Text No.11

ENERGY CONSERVATION TECHNOLOGIES IN THE INDUSTRIAL SECTOR

産業分野での省エネルギー技術

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Method to Promote Energy Conservation Measures

Energy conservation measures cannot become sufficiently effective if they are applied sporadically like some quick-cure drug. They should be carried out rationally through an effective setup with definite targets in order to produce maximum results. Table 1 shows the general method of approach.

The promotional setup may differ according to the government's policies and the corporation's scale, but at any rate a promotional committee headed by a managerial staff member should be established in order to actively support the setup in all phases of its activities.

The procedure for implementing energy conservation measures will probably have the general pattern described below.

Table 1 Procedures for Accomplishing Energy Conservation

Procedure	Description
Step 1	Setting of Targets and Planning
Step 2	Elucidation of Existing Situation
Step 3	Preparation of Improvement Plan
Step 4	Effectuation of Plan
Step 5	Evaluation of Results
Step 6	Continuance

1. Target Setting and Planning

The first step to promote energy conservation measures smoothly is to set definite targets, especially the managerial staff showing definite policies.

Target setting can be done in various ways, such as the following:

a) Abstract target: For example, 'Construction of the world's leading energy conservation type facility.'
b) Specific target: For example, 'Carrying out the waste heat recovery measures which investment could recover within three years.'
c) Absolute target: For example, 'Attainment of a fuel specific unit of less than 1.256 GJ/t (0.3 Gcal/t).
d) Relative target: For example, 'Attainment of an energy conservation ratio of 20%.'

If we compare targets a) and b) with targets c) and d), we see that the former targets are rather like slogans, while the latter targets offer specific energy-saving objectives and lend themselves to continued and increasingly easier follow-up. At least, targets such as the absolute target c) should be set up for each process in the factory, and targets such as the relative target d) for the factory as a whole.

After setting these targets, we will have to draft a plan for carrying out related measures, which would specify factors such as work assignments, contents of the work to be done, work schedules, range of operations, time period and methods.

2. Analysis of Present Situation

The primary step to taken in the actual work of conserving energy is to analyze the present energy consumption situation – to clarify what kinds of energy resources are being consumed in what quantities and for what purposes, and to clarify what kinds of energy are being dissipated wastefully at what kinds of places.

To attain this objective, we must use various kinds of measuring equipment such as flow meters, thermometers and pressure gauges, and also assign a minimum number of engineers to conduct the measurements and analyses. The data obtained through these surveys should then be represented in graphical form for use as reference data to deduce hints on what measures should be adopted to attain the energy conservation targets.

The typical types of graphs prepared for this purpose are the following:

2.1 Circular graph on energy consumption pattern

Fig. 1 classifies the energy resources consumed by a certain factory by kind and quantity (percentage breakdown).

What is most important when preparing this graph is to indicate all the energy resources, such as fuel, steam and electricity, in the same calorific unit, for which the following conversion rates can be used:

Electricity: .... 1 kWh = 2,450 kcal = 10.26 MJ (2.45 Mcal) .... $\eta = 0.352$
Steam: .... 1kg = 800 kcal = 3.35 MJ (0.8 Mcal) .... $\eta = 0.93$
Compressed Air: .. 1 Nm^3 = 250 kcal = 1.05 MJ (0.25 Mcal) .... 0.1 kWh/Nm^3
Water: .... 1 ton = 1,050 kcal = 4.4 MJ (1.05 Mcal) .... 0.43 kWh/t

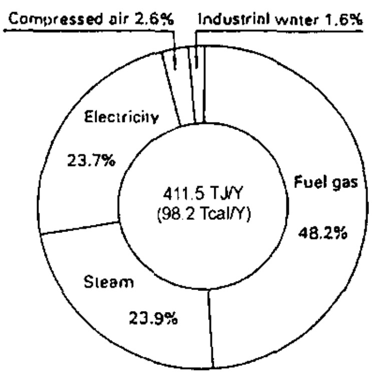


Fig. 1 Breakdown of Use of Energy by Type

Fig. 2 indicates the ratios in which a specific kind of energy resource (steam in this case) is being used, by which means it is possible to get an idea of the methods which must be adopted to carry out steam conservation measures.

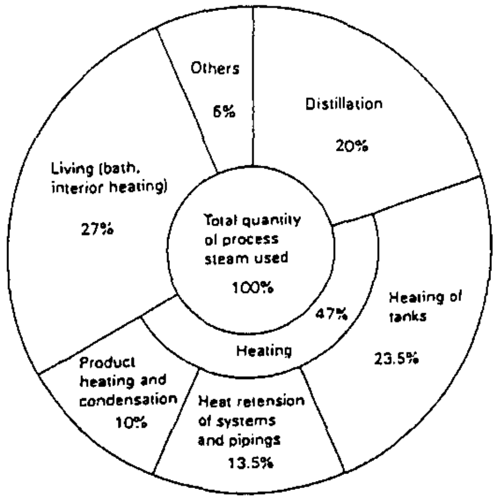


Fig. 2 Breakdown of Use of Process Steam by Purpose

2.2 Graph for control of energy consumption unit

Fig. 3 shows the relationship of a certain factory's daily production volume and energy consumption unit, or specifically, the daily fuel consumption rate (liters) / daily production volume (tons).

This graph reveals that the energy consumption unit is increased abnormally on shutting down days of production. Incidentally, this graph provides data which is fundamental to energy control, and which may also be used to represent the graphs described below.

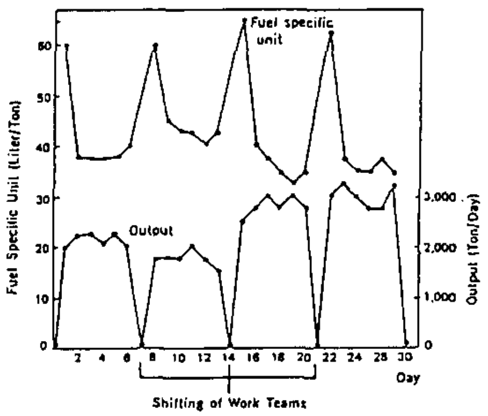


Fig. 3 Control of Fuel Specific Unit

2.3 Correlation graph for production volume and energy consumption unit

Fig. 4 indicates the production volume correlated with the quantity and the unit of the fuel consumption, by using the same data used in Fig. 3. The quantities of fuel consumed hourly are used as data for plotting and obtaining the correlation diagram.

This graph reveals that the quantity of fuel consumed consists of a fixed portion and a variable portion, and that the energy consumption unit is decreasing along with the increase of the production volume. The graph also shows that the plotted points are rather disparate, indicating that the overall fuel consumption can be decreased by adopting measures that would place the plotted points more uniformly toward the lower-consumption side. Therefore, this graph can be conveniently used to improve energy control measures.

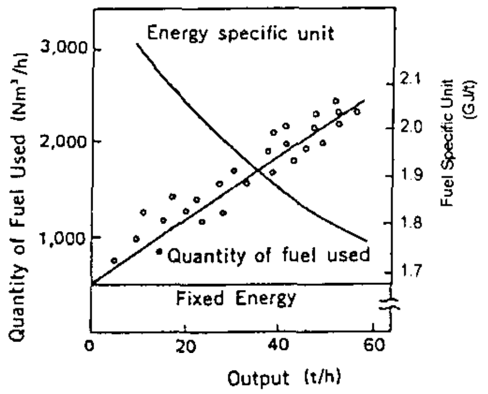


Fig. 4 Correlation Between Output and Energy Specific Unit

2.4 Energy supply flow diagram

This diagram is used to describe the patterns in which energy resources are flowing and branching in the factory. With steam, for example, the diagram may be used to coordinate the pipings efficiently so that they prevent unnecessary thermal radiation losses. Also, based on this diagram, other convenient diagrams may be prepared, such as the main energy flow diagram, a detailed piping diagram, and a flow rate diagram.

2.5 In-plant energy flow diagram

It would be most convenient to prepare a diagram that describes the changes occurring in the energies of the generating plants and user plants of the factory. For instance, the changes of the temperatures along with the energy flow routes of a factory. This would enable the heat utilization and recovery situation to be known at a glance. An example of this type of diagram is shown in Fig. 5.

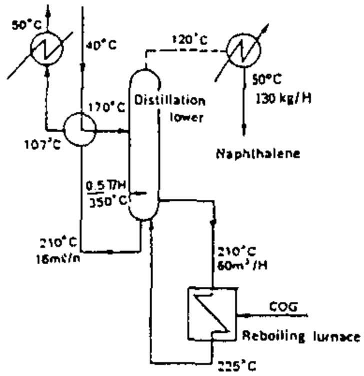


Fig. 5 In-Plant Energy Flow Diagram

2.6 Heat balancing

Heat balancing is performed in order to explain the pattern in which energy resources are being used, and to investigate where and to what extent energy is being dissipated wastefully. This is achieved under the principle of input heat is equal to output heat.

Fig. 6 indicates an example of a fuel consuming furnace, and the diagram can also be employed in other energy resources such as steam in the same manner. If we survey the existing energy consumption pattern in a factory to this extent we can boil down energy consumption targets considerably. This particular heat balancing diagram shows the energy consumption pattern of the heating of steel, and also indicates at the same time the points that require improvements.

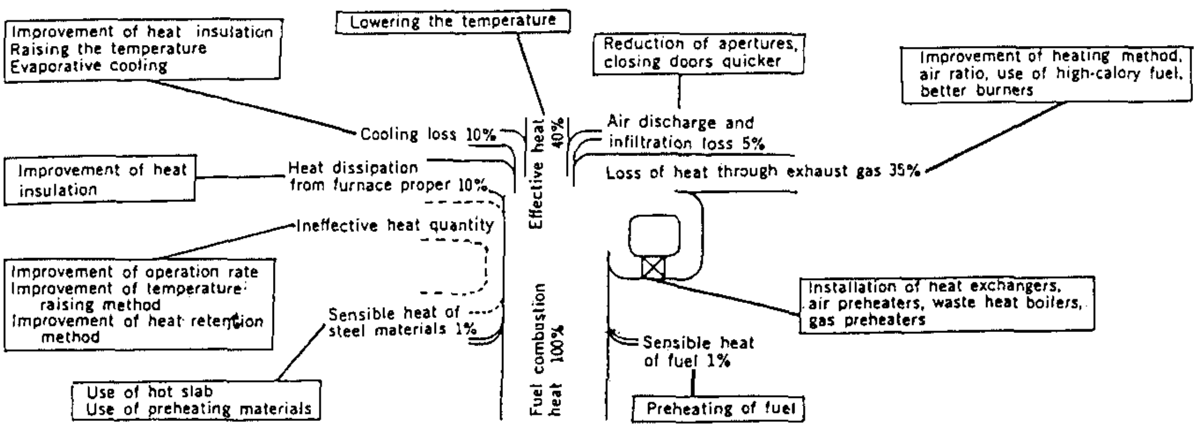


Fig. 6 Energy Conservation Based on Education of Heat Balance

2.7 Comparison with other factories, companies and countries

Fig. 7 shows a fuel consumption unit with those of other companies engaged in the same business. The comparison of the factory's energy consumption unit with that of other factories can be seen at a glance, which makes it easier to set specific energy conservation targets.

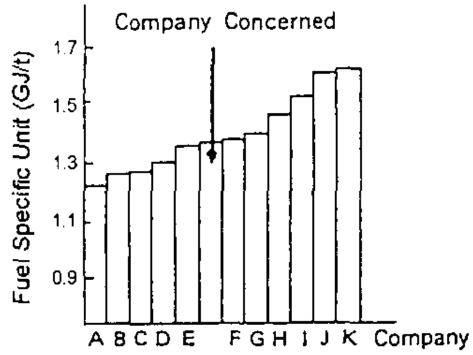


Fig. 7 Reverse Parrel Diagram (Fuel Specific Unit of Heating Furnace)

2.8 Graph showing waste heat generation pattern

With a factory wasting heat through various processes (See Fig. 8), an integrated waste heat utilization program may be mapped out by using a graph indicating the respective waste heat temperature levels and quantities, which shows at a glance the quantities of waste heat available for recovery and reutilization at different energy levels.

A high waste heat recovery efficiency is achieved if you start out by using of waste heat sources featuring the highest energy potentials and if you study factors such as the specific forms of these waste heats and how easy they are to recover.

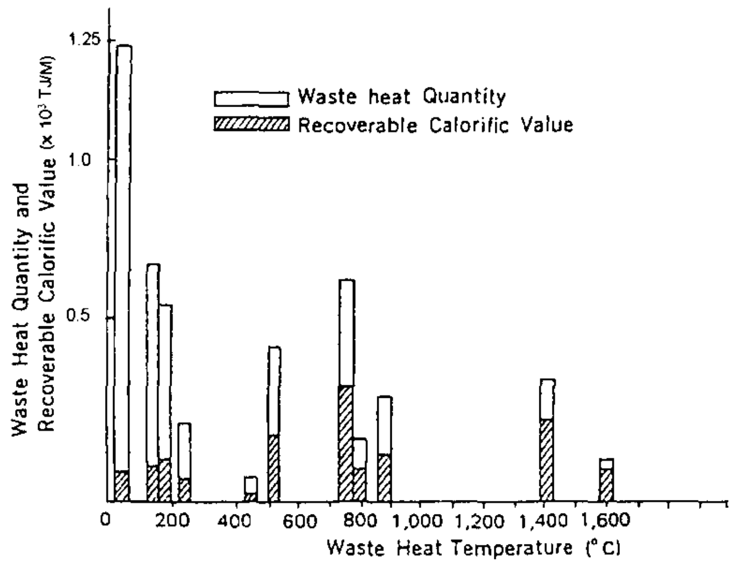


Fig. 8 Situation of Recovery and Utilization of Waste Heat

2.9 Comparison of necessary energy potential level and source energy potential level

This is a comparison between the necessary potential level of the temperature or pressure on the user side and the potential level on the supplier side. If there is a surplus potential, it is possible to decrease the supply potential level to improve the energy utilization rate.

Fig. 9 shows an example of comparing the pressure potential levels. If lowering the working pressure C is possible, it will permit in turn to decrease the supply potential level.

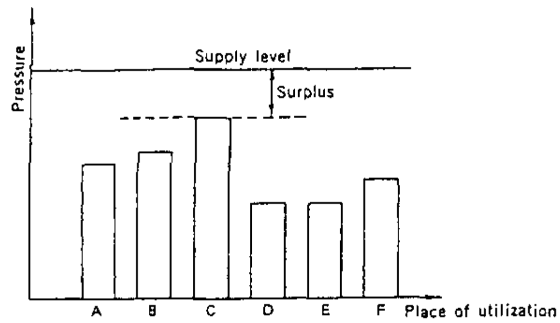


Fig. 9 Comparison of Necessary Energy Potential Levels

2.10 Representation of energy in monetary value

Implementing of energy conservation measures will require more or less some investment, so it may be necessary to represent the energy resources in monetary values, with the cost factor in mind, to promote energy conservation measures more realistically. Fig. 10 shows a typical example.

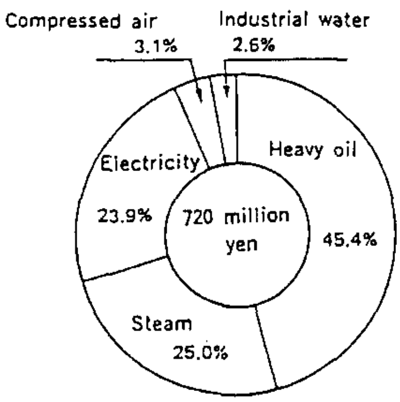


Fig. 10 Representation of Energy Resources in Monetary Values

3. Drafting of Improvement Plan

The direction of improvement is clarified by analysis of existing situation, and the improvement plan is mapped out.

3.1 Collection of ideas

Although the engineers in charge of the project may devise improvement ideas on his own, but it would be more advisable to work out an optimum improvement plan by brainstorming with the workers, who are fully acquainted with the worksite situation, or with the other engineers, specializing in energy, production, control, maintenance, safety and other phases of related facilities and equipment.

This method of approach can be accomplished by drafting a factorial diagram as shown in Fig. 11, which lists all the related factors, and then by checking and crossing out all the negligible factors one after another to arrive at the final improvement plan. There is also the method known as the KJ Process of intuitively classifying the ideas suggested. Familiarizing yourself with the following generalized terms may make it easier to think up improvement ideas: omission, thickness and thinness, change, reverse, high and low, combination and separation, direct and indirect, contraction and expansion, rearrangement, and increase and decrease.

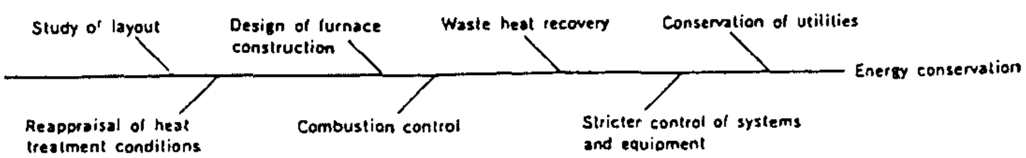


Fig. 11 Factorial Diagram for Energy Conservation Measures

3.2 Compilation into improvement plan

The improvement plan is drafted by the following procedure. The several ideas weeded out by the above process are first given technical analysis in order to clarify their influence on later processors, on product quality, on the production yield and other factors, on the working environments, on environmental pollution, and the safety of these ideas is checked. Next, the energy conservation ideas are classified into 1) those which can be implemented with certainty, 2) those which are still in the experimental stage, and 3) those which are still in the stage of being mere ideas.

The improvement plan is then mapped out, based on the ideas belonging to category 1), following an integrated evaluation of the effects of the plan, the places of installation of related systems and equipment, the opportunity to implement the plan, and other advantages and disadvantages of the plan.

3.3 Evaluation of plan

The proposed energy conservation plan's effectiveness has to be evaluated in terms of its relationship to the capital investment cost.

That is, the effectiveness of the plan should be evaluated by taking into account the investment required, checking the time necessary for investment depreciation, and, if necessary, by classifying the improvement plan according to levels of priority.

4. Implementation of Improvement Plan

The finalization improvement plan is carried out with the following points in mind:

a) Before finally carrying out the plan, its contents, the time of implementation, the methods, the procedures and other factors should be fully rechecked and make related persons know on exactly what are to be done.
b) The plan should be carried out speedily and accurately.
c) The results should be measured and evaluated comparing with the plan after the plan's implementation, and appropriate revisions should be made wherever necessary.
d) Specific targets which have been attained should be set up with work standards in order to ensure the desired effects continuously.

At this stage, emphasis should be placed on implementing the improvement plan as smoothly as possible, or on carrying out the improvement plan on the basis of the control cycle shown in Fig. 12.

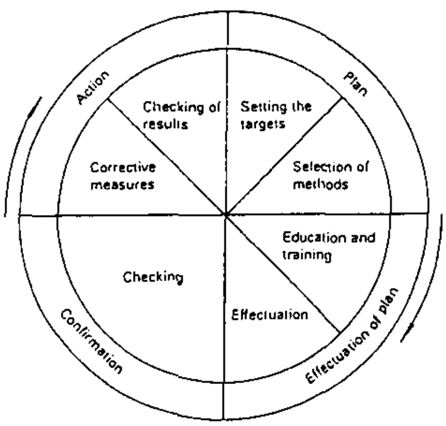


Fig. 12 Control Cycle for Energy Conservation

Heat Management

1. Energy Conservation in Combustion and, Furnace Equipments and Operations

1.1 Low air ratio combustion (low O_2 combustion)

Complete combustion of fuel in a boiler, a heating furnace or the like requires the supply of excess air. However, if too much air is supplied, the O_2 content of exhaust gas, and the quantity of the exhaust gas increases resulting in greater exhaust gas losses and heat loss.

In general, small- and medium-size enterprises pay attention to chimney smoke, and imagine that complete combustion is occurring if the smoke is invisible. For that reason, they do not notice the great amount of heat lost with the exhaust gas leaving the chimney.

The quickest way of conserving energy without investment in using equipment that uses fuel to heat is to reduce the air ratio. For example, when the temperature of combustion exhaust gas is 600°C and the air ratio is 1.6, 36% fuel combustion heat is lost in the form of combustion exhaust gas. If the air ratio is 1.3, combustion exhaust gas loss will be only 30% of total fuel combustion heat, indicating a 6% gain in effectiveness (refer to Fig. 1). In Fig. 3 a fuel conservation of about 9% is represented.

It will be understood from Figs. 1, 2 and 3 that the higher the exhaust gas temperature, the greater the exhaust gas loss. Thus, fuel conservation is increased by using low air ratio combustion.

For as efficient combustion of a fuel as practicable, the air ratio may be reduced toward 1. But, as the air ratio approaches the value of 1, part of the fuel is subject to incomplete combustion (Fig. 4). The loss due to incomplete combustion is considerably large when it is compared with the decrease of the exhaust gas, and so if the air ratio is excessively reduced, the exhaust gas loss increases.

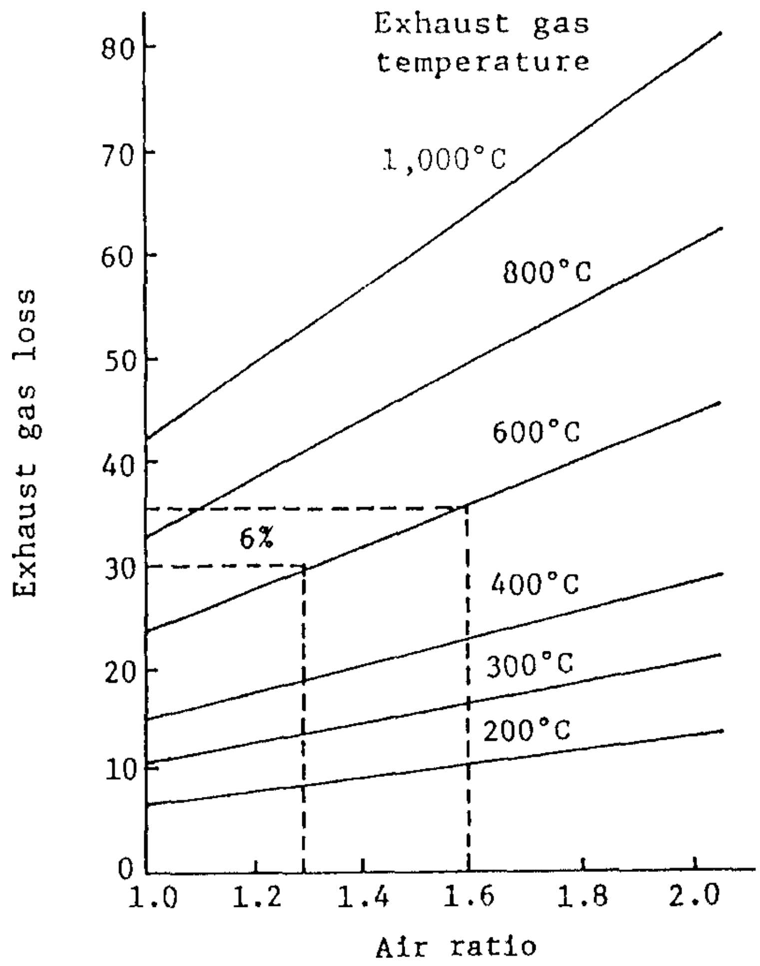


Fig. 1 Relation between Air Ratio and Exhaust Gas Loss (In the case of heavy oil)

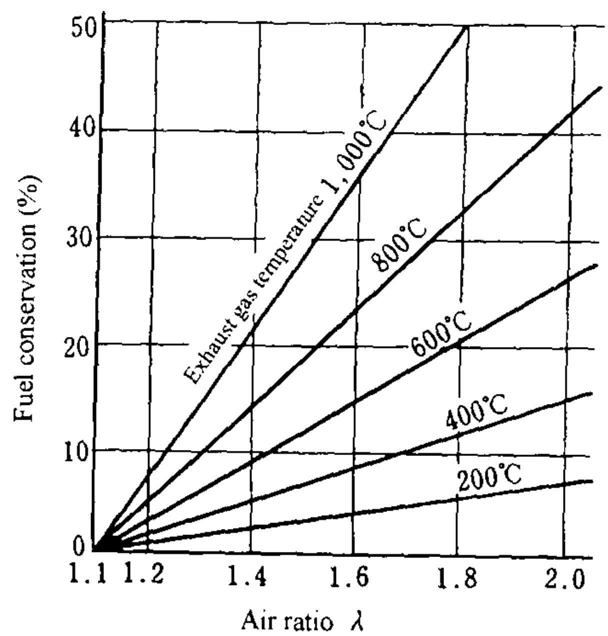


Fig. 2 Fuel Conservation Ratio with Adjustment of Air Ratio to 1.1 (In the case of natural gas)

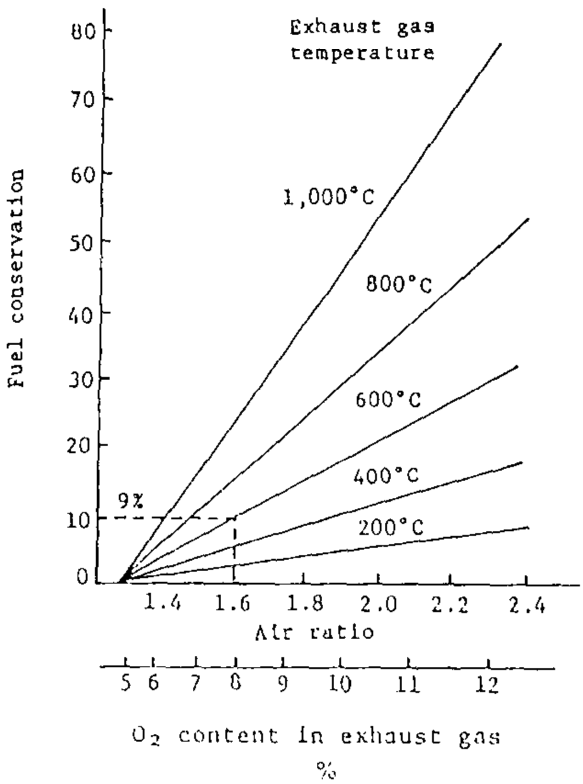


Fig. 3 Fuel Conservation Ratio with Adjustment of Air Ratio to 1.30 (In the case of heavy oil)

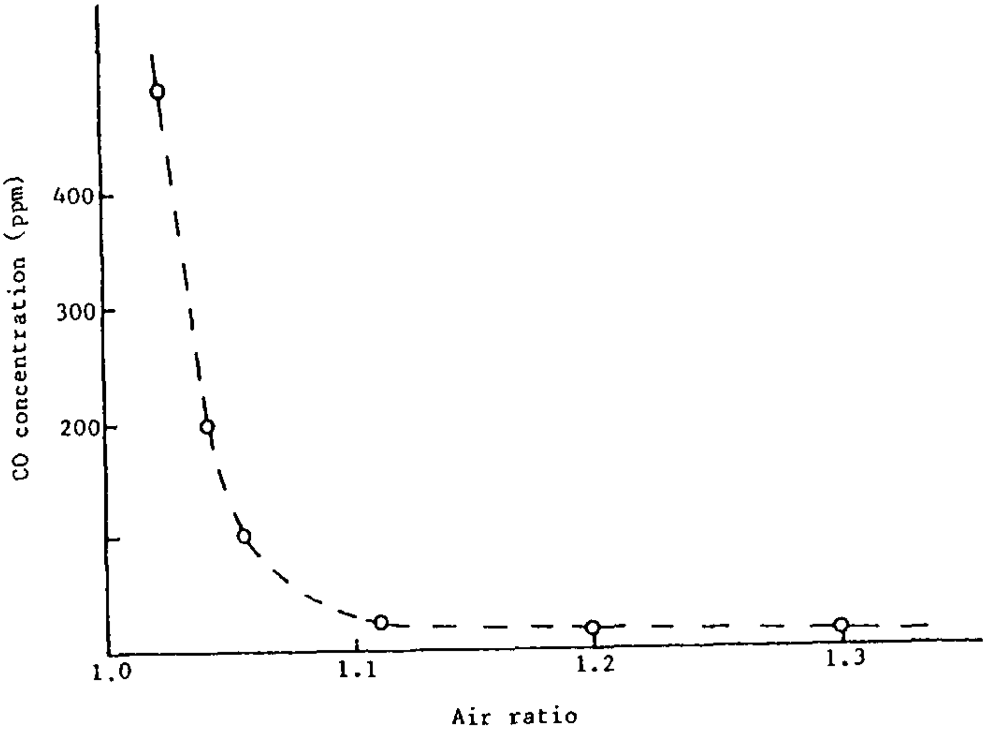


Fig. 4 Air Ratio to CO Concentration Relation

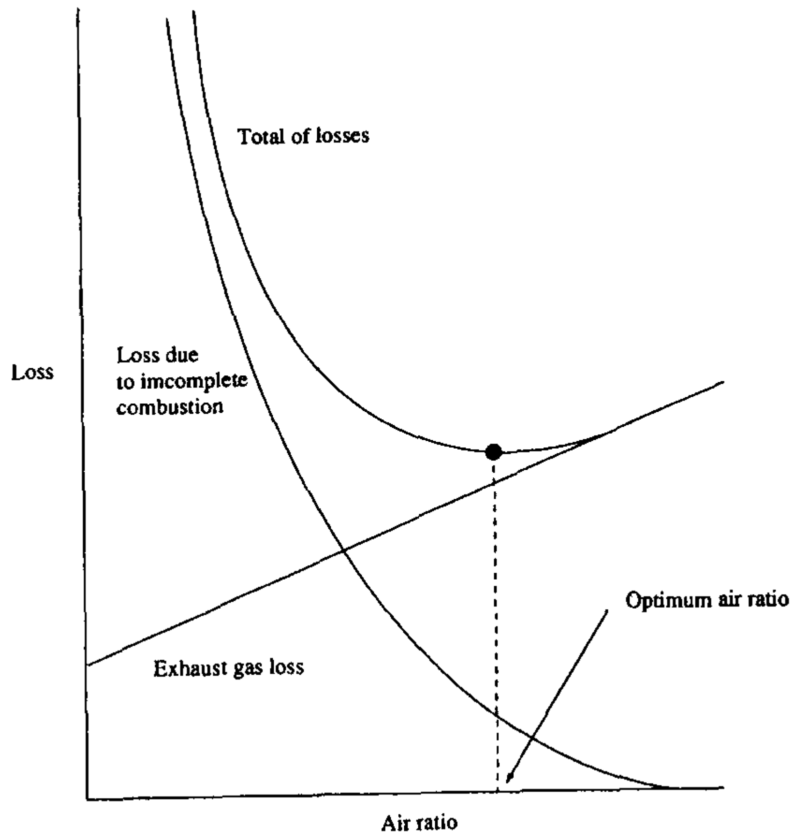


Fig. 5 Optimum Air Ratio

The heat loss due to exhaust gas is shown including that due to incomplete combustion in Fig. 5. As seen, the overall heat loss is reduced to minimum at a certain air ratio. Such air ratio is considered to be an optimum air ratio. The air ratio can be easily determined, using the equation below, by analyzing the O_2 content of exhaust gas.

$$\text{(Air ratio)} = \frac{\text{(Actually used quantity of air)}}{\text{(Theoretical combustion air)}} = \frac{21}{21 - (O_2 \text{ percentage of exhaust gas})}$$

<Example>

O_2 %		Air ratio
3	→	1.16
5	→	1.3

The O_2 content of exhaust gas now can be analyzed easily with a portable O_2 analyzer. Since the analyzer costs between 150,000 and 200,000 yen, its purchase can be paid back in a short period by fuel savings.

1.2 Burner management

A burner is the most important combustion device. Good combustion requires setting an appropriate air ratio and property atomizing the fuel. Therefore, the two points below need to be taken into consideration in using the burner.

1) The capacity of the burner must correspond to load.
2) The nozzle of the burner must be serviced periodically.

1.2.1 Selection of burners of appropriate capacity

Most recent boilers employ, an automatic control mechanism. The burners of many boilers with such mechanisms can be controlled to 1:10, which means that the burner's combustion can be reduced to one-tenth of capacity for a short time as the load fluctuates repeatedly. This does, not mean, however, that long-period operation can be performed with loads as low as 10% of capacity.

In many cases, boilers are operated with loads of 60 to 70%. Particularly in an on-off control boiler in which upper and lower limits are preset for steam pressure so that combustion is stopped when the steam pressure has reached the upper limit and is resumed when the pressure has dropped to the lower limit, the frequency of stoppage and resumption is so high that the air ratio is high and the exhaust gas loss is large.

For the reason, if operation is not at full load but at 70% load or less, the burner nozzle should be changed for another one appropriate to a 70% load.

1.2.2 Servicing of burner nozzle

Stable combustion of gas fuel can be continued even if the burner nozzle is not service for a long period. However, in the case of heavy oil fuel, if the burner nozzle is left unserviced for a long period, carbon deposits accumulate, so that atomization of heavy oil and mixing of air deteriorate to make smoke unless the air ratio is increased. In that case, the exhaust gas loss also increases.

For this reason it is necessary to prescribe checking, cleaning and replacement standards for burner servicing. Examples of such standards are mentioned below.

1) Checking and cleaning standards
   Checking (by eye) for distortions and cracks; cleaning (once a week)
2) Replacement standards
   Checking dimensions once a month.
   Replacement of burner tip if its nozzle diameter increases by 20% or more

A spare burner tip should be purchased beforehand and prepared according to standards. Furthermore, fuel management and combustion management are very important. They are explained in the next section (Steam generation equipment).

1.3 Maintaining the furnace's internal pressure at its appropriate

The door of a batch heating furnace is opened and closed to insert and extract heated objects. The charging and extraction ports of continuous heating furnaces are always open. As a result, if the internal pressures of these furnaces are positive and too high, heat loss is caused due to flame release. If the internal pressures are negative, low-temperature air enters into the furnaces and cools their interiors making temperature distributions nonuniform. Therefore, it is important to set the internal pressure of such a furnace at an appropriate level (Fig. 6).

In addition, if the temperature of the heating furnace is high, the pressure in the heating furnace changes greatly along its vertical length, as shown in Fig. 7. For example, if the temperature is 1,000°C the pressure changes at the rate of about 1 mm H_2O per 1 m of height.

As a result, it is important to take measures to minimize the cross sectional area of the openings, set the internal pressure at the opening at ±0 mm H_2O.

1.4 Establishing appropriate temperature in furnace

Temperatures in melting furnaces, heating furnaces and so forth tend to be set too high. This tendency results in the consumption of excess fuel.

An optimal temperature for a product should be reconfirmed. If a targeted temperature is lowered without dropping the quality of the product, energy conservation is attained.

Since the targeted temperature for the interior of the furnace is the reference temperature of a heated or molten object, attention should be paid to the selection of a measuring point, uniform heating in the furnace, and so forth.

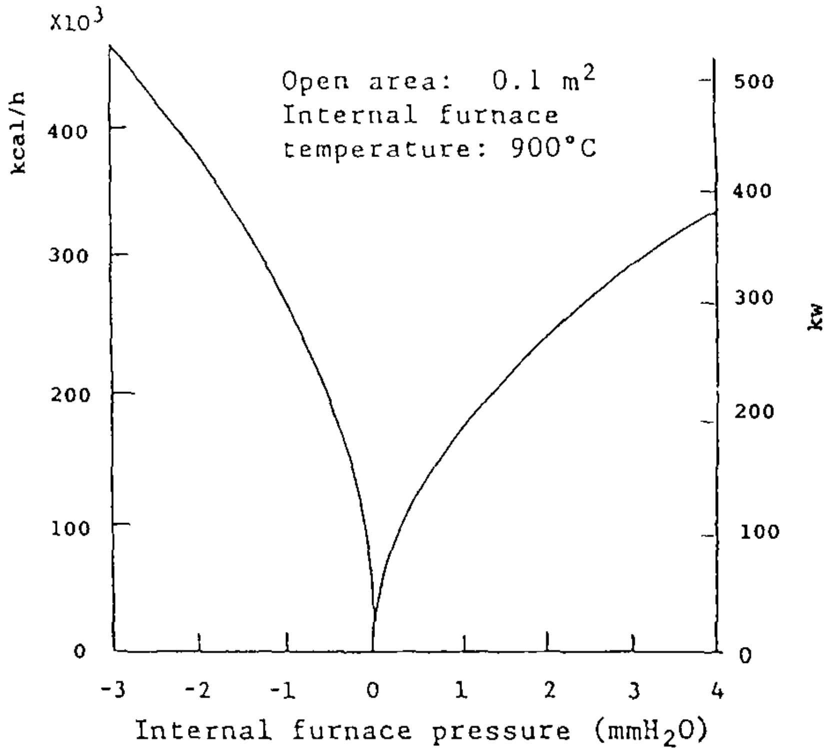


Fig. 6 Heat Loss from Openings

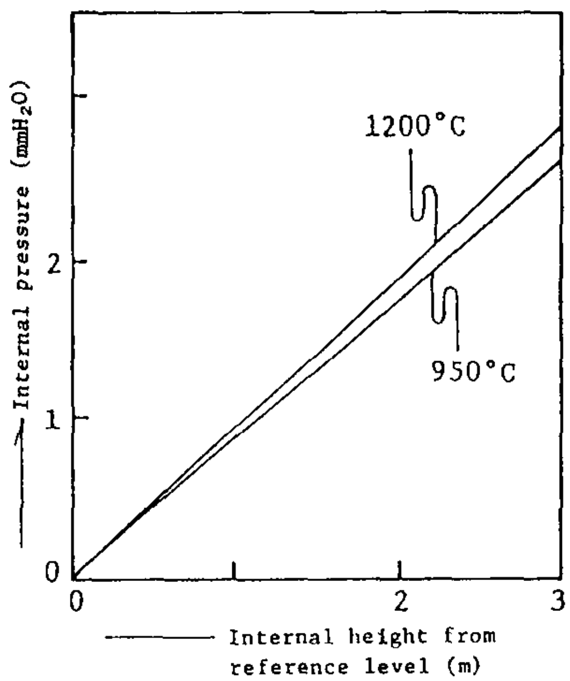


Fig. 7 Relation between Height and Pressure in Furnace

1.5 Energy Conservation through Thermal Insulation

A thermal insulator in, a furnace wall minimizes outgoing heat, thus effectively utilizing heat energy.

Thermal insulation keeps the hot water in a thermos bottle from cooling. The bottle has double construction to insulate heat using a thin vacuum layer.

Though ideally thermal insulation using vacuums also should be used in industry, there are technical and economic problems impeding their use. For that reason, air of low thermal conductivity is utilized instead to insulate heat in industry. However, if the air gap in such insulating materials is not less than 10 mm air convection (in which the air flows to transfer heat) takes place making it impossible to insulate the heat. For that reason, a thermal insulator containing air enclosed in pores is used.

Excellent thermal insulators and ceramic fibers have been developed recently. In particular, ceramic fiber development technology has been progressing conspicuously to enable the use of ceramic fibers for high temperature furnaces of 1,300°C. Since not only the thermal insulation properties of ceramic fibers are excellent but also their heat storage capacities are low, the are more effective when used batch operation furnaces.

Fig. 8 compares furnace walls with ceramic fiber insulator and furnace walls without such insulation. The quantity of heat escaping through the furnace wall can be reduced by half without changing the thickness of the wall but by simply changing the insulator (A → B). Ceramic fibers can be applied to the inside of already built furnace walls (veneering) producing effects as above (A → C).

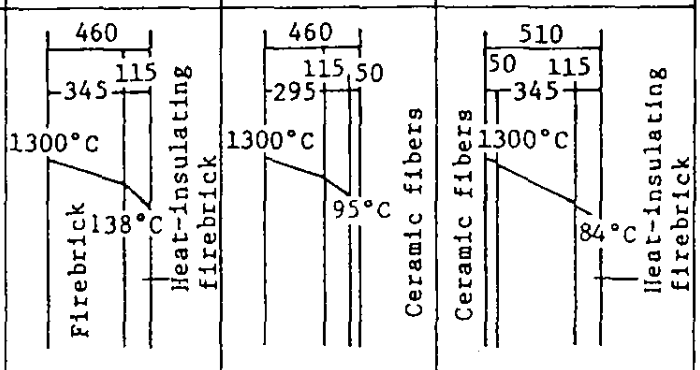
Trial design	A	B	C
Furnace wall constitution			
Heat loss	1,587kcal/m²h	947kcal/m²h	749kcal/m²h
	1,845 kw/m²	1.10 kw/m²	0.87 kw/m²
Conservation ratio		41%	53%

Fig. 8 Intensification of Furnace Wall Thermal Insulation

Three methods of determining the appropriate thickness of a insulator in thermal insulation design are mentioned below.

1) Heat loss is reduced below prescribed value (%).
2) Surface temperature is reduced below prescribed value.
3) The fuel cost savings exceed thermal insulation costs.

Judgment standards in the rationalization of energy use laws are prescribed in terms of the outside surface temperature of the furnace wall, as shown in Table 1.

Table 1 Furnace Wall Outside Surface Temperature Standards

Furnace interior temperature (°C)	Furnace wall outside surface temperature standard (°C)	
	Ceiling	Side wall
1,300	140	120
1,100	125	110
900	110	95
700	90	80

Notes: 1. The furnace wall outside surface temperature standards in Table 1 are set for the average temperatures of the outside wall surface (except for special parts) of a furnace in stationary operation with an ambient air temperature of 20°C.
2. The furnace wall outside surface temperature standards in Table 1 do not apply to the outside wall surface temperatures of the following industrial furnaces:
(1) Furnaces with rated capacities of less than 232.5 kW (837.4 MJ/h)
(2) Furnaces with forcibly cooled walls
(3) Rotary kilns

A procedure to calculate how much fuel is conserved by intensifying thermal insulation is described below.

(1) The temperatures of many points on the outside surfaces of furnace ceilings and side walls are measured and averaged for each surface.

(2) The quantities of beat escaping per hour from a unit area of 1 m^2 are determined from the averages of the temperatures using Fig. 9.

(3) The quantities ($kcal/m^2 \cdot h$) (kW/m^2) are multiplied by the surface areas to determine the total quantities of heat escaping from the ceilings and side walls.

For example, the thermal insulation of a furnace having a ceiling of 12 m^2 in surface area and 150°C in mean outside surface temperature, and a side wall of 48 m^2 in surface area and 110°C in mean outside surface temperature. is intensified so that the mean outside surface temperatures of the ceiling and side wall are lowered to 90°C and 80°C respectively. The temperature of air outside the furnace is 30°C.

The total quantities of beat escaping from the ceiling and side walls before the intensification of thermal insulation are determined from Fig. 9 as follows:

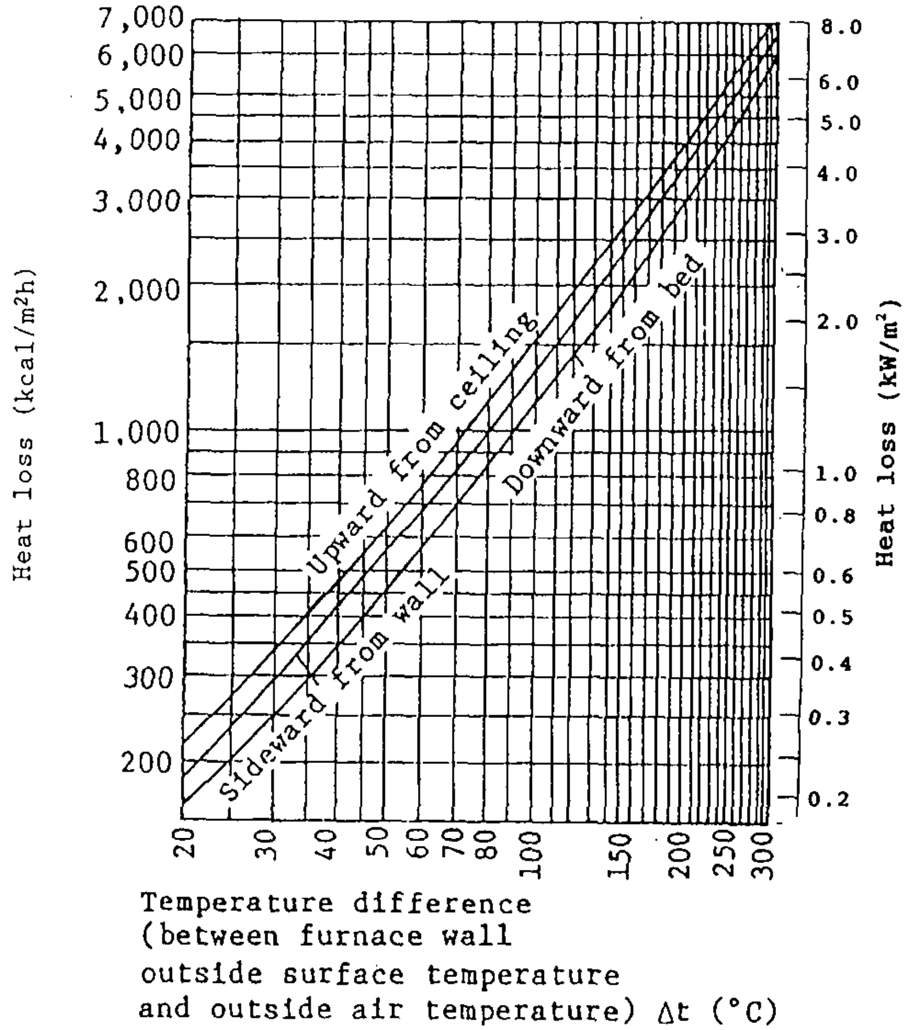
Ceiling:	2.33 $kW/m^2 \times 12\ m^2$ = 27.9 kW	
	(2,000 $kcal/m^2 \cdot h) \times (12\ m^2)$ =	(24,000 kcal/h)
Side wall:	1.16 $kW/m^2 \times 48\ m^2$ = 55.7 kW	
	(1,000 $kcal/m^2 \cdot h) \times (48\ m^2)$ =	(48,000 kcal/h)
Sum:	83.6 kW	(72,000 kcal/h)

The total quantities of heat escaping from the ceiling and said walls after the intensification of heat insulation are determined from Fig. 9 as follows:

Ceiling:	0.93 $kW/m^2 \times 12\ m^2$ = 11.2 kW	
	(800 $kcal/m^2 \cdot h) \times (12\ m^2)$ =	(9,600 kcal/h)
Side wall:	1.16 $kW/m^2 \times 48\ m^2$ = 55.7 kW	
	(550 $kcal/m^2 \cdot h) \times (48\ m^2)$ =	(26,400 kcal/h)
Sum:	41.9 kW	(36,000 kcal/h)

Thus, 41.9 kW (36,000 kcal/h) of heat or half the initial loss is conserved. This is the equivalent of 3.83 1/h of kerosene. If the furnace's annual operating time is 3,000 hours, the annual conservation of kerosene will be 11.5 kl. If kerosene costs 80, 000 yen per kilo-liter, the annual cost reduction will be 920,000 yen.

The above-described example offers simplified calculation. Since thermal insulation influences the quantity and temperature of exhaust gas, precise calculations require that the quantity of heat taken away by the exhaust gas be considered.



Note:	Upward from ceiling:	Heat escaping from ceiling
	Sideward from wall:	Heat escaping from wall
	Downward from bed:	Heat escaping from bed

Fig. 9 Heat Loss from Furnace Wall

1.6 Heat recovery from combustion exhaust gas

Even if low air ratio combustion and internal furnace pressure management are implemented well, thermal efficiency is very low for high temperature equipment such as heating furnaces. The relation between air ratio and exhaust gas loss was illustrated in Fig. 1 which indicated that when the exhaust gas temperature at the outlet port of a furnace is 1,000°C about 50% of the heat produced from fuel becomes exhaust gas heat loss even if the air ratio is lowered to 1.2. For that reason, it is necessary to recover the sensible heat of exhaust gas and effectively utilize the heat to increase the heating furnace's thermal efficiency. Fig. 10 shows typical examples of recovery and utilization of exhaust gas.

1) In examples A and D, recovered heat is used by the furnace to preheat combustion air and raw materials.
2) In examples B and E, recovered heat is used by other equipment to generate steam in a waste heat boiler and reutilized in a low temperature furnace.
3) In example C, several kinds of heat recovery are combined so that heat recovered by a turbine is converted into electric power, etc.
4) In example F, the system shown is regenerative burner heating system and has an extremely high heat recovery rate. Some apparatus of this type have achieved a heat efficiency of above 80%. This system requires a burner with NOx reduction mechanism as its integral part since it recovers heat from high-temperature air.

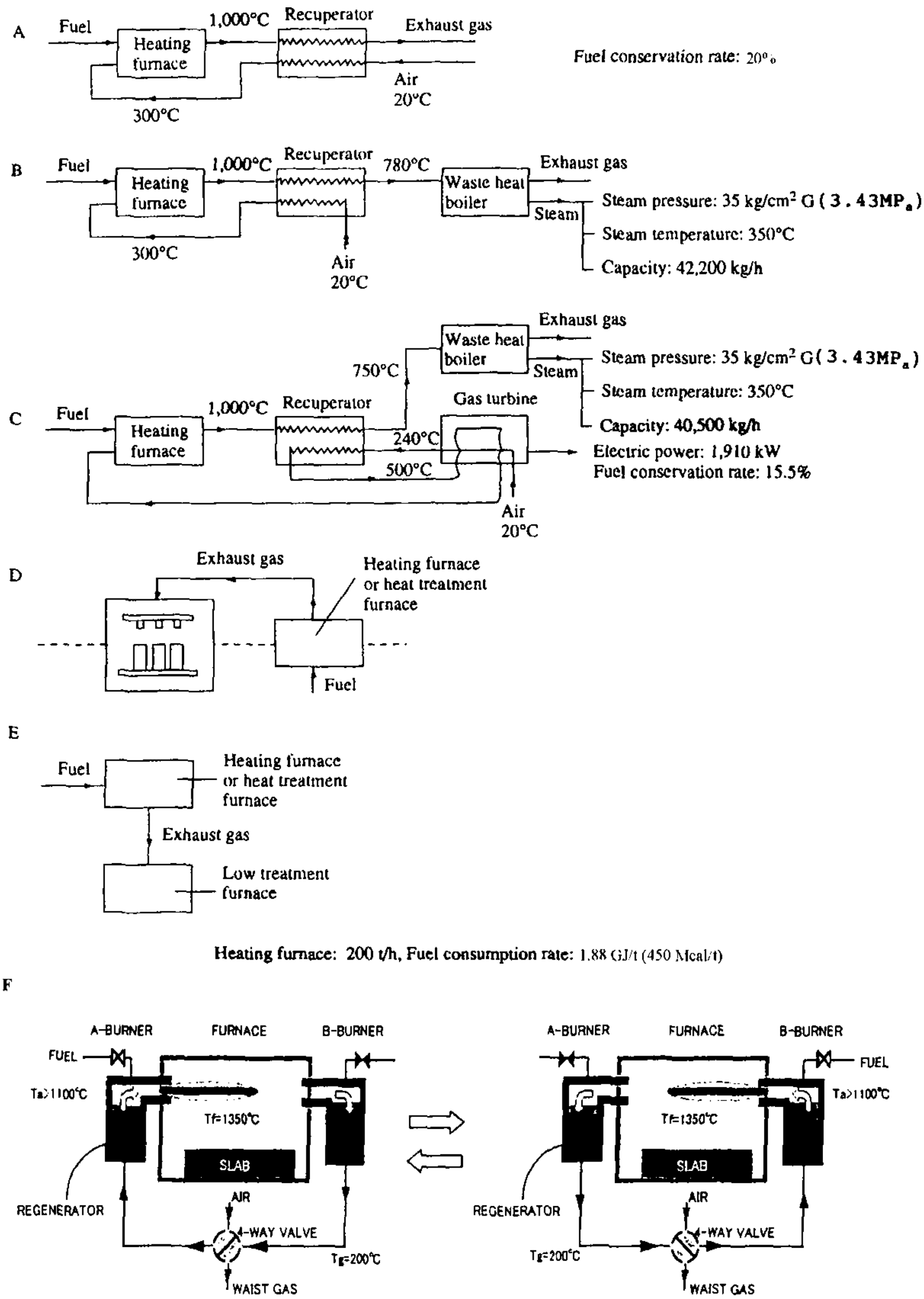


Fig. 10 System for Utilizing Waste Heat of Combustion Furnace

Waste heat recovery should be considered after all energy conservation measures have been taken. Minimizing the generation of waste heat is the most important objective.

1.6.1 Preheating of raw materials

When raw materials are preheated by exhaust gases before being placed in a heating furnace, the amount of fuel necessary to heat them in the furnace is reduced. Since raw materials are usually at room temperature, they can be heated sufficiently without using high-temperature gas.

1.6.2 Preheating of combustion air

For a long time, preheating of combustion air using the sensible heat of exhaust gas has been used for heavy boilers, metal heating furnaces and high-temperature kilns. This method is now being employed in compact boilers and compact industrial furnaces as well.

Table 2 shows the outlines of air preheaters. In addition, heat pipe type heat exchangers, high-temperature gas/gas plate heat exchangers and regenerative burners can serve as air preheaters.

When combustion air is preheated, a quantity of fuel equal to the sensible heat brought in by the preheated combustion air is conserved. The fuel conservation rate (S) due to the preheating of the combustion air is determined according to the formula below (refer to Fig. 11).

$$S = \frac{P}{H_\lambda - Q + P}$$

P: Quantity (kJ (kcal) per kg of fuel) of heat brought in by preheated air

Q: Quantity (kJ (kcal) per kg of fuel) of heat taken away by combustion gas

H_λ: Heating value (kJ (kcal) of fuel

The results of calculations of rates of conservation of fuels according to the formula above are shown in Figs. 11, 12 and 13.

Table 2 Outlines of Air Preheaters

<table>
<tr><th colspan="4">Type</th><th>Exhaust gas temperature limitation</th><th>Preheated air temperature</th><th>Object furnace</th></tr>
<tr><td rowspan="3">Recupera-tive</td><td rowspan="2">Metallic recuperator</td><td>Flue installation</td><td>Convective: Multitubular Other</td><td>1,000°C or below</td><td rowspan="2">300 to 600°C</td><td rowspan="2">Heat furnace, heat treatment furnace and other industrial furnaces</td></tr>
<tr><td>Chimney installation</td><td>Radiative (relative and convective)</td><td>1,000 to 1,300°C</td></tr>
<tr><td colspan="2">Ceramic (tile) recuperator</td><td>Armeo Stein</td><td>1,200 to 1,400°C</td><td>400 to 700°C</td><td>Soaking pit and glass kiln</td></tr>
<tr><td rowspan="4">Regenera-tive</td><td colspan="3">General</td><td>1,000 to 1,600°C</td><td>600 to 1,300°C</td><td>Coke oven, hot blast stove and glass kiln</td></tr>
<tr><td colspan="3">Rotary regenerative (Ljungstroem; Rotemuihle)</td><td>600°C or below</td><td>100 to 300°C</td><td>Boiler, hot blast stove and anti-pollution equipment</td></tr>
<tr><td rowspan="2">Regenerative burner</td><td colspan="2">Honeycomb Type</td><td>~1,300°C</td><td>~1,250°C</td><td rowspan="2">Heat furnace, heat treatment furnace and other industrial furnaces</td></tr>
<tr><td colspan="2">Ball Type</td><td>~1,300°C</td><td>~1,150°C</td></tr>
</table>

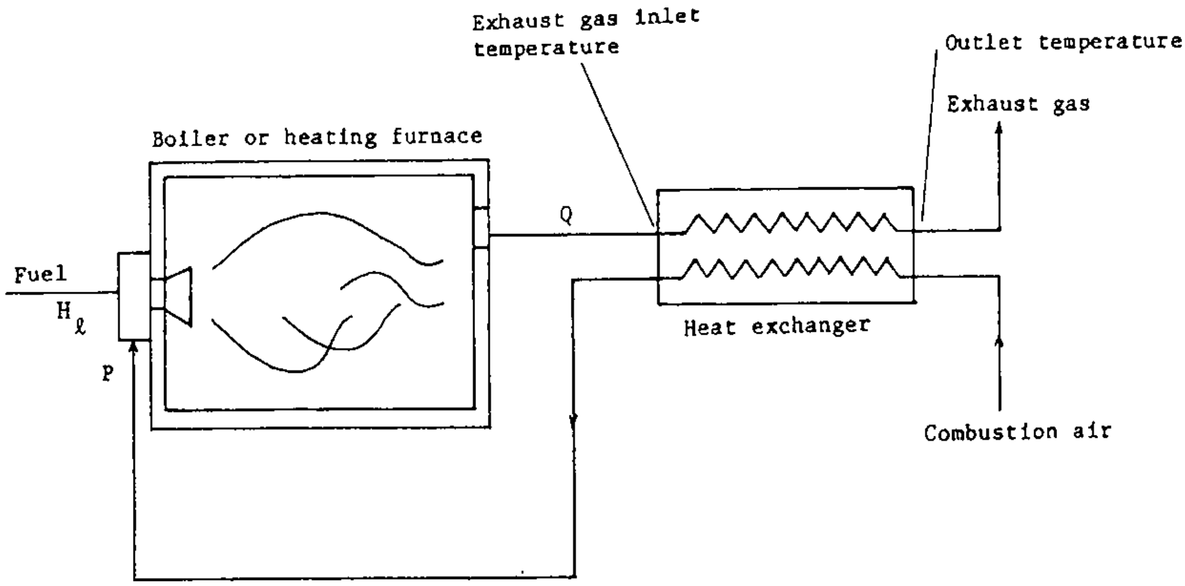


Fig. 11 Example of Preheating of Combustion Air for Boilers, Heating Furnaces and the Like

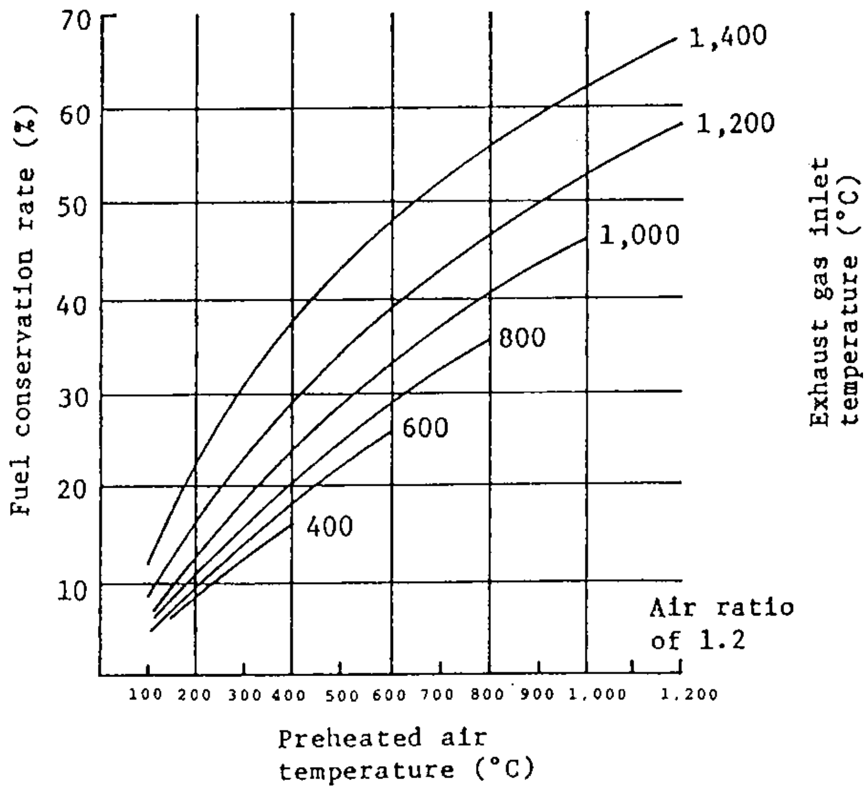


Fig. 12 Conservation Rate for Heavy Oil

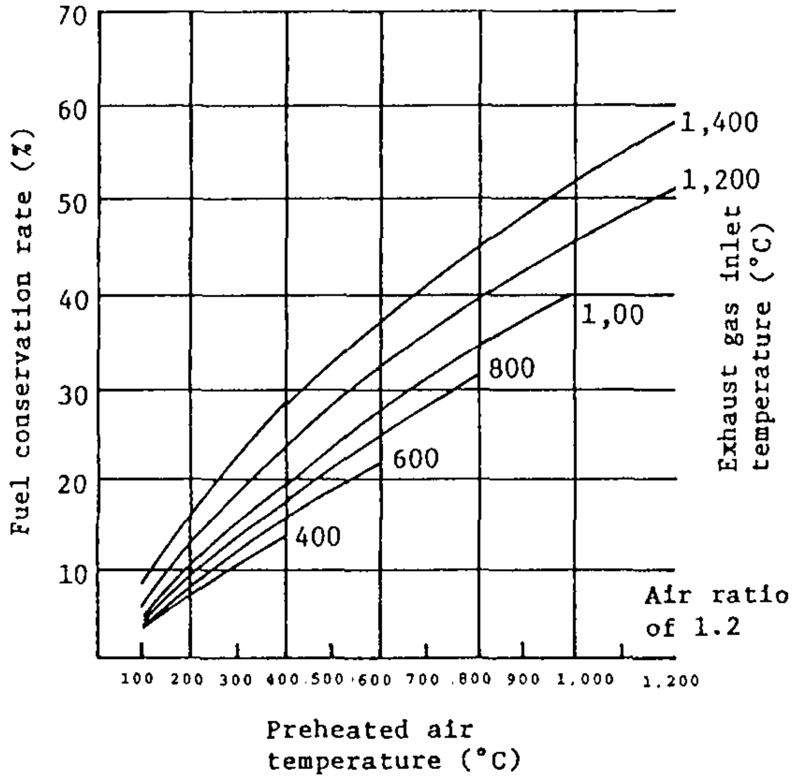


Fig. 13　Conservation Rate for LPG

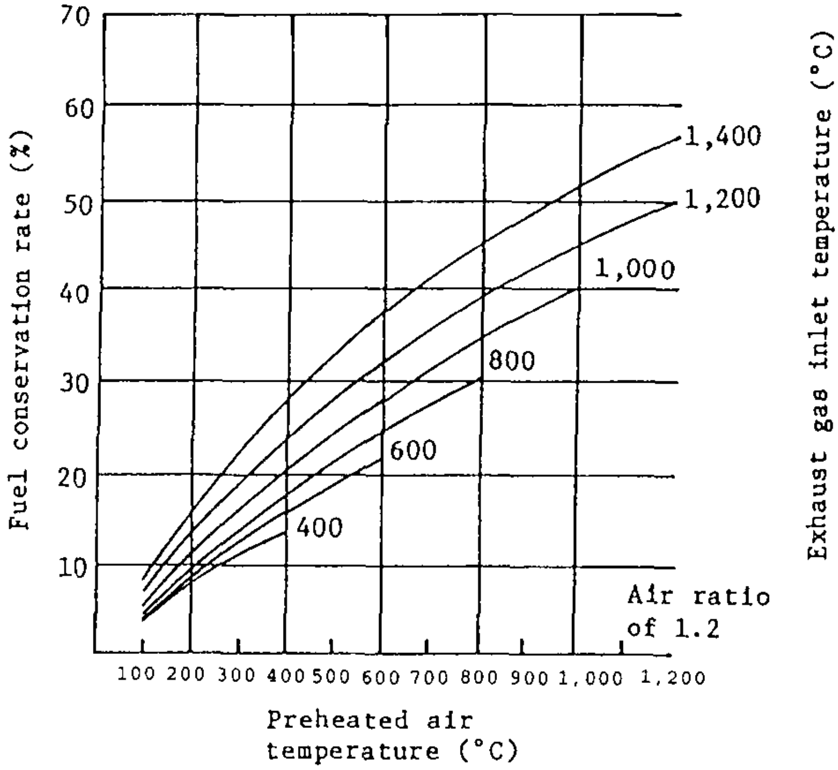


Fig. 14　Conservation Rate for LNG

For example, when combustion air for heavy oil is preheated to 400°C by a heat exchanger with an inlet temperature of 800°C, Fig. 12 suggests a fuel conservation rate of about 20%.

Since the volume of air is increased due to its preheating, it is necessary to be careful about the modification of air duct diameters and blowers. As for the use of combustion gases resulting from heavy oils with high sulfur contents, care must be paid to avoid problems such as clogging with dust or sulfides, corrosion or increases in nitrogen oxides.

(The temperature of combustion exhaust gas continues decreasing after heat recovery. It is necessary, therefore, to avoid excessive cooling down to below the acid dew point, which could cause sulfuric acid corrosion.)

2. Energy Conservation in Use of Steam

Steam is widely used as an energy source because of its useful properties. Some of steam's characteristic properties are itemized below.

1) There is a fixed relation between the pressure and temperature of saturated steam. The temperature can be kept constant by keeping the pressure constant (refer to Fig. 15).
2) Steam has great latent heat of vaporization (condensation). The less the pressure of the steam, the greater the latent heat (refer to Fig. 16).
3) Although steam's volume is large, after doing its work, it condenses in relatively small volumes making it easy to handle.
4) Steam is a chemically stable and harmless substance.

Full understanding and effective utilization of the above-mentioned properties leads to efficient energy conservation.

This discussion of steam energy conservation will address the following items:

1) Steam generation equipment
2) Steam conveyance piping
3) Steam-using equipment

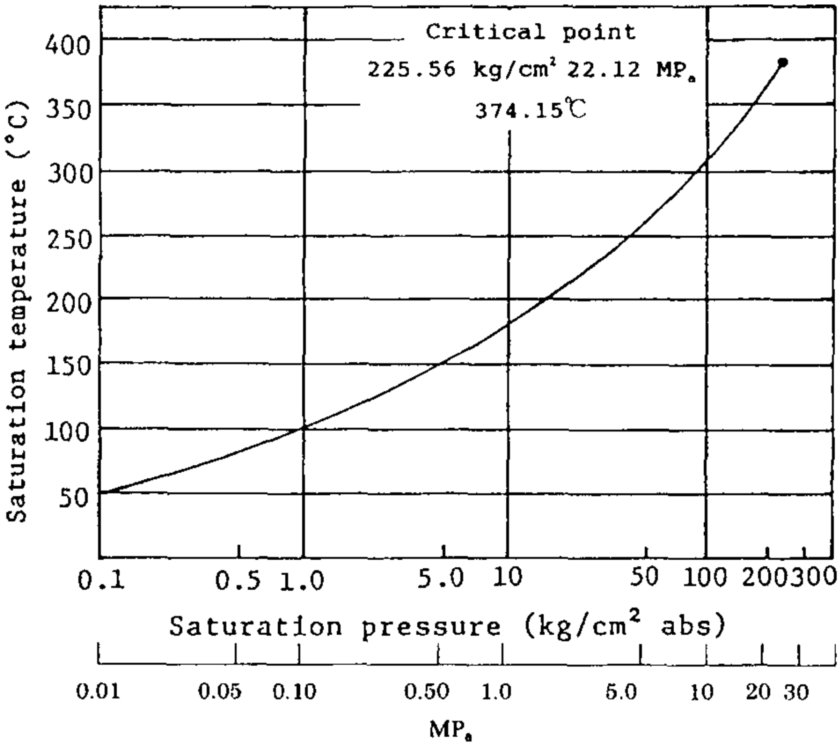


Fig. 15 Relation between Saturation Pressure and Temperature of Steam

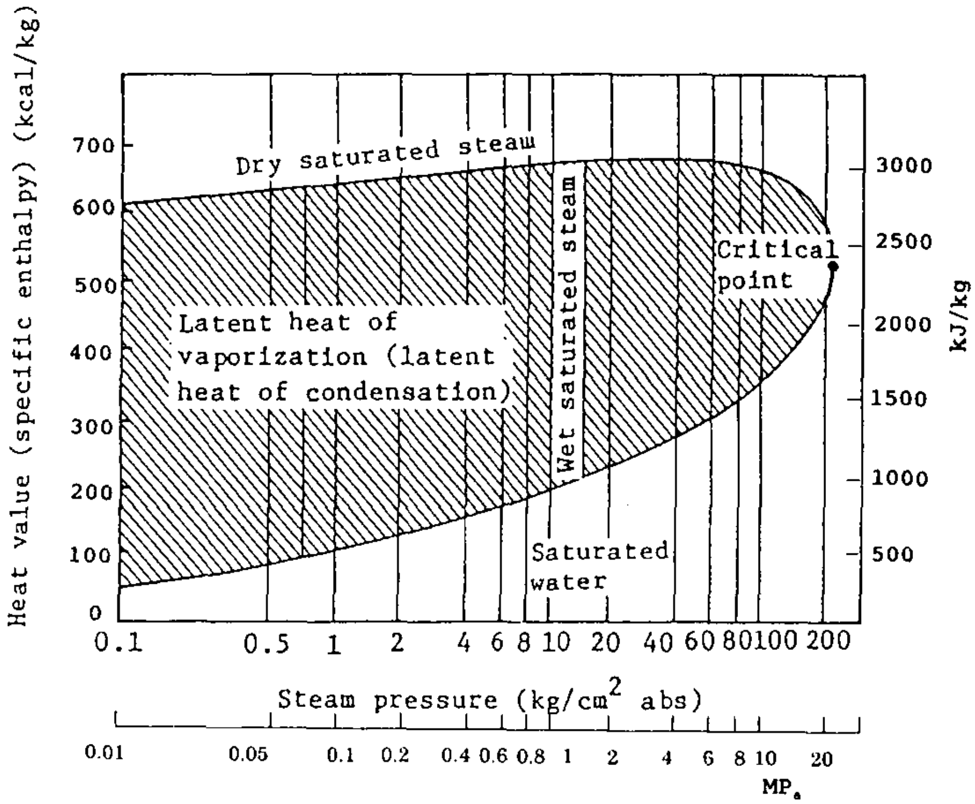


Fig. 16 Heat Content of Steam

2.1 Steam generation equipment (boilers)

2.1.1 Maintenance management

The maintenance management of boilers is necessary not for energy conservation but in order to keep the boiler always in safe condition and enable its use over a long period without troubles. The fuel line, air line, body, and exhaust gas of the boiler should be checked and maintained constantly.

The regular cleaning of the boiler and the filling of cracks in the furnace wall are discussed below.

(1) Regular cleaning of the boiler

Scale and soot cling to the inside and outside of the boiler during its use hindering heat transfer and reducing its efficiency. In many small- and medium-sized enterprises, boilers are cleaned and serviced only during annual performance tests conducted by a government agency in charge. If boiler efficiency is found to have dropped, it is necessary to conduct a voluntary inspection every six months, in addition to the performance test by the government agency, and to check the feed water treatment and blow down.

(2) Filling cracks in furnace walls

Some kinds of boilers require the building of a furnace in installing the boiler. Furnace bricks are likely to undergo cracking after a long period of use. If cracks are left unrepaired, cool air enters from outside not only lowering the temperature in the furnace but also causing combustion with excess air (the O_2 content of exhaust gas increases) to increase the quantity of the exhaust gas and heat loss through the chimney (refer to Figs. 1, 2 and 3). Therefore, if a crack is found, a filler should be applied to prevent cool air from entering.

2.1.2 Fuel management

Since small- and medium-sized enterprises entrust the quality and quantity of their purchased fuel to vendors, the enterprises generally do not check the quality and quantity of fuel in the presence of the vendors. Although it is necessary to heat B heavy oil and C heavy oil to lower their high viscosity for combustion, their temperature management is so insufficient in some plants that the burning condition of the heavy oil remains poor.

(1) Checking quality

It is hard to judge with the naked eye on the quality of liquid fuel. Therefore, an analysis record submitted by the vendor is only one basis for such a judgment. However, surprisingly, few plants don't receive even this kind of record Vendors should be obliged to submit analysis records to plants.

(2) Checking received quantities

Liquid fuel changes in volume and specific gravity depending on its temperature, even if its weight is constant.

In particular a plant which receives heated oil such as B or C heavy oils should prescribe that the volume of received oil refers to its volume at 15°C unless a temperature provision is already included in the fuel purchase contract. It is important to confirm the exact volume of the received oil by calculating the volume in terms of the reference temperature of 15°C.

The method of calculating volume at different temperatures is prescribed in the Japanese Industrial Standard (JIS K 2250). The coefficients for calculating the volume of heavy oil in terms of temperature are shown in Table 3.

Table 3 Coefficients for Calculating Volumes of Heavy Oil in Terms of Temperature

Specific gravity (15°C/4°C) / Measured temperature (°C)	Coefficient to 15°C	
	0.8495 to 0.9653	0.9654 to 1.0754
10	1.0036	1.0031
15 (reference)	1.0000	1.0000
20	0.9964	0.9969
25	0.9929	0.9937
30	0.9893	0.9906
35	0.9857	0.9875
40	0.9822	0.9844
45	0.9787	0.9813
50	0.9752	0.9782
55	0.9720	0.9750
60	0.9686	0.9719
65	0.9652	0.9688
70	0.9619	0.9656
75	0.9586	0.9626
80	0.9553	0.9596
85	0.9520	0.9566
90	0.9488	0.9536
95	0.9455	0.9507

(Example of use of Table 3)

When 10 kl of heavy oil whose specific gravity is 0.92 at the reference temperature of 15°C is received at 50°C, the volume is multiplied by a coefficient of 0.9752 for specific gravity of 0.8459 to 0.9653 at 50°C in Table 3 as follows:

$$(10\ \text{kl}) \times 0.9752 = 9.752\ \text{kl}$$

This moans that the 10 kl of heavy oil received at 50°C become 9.752 kl at 15% and an extra fee might be paid for the difference of 0.248 kl.

The volume can be determined by simple calculation with the use of a volume expansion coefficient of 0.0007/°C, as well.

(Example of simple calculation)

$$(10\ \text{kl})/[1 + 0.0007 \times (50 - 15)] = 9.761\ \text{kl}$$

(3) Fuel temperature management

Liquid fuel is atomized by a burner for combustion. The diameter of each atomized particle should be reduced as much as possible to increase combustion efficiency.

Since the viscosity of B and C heavy oils are high, it is hard to atomize them for complete combustion. Therefore, it is necessary to heat them to lower their viscosity to a level appropriate for complete combustion. The temperature to which the oil should be heated depends on the kind of oil and the type of burner. Table 4 shows examples of heating temperatures.

Table 4 Heating Temperature of Oil

Kind of oil	Type of burner	Heating temperature
Kerosene, light oil & A heavy oil		Unnecessary to heat
B heavy oil		50 to 60°c
C heavy oil	Steam atomization	60 to 80°C
C heavy oil	Rotary	85°C
C heavy oil	Air atomization	95°C

Table 5 Standard Properties of Fuel Oil (JIS K 2205-1980)

Kind	Property	Flash point (°C)	Kinetic viscosity (50°C) (mm^2/s)	Pour point (°C)	Residual carbon content (mass%)	Water content (vol%)	Ash content (mass%)	Sulfur content (mass%)	Main applications
Class 1	No.1	60 or more	20 or less	5 or less *1)	4 or less	0.3 or less	0.05 or less	0.5 or less	For ceramic industry, metal refining, small internal combustion for space heating, space heating
	No. 2	60 or more	20 or less	5 or less *1)	4 or less	0.3 or less	0.05 or less	2.0 or less	
Class 2		60 or more	50 or less	10 or less *1)	8 or less	0.4 or less	0.05 or less	3.0 or less	For internal combustion engine
Class 3	No.1	70 or more	250 or less	–	–	0.5 or less	0.1 or less	3.5 or less	For general, large boiler, iron & steel, large internal combu-tion engine
	No. 2	70 or more	400 or less	–	–	0.6 or less	0.1 or less	–	
	No. 3	70 or more	More than 400 to 1,000	–	–	2.0 or less	–	–	For high viscosity burner

*1) The fuel oil of Classes 1 and 2 for cold weather shall be 0°C or less in pour point, and the fuel oil of Class 1 for warm weather shall be 10°C or less in pour point.

$1\ mm^2/s = 1\ cSt$

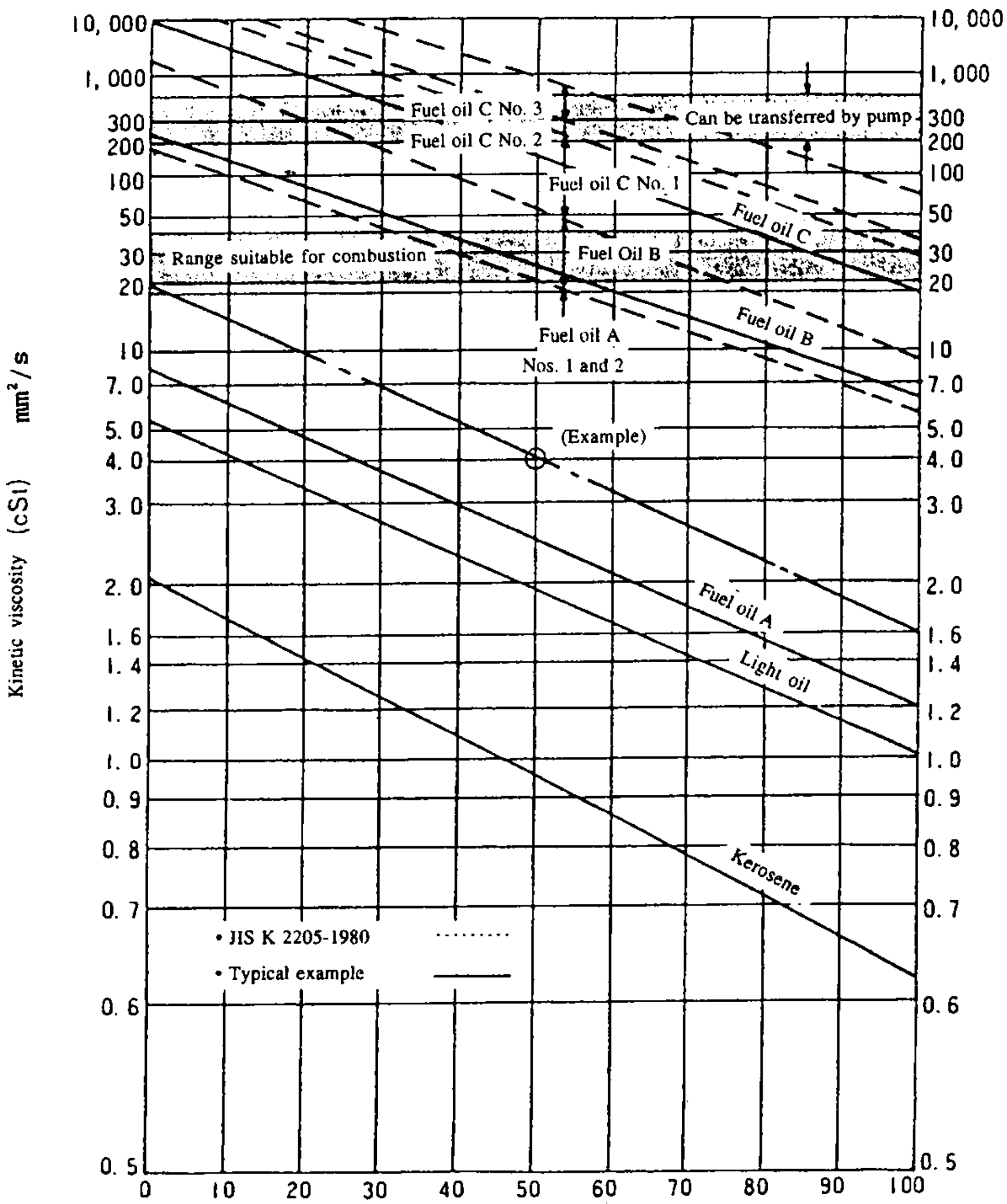


Fig. 17 Kinetic Viscosity and Temperature of Liquid Fuel

2.1.3 Combustion management

Oil combustion management consists of the following three tasks:

1) Maintaining low air ratio combustion
2) Use of burner capacity appropriate to load
3) Maintenance of burner

These three items are discussed in "1.1 Low air ratio combustion (low O_2 combustion)" and "1.2 Burner management." Combustion management using the naked eye will be discussed here. Though an O_2 analyzer is needed for combustion management, combustion abnormality can be detected early, and measures taken by observing the state of the flame. For that purpose, it is necessary to train operator in detecting such abnormalities.

Table 6 shows examples o the state of flame and anti-abnormality measures for types of fuels and burners.

Table 6 State of flame

Kind of fuel	Burner			Form and color	Abnormality	
	Type		Details of type		State	Measures
Liquid fuel	Pressure atomization		Pressure of fuel oil is set at 15 to 20 kglcm^2 G (1.47 ~ 1.96 MPa) to eject the oil from nozzle to atomize the oil	(Form) When pressure is high and atomization is good, the spread of flame is small and its length is short (Color) Reddish bright flame	Flame lengthens Soot is generated	1. Check if pressure has dropped 2. Increase in nozzle diameter due to wear 1. Increase air ratio 2. Check atomization
	High-pressure gas flow atomization burner		Oil is atomized by steam or air pressure.	(Form) Flame is shorter than pressure atomization type. (Color) Heavy oil: Reddish bright flame Kerosene: Reddish bright flame or blue flame	Flame lengthens Soot is generated	1. Check nozzle tip 2. Drop in pressure of atomizing gas flow 1. Clogging of nozzle tip (poor mixing) 2. Increase air ratio
Gas fuel	Nozzle mixing	Diffusion	Air and gas fuel are ejected from parallel holes and burned while being diffused into each other.	Flame is long and reddish		
		Forcible mixing	Air or gas fuel is forcibly mixed (ejection port is oriented at angle or rotary blades are provided).	Flame is short and of bluish translucency.	1. Reddish opaque-ness 2. Lif ted	· Deterioration of mixing due to air shortage or trip defectiveness · Gas pressure drop
	Premixing		Gas fuel is pre-mixed with 10 to 20% of theoretical quantity of air, and the mixture is ejected and burned.	Same as above	Same as above	· Air pressure drop · Improper operation of zero governor

2.1.4 Feed water management

If the feed water for a boiler contains $CaCO_3$ or $CaSO_4$, scale deposits on the heat transfer surfaces of boiler tubes and drums, and sludge deposit on the inside bottom of the drum, will accumulate so that heat transfer is hindered. In such a case, even in intensification of combustion management will not yield energy conservation. Fig. 18 shows the relation between scale deposits an fuel loss.

In order to prevent the depositing of scales and sludge, a water softener is often used to change the feed water into soft water.

Since boiler water, evaporates into vapor that does not contain impurities such as the $CaCO_3$ or $CaSO_4$, these impurities become concentrated in the boiler water. It is necessary to drain some of the boiler water to prevent such concentration. This draining is called blow down. In many small- and medium-sized enterprises' plants, the quantity of blow down is determined by intuition. If the quantity is excessive, however, heat loss results. Therefore, the quality of the feed water and boiler water should be regularly analyzed to determine the appropriate quantity of blow down.

This can be determined by measuring the concentration of chlorides (such as $CaCO_3$ and $CaSO_4$) in the feed water or electric conductivity and establishing the allowable value for the concentration of chlorides in the boiler water or electric conductivity as follows:

$$X = \frac{a}{b} \times 100$$

X: Quantity of blow down

a: Concentration of chlorides in feed water (electric conductivity) (Table 7)

b: Allowable value for concentration in boiler water (electric conductivity) (Table 7)

The quantity of blow down per day is determined by multiplying the feed water quantity per day by the value X. In intermittent boiler operations, blow down is done at the time of the morning check. At this time sludge is deposited at the bottom of the boiler. In continuous boiler operations, the blow down should occur about every 6 hours.

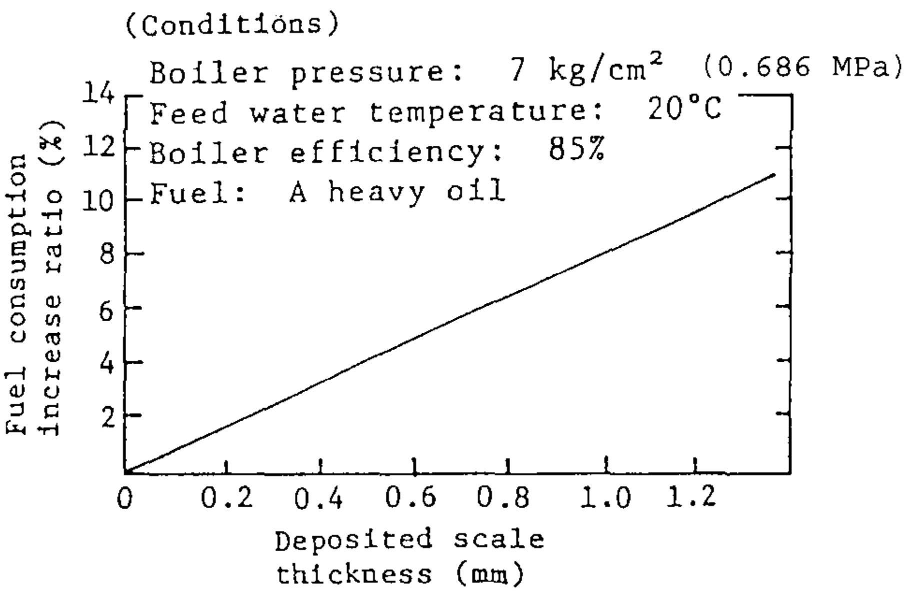


Fig. 18 Scale Deposition and Fuel Loss

Table 7 Quality of Water, Tube Boiler (Circulation Boiler) Feed Water and Boiler Water

(JIS B 8223)

Specifications	Max. operating pressure Mpa (kgf/cm^2)	up to 1 (up to 10)		above 1, up to 2 (above 10, up to 20)			above 2, up to 3 (above 20, up to 30)		above 3, up to 5 (above 30, up to 50)	
	Evaporation rate at heating surface (kg/m^2·hr)	up to 50	above 50	–	–		–		–	
	Type of make-up water	softened water			ion exchanged water (13)		ion exchanged water (13)		ion exchanged water (13)	
Feed water	pH (at 25°C)	7~9	7~9	7~9	8.0~9.5		8.0~9.5		8.0~9.5	
	Hardness (mg $CaCO_3$/L)	up to 1	up to 1	up to 1	0		0		0	
	Oils and fats (mg/L) (5)	(6)	(6)	(6)	(6)		(6)		(6)	
	Dissolved oxygen (mg O/L)	(6)	(6)	up to 0.5	up to 0.5		up to 0.1		up to 0.03	
	Iron (mg Fe/L)	–	up to 0.3	up to 0.3	up to 0.1		up to 0.1		up to 0.1	
	Copper (mg Cu/L)	–	–	–	–		–		up to 0.05	
	Hydrazine (mg N_2H_4/L) (12)	–	–	–	–		0.2 or above		0.06 or above	
	Electric conductivity (μS/cm) (at 25°C)	–	–	–	–		–		–	
Boiler water	Treatment	alkali				phosphate	alkali	phosphate	alkali	phosphate
	pH (at 25°C)	11.0~11.8	11.0~11.8	11.0~11.8	10.5~11.5	9.8~10.8	10.0~11.0	9.4~10.5		
	Acid consumption (pH4.8) (mg $CaCO_3$/L) (7)	100~800	100~800	up to 600	up to 250	up to 130	up to 150	up to 100		
	Acid consumption (pH8.3) (mg $CaCO_3$/L) (8)	80~600	80~600	up to 500	up to 200	up to 100	up to 120	up to 80		
	Total evaporation residue (mg/L)	up to 3,000	up to 2,500	up to 2,000	–	–	–	–		
	Electric conductivity (μS/cm) (at 25°C)	up to 4,500	up to 4,000	up to 3,000	up to 1,500	up to 1,200	up to 1,000	up to 800		
	Chloride ions (mg Cl^-/L)	up to 500	up to 400	up to 300	up to 150	up to 150	up to 100	up to 100		
	Phosphate ions (mg PO_4^{3-}/L) (9)	20~40	20~40	20~40	10~30	10~30	5~15	5~15		
	Sulfite ions (mg SO_3^{2-}/L)	10~50 (10)	10~50 (10)	10~20	10~20	10~20	5~10	5~10		
	Hydrazine (mg N_2H_4/L) (11)	0.1~1.0	0.1~1.0	0.1~0.5	0.1~0.5	0.1~0.5	–	–		
	Silica (mg SiO_2/L)	–	–	–	up to 50	up to 50	up to 50	up to 50		

Specifications	Max. operating pressure Mpa (kgf/cm^2)	above 5, up to 7.5 (above 50, up to 75)			above 7.5, up to 10 (above 75, up to 100)		above 10, up to 15 (above 100, up to 150)		above 15, up to 20 (above 150, up to 200)	
	Evaporation rate at heating surface (kg/m^2·hr)	–			–		–		–	
	Type of make-up water	ion exchanged water (13)			ion exchanged water (13)		ion exchanged water (13)		ion exchanged water (13)	
Feed water	pH (at 25°C)	8.0~9.5 (14)			8.0~9.5 (14)		8.0~9.5 (14)		8.0~9.5 (14)	
	Hardness (mg $CaCO_3$/L)	0			0		0		0	
	Oils and fats (mg/L) (5)	(6)			(6)		(6)		(6)	
	Dissolved oxygen (mg O/L)	up to 0.007			up to 0.007		up to 0.007		up to 0.007	
	Iron (mg Fe/L)	up to 0.05			up to 0.03 (15)		up to 0.03 (15)		up to 0.02 (16)	
	Copper (mg Cu/L)	up to 0.03			up to 0.02		up to 0.01		up to 0.005	
	Hydrazine (mg N_2H_4/L) (12)	0.01 or above			0.01 or above		0.01 or above		0.01 or above	
	Electric conductivity (μS/cm) (at 25°C)	–			–		up to 0.5 (17)		up to 0.5 (17)	
Boiler water	Treatment	alkali	phosphate	volatile matter	phosphate	volatile matter	phosphate	volatile matter	phosphate	volatile matter
	pH (at 25°C)	9.6~10.5	9.2~10.2 (18)	8.5~9.5	9.0~10.0 (18)	8.5~9.5	8.5~9.8	8.5~9.6	8.5~9.8	8.5~9.6
	Acid consumption (pH4.8) (mg $CaCO_3$/L) (7)	–	–	–	–	–	–	–	–	–
	Acid consumption (pH8.3) (mg $CaCO_3$/L) (8)	–	–	–	–	–	–	–	–	–
	Total evaporation residue (mg/L)	–	–	–	–	–	–	–	–	–
	Electric conductivity (μS/cm) (at 25°C)	up to 500	up to 400	up to 60 (17)	up to 150	up to 60 (17)	up to 60	up to 20 (17)	up to 60	up to 20 (17)
	Chloride ions (mg Cl^-/L)	up to 50	up to 50	up to 2	up to 10	up to 2	up to 2	up to 1	up to 2	up to 1
	Phosphate ions (mg PO_4^{3-}/L) (9)	3~10	3~10 (18)	(19)	2~6 (18)	(19)	0.1~3	(19)	0.1~3	(19)
	Sulfite ions (mg SO_3^{2-}/L)	–	–	–	–	–	–	–	–	–
	Hydrazine (mg N_2H_4/L) (11)	–	–	–	–	–	–	–	–	–
	Silica (mg SiO_2/L)	up to 5 (20)	up to 5 (20)	up to 5 (20)	up to 2 (20)	up to 2 (20)	up to 0.3 (20)		up to 0.2 (20)	

Note

(12): Applied to addition of hydrazine as oxygen scavenger to feed water

(13): Water purified by ion exchange equipment consisting of both strong-acid cation exchange resin and strong-base anion exchange resin, generally called desalted water, including water from steam evaporator (condensed water)

(14) pH should be slightly higher for feed water heaters consisting of steel pipes.

(15) Preferably 0.02 mg Fe/L or less

(16) Preferably 0.01 mg Fe/L or less

(17) To be measured after a sample is passed through a column filled with hydrogen ion type strong-acid cation exchange resin

(18) pH 9-10.5 and phosphate ions 2-20 mg PO_4^{3-}/L are preferred for waste heat recovery boilers

(19) If substances such as calcium and magnesium that decrease the pH value get in the water as a result of seawater leakage from the condenser, etc., a required amount of phosphate should be added to treat the substances.

(20) To keep a good relation between the silica content in the boiler water and that in the vapor, the former should be adjusted so as to maintain the latter at 0.02 mg SiO_2/L or below.

Caution: In general, hydrazine and sulfites should not be used together for dechloridation.

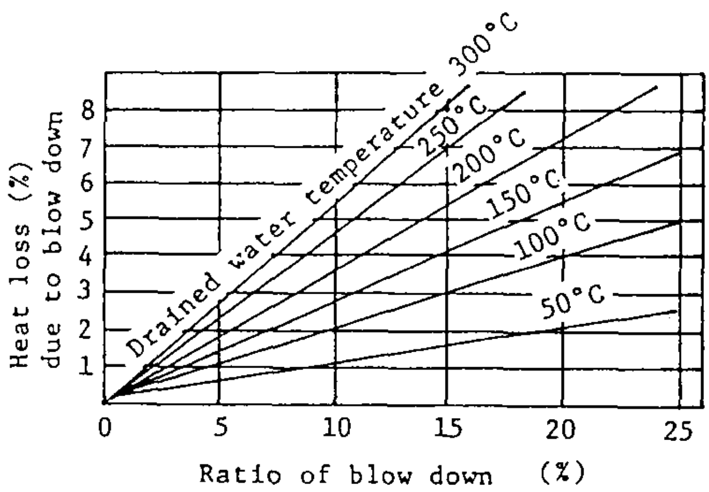


Fig. 19 Heat Loss due to Blow Down

2.2 Steam piping

2.2.1 Piping management

The length, pipe diameter, pressure drop and heat loss of steam piping should be minimized. For that purpose, the number of valves and flanges must be reduced as much as possible, and unnecessary piping and double piping eliminated. Furthermore, it is important to operate diligently the valve at the steam header in close communication with the steam consumption side in order to convey steam to the necessary place at the necessary time.

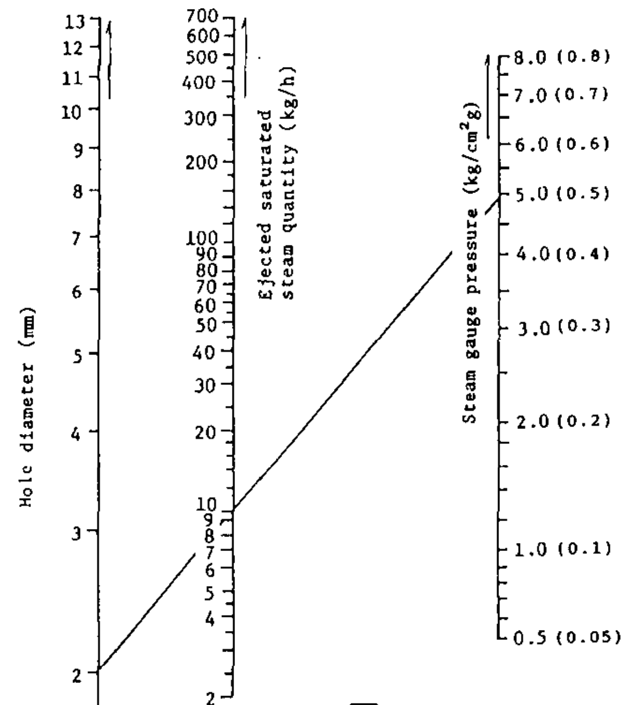
In some plants, steam is left leaking through pinholes in flanges, valves and so forth in steam piping. This reflects a failure to appreciate that the quantity of leaked steam is very large.

Fig. 20 shows that if there is a small hole of 2 mm in diameter in steam piping of 5 kg/cm^2 (0.49 MP_a) in gauge pressure, steam leaks through the hole at a rate of 10 kg per hour. If the steam is conveyed through the piping for 10 hours a day, the leakage will be 2,500 kg per month (25 days of operation), equivalent to about 200 liters of heavy oil.

2.2.2 Thermal insulation management

Though thermal insulator is effective in a newly constructed plant, some insulated equipment deteriorates over time so that thermal insulator drops off or outdoor piping covers are damaged allowing rain to drop on the thermal insulator.

If rainwater enters directly the thermal insulator, the piping 30 cm upstream and downstream from the point of the entry becomes, effectively, nothing mo e than bare piping. If the consumption of steam increases in rainy weather, the thermal insulator on outdoor piping may well be defective and should be checked thoroughly.



$$\left[G = 636 \times A \times \sqrt{\frac{P}{v}} \times 3,600 \right]$$

$$G = 199 \times A \times \sqrt{\frac{P}{v}} \times 3,600$$

G: Discharging steam quantity (kg/h)

A: Hole section area (m^2)

P: Absolute steam pressure (kg/cm^2) (MP_a)

v: Steam specific volume (m^3/kg)

Note: The steam discharge coefficient is assumed to be 1 in this figure. The discharge coefficient ranges from 0.65 to 0.97, depending on the shape of the hole. Therefore, the steam ejection quantity shown in this diagram multiplied by the figure 0.8 can be regarded as the actual steam discharge quantity.

Fig. 20 Hole Diameter and Steam Discharge Quantity

Table 8-(1) Flanged Globe Valve (10 kg/cm^2) (0.98 MP$_a$)

	15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Insulated part total (m^2)	0.078	0.090	0.131	0.170	0.211	0.294	0.349	0.455	0.616	0.776	1.137
Equivalent bare piping length of insulated surface area (m)	1.15	1.06	1.22	1.11	1.11	1.23	1.25	1.27	1.40	1.50	1.68

Table 8-(2) Flanged Sluice Valve (10 kg/cm^2) (0.98 MP$_a$)

	15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Insulated part total (m^2)	0.076	0.083	0.123	0.201	0.231	0.276	0.367	0.429	0.556	0.699	1.032
Equivalent bare piping length of insulated surface area (m)	1.12	0.98	1.15	1.31	1.22	1.16	1.31	1.20	1.27	1.35	1.52

Table 8-(3) Flanged Reducing Valve (10 kg/cm^2) (0.98 MP$_a$)

	15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Insulated part total (m^2)	0.133	0.145	0.179	0.228	0.295	0.383	0.466	0.567	0.840	0.915	1.231
Equivalent bare piping length of insulated surface area (m)	1.96	1.71	1.67	1.49	1.55	1.60	1.66	1.58	1.91	1.76	1.81

Table 8-(4) Flange (10 kg/cm^2) (0.98 MP$_a$)

	15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Insulated part total (m^2)	0.034	0.039	0.057	0.072	0.083	0.100	0.118	0.139	0.195	0.235	1.301
Equivalent bare piping length of insulated surface area (m)	0.50	0.46	0.53	0.47	0.44	0.42	0.42	0.39	0.44	0.45	0.44

An unexpectedly large number of plants with otherwise good thermal insulation management do not apply thermal insulator materials to valves and flanges. Table 8 shows that the surf ace areas of valves and flanges are equal to about 1 m and about 0.5 m of bare piping, respectively. For example, if a plant has 20 valves without thermal insulator, the heat loss is equal to what it would be if 20 m of that steam piping were left bare. Therefore, thermal insulator should be applied to valves and the like, and thermal insulator maintained in perfect condition.

Table 9 shows examples of thermal insulation efficiency calculations. The loss through the above-mentioned 20 valves without insulator is as much as 8,160 liters of heavy oil a year with 50A diameter piping.

Table 9 Examples of Insulation Efficiency

Item	Piping (1 m)				
	25A	40A	50A	65A	80A
Bare piping heat loss (kcal/mh) w/m	225	320	400	505	590
	262	372	465	587	686
Insulator thickness (mn)	50	65	65	65	65
Heat loss (kcal/mh) under insulation w/m	35	35	40	45	so
	41	41	47	52	58
Conserved steam quantity (kg/day)	9	14	17	22	27
Conserved steam quantity (kg/year)	2700	4200	5100	6600	8100
Conserved heavy oil quantity (l/year)	216	336	408	528	648

(5 kg/cm^2 saturation temperature: 158°C)
(0. 49 MP_a)

Fig. 21 shows the relation between insulator thickness and thermal insulation efficiency for 50A diameter piping. When steam piping of 200°C in saturation temperature is provided with 75 mm thickness thermal insulator, the heat loss is 50 kcal/mh (58.1 W/m) and the thermal insulation efficiency is 87%.

Though the thermal insulation efficiency rises as the insulator thickness increases, the relative, efficiency declines beyond a certain thickness, as shown in Fig. 21. Therefore, it is important to determine an economic thickness. In determining that thickness, JIS A 9501 "Standard Practice for Thermal Insulation Works" can be useful.

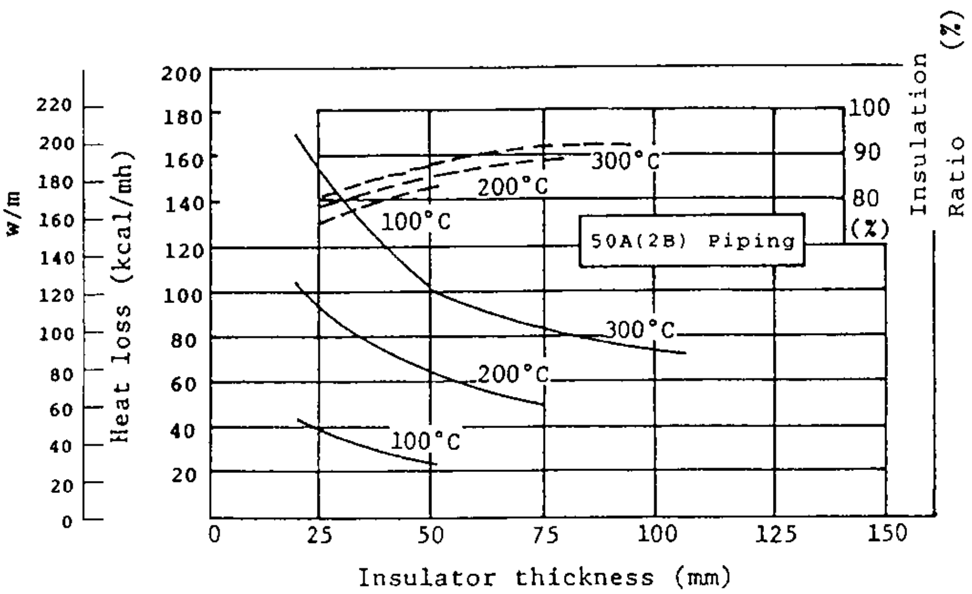


Fig. 21 Relation between Thermal Insulator Thickness and Efficiency

2.3 Steam-using equipment

2.3.1 Reviewing steam pressure

When steam is used as a heat source for heating (indirect heating), it is often thought that the use of higher pressure steam provides the greatest efficiency. However, that is not the case, as noted on the above discussion of the general properties of steam (Fig. 16). In fact, the lower the pressure, the greater the latent heat of steam condensation (which means that the quantity of heat released at the time of its liquefaction is larger). Therefore, steam is conserved by reducing steam pressure. For that reason, the boiler's set pressure should be reduced to a level corresponding to a temperature necessary for the steam to serve as a heat source (refer to Fig. 15). At that time, it is important to take the pressure regulation range of the boiler and the pressure loss in steam piping into consideration in setting the appropriate pressure level. The heat loss from the steam piping also can be decreased by reducing steam pressure.

2.3.2 Steam trap management

Since water carried by steam from the boiler and a condensate generated during tie conveyance of the steam are present in steam conveyance piping, the water and the condensate should be removed to prevent trouble such as water hammer. On the other hand, generally, a condensate is continuously generated in steam-using equipment. The quick draining of the condensate leads to efficient operation of the equipment. Therefore, the steam trap can be said to be a kind of automatic valve which plays a very important role for steam piping lines and steam-using equipment. The important functions of the steam trap are listed below.

1) Generated condensate is drained quickly.
2) Incondensable gases such as air and carbon dioxide are discharged.
3) Steam is kept from leaking.

To fulfill these functions, many types of steam traps are available as shown in Table 10. A steam trap appropriate to use and purpose should be selected, taking into consideration, steam pressure, temperature, condensate quantity, attached position and so forth. General criteria for selection are as follows:

1) A disk-type steam trap is used for steam headers, steam mains, branched pipes, etc.
2) A free-float-type steam trap is used for heaters, evaporators, distillers, driers, etc. as steam-using equipment.

What is important about the management of steam traps is to detect troubles early and apply preventive maintenance.

Steam trap problems are classified broadly as follows:

1) Blow-through:
   Condensate and steam freely pass through (impossible to close).
2) Clogging:
   Condensate never flows out (impossible to operate).
3) Steam leak:
   Structural defect

The causes of these troubles are mechanical defects in the steam traps themselves improper selection of steam traps, problems in mounting steam traps on piping, etc. An expert should be consulated in determining the causes of such problems.

The steam trap is an expendable appliance: its efficiency declines with use until it becomes unusable. For that reason, standards for the equipment mentioned below should be established for preventive maintenance.

1) Cleaning of strainer
2) Side fitting of valve
3) Replacement of trap

If many kinds of steam traps are used, it is hard to maintain them and to keep a stock of spares. Therefore, it is important to limit the number of makers and kinds of steam traps.

Table 10 Major Features of Various Types of Steam Traps

Type		Advantages	Disadvantages
Mechanical trap	Upright bucket type	· Sure operation · Water seal prevents steam leak	· Large size · Poor gas discharge performance · Likely to freeze
	Inverted bucket type	· Good gas discharge performance	· Inconvenient to attach · Likely to freeze · Low efficiency
	Lever-fitted float type	· Appropriate to light load	· Weak in water hammer · Various troubles due to wear of lever mechanism
	Free float type	· Small size · Simple construction · Continuous draining · Quiet operation · Easy to replace float and valve seat	· Necessary to take measures to withstand water hammer
Thermostatic trap	Bellows-type	· Possible to control condensate temperature · Good gas discharge performance	· Weak in water hammer · Inappropriately high pressure · Unusable for superheated steam
	Bimetal type	· Unlikely to freeze · No valve clogging troubles · Good gas discharge performance	· Unusable for superheated steam · Large temperature difference between valve opening and closing · Bimetal properties change during use
Thermodynamic trap	Orifice type	· Compact and light · Usable for superheated steam	· Various troubles due to precision parts · Steam leak · Back pressure limitation (30%)
	Disk type	· Compact and light · Simple construction · Usable for superheated steam · Endures water hammer · Condensate of saturation temperature is drained.	· Back pressure limitation (50%) · Low pressure limitation (0.3 kg/cm^2)

2.4 Recovery of steam condensate

Although steam is used most as an energy source, the rate of actual effective utilization of steam's total heat energy (heat) is about 80%. The remaining heat energy is abandoned together with a condensate. Therefore, fuel savings of about 20% can be achieved by recovering 100% of the heat of the condensate and effectively utilizing the recovered heat.

The recovered condensate generally is utilized for boiler feed water. The effects of the recovery of the condensate are mentioned below.

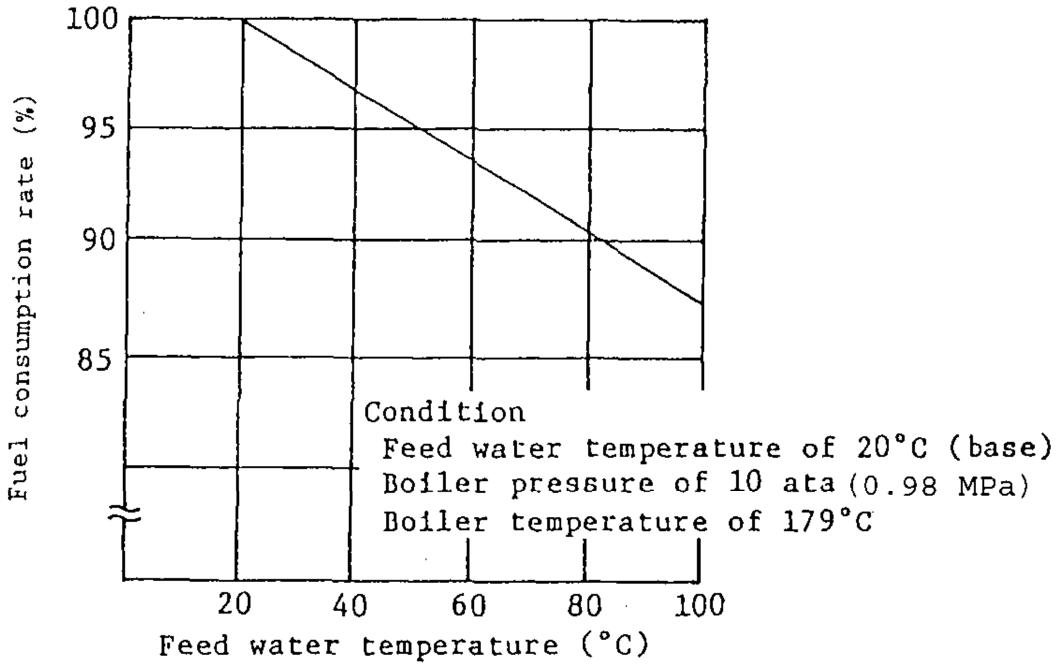


Fig. 22 Feed Water Temperature and Fuel Consumption Ratio

(1) The consumption of boiler fuel is diminished, thereby reducing air pollution. When the recovered condensate is used as boiler feed water, its temperature is raised. If the feed water temperature is raised by 10% fuel consumption can be reduced by about 1.5% as understood from the relation between the feed water temperature and fuel conservation shown in Fig. 22).

(2) Recovered condensate can be reused as boiler feed water to reduce the total amount of boiler feed water. Since the recovered condensate is pure water, the cost of water purification is reduced.

2.4.1 Planning of condensate recovery

The two factors noted below must be thought over in planning the recovery of condensates:

1) Effects of condensate recovery processes on cost reductions and management of operations.
2) Cost of installing condensate recovery equipment.

These two factors should be compared to estimate whether or not condensate recovery is cost effective and to determine the optimal recovery method if it is utilized. For these purposes, and to clarify which condensate should be recovered, it is necessary to find out how much steam in a plant is now used in each of its processes and how much condensate is abandoned. Therefore, heat balance sheets should be drawn up to help in grasping the overall heat use situation. For trial calculation of equipment costs, a condensate recovery method needs to be selected.

2.4.2 Methods for recovering condensate

There are three methods of recovering a high-temperature condensate drained through a steam trap, as follows:

1) Recovering condensate only by using steam trap.
2) Recovering condensate using steam trap and volute pump.
3) Recovering condensate using steam trap and condensate recovery pump.

In methods 1) and 2), a condensate recovery line is open to the atmosphere, and the temperature of the recovered condensate cannot be made higher than 100°C. In method 3), the condensate recovery line is closed to the atmosphere, and all the heat of the drained condensate can be recovered. Method 3) has been widely used in recent years.

Figs. 23, 24 and 25 show the condensate recovery methods.

2.4.3 Utilization of flashed steam

When a pressurized condensate with a temperature of 100°C or more is released into the atmosphere, a part of the condensate is flashed into steam. Though the pressure of the flashed steam is low, there is a process by which it can be utilized effectively.

Table 11 shows the quantity of flashed steam. It is understood from Table 11 that flashed steam of 2kg/cm^2 G (0.2 MP_a) is generated in a quantity of (10 t/h) × (10.1%) ≠ 1 t/h from 10 t/h of condensate of 10 kg/cm^2 G. (1.0 MP_a)

Fig. 26 shows an example of utilization of flashed steam. The places where condensate is generated and flashed steam is used should be near each other so that the already low pressure of the flashed steam is not reduced further through unnecessarily long piping transport. If this condition is not satisfied, large diameter piping must be used and equipment costs are high. Therefore, thorough study of the cost effectiveness of using flashed steam should be carried out before deciding on its use.

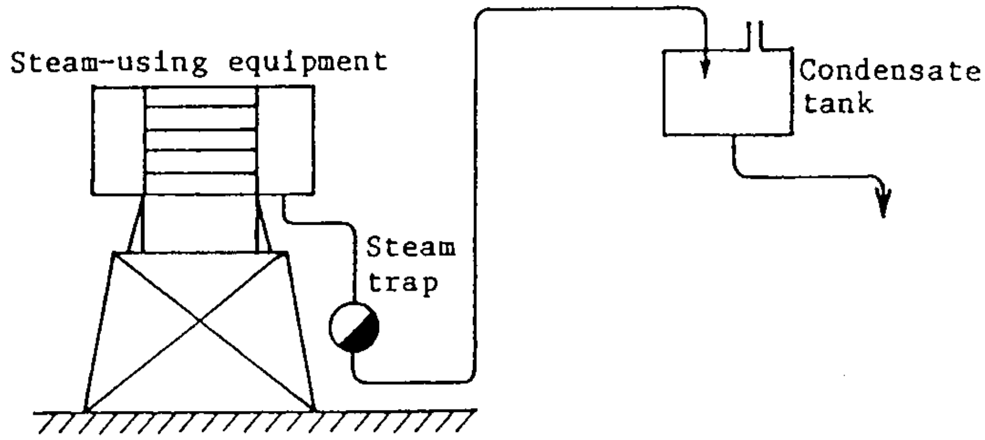


Fig. 23 Condensate Recovery only by Steam Trap

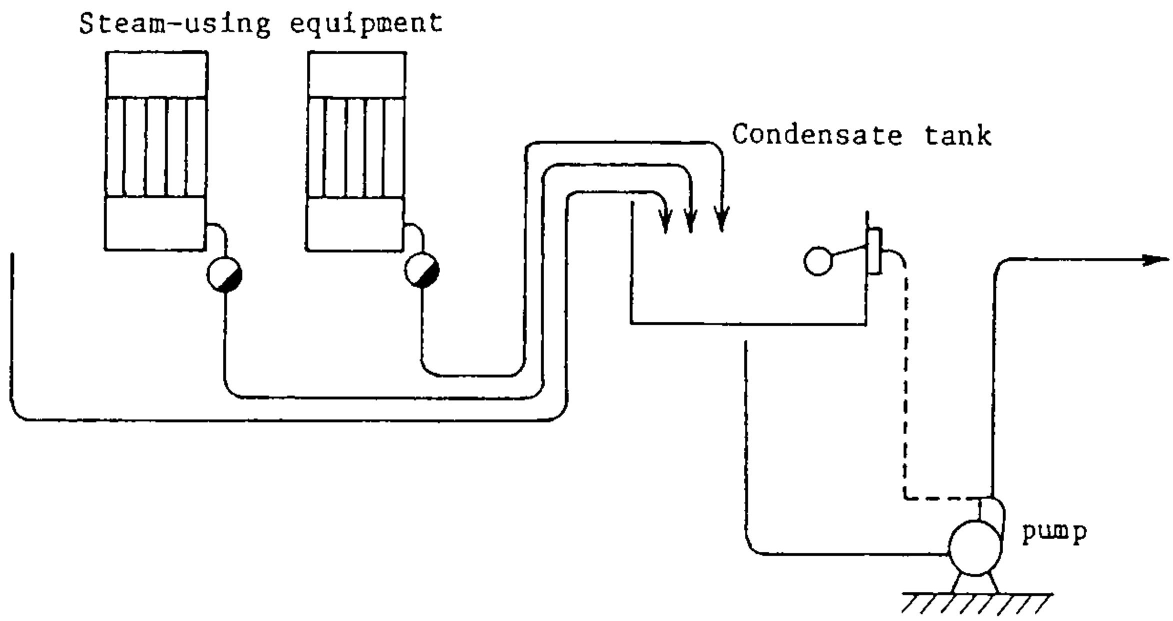


Fig. 24 Condensate Recovery by Steam Trap and Volute Pump

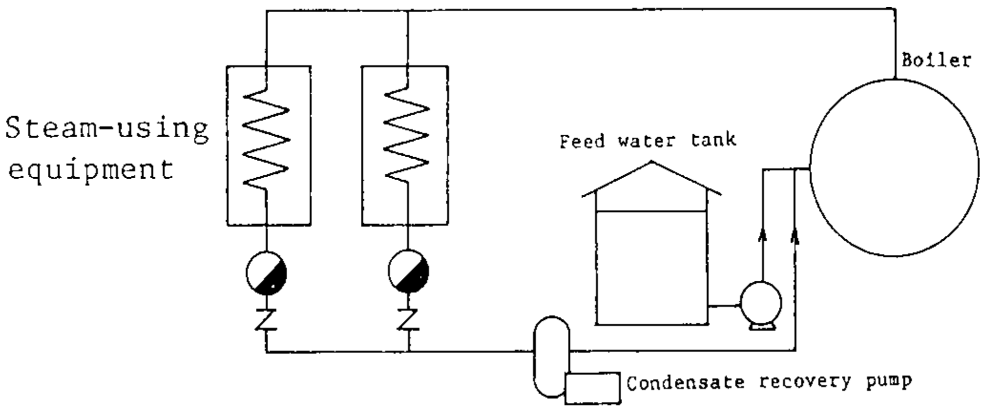


Fig. 25 Condensate Recovery by Steam Trap and Condensate Recovery Pump

Table 11 Quantity (% by Weight) of Flashed Steam

Higher pressure (kg/cm² G)		Lower pressure (kg/cm² G)															
		0	0.3	0.5	1	1.5	2	3	4	5	6	8	10	12	14	16	18
	MP_a	0	0.03	0.05	0.10	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8
1	0.1	3.7	2.5	1.7													
2	0.2	6.2	5.0	4.2	2.6	1.2											
3	0.3	8.1	6.9	6.1	4.5	3.2	2.0										
4	0.4	9.7	8.5	7.7	6.1	4.8	3.6	1.6									
5	0.5	11.0	9.8	9.1	7.5	6.2	5.0	3.1	1.4								
6	0.6	12.2	11.0	10.3	8.7	7.4	6.2	4.3	3.0	1.3							
8	0.8	14.2	13.1	12.3	10.8	9.5	8.3	6.4	4.8	3.4	2.2						
10	1.0	15.9	14.8	14.2	12.5	11.2	10.1	8.2	6.6	5.3	4.0	1.9					
12	1.2	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	1.4	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	1.6	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	1.8	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	2.0	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

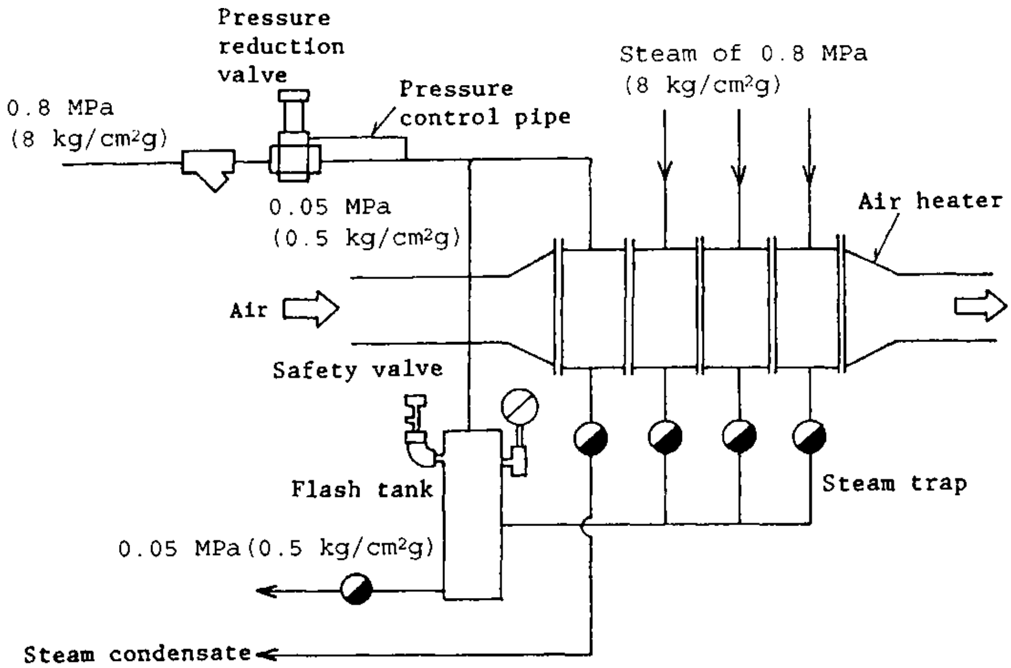


Fig. 26 Example of Use of Flashed Steam

2.4.4 Items to keep in mind concerning condensate recovery

Items which should be kept in mind about condensate recovery are noted below. Together with the maker of steam condensate recovery equipment, on-site technical study of these items is necessary.

(1) Though the recovered condensate tends to be considered pure distilled water, the condensate contains minute quantities of various substances dissolved in it. It should be studied to see if the condensate can be used as boiler feed water as is.

(2) If the condensate cannot be used as is, studies should be carried out to determine how to treat the condensate and whether or not to recover only heat if the condensate is very contaminated.

(3) Since the steam trap receives back pressure from a condensate recovery pipe or equipment, the trap should be changed for a mechanical trap. Careful appraisal s necessary in selecting the appropriate mechanical trap (refer to Table 10).

(4) If there are piping lines with different steam pressures, study will be necessary to determine if condensate recovery pipes should be provided for the different levels of steam pressure.

2.5 Heat recovery from hot waste water

Hot waste water is a form of waste heat apt to be overlooked. Though it is not readily utilized, a method of utilizing the heat should be developed if a large amount of heat is being lost.

Methods of utilizing the heat of hot waste water are mentioned below:

1) Recycling the hot waste water
2) Heat recovery using heat exchanger
3) Heating of feed water using heat pump

Typical method of recycling hot waste water involves utilizing again the water which performs indirect cooling in a condenser. The hot waste water is relatively clean so that it can be used for room heating or for bathing.

Though a heat exchanger was not used previously to recover heat because the heat exchanger soon became clogged due to unclean hot waste water, a plate-type heat exchanger which is cheap and from which scale can be completely removed has been developed and used in a dyeing plant and in a boiler to exchange heat between hot waste water and clean water in order to heat the clean water which then is used. This method has yielded good results.

Though a heat pump was developed for use in air-conditioning, it also has been used recently to recover the heat of hot waste water. Hot waste water of 30 to 40°C was used as a heat source in a heat pump to heat feed water to 70 to 80°C WC and energy savings about 50% greater than those realized with heat recovery using only a conventional heat exchanger were achieved. Fig. 27 shows basic flows in the use of a heat pump.

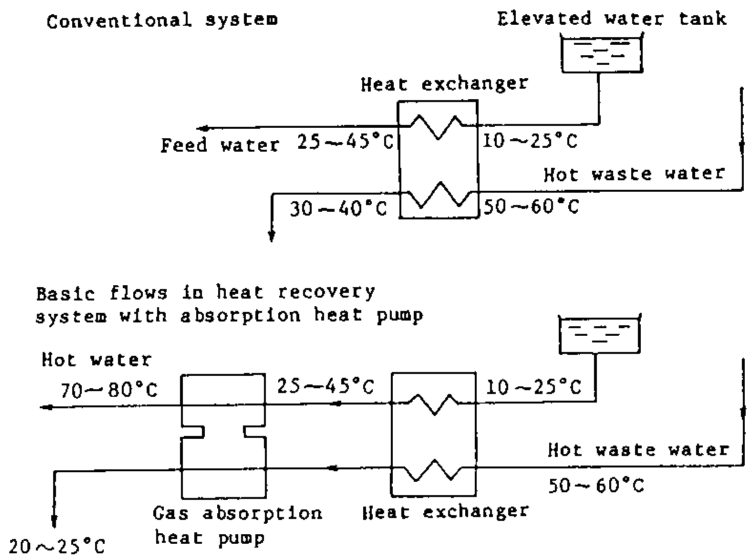


Fig. 27 Basic Flows

Electricity

1. Electricity Management for Electricity Conservation

Electricity management is classified into load management, voltage management, power factor management and distribution loss management.

Where and how electricity is used in a plant is determined by measuring the load factor, distribution loss, etc., in order to link electricity management with electricity conservation. On the basis of the results of these measurements, studies are made to determine how to reduce electricity loss, electricity consumption, electricity charge, etc. For that purpose, the four classis of management are discussed below.

1.1 Load management

1.1.1 Firm understanding of electricity consumption

It is important to understand several aspects of electricity consumption such as its seasonal fluctuations, the relation between maximum power and monthly electricity consumption during the maximum consumption season, and differenced. between daytime and nighttime electricity consumptions.

A procedure for calculating the daily load curve is explained hereafter to serve as a concrete example. Changes in electricity consumption are plotted on the basis of an electricity reception journal or a wattmeter to draw the load curve. An example curve is shown in Table 1 and Fig. 1.

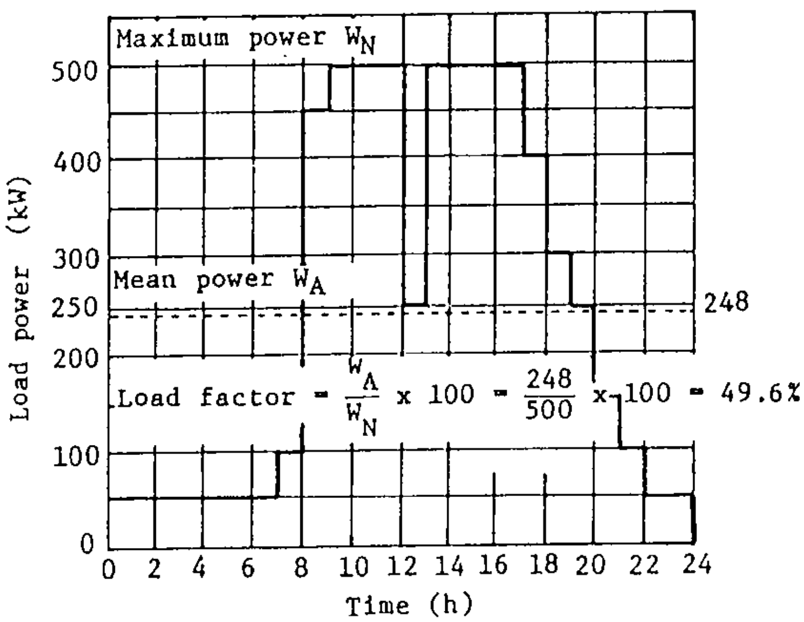


Fig. 1 Load Curve

Table 1 Electricity Consumption

Time	Watt hour meter reading kWh/h	Difference kWh/h	Time	Watt hour meter reading kWh/h	Difference kWh/h
0	237455.0	0	13	240105.0	250
1	237505.0	50	14	240605.0	500
2	237555.0	50	15	241105.0	500
3	237605.0	50	16	241605.0	500
4	237655.0	50	17	242105.0	500
5	237705.0	50	18	242505.0	400
6	237755.0	so	19	242805.0	300
7	237805.0	50	20	243055.0	250
8	237905.0	100	21	243205.0	150
9	238355.0	450	22	243305.0	100
10	238855.0	500	23	243355.0	50
11	239355.0	500	24	243405.0	50
12	239855.0				

The load factor is expressed as follows:

$$\text{Load factor} = \frac{\text{Mean power}}{\text{Maximum power}} \times 100\ (\%)$$

In the example above, the load factor is 49.6%.

The load factor indicates the situation relating to operation of the plant's electric equipment. If the load factor is small, it means that the equipment is used intensively during a limited time of day and is idle at other times.

Table 2 shows load factor standards for kinds of enterprises.

Table 2 Standards for Daily Load Factors in Enterprises with Contract Demand below 500 kW

Kind of enterprise		Daily load factor
Food	· Grain polishing; powdering	50
	· Seasoning; drinks	50
	· Ice making	80
	· Others	65
Fibers	· Filature	50
	· Spinning; twisting	60
	· Weaving	45
	· Others	40
Lumbering		40
Paper; pulp		80
Publishing; printing		50
Chemistry	· Ammonia fertilizer	45
	· Soda	75
	· Oil and fat; paint	40
	· Others	60
Rubber		40
Ceramics, earth and stone	· Class	60
	· Cement	50
	· Carbon and graphite electrodes	60
	· Others	55
Iron and steel	· Steel making and rolling	40
	· Forging and casting	35
	· Others	35
Metals		35
Machinery		35
Measuring and optical instruments; timepieces		40
Office and building		20
Schools and laboratories		15
Theaters		20
Amusement places		25
Large and small stores; restaurants		30

(Set up by Kanto Electricity Consumption Rationalizing Committee in 1971)

1.1.2 Improving load factor

In order to improve the load factor, maximum power consumption must be reduced. For that purpose, the following measures are available.

(1) Automation is used to shift a part of daytime equipment operations to nighttime.

(2) Maximum power consumption is reduced as much as possible by improving manufacturing processes introducing energy-conserving production equipment, and the like.

Improving the load factor results in the following advantages:

1) Electricity receiving equipment, such as a transformer, is provided with capacity so that it does not need to be augmented when additional production equipment is added.
2) If receiving equipment's demand for electricity is reduced during periods of maximum power consumption, the quantity of demand contracted for with an electric power company can be decreased to diminish electricity standing charges.

(Example of conservation improvement by an electric machinery maker)

(1) Plants features

1) Contracted demand: 210 kW
2) Electricity consumption: About 50,000 kWh
3) Electricity receiving transformer: 3 single-phase 100 MA transformers (delta-connected as shown in Fig. 2) for power and 1 single-phase 30 MA transformer for lighting, with total capacity of 330 kVA

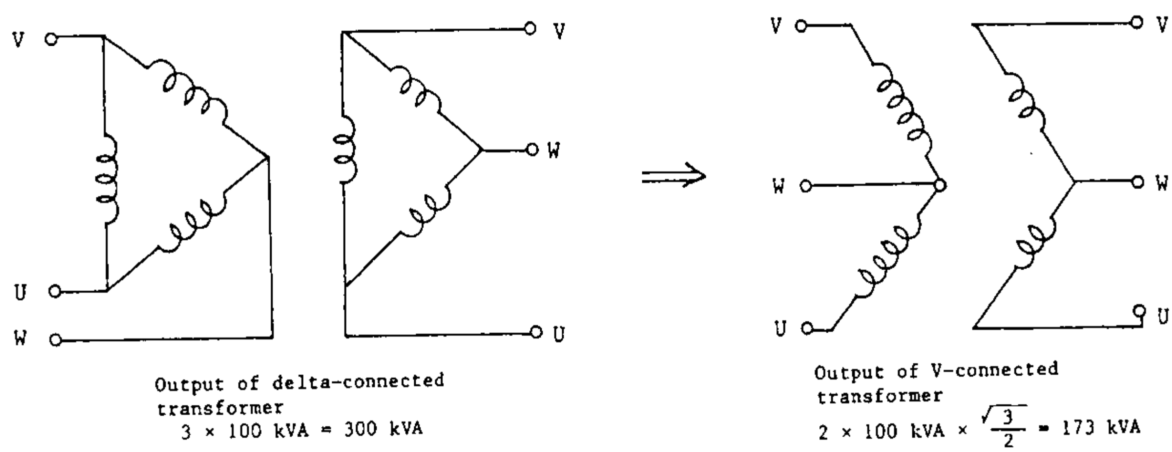


Fig. 2

(2) Improvement

The results of an investigation of existing electricity consumption showed a load factor of 50% and maximum power of 138 W. In short, only half the rated load was used by the electricity receiving transformers. For that reason, one of the power transformers was removed, and the connections were altered as shown in Fig. 2.

(3) This improvement produced the following effects:

1) Decrease in no-load loss
Even if no load is put on a transformer, a small current flows due to the application of voltage to the transformer. The flow of the current represents waste, the magnitude of which is usually 0.5 to 1% of the rated capacity of the transformer. In the plant discussed above, the loss was 500 W. For that reason, electricity conservation was achieved as follows:

(0.5 W) × (24 hours/day) × (30 days/month) × (20 yen/kWh) = 7,200 yen/month

2) Reduction in contract demand
Since one of the 100 kVA transformers was removed, the demand contracted. for with an electric power company was reduced from 210 kW to 153 kW. This resulted diminishing the standing charge as follows:

(210 kW – 153 W) × (1,560 yen/kW·month) = 88,920 yen/month

1.2 Voltage management,

Every electric machine is designed to have a standard operation voltage (rated voltage) of 100 V or 200 V, at which its operation achieves maximum efficiency. For that reason, it is necessary to check the voltage of each part of distribution lines, from electricity reception equipment to electric motors and to adjust the terminal voltage of each piece of equipment to its rated voltage.

Adjusting the tap of a transformer is the simplest way to adjust voltage. Since the magnitude of the voltage depends on the nature of plant operations, the tap of the transformer should be adjusted on the basis of the voltage magnitude measured during full-load plant operations.

1.3 Power factor management

Electric power consumed by an AC machine such as an induction motor consists of an effective part and a reactive part. The ratio of the effective part to total power is called the power factor.

The power factor will be explained through use of an example of the movement of an object. When a force (F) is applied to an object on a horizontal surface, only a part (W) of the force (P) effectively acts to move the object, as shown in Fig. 3. The angle between the vectors W and P is a characteristic of AC machines such as motors and electric furnaces. The cosine of the angle is called the power factor. If the angle θ = 60°C, cos θ is 1/2, which means that the power factor is 50%.

The closer the power factor comes to reaching 100%, the less power is lost and the more effectively electric power is used. The power factor of a general-purpose motor is usually about 85%, while that of an electric furnace and an electric welder is about 50%. A capacitor for improving the power factor is provided in many electric furnaces and electric welders.

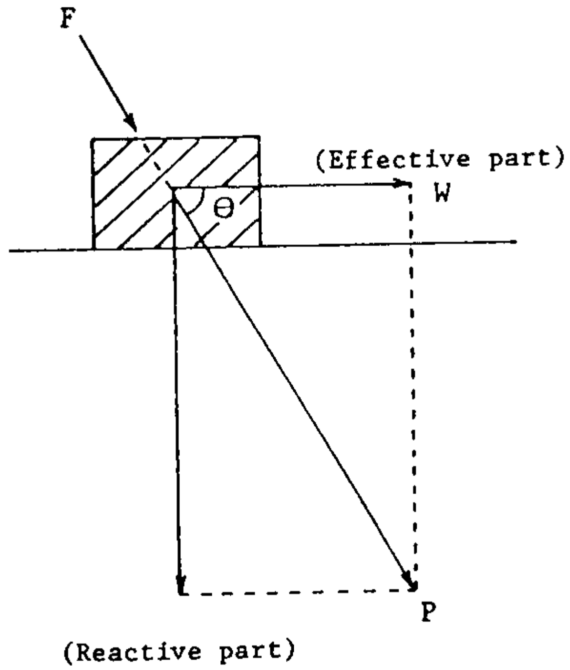


Fig. 3

The effects of power factor improvement are as follows:

(1) Decreases in voltage drops in transformers and distribution lines

(2) Substantial increases in capacity of electric equipment such as transformers

(3) Reduction in electricity charges

The mean power factor (power factor measured on the receiving panel) of the whole plant under maximum load is called the set power factor. When the set power factor is more than 85%, the standing charge of electricity is discounted by 1% for each % above the 85% level. When the set power factor is less than 85%, the standing charge of electricity is increased by 1% for each percent below the 85% level.

If the existing set power factor is less than 85%, it is desirable to attach a capacitor to the incoming panel to raise the power factor to 95%.

(Example of improvement in can production plant)

(1) Plant features

1) Contracted demand: 400 kW
2) Set power factor: 75%
3) Electricity reception transformer:
   1 three-phase 150 MA power transformer
   1 three-phase 300 kVA transformer for welder
   1 single-phase 50 MA transformer for lighting

(2) Since the power factor was as low as 75%, high-voltage phase-advancing capacitors were provided to improve the power factor to 95%, as shown in Fig. 4.

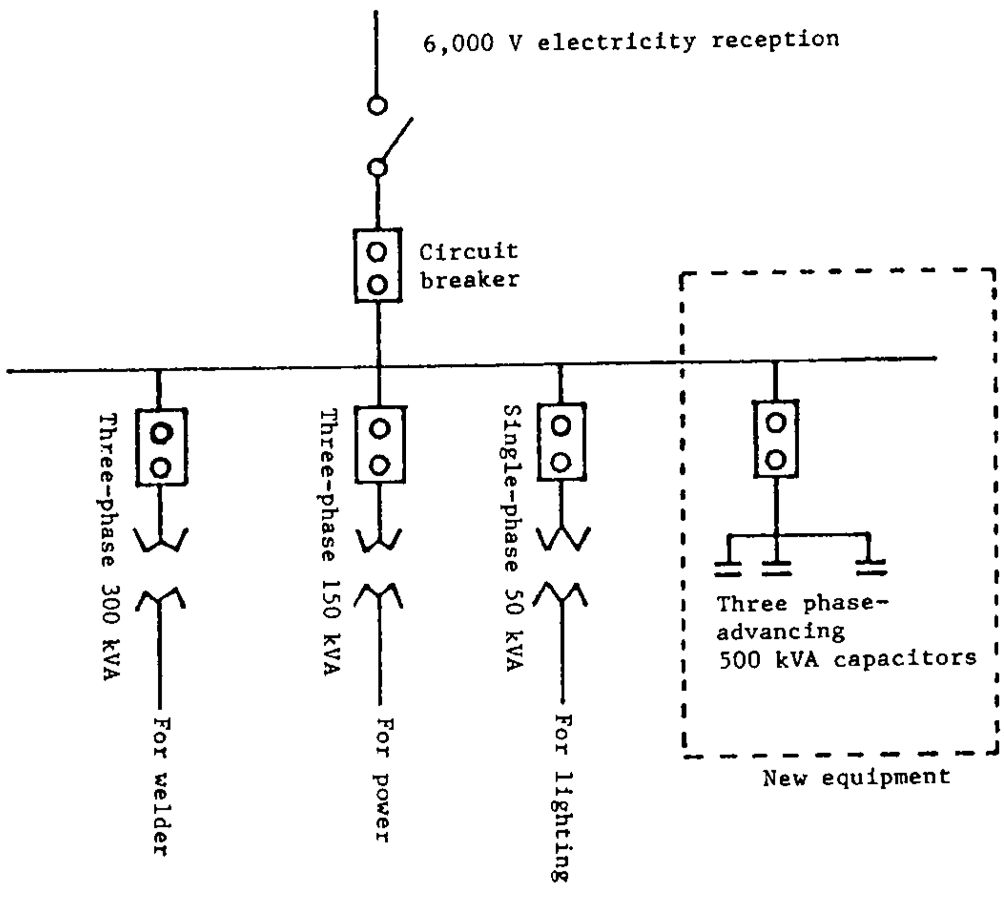


Fig. 4

(3) Effects

Standing charge before improvement

$$(400\ \mathrm{W}) \times (1{,}560\ \mathrm{yen/kW}) \times (1 + \frac{85 - 75}{100}) = 686{,}400\ \mathrm{yen}$$

Standing charge after improvement

$$(400\ \mathrm{W}) \times (1{,}560\ \mathrm{yen/kW}) \times (1 + \frac{85 - 95}{100}) = 561{,}600\ \mathrm{yen}$$

Thus, the standing charge was reduced by 124,800 yen. Since the cost of the capacitors were about 900,000 yen, the investment in the capacitors could be recovered in about 8 months.

1.4 Management of distribution loss

Distribution loss depends upon current in a power line, its resistance, the power factor of a load, etc.

The following items need to be considered in reducing distribution loss.

(1) Heavy-load equipment should be placed at as short a distance as possible from a power supply transformer. If it is impossible to place the equipment near the transformer, steps such as using 400 V power supply in place of 200 V power, should be adopted to supply the equipment with as much voltage as possible to decrease the load current and thereby reduce the line loss.

(2) The power factor of equipment should be improved to reduce loss attributed to a reactive current (power).

(3) Since power line resistance is directly proportional to its length and inversely proportional to its cross-sectional area, the resistance loss in the line is reduced by selecting an appropriate line length.

2. Managing Electric Equipment to Achieve Electricity Conservation

Electric equipment is classified broadly into electricity receiving equipment, electric motors, lighting equipment, air-conditioners, electric heating equipment and electrolyzing equipment. Since there is not enough space here to write about electricity conservation measures for all these types of equipment, discussion here will concentrate on some equipment familiar to small- and medium-sized enterprises.

2.1 Electric motors

2.1.1 Selection of motors suitable to load properties

Electric motors are used widely and should be carefully selected to assure that they are suitable to the load properties they will be driving. Proper selection leads to efficient operation which results in electricity conservation.

In selecting electric motors that will conserve energy the following factors should be considered.

(1) Determination of motor output

The loads required by the machine to be fitted with the motor should be examined under various operating conditions. Motor output appropriate to the kilowattage of the load should be selected.

It is important not to provide for motor output excess capacity.

(2) Determination of power supply

Either DC or an AC power supply is selected. If an AC power supply, it can be a single-phase or a three-phase system. Voltage can range from low (100 V, 200 V, 400 V, etc.) to high (3,300 V, 6,600 V, etc.) . Choice among these depend on the type and rating of the electric motor, the plant distribution system, etc. The optimum output of motor is shown as a function of the supply voltage in Fig. 5.

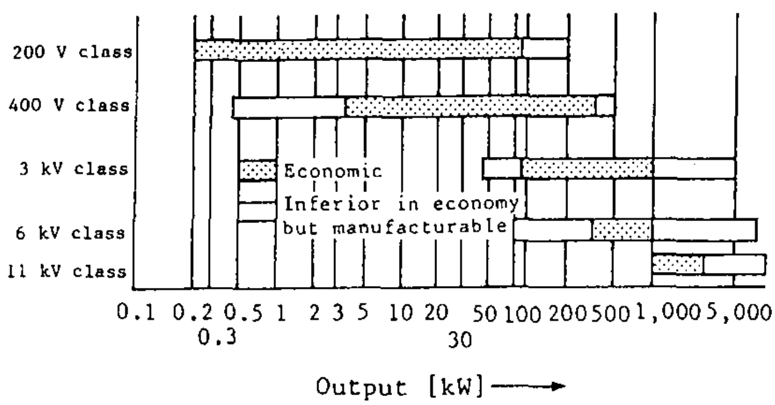


Fig. 5 Optimum Output Range by Voltage of Motor

(3) Determination of motor casing

The motor should be suit its environment (indoor, outdoor, temperature, humidity, ventilation, etc.) . Table 3 shows examples of possible selections under different conditions.

Table 3 Examples of Selection of Motor Casing

Place of installation	Environment	Selected type
Indoor	Ordinary place	Drip-proof
	Dusty place	Totally-enclosed and fan-cooled or totally-enclosed and self-cooled
	Place with corrosive gas	Totally-enclosed, fan-cooled and corrosion-proof
Outdoor	Ordinary place	Outdo or and open Outdoor, totally-enclosed and fan-cooled
	Dusty place	Outdoor, totally-enclosed and fan-cooled
	Place with corrosive gas	Totally-enclosed, fan-cooled and corrosion-proof

2.1.2 Prevention of no-load and light-load operation

The operating efficiency of a multi-purpose induction motor is highest under loads of 80 to 100%, but falls sharply under light-load operations of 50% or less, as shown in Fig. 6. The power factor also falls as the load decreases. Even in its no-load operation, there is a power loss near 20% of its rated output, as shown in Table 4.

It is understood from Table 4 that a power loss as much as 795 kWh annually is caused when five machine tools, each of which has a rated output of 3.7 kW (5 PS) and works for 300 days, are put in no-load operation for 1 hour a day.

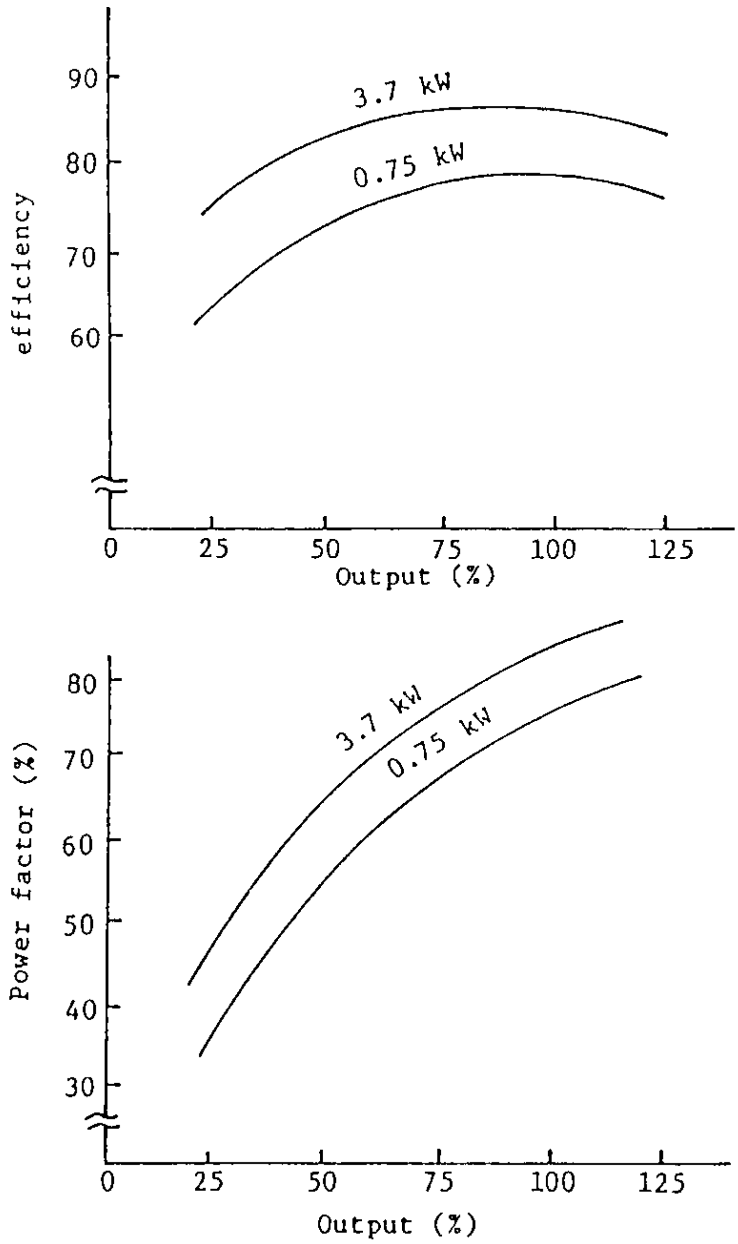


Fig. 6 Characteristics of Induction Motors

Table 4 Example of actual measurement of no-load operation of motor

Rated output (kW) of motor	3.7	5.5
Consumed power (input) A (kW) in no-load operation of motor alone	0.29	0.30
Input B (kW) in no-load operation of motor coupled to motor-driven machine and put in actual use	0.53	0.98
Comparison: B / A × 100 (%)	183	327
Annual power loss (kWh) due to no-load operation for 1 hour in each of 300 days of operation a year	159	294

Source: "Energy Conservation Measures at Cost of 100,000 Yen" by Energy Conservation Center

To reduce power loss, no-load operation needs to be prevented by reviewing work processes, attaching a no-load automatic stop device, etc.

2.1.3 Speed control

The quantity of air from a blower and the rate of fluid flow from a pump are controlled depending on the nature of plant operations. The shaft power of the blower and the pump is nearly proportional to the cube of their rotational frequency. When the quantity of air is decreased by half by an outlet damper, the input to the motor of the blower is reduced by 22%, as shown in Fig. 7. However, this graph also shows that when the quantity of air is decreased by half by lowering the rational frequency, the input to the motor is reduced by as much as 87%.

There are various method of controlling the rotational frequency of a motor, as shown in Table 5. In the methods shown in the right half of Table 5, the input to the motor is not reduced as much as is its shaft power by decreasing its speed. As a result, much of the input is lost as it is consumed by the motor and the efficiency of control is therefore low. For that reason, it is desirable to adopt a high-efficiency control method for the motor even if the cost of equipment increases.

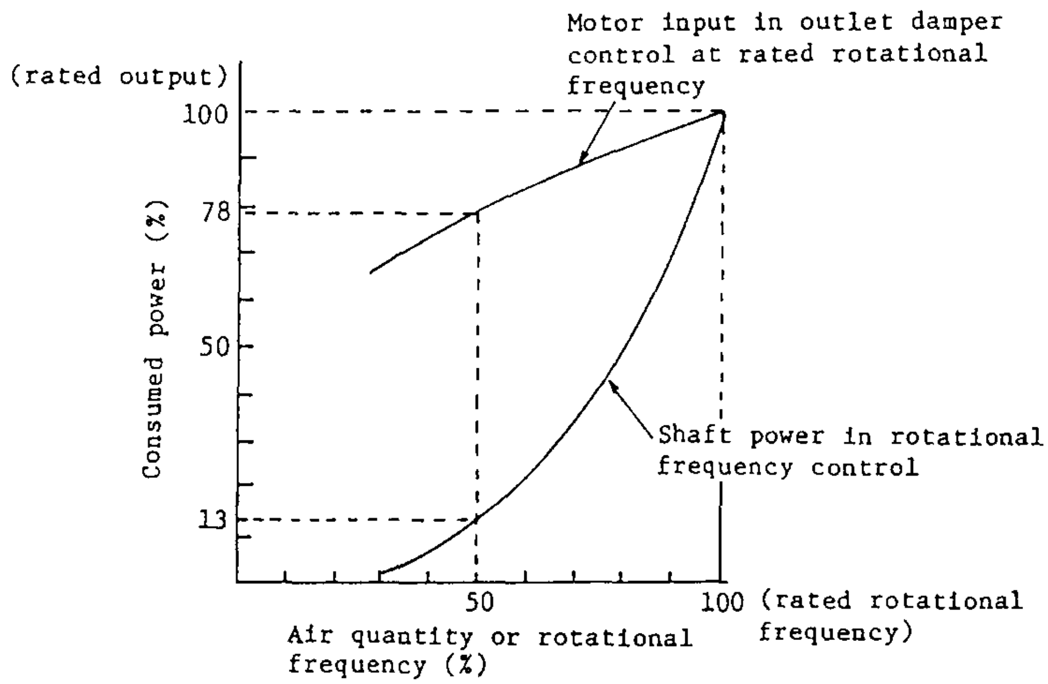


Fig. 7 Power Consumption Characteristics in Air quantity Control

Table 5 Speed Control Method

High-efficiency control	Low-efficiency control
1. Change in number of poles	1. Wound-rotor induction motor secondary resistance control
2. Primary frequency control	2. Induction motor primary voltage control
3. Secondary excitation control (Scherbius-Kraemer system)	3. Friction clutch
4. DC motor voltage control (Ward-Leonard system)	4. Electromagnetic coupling
5. DC motor field control	

(Example of improvement from "1981 Energy Conservation Cases")

Discussion of a case of electricity conservation in use of cooling pumps follows. The equipment in the case is outlined in Fig. 8.

The equipment included four cooling water pumps. Normally, two of them were in operation. When the temperature of water rose during summer, three of them were put in operation and the other served as a spare pump.

Though the average rate of operation of the cooling water pumps was 80%, regular checkups showed that it dropped as low as 50% depending on the season.

In order to conserve electric power during low rates of operation, the number of pumps in operation was controlled depending on the load. In addition, one pump was remodeled so that when two or more of the pumps were in operation, the rotational frequency of the remodeled pump could be controlled depending on the load. To control rotational frequency, a hydraulic-clutch-type frequency controller was selected due to its advantage in terms of installation space, etc.

The result of the rotational frequency control was that 318,700 kWh (about 12%) were conserved compared to actual consumption in 1979. At a price of 18 yen/kWh 5,737,000 yen was saved. The equipment investment of 4,000,000 yen could be returned in about 9 months.

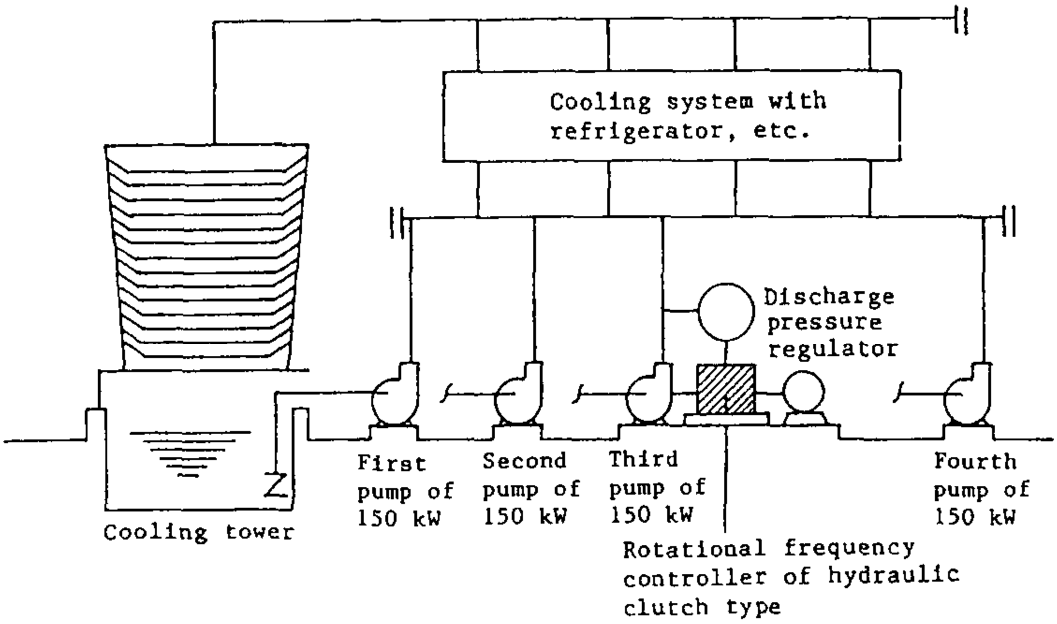


Fig. 8 Outline of Equipment with Cooling Water Pumps

In order to produce a satisfactory result using rotational frequency control as in the above-mentioned case, the following conditions are necessary:

1) The rate of operation of the pump is low or unstable.
2) The capacity of the pump drive motor is high (few dozen kW or more).

2.2 Lighting equipment

There are various kinds of lighting appliances. Lighting must be appropriate to each appliance and calculated intensity of illumination.

However, lighting should be reviewed in search of means of conserving electricity. The following points should be kept in mind:

(1) Cleaning of lamp

Illuminance drops by as much as 10 to 30% in 6 months, depending on the degree of contamination of a lamp or its cover with dust and the like.

If a cover is removed from an illumination appliance, the illuminance increases by as much as about 30%.

(2) Turn-off of unnecessary illumination appliances

An exclusive switch should be installed for illumination appliances near windows so that they can be turned off during certain times of day.

(3) Adoption of high-efficiency lamp

A lamp whose light quantity is large per unit of electric power is referred to as high-efficiency lamp. For example, a fluorescent lamp can provide the same illumination as a valve lamp using 1/3 to 1/4 as much power.

Metal halide and high-pressure sodium lamps are also high-efficiency lamps. A problem in adopting such high-efficiency lamps is that lighting stabilizers differ from lamp to lamp and from wattage to wattage.

(Example of improvement)

Monitoring, illumination controllers have been put on sale by companies recently. Such a monitoring controller for regulating electric power for illumination could be used, for example, in a relatively large supermarket, which sells mainly food and clothes and has 156 twin fluorescent lamps of 110 W, 104 twin fluorescent lamps of 40 W and 50 down-lights of 100 W. This example is discussed below.

(1) Organization of system

A monitoring control panel was connected to three terminal units, as shown in Fig. 9. For divided illumination circuits were provided in each of the terminal units for three floors. The circuits included two 30% lighting circuits and a 40% lighting circuit so that lighting could be controlled by three stages of 30%, 70% and 100%.

A microcomputer was built in the control panel so that not only a time program but also various functions could be provided.

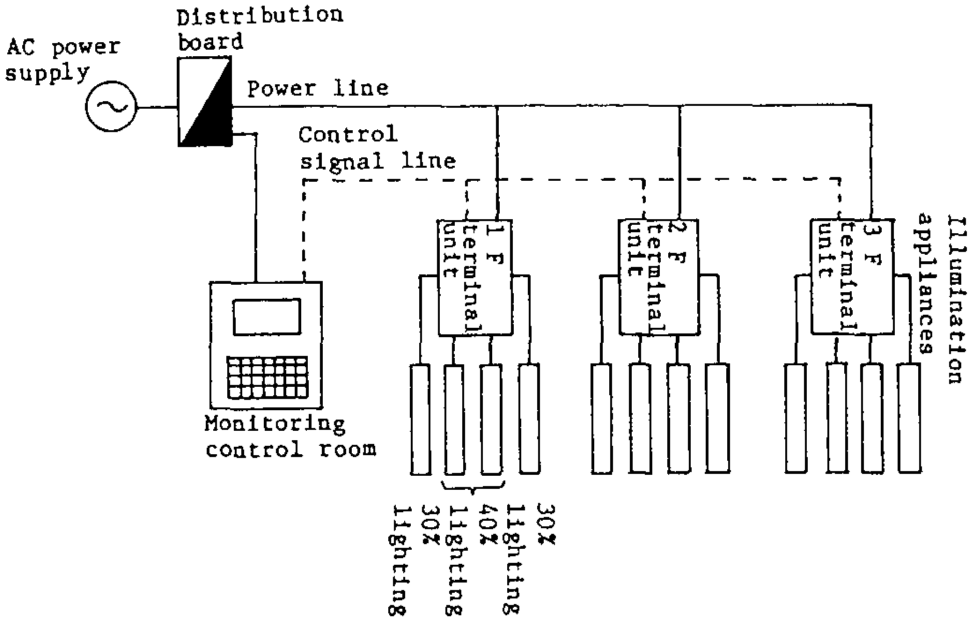


Fig. 9 System Wiring Diagram

(2) Control conditions

1) At the start of daily operations, necessary minimum 30% lighting was used in preparing for the opening of the supermarket. When the number of customers was small at the time of opening, up to 70% of lighting was used.
2) When the number of customers was large (3 to 6 p.m.), the illumination in the supermarket was increased enough for the customers to do their shopping easily.
3) Since the time of maximum crowdedness changes on weekends, the lighting adjustment time schedule was altered.
4) All illumination appliances were turned off after daily operations.

(3) Effect of electricity conservation

Because of these lighting adjustments, electricity consumption was reduced by about 28% in comparison with constant lighting.

Since the controller can be installed at a cost of 1,000,000 yen for a newly built store, the initial cost of equipment can be regained in about 9 months. Though the wiring needs to be altered, and, hence, costs are higher in applying, a controller to an established illumination system, the investment can be recouped in about 14 months.

Table 6 Effect of Electricity Conservation

(Electricity charge: 25 yen/kWh)

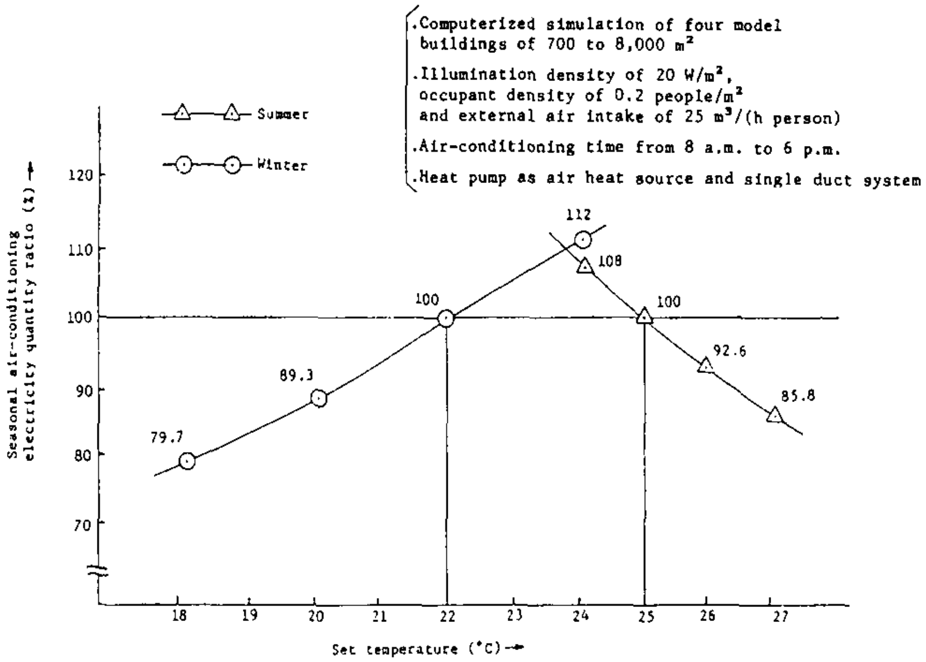
Electricity	Constant lighting	Time-schedule controlled lighting
Electricity quantity (kWh/week)	3,664 kWh	2,630 kWh
Electricity charge per year	4,776,000 yen	3,428,000 yen

2.3 Air-conditioning equipment

2.3.1 Reviewing temperature and humidity settings

In many cases, air-conditioning operates to maintain a room temperature of 24 to 25°C. Since excessive cooling or heating represents wasted energy, air-conditioning temperature and humidity settings should be reviewed.

Since human beings are more sensitive to changes in temperature than in humidity, in case of cooling, power consumption can be conserved by setting temperature slightly lower and humidity slightly higher. A 5% increase in relative humidity corresponds appropriately to a 1°C increase in temperature, due to the heating value of air. An example trial calculation suggests that the cooling load is reduced by about 8% if a set temperature is raised by 1°C. Fig. 10 shows the relation between the set temperature and air-conditioning power consumption in a building. It is understood from Fig. 10 that with a set temperature of 25°C each 1°C increment of the set temperature produces 7.0 to 7.5% savings of electricity consumption.



Origin: "Energy Conservation Book" by Kansai Electric Power Co., Ltd.

Fig. 10 Changes in Air-conditioning Energy Consumption due to Alternation of Set Temperature (Results of Joint Research with Maker)

2.3.2 Reduction in external air intake load

Fresh air must be introduced into a room as long as a person lives in it. However, cool air must be released due to the introduction of the fresh air when the room is cooled. Since the cooling load of such introduced external air accounts for 30% of all air-conditioning load, high energy conservation can be achieved by reducing the former load.

To attain this reduction, the introduced external air should be decreased by regulating a damper when few people are in the room.

Needless to say, it is best to regulate automatically the damper so that an allowable concentration limit (0.1%) of carbon dioxide gas is maintained in the room. Because of recent development of a total heat exchanger, heat exchange (humidity exchange as well) is possible between discharged air and introduced external air. As a result, it is common today to attach a total heat exchanger to newly provided air-conditioning equipment.

2.3.3 Reduction in cooling load

In a building with large window surfaces, the cooling load through solar radiation is so large that it accounts for 15 to 20% of total cooling load in some cases. Therefore, it is necessary for management to take steps such as raising the consciousness of employees to assure that blinds are shut when there is sunshine. The effect of screening sunlight with a blind is shown in Table 7.

Table 7 Proportion of Infiltrating Heat

Type		Proportion of infiltrating heat
Ordinary glass		1
Curtain	(Beige)	0.56
	(Green)	0.76
Blind	(Inside)	0.65
	(Outside)	0.15

2.3.4 Separation of heat sources

When a number of heat sources are installed in an air-conditioned room, the cooling load increases greatly. This is not limited to a plant where a heating furnace is used. In an office room, a large amount of heat is generated from illumination and office equipment. In such a case, it is required to separate the place of installation of such equipment from the air-conditioned room or collect the generated heat before it spreads to the surrounding and discharge it locally. Here, a large effect is expectable when the local discharge is combined with introduction of external air.

2.3.5 Cooling water control

Appropriate cooling water blowdown and chemical treatment are needed to prevent scaling, corrosion, slime deposition, etc., in the cooling water system.

2.4 Compressor

2.4.1 Review of set pressure

The required power of compressor varies greatly with the discharge pressure, as shown in Fig. 11. By reducing the discharge pressure by 1 kg/cm^2, the required power is decreased by about 6%. Therefore, it is important to set the pressure as close to an actually required air pressure as practicable. Such a method of feeding air of a high pressure and greatly reducing the pressure by a pressure reducing valve at the place of use should be avoided.

2.4.2 Adjustment of suction air

The required power of compressor varies greatly with the temperature and humidity of the suction air. The air inlet port should, therefore, be installed so that air of as low a temperature and moisture content as practicable would be taken in. In a compressor room where a number of compressors are operated, the room temperature is very high. In such a case, it is required to provide vent holes and prevent the room temperature from rising too high.

When the compressor room is constructed in a closed structure from the problem of noise, air inlet ports designed for sound insulation are provided, but in such case, care must be exercised of the places of installation of the inlets.

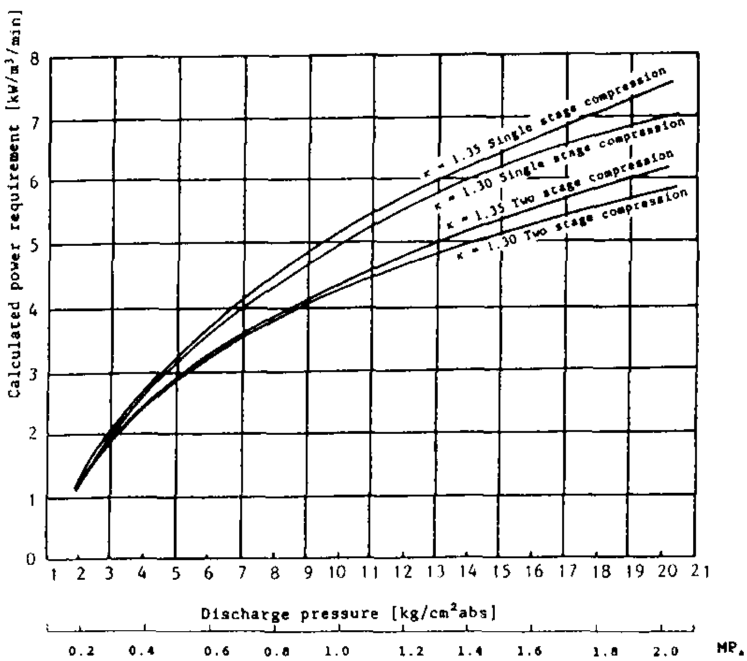


Fig. 11 Required Power of Air Compressor

2.4.3 Prevention of leak

Air leak from the piping and equipment is generally considerable, and in some case, it comes up to 30% of the air generated in the compressor. Particular care should be made for prevention of air leak, and it is required not only to immediately repair a leak when such is found but to make efforts to find out a leak through periodical inspection. The amount of air leak varies with the air pressure and the diameter of the hole through which air leaks, as shown in Fig. 12. As the leakage varies greatly with the air pressure, the pressure of feeding air should not be increased more than it is required.

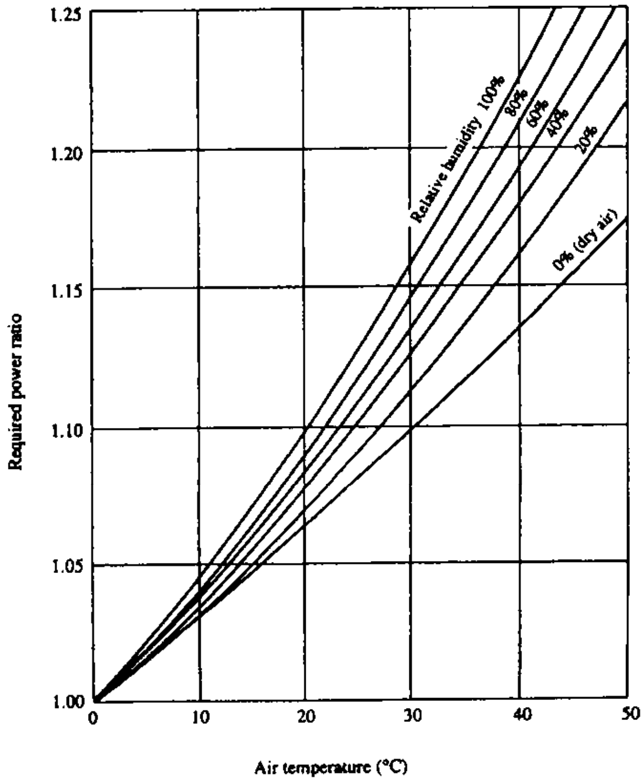


Fig. 12 Effect of Humidity on Compressor Power Requirement

2.4.4 Study of operation method

When the outlet pressure of the compressor reaches or exceeds certain pressure, it sets on the non-load operation, and when the lower limit pressure is reached, it also sets on the loaded operation. As considerable amount of electric power is consumed even during the non-load operation, stopping of the compressor should be considered if the time of non-load operation continues long.

Also, as the amount of electric power consumption during both loaded and non-load operations will differ by type of the compressor used, care should be taken so to operate making the best use of each type.

For example, the screw type compressor affords high efficiency under loaded condition, but under non-load condition, it consumes approx. 50% of electric power consumed during loaded operation. Whereas, the reciprocating compressor under the non-load state uses only approx. 20% of the electric power consumed during the loaded operation, though it is a little inferior in efficiency during loaded operation than the screw type. Therefore, an efficient operation may be attained when the screw type is operated continuously for securing the base load, and the reciprocating compressor is operated to cover the fluctuations.

2.4.5 Cooling water control

Scaling, corrosion, and slime deposition in the cooling water system would cause deterioration in cooling performance, requiring additional cooling water and pump power. Appropriate cooling water blowdown and chemical treatment are needed to prevent this.

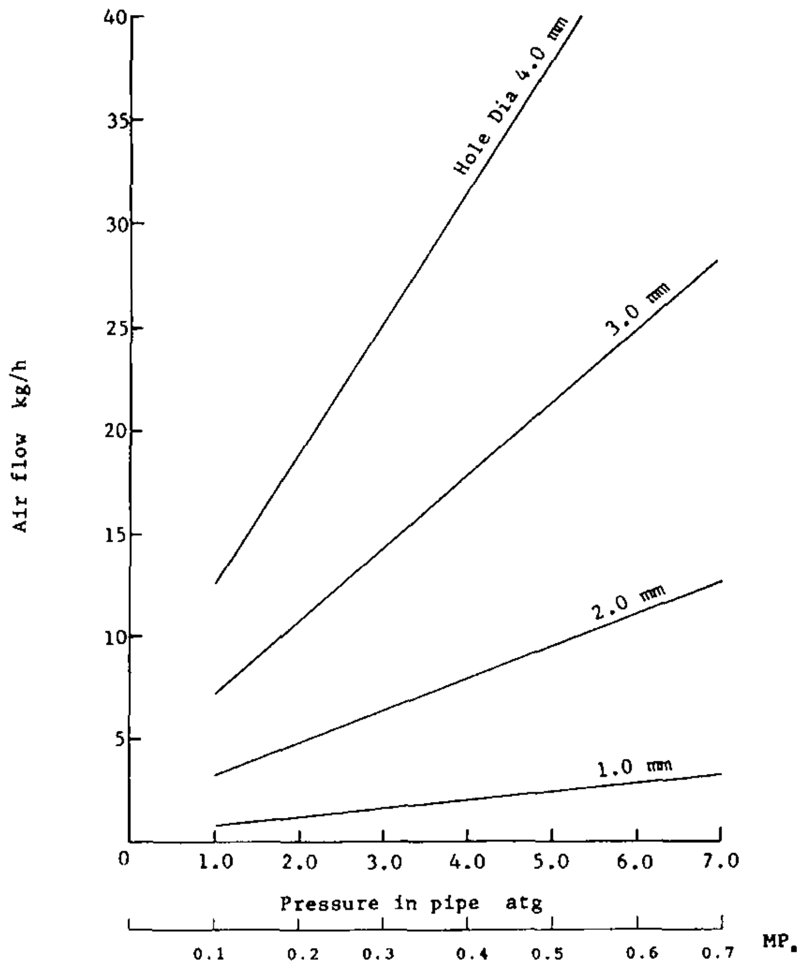


Fig. 13 Air Leakage from Hole (Flow Coefficient, 0.60)

Table8 Operational Conditions and Specifications of a Model Cooling Water System

Items	Operational conditions and specifications
Type of cooling tower	Induced draft cross flow type
Circulating water quantity (m^3/h)	3,000
Water temperature at inlet and outlet of cooling tower (°C)	43.6 and 32 (wet bulb temperature; 27°C)
Electric power of cooling tower fan	53 kW × 3 units
Electric power of water circulating pump	150 kW × 3 units
Evaporation loss (m^3/h)	60 (2% against circulating water quantity)
Windage loss (m^3/h)	3 (0.1% against circulating water quantity)
Holding water volume (m^3)	1,000
Duration of operation (h/year)	8,000
Heat exchanger	Tubular heat exchangers (4 paths) × 20 units
Heat transfer surface area	100 m^2/one unit × 20
Heat exchanger tube	Outer diameter. 19 mm Wall thickness: 2.2 mm. Length: 5 m Material: Carbon steel
Water flow rate inside the tube (m/s)	1.0
Water temperature at the outlet of heat exchanger (°C)	50 or less
Designed fouling factor (cooling water side) ($m^2 \cdot h \cdot °C/kcal$)	5×10^{-4}
Overall heat transfer coefficient (average)	500

Quality of make-up water

Turbidity (degree)	pH	Electrical conductivity (μS/cm)	M-alkalinity (mg $CaCO_3/l$)	Calcium hardness (mg $CaCO_3/l$)	Silica (mg $CaCO_3/l$)
5	6.8–7.8	200	50	50	30

Table 9 Estimated Operational Cost of the Model Cooling Water System (without Chemical Treatment)

Item		Operational cost		
		Cost (thousand yen/year)	Ratio against total cost (%)	
(1) Power cost	(a) Power cost for cooling tower fan	12,720	17	66
	(b) Power cost for water circulating pump	36,000	49	
(2) Make-up water cost		14,400	19	
(3) Cleaning cost of heat exchangers (water-jet cleaning)		3,000	4	
(4) Replacement cost of heat exchanger tubes		8,000	11	
Total cost		74,120	100	
Basis of cost estimation	Electric power cost (yen/kW)	10		
	Cycles of concentration	1.5		
	Make-up water coat (yen/m^3)	10 (Industrial water)		
	Cleaning cost of heat exchanger	1,500 thousands yen/20 units of heat exchangers for 2 times, per year		
	Replacement cost of heat exchanger tubes	1,200 thousands yen/100 m^3 of heat transfer area Heat exchanger tubes and baffle plates am changed every 3 years		

Table 10 Water Cost Saving by Applying a Chemical Water Treatment in the Model Cooling Water System

Chemical treatment	No	Yes
Circulating rate (m^3/h)	3,000	
Evaporation loss (m^3/h)	60	
Cycles of concentration	1.5	6.0
Total blowdown (m^3/h)	120	12
Maki-up water (m^3/h)	180	72
Make-up water consumption*1 (m^3/year)	1,440,000	576,000
Water cost*2 (10^3 yean/year)	14,400	5,750
Water cost saved (10^3 yean/year)	–	8,640

*1 Operation period: 8,000 h/year
*2 Water cost: 10 yen/m^3

Table 11 Cost of Cooling Water Treatment Chemicals

Cycles of concentration		6.0	
Total blowdown (m^3/h)		12	
Cost of corrosion and scale inhibitor (10^3 yean/year)		5,760	
Cost of chlorination (10^3 yean/year)		400	
Cost of non-oxidizing biocide (10^3 yean/year)		2,640	
Total cost (10^3 yean/year)		8,800	
Basis of cost estimation	Corrosion and scale inhibitor	Type	Phosphonate-polymer
		Unit price (yen/kg)	800
		Dosage (mg/*l*)	75*1
	Chlorine compound	Type	Sodium hypochlorite
		Unit price (yen/kg)	30
		Dosage (mg/*l*)	40
	Non-oxidizing biocide	Type	Organic bromine compound
		Unit price (yen/kg)	1,100
		Dosage (mg/*l*)	100/2 weeks

*1 Dosage against total blowdown

Table 12 An Example of the Operational Cost Saving of the Model Cooling Water System by Applying Water Treatment Chemicals (Comparison with the Case of No Chemical Treatment)

Item	Cost saving method	Saving ratio (%)	Amount of cost saving (10^3 yean/year)
(1) Power cost	(a) Control of fan rotating speed	74	9,400
	(b) Stoppage of one circulating pump	33	12,000
(2) Make-up water cost	(c) Application of chemicals (Increase of cycles of concentration: from 1.5 to 6.0)	60	8,640
(3) Cleaning cost of heat exchangers	(d) Application of chemicals (Reduction of cleaning frequency: from 2 times/year to once/year)	50	1,500
(4) Replacement cost of tube bundles	(e) Application of chemicals (Reduction of replacement frequency: from once/3 years to once/10 years)	70	5,600
(5) Cost saving	(a)+(b)+(c)+(d)+(e)	50	37,140
(6) Chemical cost (10^3 yean/year)	–	–	8,800
(7) Total cost saving	(5)–(6)	36	28,340

Promotion of Energy Conservation and Environment

If the consumption of fuels and electric power can be reduced by implementing energy conservation measures, the influence of the exhaust gas generated by the combustion of fuels on the environment can also be reduced. The reduction of fuel consumption directly lessens the influence of exhaust gas on the environment, and the reduction of electric power consumption indirectly lessens the influence on the environment. Among the components of exhaust gas, those which seriously affect the environment are the sulfur oxides (SOx) and nitrogen oxides (NOx) generated from solid and liquid fuels and the nitrogen oxides generated from gas fuels. Recently, in addition to them, carbon dioxide which is considered to be a causative substance of global warming attracts attention. Carbon dioxide is generated without fail as far as fossil fuels are used, but the amount of carbon dioxide emitted for the same generated calorific value is greatly different from fuel to fuel.

The generated amounts of these components contained in the exhaust gas depend on the fuel used and the amount of air used. If the fuel used is known, the respective amounts can be obtained by calculation.

1. Combustion calculation of solid and liquid fuels

Most of the elements of solid and liquid fuels are carbon and hydrogen, and in addition, small amounts of sulfur, oxygen and nitrogen are contained. If the masses of carbon, hydrogen, sulfur, oxygen and nitrogen contained per 1 kg of a fuel are respectively c, h, s, o and n kg, the amount of oxygen necessary for perfect combustion of the fuel and the amounts of respective components in the combustion gas generated by the combustion can be calculated as follows:

	C	+	O_2	=	CO_2	
(Mass)	12		32		44	kg
(Volume)			22.4		22.4	m_N^3

	4H	+	O_2	=	$2H_2O$	
(Mass)	4		32		36	kg
(Volume)			22.4		44.8	m_N^3

	S	+	O_2	=	SO_2	
(Mass)	32		32		64	kg
(Volume)			22.4		22.4	m_N^3

	$2N$	=	N_2	
(Mass)	28		28	kg
(Volume)			22.4	m_N^3

	$2O$	=	O_2	
(Mass)	32		32	kg
(Volume)			22.4	m_N^3

These formulae are based on an idea of burning the elements of the fuel by oxygen, but when a fuel is actually burned, the oxygen in air is used. So, the amount of air necessary for combustion must be obtained. The minimum amount of air necessary for complete combustion of a fuel is called the theoretical amount of air. Since the theoretical amount of air is the amount of air to cover the amount of oxygen calculated from these formulae, the theoretical amount of air can be calculated if the composition of oxygen contained in air is known.

Since the composition of oxygen contained in air is as shown in the following table, the theoretical amount of air can be expressed as follows:

Composition of dry air

Item	Volume		Mass	
	Composition	Ratio	Composition	Ratio
Nitrogen	79	3.76	76.8	3.31
Oxygen	21	1.00	23.3	1.00
Total	100	4.76	100.0	4.31

$$A_0 = \frac{1}{0.21}\left\{\frac{22.4}{12}c + \frac{22.4}{4}h + \frac{22.4}{32}s - \frac{22.4}{32}o\right\}$$

$$= \frac{1}{0.21}\left\{1.867\,c + 5.6\left(h - \frac{o}{8}\right) + 0.7\,s\right\}$$

$$= 8.89\,c + 26.7\left(h - \frac{o}{8}\right) + 3.33\,s \quad m_N^3/\text{kg-fuel}$$

If expressed by mass,

$$A_0 = \frac{1}{0.232}\{\frac{32}{12}c + \frac{32}{4}h + \frac{32}{32}s - \frac{32}{32}o\}$$

$$= \frac{1}{0.232}\{2.67\,c + 8\,(h - \frac{o}{8}) + s\}$$

$$= 11.49\,c + 34.5\,(h - \frac{o}{8}) + 4.31\,s \quad \text{kg/kg-fuel}$$

Since the theoretical amount of air calculated above is the minimum required amount, combustion with this amount of air will result in incomplete combustion. So, the actually supplied amount of air is obtained by multiplying the value by an air ratio.

$A = \mu A_0$

On the other hand, the combustion gas generated by combustion is the total of the CO_2, H_2O and SO_2 produced by the combustion of the respective combustible elements, and the nitrogen and extra oxygen in air. So, the amount of combustion gas can be expressed as follows:

$$G = \underset{N_2\,(\text{air})}{0.79\,\mu A_0} + \underset{O_2}{0.21\,(\mu - 1)\,A_0} + \underset{CO_2}{\frac{22.4}{12}c} + \underset{H_2O}{\frac{44.8}{4}h} + \underset{SO_2}{\frac{22.4}{32}s} + \underset{N_2\,(\text{fuel})}{\frac{22.4}{28}n}$$

$$= (\mu - 0.21)\,A_0 + 1.867\,c + 11.2\,h + 0.7\,s + 0.8\,n \quad m_N^3/\text{kg-fuel}$$

$$G = (\mu - 0.232)\,A_0 + 3.67\,c + 9\,h + 2\,s + n \quad \text{kg/kg-fuel}$$

The combustion gas contains the H_2O generated by the combustion of hydrogen, but since the exhaust gas is cooled to room temperature for analysis, the combustion gas without H_2O is analyzed. So, when it is necessary to distinguish them, the gas containing water is called wet combustion gas, and the gas without water is called dry combustion gas.

$$G' = (\mu - 0.21)\,A_0 + 1.867\,c + 0.7\,s + 0.8\,n \quad m_N^3/\text{kg-fuel}$$

The amounts of respective components contained in the combustion gas are mostly expressed as compositions by volume. The entire combustion gas can be either wet combustion gas or dry combustion gas. The compositions by volume of respective components of combustion gas are as follows:

	Dry combustion gas	Wet combustion gas
CO_2	$\frac{1.867\ c}{G'}$	$\frac{1.867\ c}{G}$
O_2	$\frac{0.21\ (\mu - 1)\ A_0}{G'}$	$\frac{0.21\ (\mu - 1)\ A_0}{G}$
SO_2	$\frac{0.7\ s}{G'}$	$\frac{0.7\ s}{G}$
N_2	$\frac{0.79\ \mu A_0 + 0.80\ n}{G'}$	$\frac{0.79\ \mu A_0 + 0.80\ n}{G}$
H_2O	—	$\frac{11.2\ h}{G}$

2. Combustion calculation of gas fuels

A gas fuel is carbon monoxide, hydrogen, methane, propane, butane or any of their mixtures. So, if the mixing ratio of each gas fuel is known, the theoretical amount of air and the amount of combustion gas can be calculated. The combustion equations of generally often used gas fuels are as follows:

(Methane)	CH_4	+	$2O_2$	=	CO_2	+	$2H_2O$
(Propane)	C_3H_8	+	$5O_2$	=	$3CO_2$	+	$4H_2O$
(Butane)	C_4H_{10}	+	$\frac{13}{2}O_2$	=	$4CO_2$	+	$5H_2O$

Since a gas fuel is usually calculated for a unit volume, the theoretical amount of oxygen and combustion products can be calculated simply by comparing the coefficients of the respective terms of each formula. That is, to burn 1 m^3 of methane, 2 m^3 of oxygen is necessary, and the combustion generates 1 m^3 of carbon dioxide and 2 m^3 of water vapor.

In the case of a gas fuel consisting of only one compound, the amount of air necessary for combustion and the amounts of combustion products can be immediately calculated from the corresponding combustion equation, and in the case of a gas fuel consisting of various compounds, they can be calculated using their mixing ratio. If the compositions by volume of hydrogen, carbon monoxide and a hydrocarbon of a gas fuel are (h_2), (co) and (c_mh_n), the theoretical amount of air is as follows:

$$A_0 = \frac{1}{0.21}\ \{\ 0.5\ (h_2) + 0.5\ (co) + \Sigma\ (m + \frac{n}{4})\ (c_mh_n) - (o_2)\ \}\quad m_N{}^3/m_N{}^3\text{-fuel}$$

The amount of combustion gas is the total of the carbon dioxide and water vapor generated by combustion, extra oxygen, nitrogen in air, and the incombustible gas in the fuel, and can be expressed as follows:

$$G = (\mu - 0.21)\ A_0 + (h_2) + (co) + \sum (m + \frac{n}{2})\ (c_m h_n) + (co_2) + (n_2) \quad m_N{}^3/m_N{}^3\text{-fuel}$$

3. Approximate calculation method

It is known that if the chemical composition of a fuel can be identified, the theoretical amount of air and the amount of combustion gas can be calculated, but actually in most cases, the chemical composition of the fuel is unknown. On the other hand, since the calorific value of a fuel can be easily measured and almost known, it is convenient if the theoretical amount of air and the amount of combustion gas can be calculated from the calorific value. Many approximate calculation methods are proposed, and a typical one is shown in the following table.

If the theoretical amount of air A_0 and the theoretical amount of combustion gas G_0 can be calculated from the lower calorific value H_l using the corresponding one of the following formulae, the actual amount of air and the actual amount of combustion gas can be calculated from the following formulae:

$$A = \mu A_0$$
$$G = G_0 + (\mu - 1)\ A_0$$

Approximate calculation formulae of G_0 and A_0 (Boie's formula)

Fuel	Theoretical amount of combustion gas (G_0)	Theoretical amount of air (A_0)
Solid fuel H_l: kcal/kg	$\frac{0.904\ H_l}{1000} + 1.67 \quad m_N{}^3/kg$	$\frac{1.01\ H_l}{1000} + 0.56 \quad m_N{}^3/kg$
Liquid fuel H_l: kcal/kg	$\frac{15.75\ H_l}{10000} - 3.91 \quad m_N{}^3/kg$	$\frac{12.38\ H_l}{10000} - 1.36 \quad m_N{}^3/kg$
Gas fuel H_l: kcal/$m_N{}^3$	$\frac{12.25\ H_l}{10000} \quad m_N{}^3/m_N{}^3$	$\frac{11.20\ H_l}{10000} \quad m_N{}^3/m_N{}^3$

(JIS B 8222-1986 Heat Balancing of Boilers for Land Use)

Approximate calculation formula of G_0 and A_0 (Rosin's formula)

Fuel	G_0	A_0
Solid fuel H_l: kcal/kg	$\frac{0.89\ H_l}{1000} + 1.65\ (m_N{}^3/kg)$	$\frac{1.01\ H_l}{1000} + 0.5\ (m_N{}^3/kg)$
Liquid fuel H_l: kcal/kg	$\frac{1.11\ H_l}{1000}\ (m_N{}^3/kg)$	$\frac{0.85\ H_l}{1000} + 2.0\ (m_N{}^3/kg)$
Gas fuel of lower calorific value (H_l = 500–3,000 kcal/$m^3{}_N$)	$\frac{0.725\ H_l}{1000} + 1.0\ (m_N{}^3/m_N{}^3)$	$\frac{0.875\ H_l}{1000}\ (m_N{}^3/m_N{}^3)$
Gas fuel of higher calorific value (H_l = 4,000–7,000 kcal/$m^3{}_N$)	$\frac{1.14\ H_l}{1000} + 0.25\ (m_N{}^3/m_N{}^3)$	$\frac{1.09\ H_l}{1000} - 0.25\ (m_N{}^3/m_N{}^3)$

(From " 7th Revised Edition Lectures on Heat Control Techniques)

4. Emissions of environmental pollutants

4.1 Carbon dioxide (CO_2)

The generation of carbon dioxide can be calculated if the kind of the fuel can be identified, and in the case of a solid or liquid fuel, it is

1.867 c m_N^3 by volume and 3.67 c kg by mass

In general, the generation of carbon dioxide is expressed by its mass. Furthermore, it is actually not the amount of carbon dioxide but the mass of carbon in the carbon dioxide which is called the amount of carbon dioxide in terms of carbon. If the amount of carbon is used for expression, the amount of carbon in the generated carbon dioxide is equal to the amount of carbon contained in the fuel, and is c kg per 1 kg of the fuel. So, calculation is very easy.

On the other hand, in the case of a gas fuel, both the fuel consumption and the generation of carbon dioxide are often expressed by volume as reference values for combustion calculation. So, to allow comparison with the amount of carbon dioxide generated from another fuel, the mass of carbon dioxide or the mass in terms of carbon must be calculated. If the amount of carbon dioxide generated per 1 m_N^3 of a fuel is v m_N^3,

the mass of carbon dioxide is $\frac{44}{22.4}v = 1.964$ v kg, and

the mass in terms of carbon is $\frac{12}{44} \times 1.964\ v = 0.536$ v kg

4.2 Sulfur oxides (SOx)

The sulfur oxides generated by the combustion of a sulfur-containing fuel are the SO_2 and SO_3 produced by partial oxidation of SO_2. However, since the generation of SO_3 is very small, all the sulfur oxides can be considered as SO_2 only. So, the generation of sulfur oxides is

0.7 s m_N^3 by volume and 2 s kg by mass.

Furthermore, the composition by volume of sulfur oxides in an exhaust gas is as follows:

$$\frac{0.70s}{G'}$$

4.3 Nitrogen oxides (NOx)

A combustion gas contains the nitrogen gas generated by burning the nitrogen content of a fuel and the nitrogen contained in the air used for combustion. The nitrogen is partially oxidized in the process of combustion, to produce NO and NO_2, and these are generally called nitrogen oxides. Since the rate of NO_2 in the nitrogen oxides is about 10%, the nitrogen oxides are generally considered as NO only.

The NOx generation mechanism by the nitrogen in the fuel is greatly different from that by the nitrogen in the air used for combustion. So, they are distinguished, and the former is called fuel NOx, while the latter is called thermal NOx. All the nitrogen contained in a fuel does not become fuel NOx, and the conversion rate comes into question. The conversion rate is higher when the nitrogen concentration of the fuel is lower and when the air ratio of combustion is higher, and is generally 20 to 60%. The generation of NO at a conversion rate of 100% can be calculated using the following formula:

$$N_2 + O_2 = 2NO$$

28 kg   60 kg

  $44.8\ m_N^3$

The generation of NO per 1 kg of fuel is

$1.60\ n\ m_N^3$ by volume and 2.14 n kg by mass.

Thermal NOx is very complicated in generation mechanism, and simple calculation is difficult. It is known that the maximum temperature of the combustion gas and the temperature history in the process of combustion greatly affect the generation of thermal NOx.

The generation of nitrogen oxides can be expressed by the composition by volume in the exhaust gas, as follows:

$$\frac{1.60n}{G'}$$

The amount of generation expressed in this manner becomes a smaller value when combustion is made at a larger air ratio. So, when the amounts of generated nitrogen oxide are compared as composition by volume, they are converted into the values of a certain air ratio. Since the air ratio can be calculated from the composition by volume of oxygen in the exhaust gas, the following formula is used for converting the measured rate Rm by volume of nitrogen oxides into the rate Rs by volume of the reference air ratio:

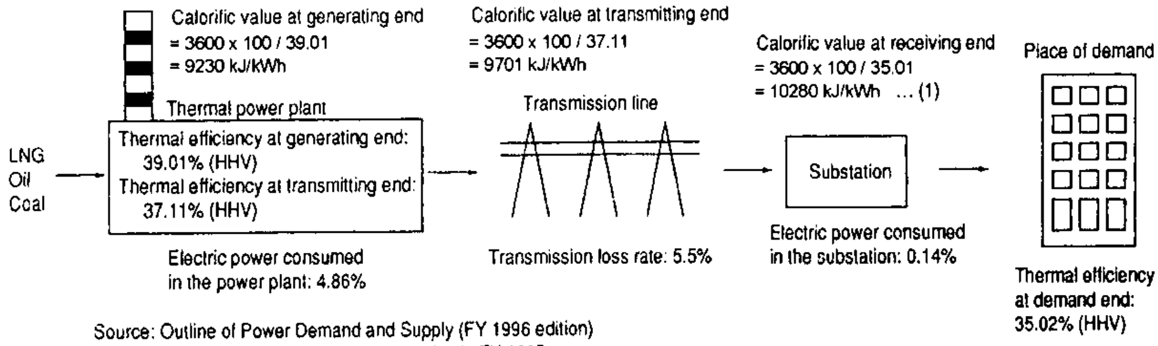
$$Rs = \frac{21 - (O_2)s}{21 - (O_2)m} Rm$$

where suffix s refers to reference, and m, measurement.

In the case of electric power, the electric energy is converted into the amount of crude oil as follows. For calculation of emissions of CO_2, NOx and SOx, we generally use the following factor.

10 MWh = 2.65 kl

In this case, the higher heating value of crude oil is assumed to be 38.7 MJ/l (9,250 kcal/l). The reason why these values are used is explained in the following figure.



Source: Outline of Power Demand and Supply (FY 1996 edition)
Data of nine electric power companies in FY 1995

From (1), the relation between the equivalent crude oil consumption per 10 MWh of generated energy and the generated energy per 1 kl of crude oil is as follows:

Calorific value of crude oil: 38.7 MJ/l (9,250 kcal/l)

- Equivalent crude oil consumption per 10 MWh of generated energy is

$$10\ \text{MWh} \times \frac{10280\ \text{MJ / MWh}}{38.7\ \text{MJ / l}} = 2.65\ \text{kl} \qquad \left(10\ \text{MWh} \times \frac{2450\ \text{kcal / kWh}}{9250\ \text{kcal / l}} = 2.65\ \text{kl} \right)$$

- The generated energy per 1 kl of crude oil is

$$1\ \text{kl} \times \frac{38.7 \times 10^3\ \text{MJ / kl}}{10280\ \text{MJ / MWh}} = 3.77\ \text{MWh} \qquad \left(1\ \text{kl} \times \frac{9250\ \text{kcal / kl}}{2450\ \text{kcal / kMh}} = 3.77\ \text{MWh} \right)$$

Relation between equivalent crude oil consumption and generated energy

Cogeneration

Because of its enormous potential, it is important to understand and apply cogeneration theory. In the overall context of Energy Management Theory, cogeneration is just another form of the conservation process. However, because of its potential for practical application to new or existing systems, it has carved a niche that may be second to no other conservation technology.

1. Definition of "Cogeneration"

Cogeneration is the sequential production of thermal and electric energy from a single fuel source. In the cogeneration process, heat is recovered that would normally be lost in the production of one form of energy. That heat is then used to generate the second form of energy. For example, take a situation in which an engine drives a generator that produces electricity: With cogeneration, heat would be recovered from the engine exhaust and/or coolant, and that heat would be used to produce, say, hot water.

Making use of waste heat is what differentiates cogeneration facilities from central station electric power generation. The overall fuel utilization efficiency of cogeneration plants is typically 70%–80% versus 35%–40% for utility power plants.

This means that in cogeneration systems, rather than using energy in the fuel for a single function, as typically occurs, the available energy is cascaded though at least two useful cycles.

To put it in simpler terms: Cogeneration is a very efficient method of making use of all the available energy expended during any process generating electricity (or shaft horsepower) and then utilizing the waste heat.

A more subjective definition of cogeneration calls upon current practical applications of power generation and process needs. Nowhere more than in the United States is an overall system efficiency of only 30% tolerated as "standard design." In the name of limited initial capital expenditure, all of the waste heat from most processes is rejected to the atmosphere.

In short, present design practices dictate that of the useful energy in one gallon of fuel, only 30% of that fuel is put to useful work. The remaining 70% is rejected randomly.
If one gallon of fuel goes into a process, the designer may ask, "How much of that raw energy can I make use of within the constraints of the overall process?"

In this way, cogeneration may be taken as a way to use a maximum amount of available energy from any raw fuel process. Thus, cogeneration may be thought of as *just good design*.

2. Components of a Cogeneration System

The basic components of any cogeneration plant are

- A prime mover
- A generator
- A waste heal recovery system
- Operating control systems

The prime mover is an engine or turbine which, through combustion, produces mechanical energy. The generator converts the mechanical energy to electrical energy. The waste heat recovery system is one or more heat exchangers that capture exhaust heat or engine coolant heat and convert that heat to a useful form. The operating control systems insure that the individual system components function together.

The prime mover is the heart of the cogeneration system. The three basic types are steam turbines, combustion gas turbines and internal combustion engines. Each has advantages and disadvantages, as explained below.

2.1 Steam turbines

Steam turbine systems consist of a boiler and turbine. The boiler can be fired by a variety of fuels such as oil, nature gas, coal and wood. In many installations, industrial by-products or municipal wastes are used as fuel. Steam turbine cogeneration plants produce high-pressure steam that is expanded through a turbine to produce mechanical energy which, in turn, drives a device such as an electric generator. Thermal energy is recovered in several different ways. Steam turbine systems generally have a high fuel utilization efficiency.

2.2 Combustion gas turbines

Combustion gas turbine systems are made up of one or more gas turbines and a waste heat recovery unit. These system are fueled by natural gas or light petroleum products. The products of combustion drive a turbine which generates mechanical energy. The mechanical energy can be used directly or converted to electricity with a generator. The hot exhaust gases of the gas turbine can be used directly in process heating applications, or they can be used indirectly, with a heat exchanger, to produce process steam or hot water.

A variation on the combustion gas turbine system is one that uses high-pressure steam to drive a steam turbine in conjunction with the cogeneration process. This is referred to as a combined cycle.

2.3 Internal combustion engines

Internal combustion engine systems utilize one or more reciprocating engines together with a waste heat recovery device. These are fueled by natural gas or distillate oils. Electric power is produced by a generator which is driven by the engine shaft. Thermal energy can be recovered from either exhaust gases or engorge coolant. The engine exhaust gases can be used for process heating or to generate low-pressure steam. Waste heat is recovered from the engine cooling jacket in the form of hot water.

Cogeneration plants that use the internal combustion engine generate the greatest amounts of electricity for the amount of heat produced. Of the three types of prime movers, however, the fuel utilization efficiency is the lowest, and the maximum steam pressure that can be produced is limited.

3. An Overview of Cogeneration Theory

As discussed in the introduction, and as may be seen from Figure 1, standard design practices make use of, at best, 30% of available energy from the raw fuel source (gas, oil, coal).

Of the remaining 70% of the available energy, approximately 30% of the heat is rejected to the atmosphere through a condenser (or similar) process. An additional 30% of the energy is lost directly to the atmosphere through the stack, and finally, approximately 7% of the available energy is radiated to the atmosphere because of the high relative temperature of the process system.

With heat recovery, however, potential useful application of available energy more than doubles. Although in a "low quality" form, all of the condenser-related heat may be used, and 40% of the stack heat may be recovered. This optimized process is depicted (in theory) as Figure 2.

Thus, it may be seen that effective use of all available energy may more than double the "worth" of the raw fuel. System efficiency is increased from 30% to 75%.

This higher efficiency allows the designer to use low grade energy for various cogeneration cycles.

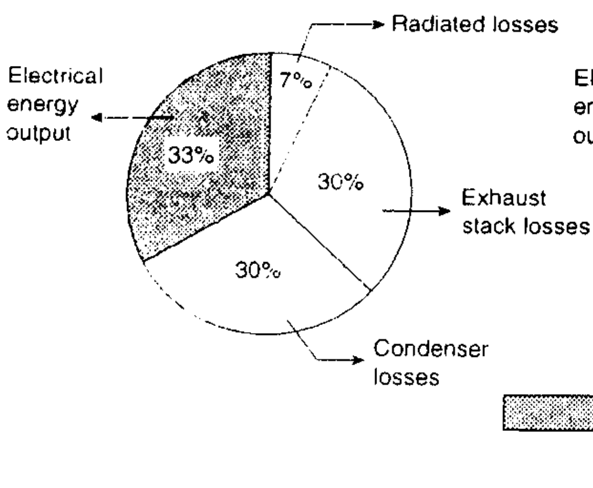


Fig. 1 Energy Balance without Heat Recovery

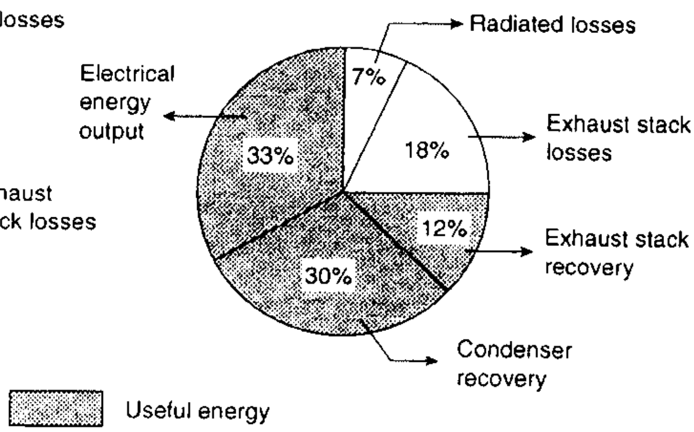


Fig. 2 Energy Balance with Heat Recovery

ENERGY CONSERVATION TECHNOLOGIES IN THE INDUSTRIAL SECTOR

1) Method of Promote Energy Conservation Measures

① Target Setting and Planning (P1)

Abstract target, specific target, absolute target, relative target

② Analysis of Present Situation (P2)

Energy consumption pattern, energy consumption unit, correlation between production volume and energy consumption unit, energy flow diagram, heat balance, waste heat pattern, necessary energy potential level, monetary value.

③ Drafting of Improvement Plan (P8)

Collection of ideas, compilation into improvement plan, evaluation of plan.

④ Implementation of Improvement Plan (P9)

2) Practice Energy Conservation Measures

① Daily Operation

Combustion management (low air ratio)(P10, 35)
Furnace internal pressure (P15)
Furnace appropriate temperature (P15)
Fuel management (P30~34)
(quality, quantity, temperature)
Feed water management (P36~
Steam pressure(P44) Air pressure (P71)
Load management (P53~)

Voltage management (P57)
Power factor management (P57~)
No load and light load operation (P62~)
(Q-RECS......plant operation)
Tern- off of unnecessary lamp (P67)
Air conditioning setting, etc (P69~)
(temperature, humidity)
Cooling water control (P73, 71)

② Daily Maintenance

Burner management(capacity size cleaning)(P14)
Boiler cleaning, filling crack(boiler) (P30)
Feed water management (P36~)
Piping management (P40~)

Steam trap management (P44~)
Lighting equipment(cleaning etc) (P67)
Prevention of leak(steam, air,gas) (P72)
meter, sensor Maintenance (P2, 35)

③ Implementation of Improvement Plan

Furnace wall thermal insulation (P17)
Heat recovery from exhaust gas (P21)
Recovery of steam condensate (P47~)
Power factor management (P59~)

Management of distribution loss (P60)
Selection of suitable motor,etc (P61)
Speed control,(P64) Q-RECS
Lighting improvement (P67~)

High efficiency machine (motor, compressor, cogeneration, others) (P62, 72, 86)

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