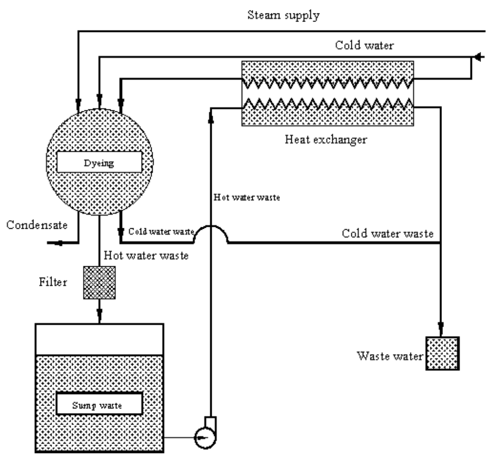
Incinerator heat load (no heat recovery) = $m \times C_p \times (800-180) = 620\ mC_p$

Incinerator heat load (with heat recovery) = $m \times C_p \times (800-400) = 400\ mC_p$

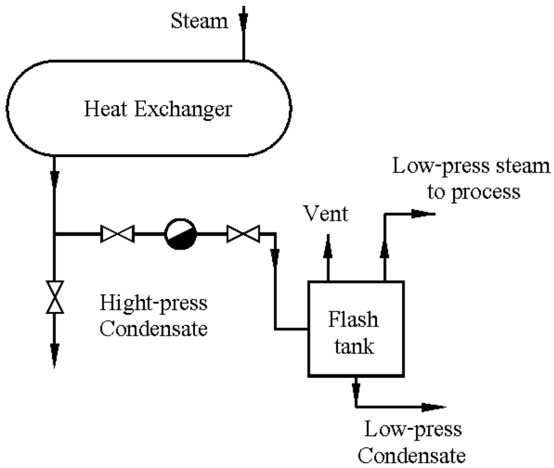
Percentage of fuel saving = (620-400) / 620 x 100 = 35.48 %

(2) How to recover heat in hot water

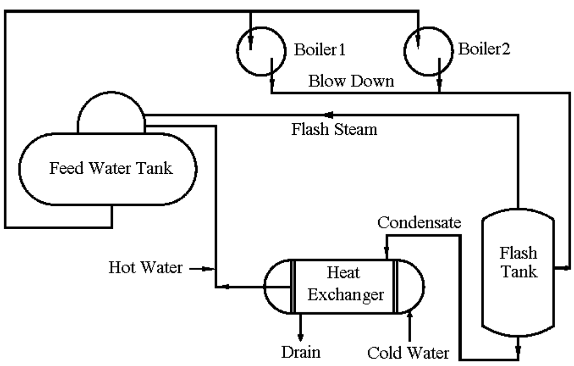
Hot water or hot liquid that has higher temperature than ambient temperature has a potential to recover its energy. In case of condensate or process cooling water that is clean hot liquid, it can be re-used as boiler feed water. But contaminated hot liquid such as blowdown water and hot water from process must be used through heat exchanger. The type of heat exchanger may be plate heat exchanger or shell and tube heat exchanger and type of flow is usually counter-flow because of its higher efficiency.



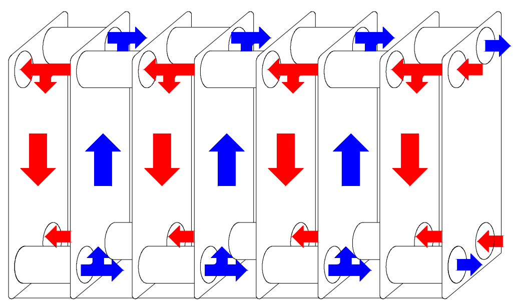

(a) Use of hot water from process



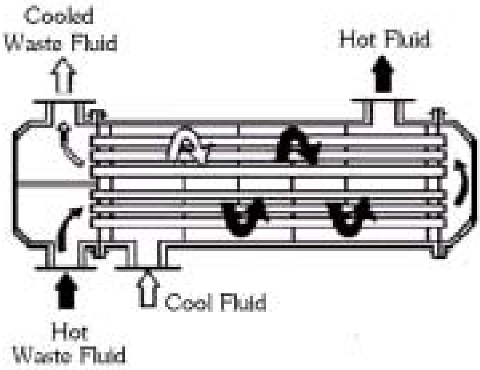

(b) Use of condensate




(c) Use of blow down water



(d) Plate heat exchanger




(e) Shell and tube heat exchanger

**Figure 3.2– 1 Utilization of waste heat from hot water or hot liquid**

- **What is consideration in heat recovery?**

Main considerations in recovery of waste heat from hot water or hot liquid are economic and stability of the system because this source has low quality waste heat. The factors that should be considered are continuity in heat flow, temperature of discharged liquid, purity of hot liquid, and area of waste heat recovery.

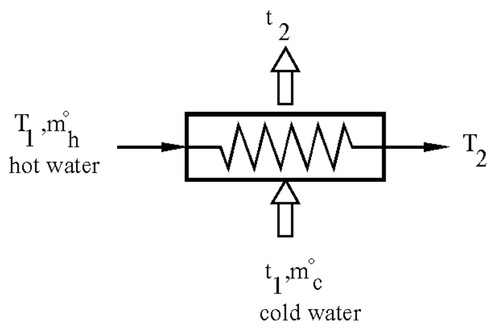
- **How much can waste heat be recovered?**

The heat from hot water or hot liquid is sensible heat. The quantity of waste heat available can be expressed as

$$Q = \dot{m} C_p \Delta T \qquad \text{———} \qquad (3.2\text{– }1)$$

Where

| | | |
|---|---|---|
| Q | = | heat recovery rate (kJ/h) |
| m | = | mass flow rate (kg/h) |
| $C_p$ | = | specific heat (kJ/kg°C) |
| $\Delta T$ | = | temperature difference (°C) |




Heat exchanger efficiency ($\eta_{HX}$) =recovering heat / heat from hot stream

$$= \dot{m}_c C_{pc}(t_2 - t_1) / \dot{m}_h C_{ph}(T_1 - t_1) \text{——} (3.2\text{– }2)$$

Rate of fuel saving = rate of recovering heat / (heating value of fuel x boiler efficiency)

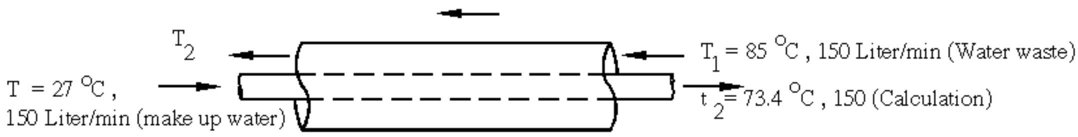
$$= \dot{m}_c C_{pc}(t_2 - t_1)/(HL \times \eta_B) \qquad (3.2\text{– }3)$$

o **How to calculate fuel saving by heat recovery**

1. Use provided calculating table
2. Fill all basic data
3. Analyze required data by substituting basic data into giving equations
4. Continue calculation to the end of table

o **Examples**

**Example1** The ECON factory has a continuous washer that discharged hot water at 85 °C to ambient at a rate of 150 liters/min. There is make-up water at 27 °C. The hot water supplied by bunker oil boiler that has an efficiency of 70%. The installation of a heat exchanger is proposed. Assuming that the heat exchanger efficiency is 80% and the plant operates 12 hours/day. Determine the make-up water temperature at the exit of heat exchanger and quantity of recovering heat.

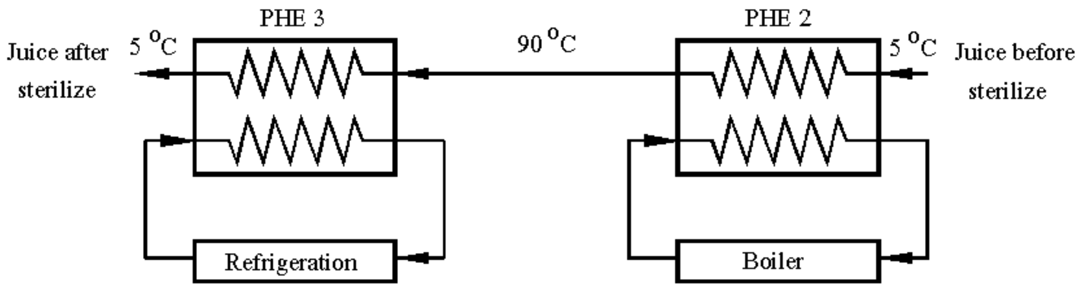



| Item | Symbol | Unit | Data | Remark |
|---|---|---|---|---|
| 1. Basic data | | | | |
| Fuel type | - | | bunker oil grade C | Actual data |
| Heating value of fuel | - | | - | From table |
| Liquid fuel | HL | MJ/kg | 38.17 | |
| Solid fuel | HL | MJ/kg | - | |
| Gas fuel | HL | MJ/Nm$^3$ | - | |
| Boiler efficiency | $\eta_B$ | %/100 | 0.7 | From heat balance or approx. 70% |
| Heat exchanger efficiency | $\eta_{HX}$ | %/100 | 0.8 | From manufacturer or approx. 80% |

| Item | Symbol | Unit | Data | Remark |
|---|---|---|---|---|
| Inlet hot water temperature | $T_1$ | °C | 85 | From meter |
| Outlet hot water temperature | $T_2$ | °C | 27 | Same as $t_1$ (assumption) |
| Inlet cold water temperature | $t_1$ | °C | 27 | From meter |
| Hot water flow rate | $m_h$ | kg/min | 150 | From meter |
| Cold water flow rate | $m_c$ | kg/min | 150 | From meter |
| Operating hour/day | h | h/day | 12 | Actual data |
| Specific heat of hot water | $C_{ph}$ | kJ/kg°C | 4.2 | From table (water: 4.2 kJ/kg°C) |
| Specific heat of cold water | $C_{pc}$ | kJ/kg°C | 4.2 | From table(water:4.2 kJ/kg°C) |
| 2. Analysis | | | | |
| Quantity of discharged hot water $\dot{m}_h / d = \dot{m}_h \times h \times 60$ | $m_h/d$ | kg/d | 108,000 | (K x M x 60) |
| Outlet cold water temperature $t_2 = t_1 + \left(\eta_{HX} \times \left(\dot{m}_h C_{ph} \times (T_1 - t_1)/\dot{m}_c C_{pc}\right)\right)$ | $t_2$ | °C | 73.4 | J + (G x (K x N x (H - I))/(L x O)) |
| Heat recovery per day $Q = \dot{m}_c \times C_{pc} \times (t_2 - t_1) \times 10^{-3}$ | Q | MJ/d | 21,047.04 | L x O x (22 - J) x $10^{-3}$ |
| Fuel saving per day $Fuel = Q/(HL \times \eta_B)$ | Fuel | | | |
| 2.4.1 Liquid fuel | | kg/d | 787.72 | 23 / (C x F) |
| 2.4.2 Solid fuel | | kg/d | - | 52 / (D x L) |
| 2.4.1 Gas fuel | | $Nm^3/d$ | - | 23 / (E x F) |

Example2

The ECON factory has a pasteurization process of fruit juice that use steam at 110 °C to heat fruit juice from 5 °C to 90 °C. Then the fruit juice is cooled down from 90 °C to 5 °C by refrigeration system.



**Case I: No heat recovery,**

Energy used for heating fruit juice from 5 °C to 90 °C

$= m \times C_p \times (90\text{-}5) = 85\ mC_p$

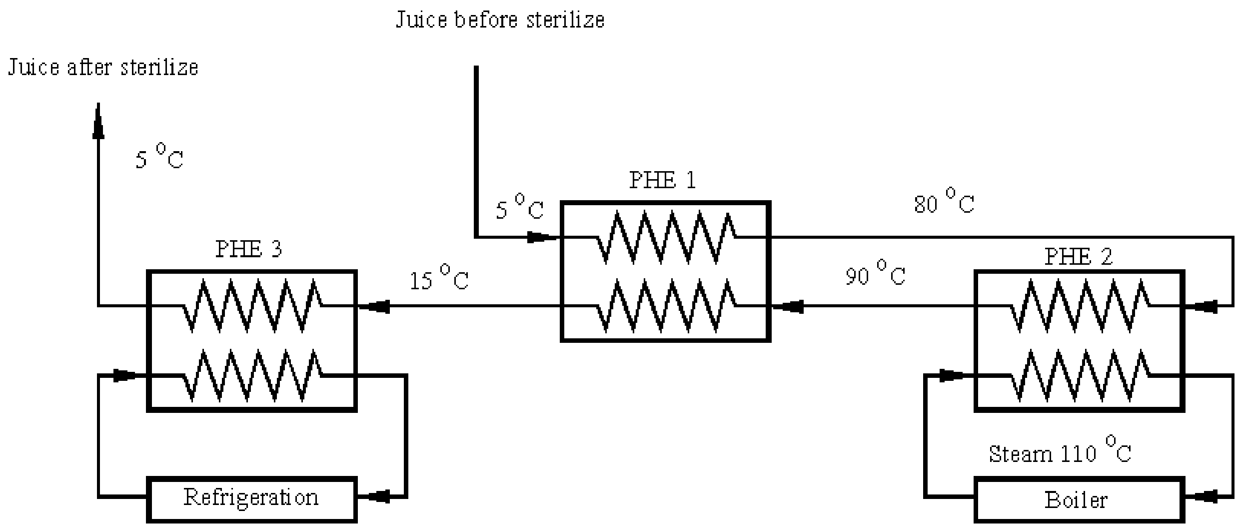
Energy used for cooling fruit juice from 90 °C to 5 °C

$= m \times C_p \times (90\text{-}5) = 85\ mC_p$

Total energy in pasteurization process = $170\ mC_p$

**Case II: Heat recovery,**

Installation of a plate heat exchanger (PHE 1) to transfer heat from hot fruit juice entering PHE 3 to cold fruit juice entering PHE 2 results in reducing energy consumption in boiler and refrigeration system.




Energy from boiler used for heating fruit juice from 80 °C to 90 °C

$= m \times C_p \times (90\text{-}80) = 10\ m\ C_p$

Energy from refrigeration system used for cooling fruit juice from

15 °C to 5 °C $= m \times C_p \times (15\text{-}5) = 10\ mC_p$

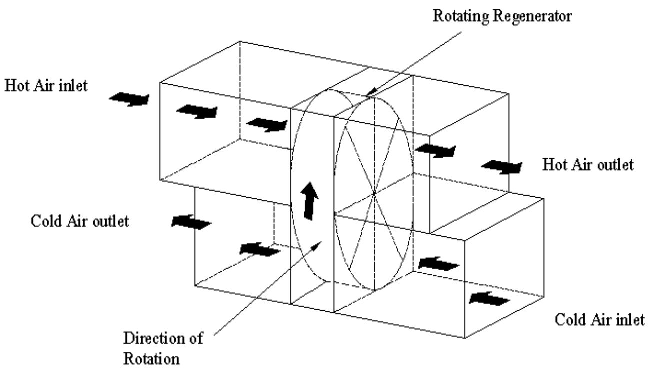
Total energy used after install heat exchanger = $20\ mC_p$

Energy reduction in pasteurization process = $170mC_p - 20mC_p = 150\ mC_p$

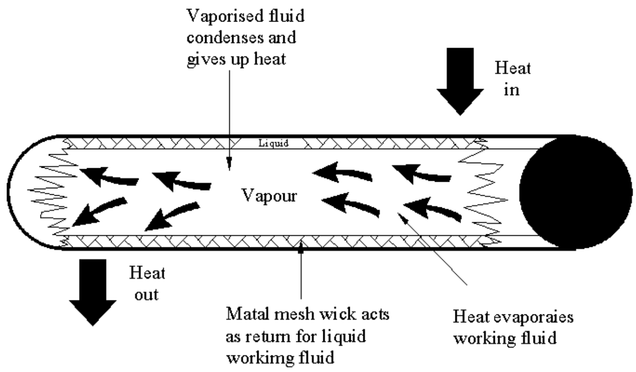
Percentage of energy reduction 150 / 170=88 %

(3) Measures to recover heat in hot air

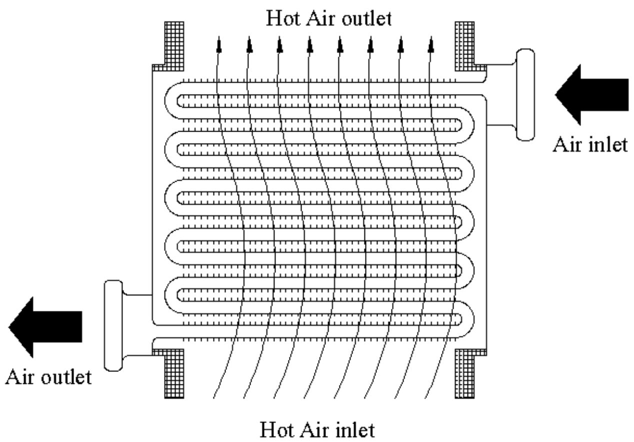
Hot air is usually discharged from several production processes such as drying process and equipment cooling system (i.e. cooling of air compressor, refrigeration and air conditioning system). Heat of those discharged hot air, that has higher temperature than ambient air, should be recovered. Clean hot air can be re-used in the same or new process directly, but the heat exchanger is required in case of contaminated hot air. The types of heat exchanger that used frequently are heat wheels, heat pipes, and heat coils.



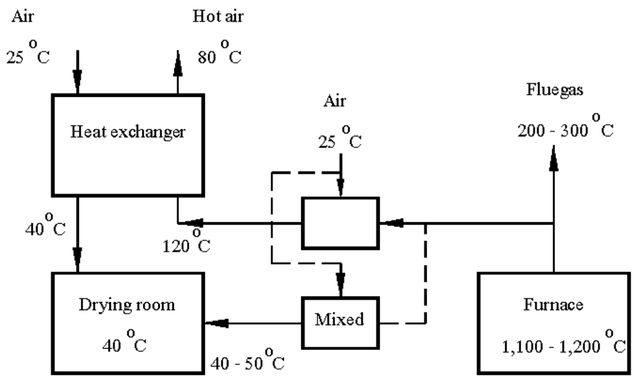

(a) Heat wheel recovery




(b) Heat pipe




(c) Heat coil




(d) Use of hot air

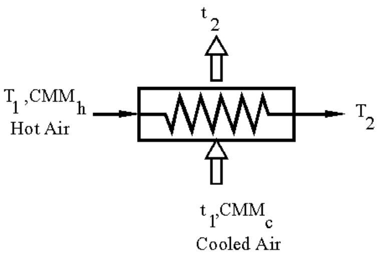
Figure 3.3 – 1 Utilization of waste heat from discharged hot air

o **What is consideration in heat recovery?**

Main considerations in recovery of waste heat from hot air are economic and stability of the system because this source has low quality waste heat. The factors that should be considered are continuity in heat flow, temperature of discharged hot air, heat recovering quantity, cleanness of hot air, and area of waste heat recovery.

o How much can waste heat be recovered?

When heat is added or removed from air the water vapor content does not change or the humidity ratio remains constant so the heat from hot air is sensible heat. The quantity of waste heat available from hot air can be expressed as




$$Q = \dot{m} C_p \Delta T$$

$$Q = 72CMM \times \Delta T \qquad \text{(3.3– 1)}$$

Where

| | | |
|---|---|---|
| Q | = | heat recovery rate (kJ/h) |
| CMM | = | air flow rate ($m^3$/min) |
| | = | V x A |
| V | = | mean air velocity (m/min) |
| A | = | cross section area ($m^2$) |
| ΔT | = | temperature difference (°C) |

Heat exchanger efficiency ($\eta_{HX}$) = recovering heat / heat from hot stream

$$= \dot{m}_c C_{pc}(t_2 - t_1) / \dot{m}_h C_{ph}(T_1 - t_1)$$

$$= 72CMM_c(t_2 - t_1) / 72CMM_h(T_1 - t_1) \qquad \text{(3.3– 2)}$$

Rate of fuel saving

= rate of recovering heat / (heating value of fuel x boiler efficiency)

$$= \dot{m}_c C_{pc}(t_2 - t_1) / (HL \times \eta_B) \qquad \text{(3.3-3)}$$

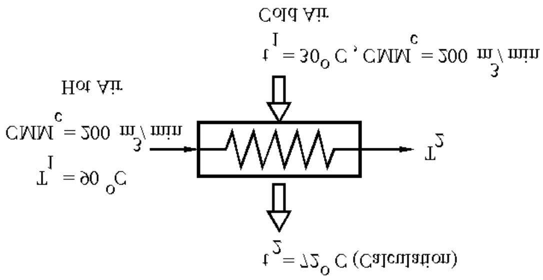
o How to calculate fuel saving by heat recovery

1. Use provided calculating table
2. Fill all basic data
3. Analyze required data by substituting basic data into giving equations
4. Continue calculation to the end of table

o Examples

Example1

The ECON factory has a continuous drier that discharges hot air at 90 °C to ambient at a rate of 200 m³/min. There is fresh air at 30 °C filled in. The bunker oil boiler that supplies heat to the drier has an efficiency of 70%. The installation of a heat exchanger is proposed. Assuming that the heat exchanger efficiency is 70% and the plant operates 12 hours/day. Determine the outlet cold air temperature and quantity of recovering heat.



| Item | Symbol | Unit | Data | Remark |
|---|---|---|---|---|
| 1. Basic data | | | | |
| Fuel type | - | | Bunker oil grade C | Actual data |
| Heating value of fuel | - | | - | From table |
| Liquid fuel | HL | MJ/kg | 38.17 | |
| Solid fuel | HL | MJ/kg | - | |
| Gas fuel | HL | MJ/N m³ | - | |
| Boiler efficiency | $\eta_B$ | % / 100 | 0.7 | From heat balance or approx. 70% |
| Heat exchanger efficiency | $\eta_{HX}$ | % / 100 | 0.7 | From manufacturer or approx.70% |
| Inlet hot air temperature | $T_1$ | °C | 90 | From meter |
| Inlet cold air temperature | $t_1$ | °C | 30 | From meter |
| Hot air flow rate | $CMM_h$ | m³/min | 200 | From meter |
| Cold air flow rate | $CMM_c$ | m³/min | 200 | From meter |
| Operating hour/day | h | h/day | 12 | Actual data |
| 2. Analysis | | | | |
| Quantity of discharged hot water $CMM_h / d = CMM_h \times h \times 60$ | $CMM_h/d$ | m³/d | 144,000 | J x L x 60 |

| Item | Symbol | Unit | Data | Remark |
| --- | --- | --- | --- | --- |
| Outlet cold water temperature<br>$t_2 = t_1 + \left(\eta_{HX} \times \left(CMM_h \times \left(T_1 - t_1\right) / CMM_c\right)\right)$ | $t_2$ | °C | 73.4 | I + (G × (J × (H - I)) / K) |
| Heat recovery per day<br>$Q = 72 \times CMM_c \times \left(t_2 - t_1\right) \times 10^{-3}$ | Q | MJ/d | 21,047.04 | 72 × K × (2.2 - I) × $10^{-3}$ |
| Fuel saving per day<br>$Fuel = Q / \left(HL \times \eta_B\right)$ | Fuel | | | |
| 2.4.1 Liquid fuel | | kg/d | 22.64 | 2.3 / (C × F) |
| 2.4.2 Solid fuel | | kg/d | - | 2.3 / (D × F) |
| 2.4.1 Gas fuel | | $Nm^3/d$ | - | 2.3 / (E × F) |

### 3.3 Selection of Proper Heat Exchanger?

Heat Exchanger is the most important equipment in waste heat recovery system. There are several considerations in the selection of heat exchanger such as heating load, properties of fluid, operating pressure, service temperature, maintenance requirement and cost.

Table 3.3– 1 Characteristic of Heat Exchangers

| Type | Maximum Pressure (MPa) | Temperature Range(°C) | Restriction of Fluid | Specified Surface Area($m^2$) | Notes |
| --- | --- | --- | --- | --- | --- |
| Shell-and-tube | 30.7 | -200 to 600 | Depends on material | 10 to 1,000 | High flexibility, suitable for almost all applications |
| Double-pipe | Shell side: > 30.7<br>Tube side: >140 | -100 to 600 | Depends on material | 0.25 to 200 | Most suitable for low capacity, Constructed in standard module |
| Gas-to-gas | Shell side: Near atm. pressure<br>Tube side: higher | 250 in general but higher in some types | Gas Exhaust gas | Low temperature: 6 to 100<br>Cast iron type: 1,200 to 3,000 | Wide range of types, Selection depends on corrosion of gas |
| Air-cooled | High at shell side | High at shell side | Depends on material | 5 to 200 | |
| Plate | 25 | -25 to 175 (-40 to 200 | Not suitable for | 1 to 1,200 | Module constructed, |

| Type | Maximum Pressure (MPa) | Temperature Range(°C) | Restriction of Fluid | Specified Surface Area($m^2$) | Notes |
|---|---|---|---|---|---|
| | | for special type) | gas or two phase fluid (restriction of gasket) | | Most economic (if available) |
| Rotary regenerator | Near atm. pressure | 980 maximum | Low pressure gas | | Fluid can mix together due to leakage |

Table 3.3– 2 Comparison of Convenience of Inspection and Maintenance

| Inspection and maintenance items | Types of Heat Exchanger | | |
|---|---|---|---|
| | Plate | Double-pipe | Shell-and-tube |
| 1. Check for dirty | | | |
| - each side | A | B | B |
| - both sides | A | B or D | B or D |
| 2. Check for leakage | | | |
| - each side | B | A or B | A |
| - both sides | B | A or B | A |
| 3. Check for corrosion | | | |
| - each side | A | A or C | B |
| - both sides | A | B or D | B or D |
| 4. Chemical cleaning | | | |
| - each side | A | A | B |
| - both sides | A | A | B or C |
| 5. Mechanical cleaning | | | |
| - each side | A | B or C | B |
| - both sides | A | B or D | B or D |

Remark: A = very convenient B = quite convenient

C = difficult D = not available

3.4 Measures to inspect and maintain

- Inspection of Heat Exchanger

| Item | Unit | Source of Waste Heat | | |
|---|---|---|---|---|
| | | Flue Gas | Hot Water | Hot Air |
| 1. Source of waste heat | - | | | |

| Item | Unit | Source of Waste Heat | | |
|---|---|---|---|---|
| | | Flue Gas | Hot Water | Hot Air |
| 2. Discharge temperature<br>3. Is it discharged continuous?<br>4. How many hours per day of discharging?<br>5. Is it clean?<br>6. Quantity of waste heat per day<br>7. Can it be utilized by direct contact?<br>8. How to utilize waste heat? | °C<br>Continuous / Discontinuous<br>h/day<br>Clean / Dirty<br>MJ/day<br>Yes / No<br>- | • Preheat combustion air by air preheater<br>• Preheat feed water by economizer<br>• Preheat material | • Using in other process directly (if clean enough)<br>• Mixing with condensate in deaerator<br>• Generatin g flash steam | • Using in other process directly (if clean enough)<br>• Exchanging heat with air entering oven or equipment<br>• Re-using in the same equipment |
| | | • Preheat fuel<br>• Preheat combustion air by recuperative burner and regenerativ e burner<br>• Generatin | • Using blow down to preheat feed water<br>• Exchanging heat with water using in process | |

| Item | Unit | Source of Waste Heat | | |
|---|---|---|---|---|
| | | Flue Gas | Hot Water | Hot Air |
| | | g steam by waste heat boiler<br>• Generating power and cogeneration<br>• Using for absorption chiller<br>• Using in other process | | |

- Maintenance of Heat Exchanger

| Implementation | Appropriate period |
|---|---|
| 1. Inspection of temperature difference between exit hot and cold stream | Every day |
| 2. Cleaning surface area | Every 6 months |
| 3. Inspection of leakage | Every month |
| 4. Inspection of corrosion | Every 6 months |
| 5. Inspection of fan or pump power | Every month |
| 6. Inspection of pressure drop in equipment | Every month |

# Part III

## Thermal Energy Technology Management

Thermal energy is very important for most of industries in Thailand. It is widely used from small  through large industries. Nowadays, the new thermal energy technology has rapidly research and development for serving industry. This chapter, will give an idea and view point of thermal energy technology to readers how to use and optimize of thermal energy in order to reduce the production cost. This chapter divides into 3 categories:

- Thermal Energy Sources
- Thermal Energy Generation
- Thermal Energy Management

Chapter 1

# Thermal Energy Sources

## 1.1 Fuel Selection

### How to select fuel?

Fuel selection is a critical aspect of combustion application efficiency as the cost of the energy source can be in excess of 70% of the total cost of operation. Fuels vary greatly in their cost depending on their ease of use, qualities and availability. In general fuels of low quality and energy value cost less than fuels of high quality and energy value. Fuels also have characteristics that affect their cost and make them more or less suitable for particular applications. The over-riding principle in fuel selection is to choose “The Most Economic Fuel Suitable for the Application”. The problem is arriving at this balance, as a bias exists between the buyers and users. Operational staff, whose responsibility it is to ensure consistent and reliable operation, demand better quality fuel and argue for using higher quality fuels. On the other hand, management aims to purchase at the lowest possible cost. To arrive at the suitable choice requires some understanding of the effects and real costs.

### What parameters must be concerned?

- Fuel Cost

Fuel costs vary significantly depend on types of fuel. The cost of fuel is compare with price of fuel and its calorific heating value ( MJ or GJ), for example ; fuel oil has price of 15.34 Baht per liter, one liter of fuel oil has calorific heating value of 39.77 MJ, so that the cost of fuel oil is 15.34 / 39.77 or 0.3857 B/MJ.

- Fuel Characteristics

### Energy Value

The usefulness of a fuel in combustion is in the amount of energy it contains. Energy is measured in joules and the energy content of a fuel is given in joules per kilogram. In the process of combustion, the hydrocarbon (hydrogen and carbon) molecules are chemically converted into carbon dioxide ($CO_2$) and water ($H_2O$) releasing heat in the process. The energy value of a fuel is usually given as the Gross Energy value. However not all of the Gross Energy is usable in the heating application as the hydrogen, which is converted into water, is usually released up the stack as a vapour, carrying with it the latent heat of evaporation. The energy left is called the Net Energy value of the fuel. Thus a fuel with a greater mass of hydrogen atoms to carbon atoms will have a larger difference between the Gross and Net Energy values. Therefore the fuel with the highest Net Energy value will provide the most energy in joules per kilogram.

| DESCRIPTION | UNITS | GROSS ENERGY (MJ/kg) | NET ENERGY (MJ/kg) |
|---|---|---|---|
| LPG | MJ/kg | 50 | 46.3 |
| Paraffin | MJ/kg | 46,5 | 43.3 |
| Diesel | MJ/kg | 46 | 43.0 |
| Light Oil | MJ/kg | 45,5 | 42.7 |
| Heavy Oil | MJ/kg | 43,5 | 41.7 |
| Coal Tar | MJ/kg | 37 | 37.2 |
| Natural Gas | MJ/kg | 29 | |
| Coal –A grade | MJ/kg | 28 | 27 |
| Electricity | MJ/kWh | 3,6 | N/A |

### Density

The density of a fuel is usually only of interest in liquid fuels if the cost is given in cents per litre. In order to convert this cost into joules per kilogram, this property is required.

### Viscosity

This property applies to liquid fuels only. Viscosity is a characteristic of a liquid that describes its resistance to flow. The relevance of this is in its ease of use as a combustion fuel. In order to effect good combustion, a liquid fuel must be sprayed into the combustion chamber mixed with air in sufficiently small droplets to achieve full combustion in the available flame residence time. This is the process of atomization, which can only occur if the viscosity is low enough. It is generally accepted that a liquid fuel must have a viscosity below 20 centiStokes (cSt) in order to achieve adequate atomization in most burner designs. This does not preclude the use of heavy fuel oil, as pre-heating liquid fuel reduces its viscosity. There is however a cost penalty in doing this, however it is usually very small in relation to the large differential in cost between light and heavy fuels, at about 0,5 – 0,75% of total energy cost.

### Contaminants

All fuels contain contaminants but in varying amounts. The most important of these contaminants are ash, water and sulphur.

### Pour Point

The pour point of a liquid fuel is the temperature at which the fuel will start to flow. Some oils contain waxes that become solid below a certain temperature and other oils just become too thick at low temperatures, so that they effectively become non-flowable. In unheated fuel reticulation systems, the choice of fuel must be suitable for the minimum temperature of the area. Once a heated fuel reticulation system is installed this is of less concern.

### Flash Point

Liquid fuels contain volatile components that produce flammable explosive gases. The propensity of a fuel oil to produce flammable explosive gases is related to the amount of volatile components in the fuel and the temperature of the fuel. The flash point of the fuel represents the temperature at which the fuel oil will produce sufficient vapour as to cause combustion in the presence of a naked flame. This property gives an indication as to the relative hazard that exists in using and storing this fuel oil at a given temperature. The most common method is called the closed-cup flash point. It should be noted that enclosed spaces such as the void space of fuel storage tanks should be treated as hazardous flammable areas and all flames and sources of ignition must be kept well away regardless of the temperature or flash point of the fuel. The fuel oil's flash point should not be confused with the auto-ignition point, which is a much higher temperature.

- suitable fuels

The selection of suitable fuels is dependent on:

- The relative cost of the available heating fuels
- The applications tolerance to impurities (ash, water, metals etc)
- The design of the appliance (radiance/convection, size/shape)
- The environmental sensitivity of the area (sulphur, particulates, smutting)

- Existing installations: The type of burner installed (wear, viscosity, turn-down, temperature limitations) and the type of fuel reticulation system installed.

- Quality Cost

Estimating the cost of quality is usually a relatively simple calculation in most applications. The process is as follows:

- Determine what the base maintenance cost is disregarding wear and tear from the fuel. For example a pump may have on average a 9 months life running on a high quality ash-free fuel, and a minimum amount of monthly maintenance. Knowing the pump cost, the average monthly minimum maintenance cost and the fuel consumption, the cost per ton of fuel can be calculated.

- Then determine the maximum level of contaminant usable and the worst-case cost running on this lowest fuel quality.

- A logarithmic function will give a rational estimate of the relationship between fuel quality and ash content, allowing costs between these limits to be determined, on the premise that the wear will increase disproportionately with higher solids (ash) contaminates.

- Add the cost of cleaning and the cleaning cycle as a fuel cost per ton.

- Include the cost of downtime, if any.

Conclusion

1. Fuel selection does not have to be a subjective decision as most considerations can be reduced to a cost and the alternatives then objectively compared.
2. Very significant cost savings can be achieved by selecting the most suitable fuel for the application.
3. The first step in establishing the suitability of the available fuels is to determine the constraints on the application and the available fuels' properties and characteristics.
4. It is possible to put a cost to all of the factors that affect the combustion application and arrive at the most cost effective fuel to use.

5. By objective analysis, a balance can be achieved between financial and operational demands.

## 1.2 NG / LNG / LPG

### What is natural gas?

Natural gas (NG) is a colourless, odourless mixture of gases made up mostly of methane (CH4). Other gases that can form part of natural gas include small amounts of ethane (C2H6), propane (C3H8) and butane (C4H10). Methane burns relatively cleanly to produce heat energy and the by-products of water and carbon dioxide. Inefficiencies in burning can produce small amounts of pollutants such as nitrogen oxides. Natural gas is lighter than air. So if it leaks from a pipe or appliance, it won't sink and form dangerous pools of explosive gas but will disperse in the air. In certain concentrations, natural gas can be explosive, so it should always be treated with care. For safety reasons, an odour is added to the gas so that a person with a normal sense of smell can easily detect leakages.

### What is Liquefied Petroleum Gas ?

Liquefied Petroleum Gas (LPG) is predominantly a mixture of hydrocarbon gases (mainly propane ($C_3H_8$) and butane ($C_4H_{10}$)). These gases can occur either individually or in combination. Under pressure, these gases liquefy, hence the term liquefied petroleum gas. LPG can occur naturally with other hydrocarbons such as wet natural gas in oil and gasfields, or it can be extracted at oil refineries during the production of other petroleum products. LPG is used as a fuel source for commerce/industry and domestic use, in particular, industrial, space and water heating. LPG is also used as an automotive fuel, commonly known as autogas.

### What is Liquid Natural Gas?

Another successful development has been the conversion of natural gas into a liquid state. In its liquid state, natural gas is called LNG, or liquid natural gas. LNG is made by cooling natural gas to a temperature of minus 260 F. At that temperature, natural gas becomes a liquid and its volume is reduced 615 times. (A car reduced 615 times would fit on your thumbnail.) Liquid natural gas is easier to store than the gaseous form since it takes up much less space. LNG is also easier to transport. People can put LNG in special tanks and transport it on trucks or ships.


Figure 1-1 Natural gas resource from Gulf of Thailand

How natural gas has been utilized in Thailand?

In Thailand, natural gas and its product has been utilized by three major economic sectors namely power, industrial, and petrochemical sector.

- Methane : power generation , fuel for industry , compressed natural gas for vehicles (NGV)
- Ethane, Propane : Feedstock for petrochemical industry
- Propane, Butane : LPG for household and vehicle
- LNG : for industry and oil refinery, feedstock for petrochemical industry
- $CO_2$ : for industry

## 1.3 Clean Coal technology

What is Clean Coal Technology?

The term "Clean Coal Technology" (CCT) describes a new generation of processes for the production of electricity and fuels from coal. CCTs are designed to increase the energy efficiency and to reduce the environmental effects of coal use. CCTs reduce air emissions, waste products and other pollutants compared to older coal-based systems, and increase the amount of energy gained from each ton of coal used.

In the late 1980s and early 1990s, the U.S. Department of Energy conducted a joint program with industry and State agencies to demonstrate the best of these new technologies at scales large enough for companies to make commercial decisions to utilize them. More than 20 of the technologies tested in the original program achieved commercial success.

The early program was focused on the environmental challenges of that time, which centered on concerns over the impact of acid rain on forests and watersheds. In the 21st century, additional environmental concerns have emerged, including the potential health impacts of trace emissions of mercury, the effects of particulate matter on people with respiratory problems, and the potential global climate-altering impact of greenhouse gases.

## How many Types of Coal?

Coal is a black or brownish-black solid combustible substance formed by the partial decomposition of vegetable matter without access to air. The rank of coal, which includes anthracite, bituminous coal, sub bituminous coal, and lignite, is based on fixed carbon, volatile matter, and heating value. Coal rank indicates the progressive alteration from lignite to anthracite. Lignite has a heating value of 9 to 17 million Btu per ton. The heating values of sub bituminous and bituminous coals range from 16 to 24 million Btu per ton and from 19 to 30 million Btu per ton, respectively. Anthracite contains approximately 22 to 28 million Btu per ton.

### Hard Coals

Anthracite: The hardest coal type, (often referred to as “hard coal”), contains a high percentage of fixed carbon and a low percentage of volatile matter. Anthracite is the highest rank coal and it contains about 90% fixed carbon, more than any other form of coal. Anthracite has a semi-metallic luster and is capable of burning with little smoke (smokeless fuel). It is used in domestic and industrial applications.

Bituminous Coal: The most commonly used coal in the United States, it is soft, dense and black. Its moisture content usually is less than 20 percent. It is used for generating electricity, making coke, and space heating. Bituminous coal can be metallurgical (also known as coking coal) or thermal (also known as steam coal). Metallurgical/Coking coal is a coal which can be usefully converted into coke, or one which gives a coke strong enough to resist pressure and breakage. The term coking coal covers a range of coals, the cokes from which serve different purposes depending primarily on the fixed carbon and volatile matter of the original coal. Thermal/Steam Coal is a coal considered particularly suitable for boiler use, or power generation.

Low Rank Coals

Lignite: Lignite is a brownish-black coal of low rank with high inherent moisture and volatile matter (used almost exclusively for electric power generation). It is also referred to as brown coal. It is characterized by its high moisture content and low carbon and energy content compared to high rank coals such as anthracite. Due to its high moisture content and relatively low calorific value, lignite is usually consumed at or close to where it is produced/mined.

Sub bituminous Coal: Sub bituminous coal is dull black and generally contains 20 to 30 percent moisture. The heat content of sub-bituminous coal ranges from 16 to 24 million Btu per ton and is used for generating electricity and space heating. Sub bituminous coal is the next highest coal in rank after lignite and is softer than bituminous coal. Because it contains more moisture than bituminous coal, it less economic to transport long distances.

Pollution Controls for Existing Power Plants

Pulverized coal combustion is the most widely used method for burning coal for power generation among the units in service today. In pulverized coal combustion, coal is crushed to a powder and blown with air though burners into a furnace. As a powder, the coal has a large surface area and is easily combusted. This provides the heat that is used to produce superheated steam to drive turbines and generate electricity. Most of the world’s coal-based electricity is produced using pulverized coal combustion systems. Because coal contains nitrogen, sulfur and other elements, coal combustion can result in the emission of pollutants such as sulfur and nitrogen oxides (SOx and NOx). Various technologies have been developed and are used to reduce these emissions, and research is underway to improve their process and economic performance. Some of the currently available commercial technologies are described below.

## How to Manage Clean Coal Technology?

### NOx Controls

Low-NOx burners are used to reduce the formation of NOx in the combustion furnace by controlling the flame temperature and chemical environment in which the coal combusts. Low-NOx burners can reduce emissions of nitrogen oxides by up to 70%, depending on the coal used and the configuration of the furnace.

Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) are advanced post-combustion advanced control technology for NOx control. In these processes, NOx in the flue gas downstream of the combustion zone is reacted with ammonia to convert it to water and elemental nitrogen ($N_2$). SCR can achieve NOx reductions of 80-90%.

### SOx Controls

Flue Gas Desulphurization (FGD) is a post-combustion control technology that removes SO2 from the flue gas by reacting it with an alkaline sorbent, such as lime or limestone. In "wet" FGD, the most common technology, the sorbent is contained in a water slurry that is sprayed into an absorber vessel through which the flue gas flows. Wet FGD processes typically remove 90-97% of the SOx from flue gases. The wet FGD process can be configured to produce high quality gypsum (calcium sulfate) for construction use.

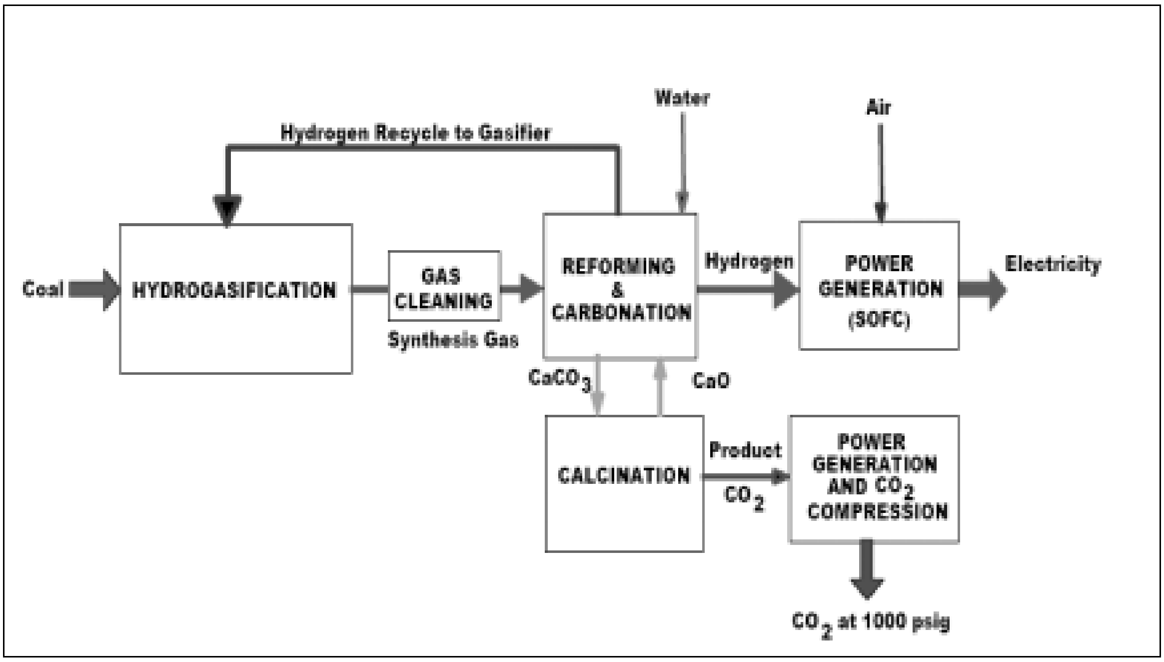



Figure 1-2 Clean Coal Technology Process

## 1.4 Biomass

### What is Biomass?

Biomass is the name given to any recent organic matter that has been derived from plants as a result of the photosynthetic conversion process. Biomass energy is derived from plant and animal material, such as wood from forests, residues from agricultural and forestry processes, and industrial, human or animal waste. Thailand is richly endowed with a variety of biomass resources.

### How it Used For?

Biomass can be used directly for electricity generation, steam for industrial uses, heating, cooking or indirectly by converting into a liquid or gaseous fuel (e.g. ethanol, biodiesel, biogas, producer gas). Biomass is a major contribution to energy needs in the fast-growing country like Thailand. It is an essential source of energy for energy production particularly for saving the environment of the country. There are many potential biomass energy resources, which are suitable for energy production in both industry and residential sectors. Various technologies for biomass utilization are currently used, ranging from local made to imported technology. Still, many technologies used, especially in rural use and some factories, are considered to be quite an old technology with low efficiency.

While there are several constrains still to be overcome, it can be clearly seen that there are enormous opportunities for promoting the utilization of biomass and improving an efficient and most promising biomass technology. In Thailand, the biomass are used for:

### Direct Combustion

Combustion is generally the most economical way to produce heat from biomass. It involves burning the crop with enough oxygen to convert nearly all the material to carbon dioxide and water. The heat emitted can be used directly (eg to produce hot water in a central heating system) or it can raise steam and drive a steam engine or turbine to generate electricity.

### Gasification

Gasification (heating with restricted air supply) converts solid organic material into a combustible gas that is generally used in an engine or gas turbine.

### Pyrolysis

Pyrolysis involves heating in the absence of oxygen (rather like traditional charcoal production) to produce a liquid fuel and a solid char, together with combustible gas. The composition of pyrolysis products depends on the heating rate, residence time and temperature, as well as on the composition of the fuel.

### Thailand Biomass Resource

The biomass resource of Thailand as possible fuel for power :

- Rice husk
- Oil palm residues
- Bagasse
- Wood residues
- Corncob
- Cassava residues
- Distillery slop
- Coconut residues
- Sawdust
- Forrest woods

### Advantages and Disadvantage

There are many advantages of using biomass as a power in Thailand.

- Thailand is agriculture country. There is abundance of biomass production.

- The price of conventional energy increase rapidly. The price of biomass is still low. The cost of steam production is about one third compare to fuel oil.
- Biomass is an environment friendly fuel.
- There are many support programmes from government and others international funds'

The Disadvantages of biomass are :

- High investment cost for modern biomass technologies.
- People don't want any new plant in their area.
- Lack of research personnel in the area of thermal conversion.
- The conversion efficiency in utilizing biomass as an energy source is generally low.
- Difficult assess to financing.

## 1.5 Biogas

### What is Biogas?

Biogas is produced naturally by the action of certain bacteria on water-logged organic materials in the absence of air : a process known as ' an aerobic digestion'. It consists of about 60 % of methane while remaining 40 % is mainly inert carbon dioxide. As a fuel, raw biogas has a calorific value of about 23 $MJ/m^3$. The carbon dioxide can be removed by bubbling the raw biogas through slaked lime (calcium hydroxide), but this process requires regular replacement of the lime. After this treatment, known as 'scrubbing', biogas approximates to pure methane with a calorific value of about 50 $MJ/m^3$.


Figure 1-3 Biogas Production

How It Used For?

The main used of biogas are cooking, heating water and lighting (with gas lamps using incandescent mantles). It is also an attractive fuel for use with internal combustion engines since it is relatively free of pollutants that can cause damage. Biogas has excellent anti-knock properties and can be safely used as the sole fuel with very high compression ratio spark-ignition engines. It can also be used with unmodified diesel engines, but only as a supplementary fuel because diesel is needed to fire the mixture; this can generally reduce diesel requirements by 50 to 70 percent. Some special biogas engines have been built, which run on 100 percent biogas more efficiently than an unconverted petrol engine.

## 1.6 Biodiesel

What is Biodiesel?

Biodiesel is a diesel replacement fuel that is manufactured from vegetable oils, recycled cooking oils, or animal fats. The biodiesel manufacturing process converts oils and fats into chemicals called long chain mono alkyl esters, or biodiesel. These chemicals are also referred to as fatty acid methyl esters. In the manufacturing process, 100 kilograms of oils or fats are reacted with 10 kilograms of short chain alcohol (usually methanol) in the presence of a catalyst (usually sodium or potassium hydroxide) to form 100 kilograms of biodiesel and 10 kilograms of grycerene. Glycerene is a co-product of the biodiesel process.

## Advantages of Biodiesel

Biodiesel offers many advantages

- It is renewable.
- It is energy efficient.
- It displaces petroleum derived diesel fuel.
- It can be used in most diesel equipment with no or only minor modifications.
- It can reduce global warming gas emissions.
- It can reduce tailpipe emissions, including air toxics.
- It is nontoxic, biodegradable, and suitable for sensitive environments.
- It is made in Thailand from either agriculture or recycled resources.
- It can be easy to use if you follow these guidelines.

## How It Used For?

Biodiesel can be used in several different ways. You can use 1% to 2% biodiesel as a lubricity additive, which could be especially important for ultra low sulfur diesel fuels (less than 15 ppm sulfur), which may have poor lubricating properties. You can blend 20% biodiesel with 80% diesel fuel (B20) for use in most applications that use diesel fuel. You can even use it in its pure form (B100) if you take proper precautions. In Thailand, use biodiesel as B5 and B10. The number following the “B” indicates the percentage of biodiesel in a litre of fuel. The higher blend levels, such as B50 or B100, require special handling and fuel management and may require equipment modifications such as the use of heaters or changing seals and gaskets that come in contact with the fuel to those compatible with high blends of biodiesel. The level of special care needed largely depends on the engine and vehicle manufacturer. High blend levels are not recommended for the first-time biodiesel.

## 1.7 Gasohol

### What is Gasohol?

Ethanol or ethyl alcohol, capable of being blended with gasoline to produce an alternative fuel namely gasohol, can be produced from diversified carbohydrate-containing materials. Those important ones are agricultural materials and industrial wastes such as crop biomass, sawdust and agriculture residues. In Thailand, the main economic crops potentials being used as the raw materials for ethanol production are sugar cane, cassava and molasses which is a by-product of sugar industry.

### How It Used For?

Gasohol can be used as fuel substitution gasoline in internal combustion engines by blending or the straight use of alcohol as fuel. No adjustments to the engines are required for up to a 20 % ethanol blend in gasoline. Straight ethanol on the other hand has significantly different combustion properties to gasoline. To take an advantage of the specific properties of ethanol (e.g. a higher research octane number than gasoline), the engine needs to be different. Engines for straight ethanol combustion have been developed and introduced in Brazil. In Thailand, a blended fuel consisting of 10 % ethanol in unleaded gasoline, ‘gasohol’, is marketed. The policy on alternative energy by ethanol of Thailand, Ministry of energy had set target on using an ethanol for MTBE substitution in gasoline 95 by 1 million liters per day by 2006 and on using an ethanol for MTBE substitution in gasoline 95 and for oil substitution in gasoline 91 for 3 million liters per day by 2011.

### Conclusion

Thailand has confronted with the oil crisis as well as many parts in the world and is seeking for other challenging energy source. Ethanol, an environmentally friendly fuel, which can be produced from various renewable agricultural materials, can be a solution for an agricultural country as Thailand.

## 1.8 Energy from Solid Waste

### What is Solid Waste?

Solid waste is an unneeded solid materials. Municipal solid waste (MSW) has became a major problem of several cities in Thailand. Survey data in Bangkok shows that about 8,000 tons of MSW is created each day.

Figure 4-4 Solid Waste

### Who Produce Solid Waste?

Solid waste can be produced by many sources :

- Households
- Packaging industry
- Construction industry
- Process industry
- Car shredding, etc.

### How to Manage the Solid Waste?

The basic aims of solid waste management are along the lines of the general goals :

- To prevent the generation of waste.
- To make use of waste in the form of materials and energy.
- To carry out safe final disposal for unusable waste.

The solid waste management can be done by many ways :

- Recycle
- Reuse
- Energy generation
- Landfill for unusable waste

The combustible solid waste can be converted to energy by using as fuel in power plants, gasification, biogas, pyrolysis and mass burning. Furthermore, municipal solid waste which common practice to dispose MSW in a landfill. As a landfill of MSW normally creates landfill gasses (mainly $CH_4$ and $CO_2$) which can be used as a fuel for combustion. In Thailand, there is a pilot plant of landfill gas at Nakhon Phathom province capacity of 1,300 kW .

# Chapter 2

# Thermal Energy Generation

## 2.1 Absorption Chiller

### What is Absorption Chiller?

The absorption cycle uses a condenser and evaporator just like vapor compression systems, but replaces the motor and compressor assembly with a thermal fluid compressor (absorber, generator and small fluid pump) to transfer low-temperature energy to high-temperature heat rejection. The absorption cycles uses thermal energy (natural gas, waste heat or solar energy), not electricity, to create chilled water.

### How it work?

Figure 4-5 shows a schematic of the essential elements in an absorption system. The cooling cycle begins in the evaporator where the refrigerant (which is water) is sprayed over tubes containing chilled water that is circulated through the building as a cooling medium. The evaporator operates under a vacuum, which permits the refrigerant (water) to boil at low temperature and remove heat from the chilled water. The refrigerant vapor migrates to the absorber where it is absorbed into a concentrated solution of Lithium Bromide (LiBr). The combined LiBr/water solution is pumped to the generator where heat is added by natural gas combustion or another heat source to vaporize the refrigerant (water) from the absorbent (LiBr). The concentrated LiBr returns through intermediate heat exchangers to the absorber to repeat its cycle. The refrigerant enters the condenser where it is liquefied and returned to the evaporator to repeat the process.

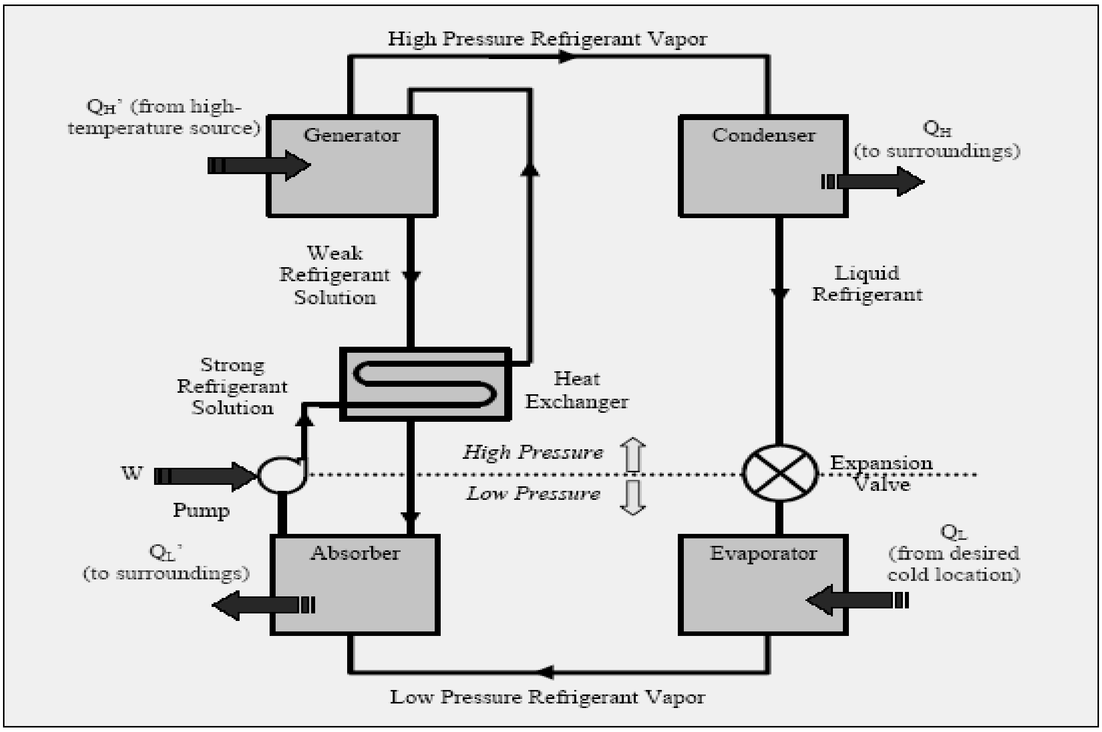



Figure 2-5 Absorption Chiller

### Advantages and Disadvantages

The distinctive feature of the absorption system is that very little work input is required because the pumping process involves a liquid. Another advantage is that they have been around for a long time, such that there is a manufacturing basis for larger systems (e.g. applications for manufacturing plants, buildings).

## 2.2 Cogeneration

### What is Cogeneration?

The principle behind cogeneration is simple. Conventional power generation, on average, is only 35% efficient – up to 65% of the energy potential is released as waste heat. More recent combined cycle generation can improve this to 55%, excluding losses for the transmission and distribution of electricity. Cogeneration reduces this loss by using the heat for industry, commerce and home heating/cooling.

Cogeneration is the simultaneous generation of heat and power, both of which are used. It encompasses a range of technologies, but will always include an electricity generator and a heat recovery system. Cogeneration is also known as ‘combined heat and power (CHP)’ and ‘total energy. In conventional electricity generation, further losses of around 5-10% are associated with the transmission and distribution of electricity from relatively remote power stations via the electricity grid. These losses are greatest when electricity is delivered to the smallest consumers. Through the utilization of the heat, the efficiency of cogeneration plant can reach 90% or more. In addition, the electricity generated by the cogeneration plant is normally used locally, and then transmission and distribution losses will be negligible. Cogeneration therefore offers energy savings ranging between 15-40% when compared against the supply of electricity and heat from conventional power stations and boilers. Because transporting electricity over long distances is easier and cheaper than transporting heat, cogeneration installations are usually sited as near as possible to the place where the heat is consumed and, ideally, are built to a size to meet the heat demand. Otherwise an additional boiler will be necessary, and the environmental advantages will be partly hindered. This is the central and most fundamental principle cogeneration. When less electricity is generated than needed, it will be necessary to buy extra. However, when the scheme is sized according to the heat demand, normally more electricity than needed is generated. The surplus electricity can be sold to the grid or supplied to another customer via the distribution system (wheeling).

## The Benefits of Cogeneration

Provided the cogeneration is optimized in the way described above (is sized according to the heat demand), the following benefits arise:

- Increased efficiency of energy conversion and use;
- Lower emissions to the environment, in particular of $CO_2$ , the main greenhouse gas;
- In some cases, where there are biomass fuels and some waste materials such as refinery gases, process or agricultural waste (either anaerobically digested or gasified), these substances can be used as fuels for cogeneration schemes, thus increasing the cost-effectiveness and reducing the need for waste disposal;

- Large cost savings, providing additional competitiveness for industrial and commercial users, and offering affordable heat for domestic users;
- An opportunity to move towards more decentralized forms of electricity generation, where plant is designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier;
- Improved local and general security of supply - local generation, through cogeneration, can reduce the risk that consumers are left without supplies of electricity and/or heating. In addition, the reduced fuel need which cogeneration provides reduces the import dependency - a key challenge for Europe's energy future;
- An opportunity to increase the diversity of generation plant, and provide competition in generation. Cogeneration provides one of the most important vehicles for promoting liberalization in energy markets;
- Increased employment - a number of studies have now concluded that the development of cogeneration systems is a generator of jobs.

### Energy and cost savings

A well-designed and operated cogeneration scheme will always provide better energy efficiency than conventional plant, leading to both energy and cost savings. A single fuel is used to generate heat and electricity, so cost savings are dependent on the price-differential between the primary energy fuel and the bought-in electricity that the scheme displaces. However, although the profitability of cogeneration generally results from its cheap electricity, its success depends on using recovered heat productively, so the prime criterion is a suitable heat requirement. As a rough guide, cogeneration is likely to be suitable where there is a fairly constant demand for heat for at least 4,500 hours in the year.

The timing of the site’s electricity demand will also be important as the cogeneration installation will be most cost effective when it operates during periods of high electricity tariffs, that is, during the day. At current fuel prices and electricity tariffs, and allowing for installation and life-cycle maintenance costs, payback periods of three to five years can be achieved on many cogeneration installations.

### Environmental savings

In addition to direct cost savings, cogeneration yields significant environmental benefits through using fossil fuels more efficiently. In particular, it is a highly effective means of reducing carbon dioxide ($CO_2$) and sulphur dioxide ($SO_2$) emissions. Oxides of nitrogen ($NO_x$) are also generally reduced by the introduction of modern combustion plant.

### Where is Cogeneration suitable?

Cogeneration has a long history of use in many types of industry, particularly in the paper and bulk chemicals industries, which have large concurrent heat and power demands. In recent years the greater availability and wider choice of suitable technology has meant that cogeneration has become an attractive and practical proposition for a wide range of applications. These include the process industries, commercial and public sector buildings and district heating schemes, all of which have considerable heat demand. These applications are summarized in the table below. The table also lists renewable fuels that can enhance the value of cogeneration, although fossil fuels, particularly natural gas, are more widely used.

### Possible opportunities for application of cogeneration

*Industrial*

- Pharmaceuticals & fine chemicals , Paper and board manufacture ,Brewing, distilling & malting ,Ceramics , Brick , Cement , Food processing ,Textile processing ,Minerals processing , Oil Refineries , Iron and Steel , Motor industry, Horticulture and glasshouses , Timber processing, etc.

*Buildings*

- District heating , Hotels , Hospitals , Leisure centres & swimming pools , College campuses & schools , Airports , Prisons, police stations, barracks , Supermarkets and large stores , Office buildings , Individual Houses etc.

### 2.3 Trigeneration Technology

#### What is Trigeneration?

Trigeneration is the simultaneous production of cooling, heating and power, in one process. Trigeneration, when compared to (combined-cycle) cogeneration, may be up to 50% more efficient than cogeneration. When found in a hospital, university, office-campus, military base, downtown or group of office buildings, has also been referred to as a "district energy system" or "integrated energy system" and as previously mentioned, can be dramatically more efficient and environmentally friendly than "cogeneration." A trigeneration plant, defined in non-engineering terminology, is most often described as a cogeneration plant that has added absorption chillers - which takes the "waste heat" a cogeneration plant would have "wasted," and converts this "free energy" that would have been wasted by cogeneration, into useful energy in the form of chilled water. The trigeneration energy process produces four different forms of energy from the primary energy source, namely, hot water, steam, cooling (chilled water) and power generation (electrical energy).

Trigeneration has also been referred to as CHCP (combined heating, cooling and power generation), this option allows having greater operational flexibility at sites with demand for energy in the form of heating as well as cooling. This is particularly relevant in tropical countries where buildings need to be air-conditioned and many industries require process cooling.

#### What is a technology benefit?

A factory requires 1 MW of electricity and 500 refrigeration tons* (RT). The gas turbine generates electricity required for the on-site energy processes as well as the conventional vapor compression chiller. Assuming an electricity demand of 0.65 kW/RT, the compression chiller needs 325 kW of electricity to obtain 500 RT of cooling. Therefore, a total of 1325 kW of electricity must be provided to this factory. If the gas turbine efficiency has an efficiency of 30 per cent, primary energy consumption would be 4417 kW. However, a cogeneration system with an absorption chiller (thereby making this a "trigeneration" plant) can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy versus 4417 kW thereby saving nearly 25% in primary energy usage. This is why a trigeneration plant is even more efficient than a cogeneration plant. This example clearly points out the advantages of trigeneration over cogeneration. A trigeneration plant (with an absorption chiller) can save about 24.5 per cent of primary energy in comparison with a cogeneration plant and vapor compression chiller.

### 2.4 Micro Gas Turbine Power Plant for Industry

Micro turbines, systems smaller than 1 MWe have so far been uneconomic, but this is starting to change. Manufacturers are developing smaller and smaller systems and nowadays there are microturbines as small as 25 kWe. In general, microturbines can generate anywhere from 25 kWe to 200 kWe of electricity. Microturbines are small high-speed generator power plants that include the turbine, compressor, generator, all of which are on a single shaft as well as the power electronics to deliver the power to the grid. Microturbines have only one moving part, use air bearings and do not need lubricating oil. They are primarily fuelled with natural gas, but they can also operate with diesel, gasoline or other similar high-energy fossil fuels. Research is ongoing on using biogas.


Figure 2-6 Typical 30 kW Micro turbine

Micro-turbines are smaller than conventional reciprocating engines, and capital and maintenance costs are lower. There are environmental advantages, including low NOx emissions of 10-25 ppm (02 – 15% equivalent) or lower.

Micro turbines emit low levels of noise ( approximately 70 dB at 10 feet ), and noise can be further reduced through readily available, inexpensive control technologies.

Micro turbines are currently available in nominal 25, 30, 45, 75, 100 and 200 kWe sizes ( larger sizes up to 350 kWe are being developed), and individual units can be packaged together to serve larger loads.

Micro turbines are capable of producing power at 20-30 % efficiency (LHV). Research and development efforts to use advanced ceramics technologies target 40 % efficiency for the next generation of products.

Micro turbines can be used as a distributed generation resource for power producers and consumers, including industrial, commercial and, in the future, even residential users of electricity.

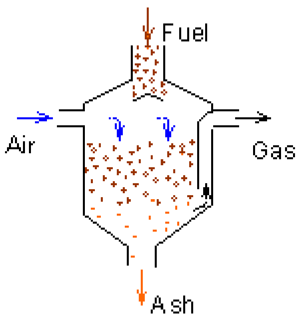
Technology Benefits

- Few moving parts
- Low nitrous oxide emissions
- Capable of using several fuels
- Waste heat recovery possible

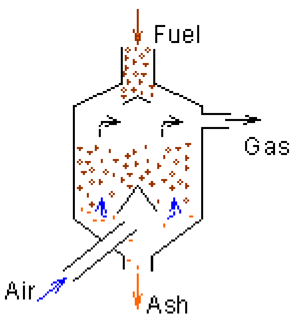
## 2.5 Gasifier

### What is Gasifier?

Gasifier is an equipment in which produce gaseous fuel (usually called producer gas) from the biomass in the presence of controlled amounts of air. The producer gas is a low calorific value, formed mainly of carbon monoxide and hydrogen. It can be burned directly to provide process heat, or cooled and cleaned for use in internal combustion engines as a partial or complete substitute for liquid fuels.




Downdraft gasifier




Updraft gasifier

## How It Used For?

The producer gas used as a fuel directly for industrial heat processes is extremely attractive because, unlike raw biomass, it is clean, easy to control and its combustion is generally more efficient. Producer gas is in relatively common use for the provision of heat for large-scale process systems in the industrialized world. There are significant plants in a few developing countries, especially Brazil, India , and in small to medium sized industries in South East Asia , where their performance is well proven.

## Advantages and Disadvantages

The advantage of producer gas over other biomass-fuelled power systems is that, at least in theory, existing diesel engines can be converted to dual fuel operation using producer gas with 15 to 20 percent diesel fuel gas, merely by retro-fitting low-cost gas generators. This requires only minor modifications, thus minimizing capital cost. Although there are many different designs, most gasifiers are of the downdraught type in which air is drawn through the burning bed. Conversion efficiencies (energy in the gas/energy in the fuel) of 70 percent are common. For use in engines, producer gas should be cleaned and cooled in a wide range of scrubbers, filters, electrostatic precipitators and other machinery. The gas can then be mixed with diesel to power a diesel engine, or used alone to fuel a petrol engine. The calorific value of the gas is approximately one third of petroleum fuels, and engines have to be derated when run on producer gas.

The main problem in the technical areas is that the gas given off from most fuel contains a high proportion of tarry substances and small particles which, if not removed, can dramatically reduce the lifetime of modern high-speed diesels. Cleaning the gas sufficiently to give the ease of operation and long life normally expected from diesel engines is technically possible but expensive, especially on a small scale in isolated rural areas. Where less effective cleaning is carried out, the wear on the engine increases rapidly due to entrainment of particulate matter in the gas stream. Poor filter design and maintenance can also contribute to this problem. Finally, field operations have not achieved the efficiencies obtained from laboratory tests, and fuel consumption is often higher than expected.

## 2.6 Electrical Resistance Heater

### What is Electrical Resistance Heater?

Electrical Resistance Heater is a device used to produce heat from electricity. Electrical resistance heater consists of an electrical resistor when passing electricity through it, electrical energy is dissipated into heat which results in rapid and uniform heating.

### How to Applications?

Electrical resistance heater can be used directly such as electrical water heater or indirectly. Most of electrical resistance heating applications are widely used by indirectly.

Indirect resistance heating is used primarily in the metals, ceramics, electronics and glass industries. The more frequently used processes that incorporate this heating technique include:

### Heat Treatment of Metals

Indirect-resistance heating is used for annealing, austenitizing, normalizing, hardening, tempering, nitriding, carburizing, and centering a wide range of ferrous materials. It is also used for annealing, solution treating, and aging nonferrous metals.

### Metal Melting

Indirect-resistance furnaces are widely used for melting and holding metals, especially nonferrous alloys, because of the increased availability of light-weight refractory materials for building indirect-resistance-heated crucible furnaces. The low thermal mass of these materials makes the furnaces very energy efficient.

### Heating Prior to Forming

In the forging industry, electric-based heating is gaining in popularity for billet preheating. The reason is that indirect-resistance furnaces are considerably more efficient than gas-fired furnaces, even those with recuperators, at preheating temperatures (around 2,100°F, the exact temperature depending on the specific material).

### Brazing

Metal components are often brazed in indirect-resistance furnaces because of the need for a controlled atmosphere (or vacuum) or a carefully controlled thermal cycle.

### Sintering Ceramics

Ceramic materials must often be fired, or sintered, at temperatures as high as 3,000 F, and both temperature and furnace atmosphere have to be precisely controlled. Indirect-resistance heating provides this level of precision. The electronics industry also uses indirect resistance furnaces for growing, purifying and processing the silicon and germanium crystals and wafers used in many semiconductor devices.

### Curing coatings

Indirect-resistance furnaces are used in the finishing industry for baking vitreous enamel coatings onto metal substrates and for drying and curing organic coatings, such as paints and varnishes, on a variety of materials.

### Glass tempering

Tempering is almost always carried out in indirect-resistance furnaces. Glass is tempered by heating to a carefully controlled temperature (usually around 1,100 to 1,200°F) followed by rapid but uniform cooling. Tempering results in residual compressive stresses on the surface that provide greater resistance to fracture and damage. Typical products include automobile and architectural glass.

Encased resistance heaters, are generally used when reliable, long-term heating at low to medium temperatures is required. Since their uses are so varied, it is difficult to define benefits of encased resistance heaters independent of application. However, this diversity is an advantage in itself, since a heater can be found for practically any application. Other advantages include:

- Low cost. Heaters are fairly inexpensive, reliable and durable, and they require little maintenance.
- Energy efficiency. Nearly all of the applied energy is converted to useful heat.
- Precise temperature control. Thermostats and electric power's inherent controllability ensure precise control heating temperatures.

## 2.7 Infrared Heater

### What is Infrared ?

Infrared radiation is a form of electromagnetic energy that is generated by the vibration and rotation of atoms and molecules within all objects with temperatures above absolute zero (-273 $^{0}$C). Infrared radiation derives from two sources, natural and artificial. The most significant natural source is the sun : approximately 50 % of the energy received by the earth from the sun is in the form of infrared energy. Commercially manufactured artificial sources (emitters) include incandescent, fluorescent, and high intensity lamps, flames and heaters. In industry, infrared heaters are generally categorized into three wavelength bands, according to the intensity of the radiation and temperature at which the emitter operates:

**Short band:** 0.75 to 2.0 microns, high intensity radiation, high temperature range 1,600-2,200 $^{0}$C (2,900-4,000 $^{0}$F)

**Medium, or intermediate band:** 2.0 to 4.0 microns, medium intensity, temperature range 700-1,000 $^{0}$C (1,300-1,800 $^{0}$F)

**Far, or long band:** 4.0 to 10 microns, low intensity, temperature range 300-700 $^{0}$C (572-1,300 $^{0}$F)

Infrared radiation is absorbed and converted into thermal energy by most materials. The emission wavelength controls the amount of energy absorbed. When infrared radiation is absorbed by an object, changes occur in the object’s molecules that affect the frequency and amplitude of their oscillation. During the absorption process, the oscillation rate of the object’s molecules rises to a higher energy level before returning to normal. During the returning stage, thermal energy is released in the form of heat. It is this thermal energy that warms objects during space and spot heating and has proved useful in a wide variety of industrial applications. This method of radiant heat transfer transmits energy to the receiver without heating the ambient air, in much the same manner that a microwave oven cooks food.

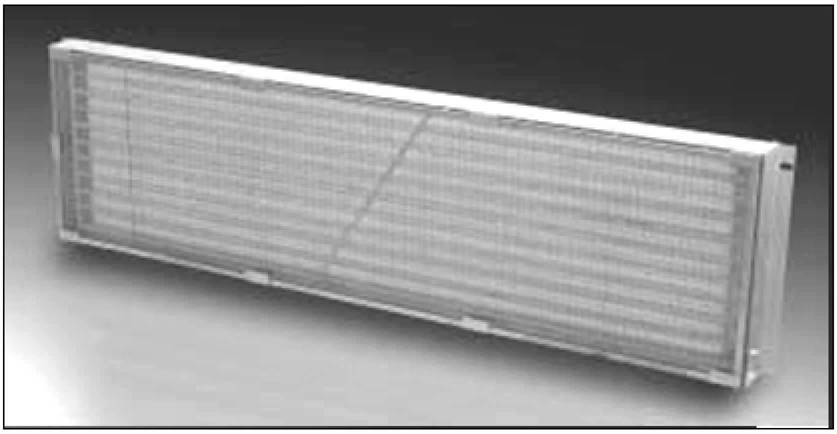


Figure 2-7 Electric Infrared Heater

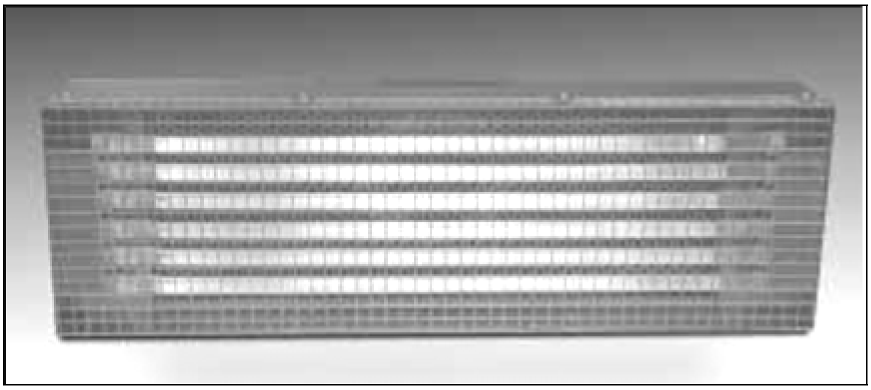


Figure 2-8 Quartz Infrared Heater

How to Application in Industry?

Infrared heater has been widely utilized throughout industry for drying, sterilization and curing operations.

2.8 Microwave Heating

What is Microwave?

Microwave is a form of electromagnetic wave like radio wave or visible light. Industrial Microwave Systems use frequencies between 460 and 2,450 MHz with corresponding wavelengths between 24 and 4 inches (60 to 10 cm).

How does microwave compare to conventional heating?

In conventional or surface heating, the process time is limited by the rate of heat flow into the body of the material from the surface as determined by its specific heat, thermal conductivity, density and viscosity. Surface heating is not only slow, but also non-uniform with the surfaces, edges and corners being much hotter than the inside of the material. Consequently, the quality of conventionally heated materials is variable and frequently inferior to the desired result.

Imperfect heating causes product rejections, wasted energy and extended process times that require large production areas devoted to ovens. Large ovens are slow to respond to needed temperature changes, take a long time to warm up and have high heat capacities and radiant losses. Their sluggish performance makes them slow to respond to changes in production requirements making their control difficult, subjective and expensive.

Conversely, with microwaves, heating the volume of a material at substantially the same rate is possible. This is known as volumetric heating. Energy is transferred through the material electro-magnetically, not as a thermal heat flux. Therefore, the rate of heating is not limited and the uniformity of heat distribution is greatly improved. Heating times can be reduced to less than one percent of that required using conventional techniques.

What is the advantage?

Because volumetric heating is not dependent on heat transfer by conduction or convection, it is possible to use microwave heating for applications where conventional heat transfer is inadequate. One example is in heterogeneous fluids where the identical heating of solids and liquids is required to minimize over-processing. Another is for obtaining very low final moisture levels for product without over-drying. Other advantages include:

- Microwaves generate higher power densities, enabling increased production speeds and decreased production costs.

- Microwave systems are more compact, requiring a smaller equipment space or footprint.

- Microwave energy is precisely controllable and can be turned on and off instantly, eliminating the need for warm-up and cool-down.

- Lack of high temperature heating surfaces reduces product fouling in cylindrical microwave heaters. This increases production run times and reduces both cleaning times and chemical costs.

- Microwaves are a non-contact drying technology. One example is the application of IMS planar dryers in the textile industry, which reduce material finish marring, decrease drying stresses, and improve product quality.

- Microwave energy is selectively absorbed by areas of greater moisture. This results in more uniform temperature and moisture profiles, improved yields and enhanced product performance.

- The use of industrial microwave systems avoids combustible gaseous by-products, eliminating the need for environmental permits and improving working conditions.

What is the disadvantage of microwave?

The disadvantage is the depth of penetration achievable using microwave energy. This is a function of microwave frequency, dielectric properties of the material being heated and its temperature. As a general rule, the higher the frequency, the lower the depth of penetration.

How to Application?

Microwave can be used in drying process all industries that need both fast drying and gentle on the products.

## 2.9 Induction Heater

What is induction heating?

Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. It is also very efficient since the heat is actually generated inside the workpiece. This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the workpiece. For these reasons Induction Heating lends itself to some unique applications in industry.

How does Induction Heating work ?

A source of high frequency electricity is used to drive a large alternating current through a coil. This coil is known as the work coil. The passage of current through this coil generates a very intense and rapidly changing magnetic field in the space within the work coil. The workpiece to be heated is placed within this intense alternating magnetic field. The alternating magnetic field induces a current flow in the conductive workpiece. The arrangement of the work coil and the workpiece can be thought of as an electrical transformer. The work coil is like the primary where electrical energy is fed in, and the workpiece is like a single turn secondary that is short-circuited. This causes tremendous currents to flow through the workpiece. These are known as eddy currents. In addition to this, the high frequency used in induction heating applications gives rise to a phenomenon called skin effect. This skin effect forces the alternating current to flow in a thin layer towards the surface of the workpiece. The skin effect increases the effective resistance of the metal to the passage of the large current. Therefore it greatly increases the heating effect caused by the current induced in the workpiece.

### What is Induction Heating used for ?

Induction heating can be used for any application where we want to heat an electrically conductive material in a clean, efficient and controlled manner.
One of the most common applications is for sealing the anti-tamper seals that are stuck to the top of medicine and drinks bottles. A foil seal coated with "hot-melt glue" is inserted into the plastic cap and screwed onto the top of each bottle during manufacture. These foil seals are then rapidly heated as the bottles pass under an induction heater on the production line. The heat generated melts the glue and seals the foil onto the top of the bottle. When the cap is removed, the foil remains providing an airtight seal and preventing any tampering or contamination of the bottle's contents until the customer pierces the foil.

Another common application is "getter firing" to remove contamination from evacuated tubes such as TV picture tubes, vacuum tubes, and various gas discharge lamps. A ring of conductive material called a "getter" is placed inside the evacuated glass vessel. Since induction heating is a non-contact process it can be used to heat the getter that is already sealed inside a vessel. An induction work coil is located close to the getter on the outside of the vacuum tube and the

AC source is turned on. Within seconds of starting the induction heater, the getter is heated white hot, and chemicals in its coating react with any gasses in the vacuum. The result is that the getter absorbs any last remaining traces of gas inside the vacuum tube and increases the purity of the vacuum.

Yet another common application for induction heating is a process called Zone purification used in the semiconductor manufacturing industry. This is a process in which silicon is purified by means of a moving zone of molten material. An Internet Search is sure to turn up more details on this process that I know little about.

Other applications include melting, welding and brazing or metals. Induction cooking hobs and rice cookers. Metal hardening of ammunition, gear teeth, saw blades and drive shafts, etc are also common applications because the induction process heats the surface of the metal very rapidly. Therefore it can be used for surface hardening, and hardening of localized areas of metallic parts by "outrunning" the thermal conduction of heat deeper into the part or to surrounding areas. The non contact nature of induction heating also means that it can be used to sterilize metal instruments by heating them to high temperatures whilst they are already sealed inside a known sterile environment in order to kill germs.

## 2.10 Radio Frequency Heating

### What is Radio Frequency Heating?

Radio Frequency (RF) energy and microwave energy are both dielectric heating technologies, where high-frequency electromagnetic radiation generates heat to dry moisture in nonmetallic materials. RF waves are longer than microwaves, enabling them to penetrate larger objects better than microwave energy. Industrial radio frequencies typically operate between 10 and 30 MHz with wavelengths of 100 to 35 feet (30 to 10 meters).

### How does RF works?

Material to be dried is placed in a high-frequency electric field created between a set of parallel plates or bars. Water molecules in the material are heated until they become steam. Air circulating through the drying chamber removes the steam and prevents condensation.

Radio Frequency (RF) drying has been successfully used in the textile and furniture industries for over 30 years and its use has progressively grown in other industries such as food processing and paper manufacturing.

Industrial Applications

- Instantaneous glue setting in furniture manufacturing
- Drying natural and synthetic textiles
- Drying water-based adhesives, emulsions and coatings at high production speeds
- Post-bake drying and moisture control in food
- Moisture removal from glass fibers in both roving and bale form
- Preheating fiber mat board

Industrial Benefits

- Quick response time
- Accurate final moisture control/moisture leveling
- Environmentally friendly
- Moisture removal at low temperatures
- Low maintenance
- Energy efficient

## 2.11 Heat Pump

### What is Heat Pump?

Heat pump is a device that uses a refrigerant cycle to take low-quality heat(low temperature), compresses it to a higher quality heat(high temperature) and moves that heat to another location in the cycle. It does so with the addition of energy, usually in the form of electricity. This refrigerant cycle is similar to the cooling process employed by a standard household refrigerator. In the heating mode, the heat pump removes heat from a relatively low temperature sources, such as outside air, and delivers that heat to warm space or exchange heat with cool water to produce hot water. In the cooling mode, heat is removed from the relatively warm building interior and rejected outside the building.

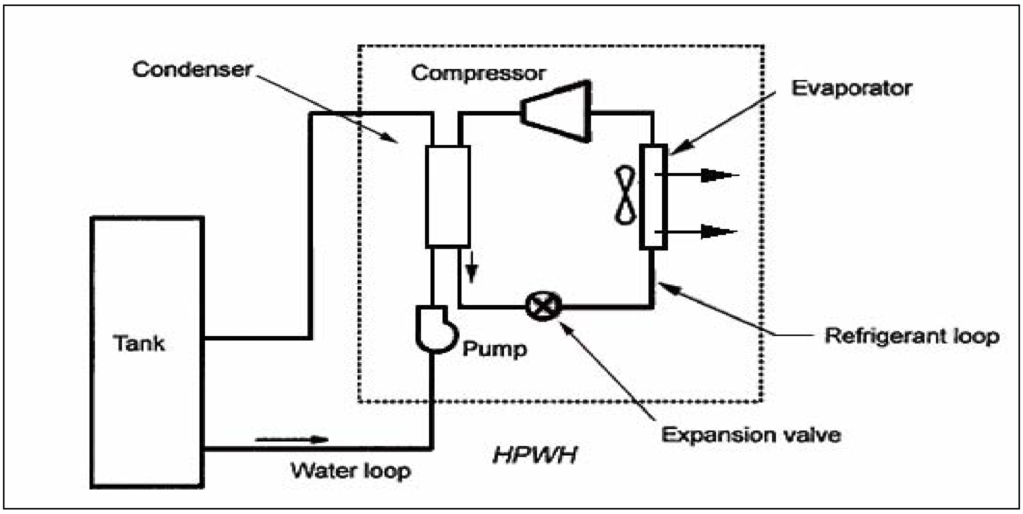


Figure 2-9 Heat Pump Water Heater

How It Used For?

Most of heat pumps are usually to produce a hot water, heat pump water heater (HPWH). A HPWH is an effective and efficient way to provide hot water for commercial buildings and factories. The HPWH tends to be much more efficient than an electric resistance water storage tank. In the case of the HPWH, units with a coefficient of performance (COP) higher than 3 can be found. This means that for every kWh of electricity energy to the HPWH, more than three kWh of thermal energy is produced as hot water.

Technology Benefits

One of the major benefits of the HPWH is the cooling that is generated as the HPWH operates to heat water. If the HPWH has an air-cooled evaporator that is located inside the building, then this cooling can be used to help cool the building interior during times when the HPWH is working to generate hot water.

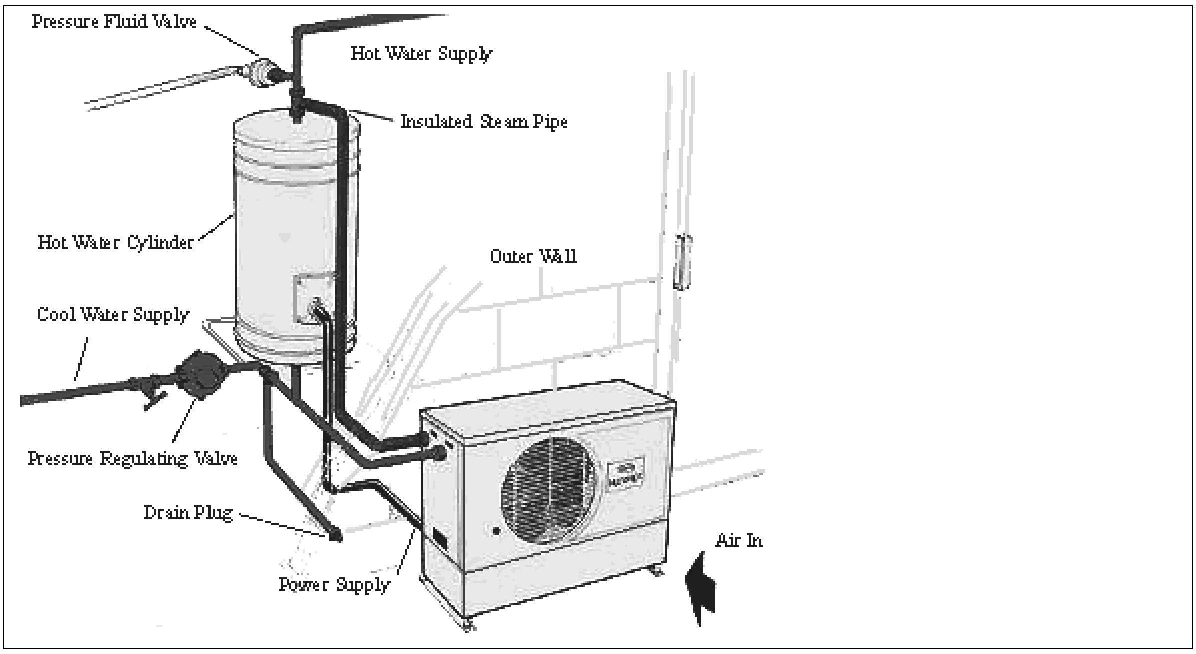



Figure 2-10 Separate heat-pump air-source water heater

How to Application ?

In commercial building, industrial processes where large amounts of hot water are used. HPWH is one of solution to provide hot water for these purposes. A boiler for making hot water (not steam) can be replaced with HPWH.

## 2.12 Heat Pipe

What is Heat Pipe?

A heat pipe is a hermetically sealed evacuated tube normally containing a mesh or sintered powder wick and a working fluid in both the liquid and vapor phase.

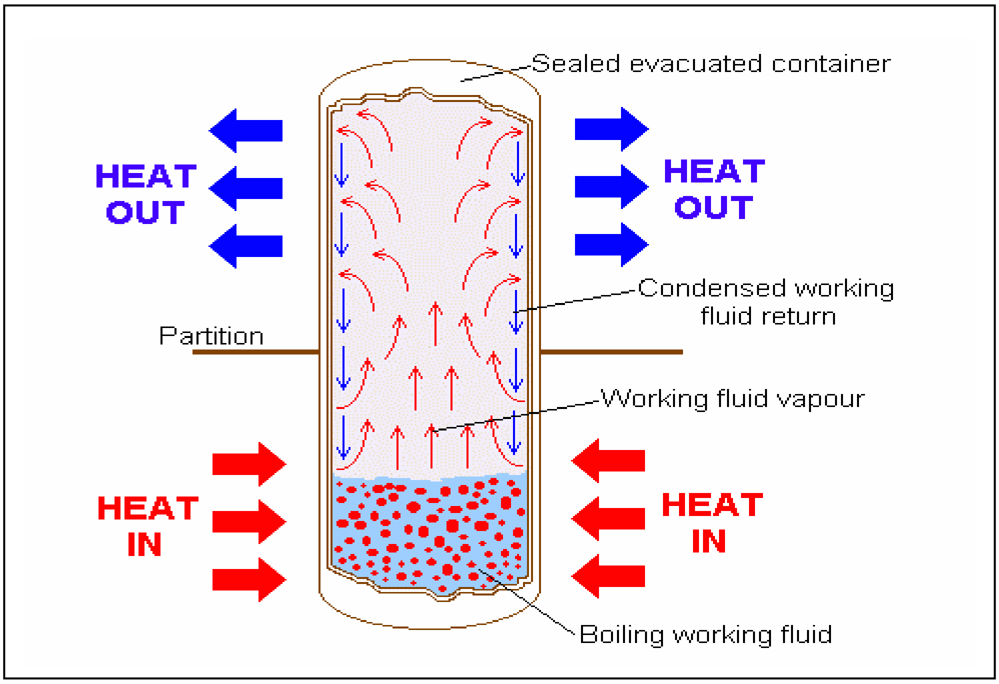


Figure 2-11  Heat Pipe

When one end of the tube is heated the liquid turns to vapor absorbing the latent heat of vaporization. The hot vapor flows to the colder end of the tube where it condenses and gives out the latent heat. The recondensed liquid then flows back through the wick to the hot end of the tube.

Since the latent heat of evaporation is usually very large, considerable quantities of heat can be transported with a very small temperature difference from one end to the other.

The vapor pressure drop between the evaporator and the condenser is very small; and, therefore, the boiling – condensing cycle is essentially an isothermal process. Furthermore, the temperature losses between the heat source and the vapor and between the vapor and the heat sink can be made small by proper design. Therefore, one feature of the heat pipe is that it can be designed to transport heat between the heat source and the heat sink with very small temperature losses.

The amount of heat that can be transported as latent heat of vaporization is usually several orders of magnitude larger than can be transported as sensible heat in a conventional convective system with an equivalent temperature difference. Therefore, a second feature of the heat pipe is that relatively large amounts of heat can be transported with small lightweight structures. The performance of a heat pipe is often expressed in terms of equivalent thermal conductivity. The huge effective thermal conductivity of the heat pipes can be illustrated by the following examples.

A tubular heat pipe using water as the working fluid and operated at 150 ºC would have a thermal conductivity several hundred times that of a copper bar of the same dimensions.

A heat pipe using lithium as the working fluid at a temperature of 1,500 ºC will carry an axial heat flux of 10 - 20 kW/cm$^2$.

By suitable choice of working fluid and container materials it is possible to manufacture heat pipes for use at temperatures ranging from - 269 ºC to in excess of 2,300 ºC.

## Applications of the Heat Pipe

Features of heat pipe heat exchangers that are attractive in industrial heat recovery applications are:

- No moving parts and no external power requirements, implying high reliability.
- Cross-contamination is totally eliminated because of a solid wall between the hot and cold fluid streams.
- Easy to clean.
- A wide variety of sizes are available, and the unit is in general compact and suitable for all.
- The heat pipe heat exchanger is fully reversible – i.e. heat can be transferred in either direction.
- Collection of condensate in the exhaust gases can be arranged, and the flexibility accruing to the use of a number of different fin spacing can permit easy cleaning if required.

The application of heat pipe heat exchangers fall into three main categories:

1. Recovery of waste heat from processes for reuse in the same process or in another, e.g. preheating of combustion air. This area of application is the most diverse and can involve a wide range of temperatures and duties.

2. Recovery of waste heat from a process to preheat air for space heating.

3. Heat recovery in air – conditioning systems, normally involving comparatively low temperatures and duties.

## 2.13 Steam Ejector Refrigerator

### What is Steam Ejector Refrigerator?

Ejector refrigeration cycles differs from vapor-compression cycles in the manner in which compression is achieved. In the ejector cycle, the low-pressure refrigerant (e.g. water) is driven by fluid kinetic or thermal energy as opposed to pumps or compressors which are driven by mechanical energy.

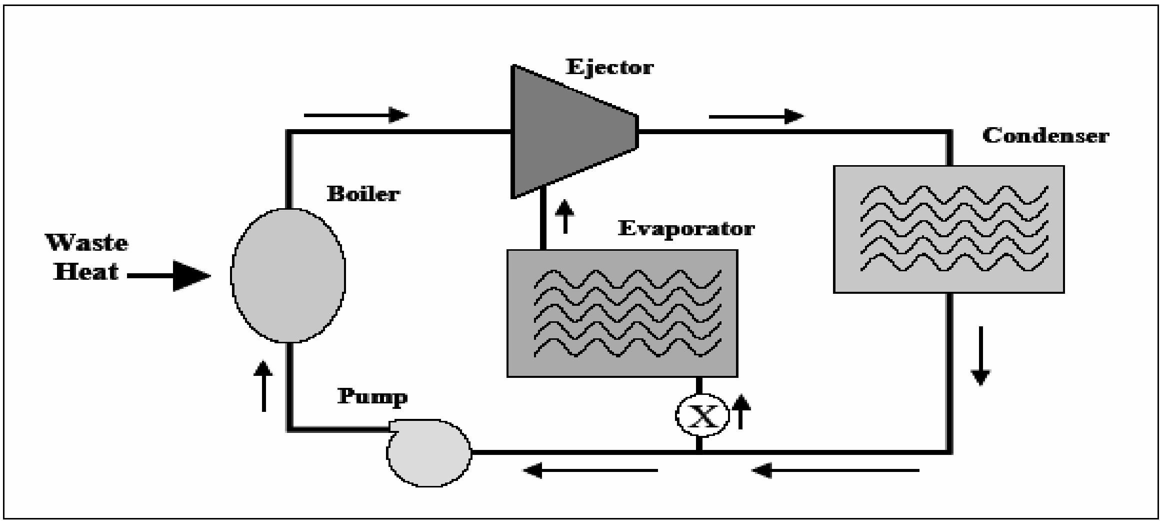


Figure 2-12 A schematic of the essential elements in an ejector system

How it work?

Figure 4-12 shows a schematic of the essential elements in an ejector system. The waste heat from the exhaust would be utilized to convert water to super heated steam. The steam would then be utilized by a steady-stream ejector or turbomachinery to compress a secondary water stream.

Advantages and Disadvantages

The ejector refrigeration cycle has the distinct advantage of being environmentally friendly when water is used as the working fluid-other refrigerants can be used in the cycle. Like the absorption system, the ejector refrigeration cycle requires very little work input because the pumping process involves a liquid.

The ejector can either be a steady-flow ejector or can be replaced by a turbine compressor. Steady-flow ejectors have been in development over the past century and are unlikely to attain COP greater than 0.2 . Turbine ejectors have the potential for greater COP but such a system would be expensive and require large components if water were used as a refrigerant. Furthermore, turbomachinery is somewhat unforgiving with regards to sealing and bearing requirements considering the rotational speed of the turbine, upwards of 75,000 rpm.

2.14 Solar Water Heater

What is Solar Water Heater?

The most common conception of the use to which solar energy can be put centers on the heating of water in solar collectors. Solar water heating is a renewable energy technology that is well-proven and readily available and has considerable potential for applications at federal facilities. Solar water heating systems can be used effectively throughout the country and most facilities will have an appropriate nearby unshaded grounds of installation of a collector. The most common type of solar water heater is flat-plate solar collector for low temperature applications and parabolic trough solar collector for high temperature applications.

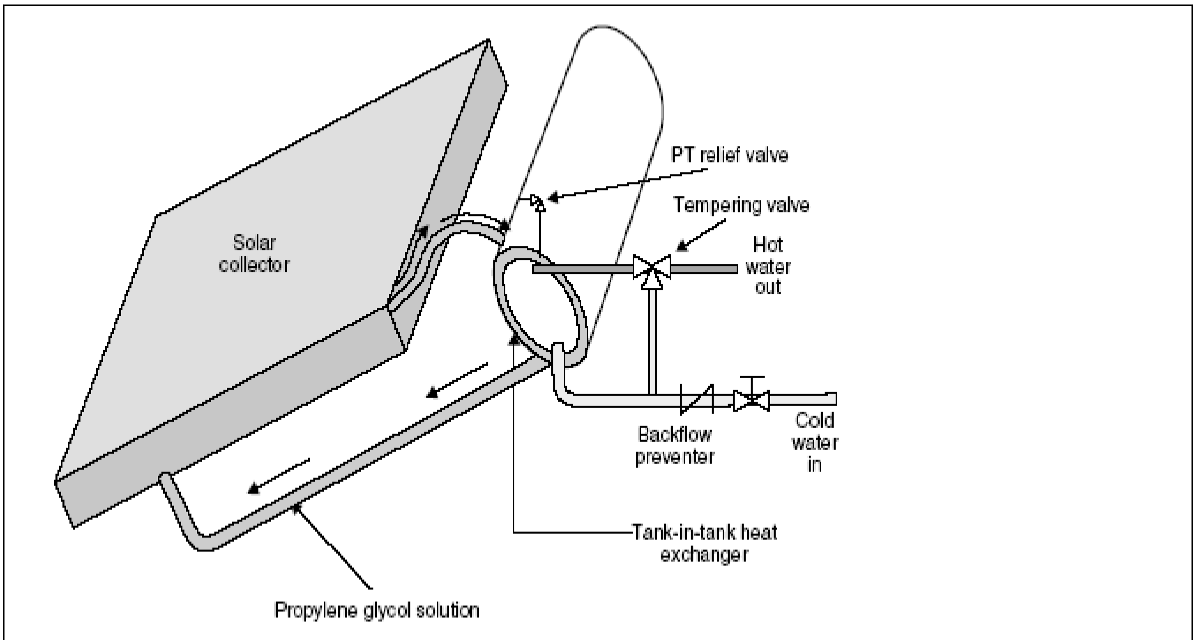



Figure 2-13 Solar flat-plate collector

Figure 2-14 Parabolic trough solar collector

How It Used For?

The hot water produced by solar collector is suitable for many applications. For example, household use, hospitals, feed-water for boiler and others facilities in areas with good solar resources that consistently use large volumes of hot water.

## 2.15 Heat Exchanger

What is Heat Exchanger?

Heat exchanger is  device specifically designed for the efficient transfer of heat from one fluid to another fluid over a solid surface. This transfer of heat can either take the form of absorption or dissipation of heat. Heat exchangers can be found in everyday equipment from boilers, furnaces, refrigerators to air conditioning systems.

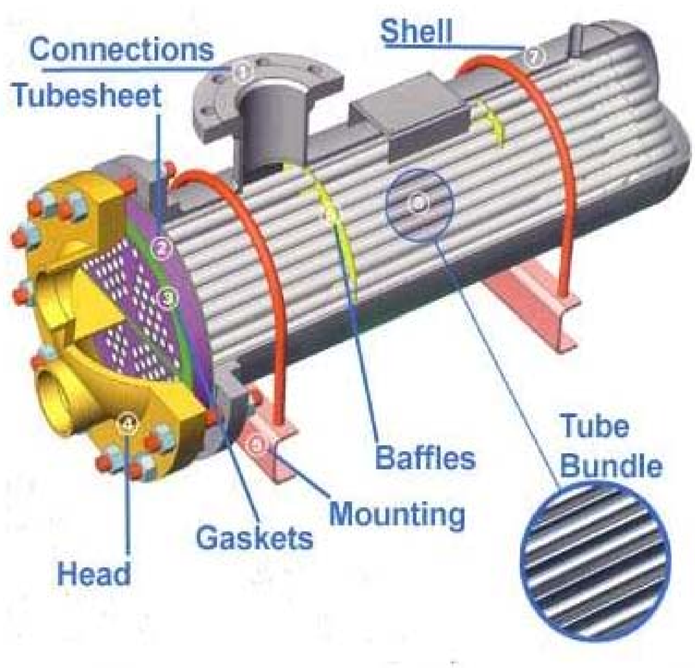



Figure2-15  Shell and Tube            Figure 2-16 Plate Heat Exchanger

How can heat exchangers be put to use for you?

As a heat transfer device, it is the function of a heat exchanger to transfer heat as efficiently as possible. This makes it the ultimate device of choice, for instance, when it comes to saving energy by recovering wasted heat and making it useful again. When there is a waste of energy or a heat stream that is not recovered, a heat exchanger can covert that heat stream into something that we can use.

Industrial applications :

- Process liquid or gas cooling
- Process or refrigerant vapor or steam condensing
- Process liquid, steam or refrigerant evaporation
- Process heat removal and preheating of feed water
- Thermal energy conservation efforts, heat recovery
- Compressor, turbine and engine cooling, oil and jacket water
- Hydraulic and lube oil cooling  etc.

# Chapter 3

# Thermal Energy Management

## 3.1 Thermal Energy Storage

### What is Thermal Storage?

Thermal energy storage (TES) is a new application of an old idea that can cut air conditioning energy costs in half. Air conditioning system during daytime hours is the largest single contributor to electrical peak demand. In the afternoon, as more air conditioning is needed to maintain comfortable temperatures, the increased demand for electricity adds to the load already created by lighting, operating equipment, computers and many other sources.

This requires the electric suppliers to bring additional, more costly generating equipment on line to handle this increased demand. Commercial users, whose large air conditioning loads greatly contribute to the need for these seldomly used generating stations, are charged more for this "On Peak" energy, either in the form of higher energy charges (kWh) or a "Demand Charge" which is based on their highest on-peak demand (kW) for electricity. The "On-Peak" demand charge is normally based on the electricity required (in kW) over a specified time period, usually 15 minutes, assessed on a monthly or yearly basis. In Thailand energy charge for TOU rate on the peak period (09.00-22.00 Monday through Friday ) is 2.695 B/kWh while off peak period ( 22.00-09.00 Monday through Friday and National Holidays) is 1.1914 B/kWh and demand charge during on peak period is 132.93 B/kW while off peak period is no charge. For TOD rate demand charge during on peak period (18.00-21.30 all days ) is 285.05 B/kW and energy charge is 1.7034 B/kWh.

Thermal Energy Storage (TES) System is a technology which shifts electric load to off-peak hours which will not only significantly lower energy and demand charges during the air conditioning season, but can also lower total energy usage (kWh) as well. It uses a standard chiller to produce solid ice at night during off-peak periods when the building’s electrical loads are at a minimum. The electric supplier's generating capacity is also typically under-utilized at night and, consequently, its rates are lowest then. The ice is built and stored in modular ice tanks to provide cooling to help meet the building’s air conditioning load requirement the following day allowing chillers to be downsized or turned off.

Ice Bank Systems not only can cut operating costs in half but they can also substantially reduce capital outlays when systems are suitably designed for new commercial and industrial buildings. Engineers can specify half-size chillers operating 20-24 hours a day rather than full-size chillers operating only 10 or 12 hours per day. In retrofit applications, an Ice Bank TES System can often provide cooling for an addition or increased loads to a building without adding chiller capacity.

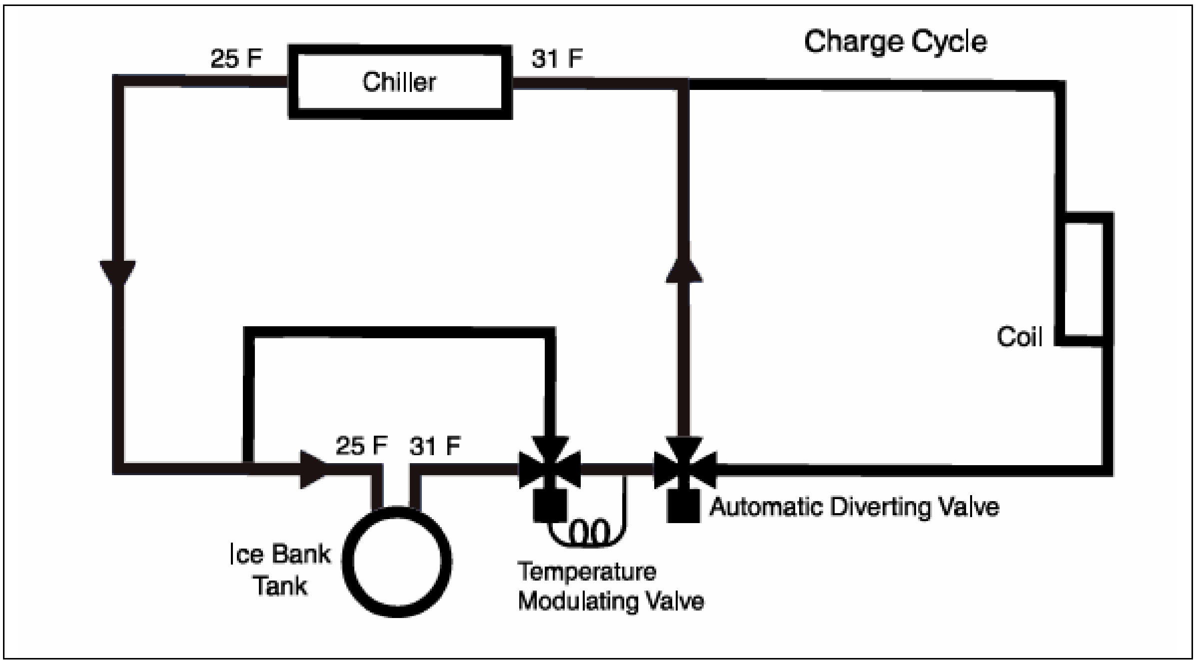



Figure 3-17 Thermal storage system on charge cycle

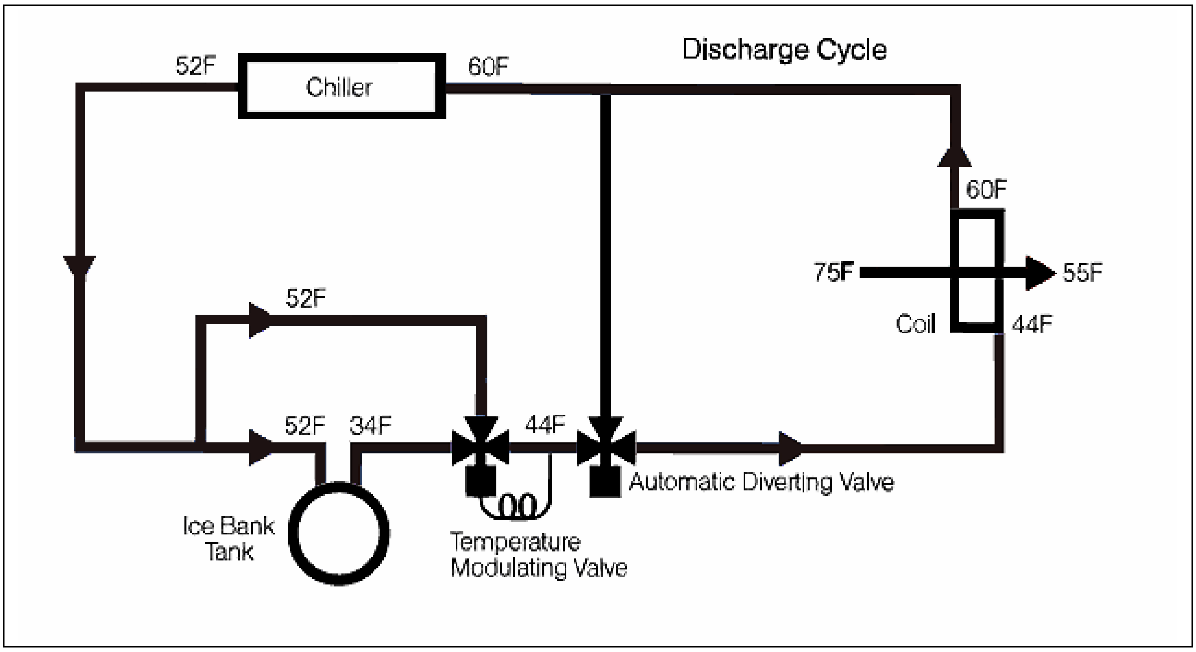



Figure 3-18 Thermal storage system on discharge cycle

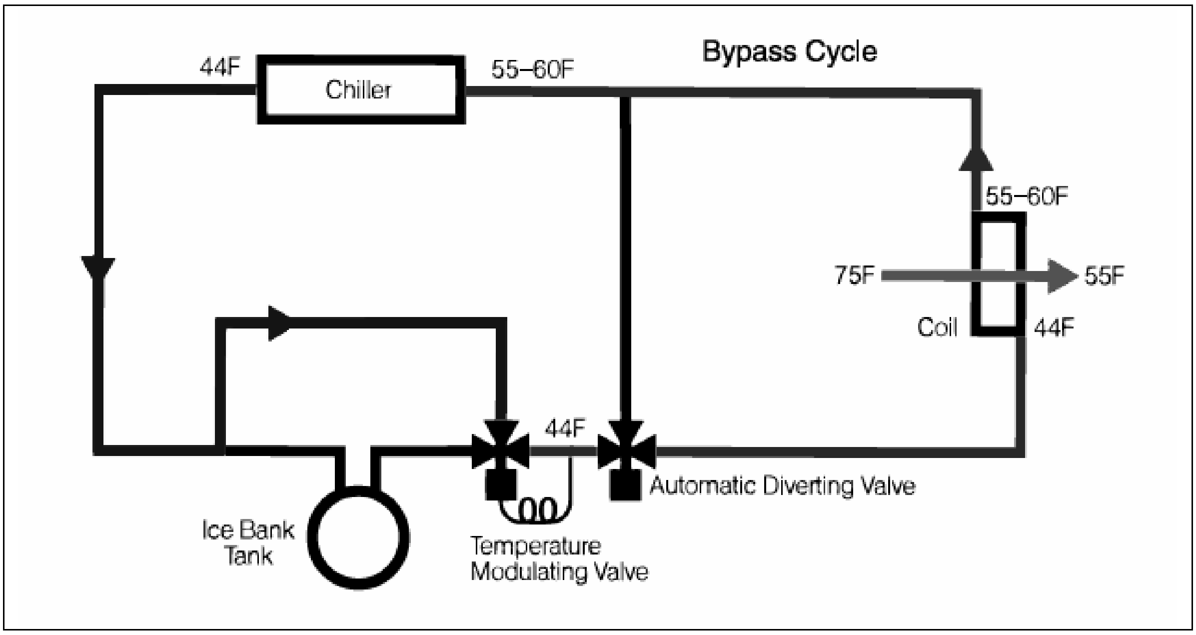



Figure 3-19 Thermal storage system on bypass cycle

How to application?

Thermal energy storage is suitable for buildings or factories which use large amount of Air Conditioning system and use TOU or TOD Tariff rate.

## 3.2 Heat Reclaim Technology

A refrigeration heat reclaim (RHR) water heating system links two common functions in commercial buildings to reduce purchased energy consumption and achieve cost savings. A refrigeration heat reclaim water heating system harvests heat that would normally be rejected through refrigeration system condensers and applies the heat for water heating. See Figure 1. Refrigeration heat reclaim water heating has the advantages of relatively low cost and simplicity. The primary limitation of refrigeration heat reclaim water heating systems is the fact that heat is available only when the refrigeration system is in operation. However, in many applications heat storage capacity and the operating diversity of heat source equipment remove this concern.

A refrigeration heat reclaim device is simply a refrigerant-to-water heat exchanger installed between the host refrigeration system's compressor and condenser. On heat pumps, the heat exchanger is installed between the compressor and the reversing valve. Water is circulated through one side of the heat exchanger and hot refrigerant gas from the compressor is routed through the other side. Heat is transferred from the hot refrigerant gas to the water.

Most refrigeration heat reclaim devices are desuperheaters. Superheat refers to heat stored in the refrigerant vapor when it is heated above the temperature at which it evaporates for a given pressure. See Figure 3. Acting as a desuperheater, a heat reclaim device cools the refrigerant only to the saturation point; no condensing takes place in the desuperheater. Under typical conditions a desuperheater can remove about 10 to 30% of the total heat that would have been rejected by the condenser.

A heat reclaim device may also be designed to do condensing rather than just desuperheating. More heat can be extracted, but at a lower temperature. However, most refrigeration heat reclaim equipment manufacturers have intentionally prevented condensing to avoid problems with host equipment operation. Excessive subcooling (reduction of liquid refrigerant temperature below the saturation point) in the condenser at low outdoor temperature is the concern. With excessive subcooling, problems can occur with low compressor head pressure, improper expansion device operation from inadequate pressure drop, and liquid slugging in the compressor.

Most refrigeration heat reclaim units are designed for retrofit installation. Since installation involves cutting into the sealed refrigerant system, a qualified refrigeration mechanic should do the work. The effect of the installation on any warranties for the refrigeration system should be investigated. Some manufacturers of air conditioners and refrigeration systems place limitations on warranties if heat reclaim systems are installed.

### 3.3 Hot Water from Air Compressor System

#### Heat Recovery and Compressed Air Systems

As much as 80-93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50-90% of this available thermal energy and put it to useful work heating air or water.

Typical uses for recovered heat include supplemental space heating, industrial process heating, water heating, makeup air heating, and boiler makeup water preheating. Recoverable heat from a compressed air system is not, however, normally hot enough to be used to produce steam directly.

Heat recovery systems are available for both air- and water-cooled compressors.

### Heat Recovery with Air-Cooled Rotary Screw Compressors

*Heating Air.*Air-cooled packaged rotary screw compressors are very amenable to heat recovery for space heating or other hot air uses. Ambient atmospheric air is heated by passing it across the system's aftercooler and lubricant cooler, where it extracts heat from both the compressed air and the lubricant that is used to lubricate and cool the compressor.

Since packaged compressors are typically enclosed in cabinets and already include heat exchangers and fans, the only system modifications needed are the addition of ducting and another fan to handle the duct loading and to eliminate any back pressure on the compressor cooling fan. These heat recovery systems can be modulated with a simple thermostatically-controlled hinged vent. When heating is not required -- such as in the summer months -- the hot air can be ducted outside the building. The vent can also be thermostatically regulated to provide a constant temperature for a heated area.

Hot air can be used for space heating, industrial drying, preheating aspirated air for oil burners, or any other application requiring warm air. As a rule of thumb, approximately 50,000 Btu/hour of energy is available for each 100 cfm of capacity (at full-load). Air temperatures of 30 to 40oF above the cooling air inlet temperature can be obtained. Recovery efficiencies of 80-90% are common.

Caution should be applied because if the supply air for the compressor is not from outside, and the recovered heat is used in another space, you can decrease the static pressure in the cabinet and reduce the efficiency of the compressor. If outside air is used, some return air may be required to avoid damaging the compressor with below freezing air.

*Heating Water.*Using a heat exchanger, it is also possible to extract waste heat from the lubricant coolers found in packaged water-cooled reciprocating or rotary screw compressors and produce hot water. Depending on design, heat exchangers can produce non-potable (gray) or potable water. When hot water is not required, the lubricant is routed to the standard lubricant cooler.

Hot water can be used in central heating or boiler systems, industrial cleaning processes, plating operations, heat pumps, laundries, or any other application where hot water is required. Heat exchangers also offer an opportunity to produce hot air and hot water, and allow the operator some ability to vary the hot air/hot water ratio.

### Heat Recovery with Water-Cooled Compressors

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is lower. Since many water-cooled compressors are quite large, however, heat recovery for space heating can be an attractive opportunity. Recovery efficiencies of 50-60% are typical.