3. Guideline for Energy Efficiency Improvement and Conservation for Specified Industries and Commercial Buildings

3.1 Common Technology

3.1.1 Energy Conservation for Lighting

(1) Terms and Unit of Lighting

1) Luminous Flux

A light source radiates various wavelength energies. Among these, only the energy levels between wavelengths 380 and 780 nm can be sensed by the human eye as light. The amount of radiant energy that passes through a given plane in unit time is called radiant flux. The amount of radiant flux passing through a filter that has the sensitivity of the human eye (luminosity factor) is called luminous flux. Luminous flux is expressed in lumens (lm).

2) Luminous Intensity

Even when light is radiated in all directions from a light source, the strength of light often varies depending on the direction. Luminous intensity is used to express the strength of light in such a direction and is given by the luminous flux per unit solid angle in a given direction. Luminous intensity is expressed in candela [cd].

3) Illuminance

Illuminance is used to express the degree of brightness of a surface illuminated by a light source. It is given by the incoming beams per trait area. Illuminance is expressed in lux (lx).

4) Luminance

Some light sources radiate brighter than others when viewed. This happens because the amount of light that enters the eye from each portion varies. Luminance is the amount of light corresponding to the brightness sensed by the human eye looking at an object. The luminance in a given direction at a specific point on a luminescent plane is calculated by dividing the luminous intensity in a given direction of an extremely small area, including this point, by a projected area in this direction. Luminance is expressed in candela per square meter (cd/m^2).

5) Luminous Exitance

Luminous exitance is the degree of brightness sensed by the human eye. It is given by the luminous flux emitting from a unit area. Luminous exitance is expressed in lumens per square meter (Im/m^2).

6) Distribution of Luminous Intensity

The distribution of luminous intensity for each direction of a light source or luminaire is called light distribution. The curve that expresses the luminous intensity distribution of light radiated in all directions in a space from the center of a light source or the light measuring center of the luminaire is called the luminous intensity distribution curve.

(2) Color Temperature and Color Rendering Properties of a Light Source

1) Color Temperature

When a blackbody (ideal radiator) is heated and its temperature increases, it starts emitting light. This light has a dependence on the surface temperature of the blackbody, and the luster increases as temperature increases. The color gradually turns whiter from red. The color will change in the following manner: red → yellowish red → white → bluish white. The color temperature of alight source is expressed by the absolute temperature (K: Kelvin) of a black-body when the color of the light of this body equals the apparent color of the light of a specific light source.

2) Color Rendering Properties

If the composition of the lighting varies, the composition of the light reflected from an identical object also varies. As a result, the color will be different. The influence of lighting made on the appearance of the color of an object is called color rendering. The color rendering index is used as a scale to determine whether the color rendering of a light source is good or poor. The color rendering index is a numeric value obtained by comparing the appearance of the selected 8 types of test colors among 15 types produced by a lamp with that produced by a standardized light source (the color temperatures of both lamp and light source are the same), and expresses the difference hr color. The average color rendering index Ra is calculated and expressed by an average value of the color difference in an individual test color with 8 hues (the middle brightly colored hues with equal brightness) among the 15 types of test colors.

(3) Light Source

1) Performance Factors of Light Source

Au incandescent lamp, fluorescent lamp and High Intensity Discharge (HID) lamp are used as light sources for general-purpose lighting. (HID lamp is a generic name for high-pressure mercury lamps, metal halide lamps and high-pressure sodium lamps.) Table 3.1.1-1 summarizes the main factors that indicate the performance of these light sources.

a) Incandescent Lamp
The current is passed along the filament in a bulb to heat it to 2,000°C or more. Thus, the lamp utilizes the luminescence produced by thermal radiation to give light.

b) Fluorescent Lamp
The ultraviolet rays (mainly the wavelengths of 253.7 nm and 185 nm) radiated by electric discharge in low-pressure (0.6 - 0.8 Pa) mercury vapor excite the luminophor and the light is converted into visible light. The lamp gives off this visible light.

There are a Hf fluorescent light and a compact fluorescent lamp (CFL) with the electronic stabilizer other than a fluorescent light with a glim lamp starter. A Hf fluorescent light has an electronic stabilizer which changes the commercial frequency of 50Hz, or 60Hz into the high frequency electric power of 30 to 70 Hz by the transistor inverter circuit. A CFL is an electric bulb form fluorescent light united with the high frequency lighting electronic stabilizer. A CFL sectional view is shown in Figure 3.1.1-1.

c) High-pressure Mercury Lamp
A high luminance discharge lamp which gives off light radiated by an arc discharge in a mercury vapor atmosphere of 100 kPa or more.

d) Metal Halide Lamp
A high luminance discharge lamp utilizing a unique metal structure which gives off Tight radiated by an arc discharge in a vapor of a metal halogen compound (iodide compounds such as sodium, thallium, indium, scandium, dysprosium, and tin used singly or in a combination).

e) High-pressure Sodium Lamp
A high intensity discharge lamp that gives off light radiated by arc discharge in a sodium vapor of approximately 10 kpa.

f) Low-pressure Sodium Lamp
A hot cathode discharge lamp which gives off light of yellowish orange D rays (589.0 nm and 589.6 nm) radiated by au arc discharge in sodium vapor of approximately 0.5 Pa. The efficiency of this lamp is highest among practical light sources. The color rendering properties of this lamp are extremely poor because of the single light color (yellowish orange). It is not possible to identify colors under this light.

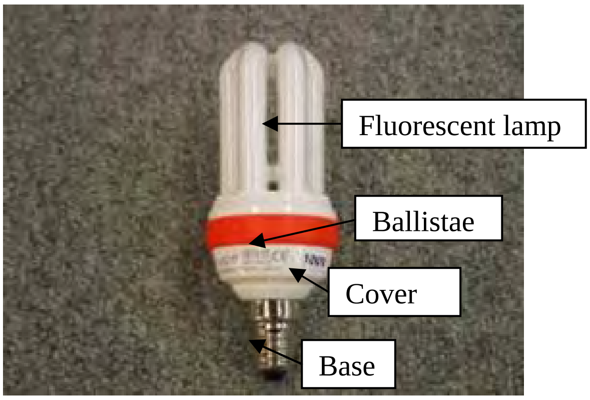


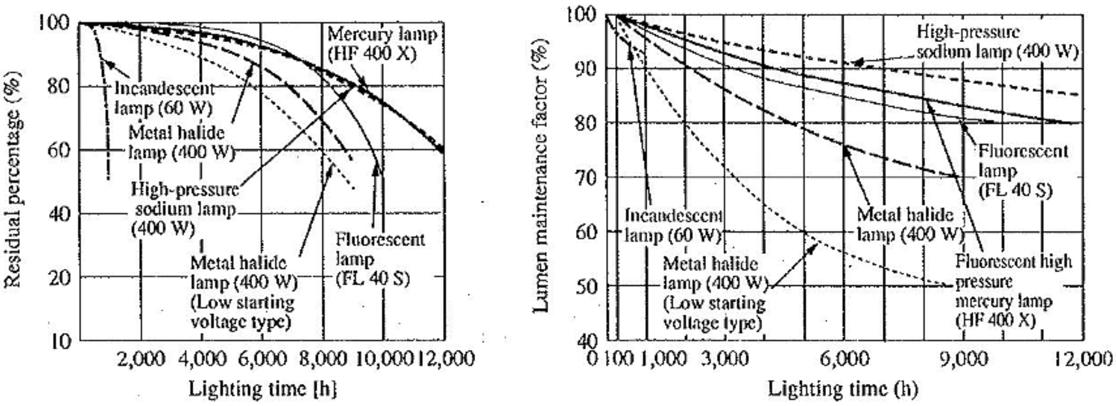
Figure 3.1.1-1 Compact Fluorescent Lamp

Table 3.1.1-1 Performance Factor of Light Source

Element	Description
1. Total luminous flux	The amount of light radiated from a light source per unit time. Unit: 1m
2. Lamp efficiency	Value obtained by dividing the toral luminous flux of a light source (lamp) by the input power of a lamp. Unit: 1m/W
3. Overall efficiency	Value obtained by dividing the total luminous flux of a light source (lamp) by the input power of a lamp and a lighting circuit. Unit: 1m/W The loss of input power is 5 to 20% depending on the type of lighting circuit.
4. Light color	The color temperature (K) serves as a guide. The color of an incandescent lamp is approximately 2,850K, and that of a daylight is approximately 6,500K.
5. Color rendering properties	Expressed by the color rendering index Ra. A lamp whose Ra value is closer to 100 has better color rendering properties.
6. Luminance	When a lamp has high luminance, it will affect glare. Unit: cd/m^2
7. Life	The period until the life of a light ends or until the luminous flux drops below the specified value, whichever comes first. The rated life indicated by a manufacturer means average life when a number of light sources are used under normal conditions.
8. Lumen maintenance factor	A value (%) obtained by dividing the luminous flux value of the rated life period by the initial luminous flux value.
9. Starting characteristics	Indicated the initial startup state of lighting. The luminous flux of an incandescent lamp and fluoreseent lamp stabilizes comparatively fast. However, it takes several minutes or more until the Juminous flux oa a HID lamp becomes stable.
10. Dimming	Dimming may be necessary for power saving. Incandescent and fluorescent lamps can be dimmed in a continuous dimming operation. A mercury lamp and high-pressure sodium lamp can be dimmed stepwise only.

2) Comparison of Characteristics of Various Light Sources

Incandescent, fluorescent, high-pressure mercury, metal halide, and high-pressure sodium lamps are used as general-purpose light sources. These light sources Have individual characteristics and must be selected after considering the purpose and application of lighting. As a reference for proper selection of a light source, Table 3.1.1-2 provides the comparison table of various light sources while Figure 3.1.1-2 lists their applications.



(a) Residual percentage curves of various light sources

(b) Lumen maintenance characteristics of various light sources(based on 100-hour lighting as 100 % for lamps other than incandescent lamps)

Figure 3.1.1-2 Life Characteristics of Various Light Source

Table 3.1.1-2 Comparative Example of the Characteristics of Various Light Source

Type of light source		Lamp Power (W)	Total luminous flux [1] (lm)	Lamp efficiency (lm/W)	Overall efficiency [2] (lm/W)	Color temperature (K)	Average color rendering index (Ra)	Life (h)
Incandescent lamps	White coated lamp	100	1,520	15.2	15.2	2,850	100	1,000
	White thin film coated lamp*	95	1,520	16.0	16.0	2,850	100	1,000
	White coated ball lamp	100	1,370	13.7	13.7	2,850	100	2,000
	Floodlighting tungsten halogen lamp	500	10,500	21.0	21.0	3,000	100	2,000
	Small tungsten halogen lamp	500	9,500	19.0	19.0	3,000	100	2,000
Fluorescent lamps	Fluorescent lamp White	40	3,100	78	61	4,200	64	12,000
	Fluorescent lamp High color rendering	40	2,400	60	47	5,000	92	12,000
	Fluorescent lamp* White	37	3,100	84	67	4,200	64	12,000
	Fluorescent lamp* 3 wavelength zone luminescence type	37	3,350	91	73	5,000	84	12,000
	Rapid start fluorescent lamp White	40	3,000	75	59	4,200	64	12,000
	Rapid start fluorescent lamp High color rendering	40	2,380	60	47	5,000	92	12,000
	Rapid start fluorescent lamp 3 wavelength zone luminescence type	40	3,450	79	68	5,000	88	12,000
	Rapid start fluorescent lamp* White	36	3,000	83	65	4,200	64	12,000
	Compact type fluorescent lamp (Dual-tube type) 3 wavelength zone luminescence type	36	2,900	81	67	5,000	88	7,500
	Bulb type fluorescent lamp (ball shape) Bulb color	17	760	45	45	2,800	82	6,000
	Hf-fluorescent lamp (Dedicated lamp for high frequency lighting)	32	3,200	100	84	5,000	88	12,000
HID lamp	Mercury lamp Transparent	400	20,500	51	48	5,800	23	12,000
	Fluorescent mercury lamp	400	22,000	55	52	4,100	44	12,000
	Mercury lamp with built-in ballast stabilizer	500	14,000	28	28	4,200	57	9,000
	Metal halide lamp Diffusion type	400	32,000	80	76	5,000	65	9,000
	Metal halide lamp, lower starting voltage type Diffusion type	400	38,000	95	87	3,800	70	9,000
	Metal halide lamp High color rendering	400	19,000	48	41	5,000	92	6,000
	High-pressure sodium lamp Diffusion type	400	50,000	125	111	2,100	25	12,000
	High-pressure sodium lamp, high color rendering type Diffusion type	400	21,500	54	48	2,500	85	9,000
	High-pressure sodium lamp, with built-in starter* Diffusion type	360	48,500	135	121	2,100	25	12,000
	High-pressure sodium lamp, improved color rendering type* Diffusion type	360	36,000	100	90	2,100	60	12,000
	Lower-pressure sodium lamp	180	31,500	175	140	-	-	9,000

Lamps marked with an asterisk (*) have a power-saving design.

*1: The total luminous flux for an incandescent lamp indicates a zero-hour value; that for other lamps indicates a 100-hour value.

*2: Indicates the efficiency including the ballast stabilizer loss. The calculation is performed assuming that the ballast stabilizer is a 200 V single-lamp high-power-factor model.

(4) Factory Lighting

1) Purpose of Factory Lighting

Good lighting facilitates various visual operations and has the following effects:

a) Improved operation efficiency
Proper illuminance diminishes nerve strain, reduces defective products and improves the operation efficiency.

b) Improved operation safety
Since things can be clearly seen and the visual range is widened, employees are careful for their operation and airy disasters due to mistakes, etc. can be prevented.

c) Thorough shop management
It becomes easier to point out any defects in the operation and shop, morale for proper arrangement and environmental hygiene is enhanced, and management for the operation and equipment, etc. can be thoroughly achieved.

d) Improved operator's morale
A shop with a well-ordered working environment including lighting enhances the employees' pride and responsibility for their appointed tasks, and excites their desire to work.

2) Good Factory Lighting

Good factory lighting has the following factors:

- Proper illuminance and illuminating distribution
- Free from flickering and glare
- Color rendering properties of light source should not be exceedingly improper.
- Good economical efficiency

For proper luminance, the necessary value is determined by content of the operation, size of the object and color, etc. Values specified in Table 3.1.1-3 are recommended as illuminance standard values in Indonesia. For the aged, these standard values should be somewhat increased.

Table 3.1.1-3 Illumination Standard for Factory and Building in Indonesia

Function of room	Intensity of Light (Lux)	Function of room	Intensity of Light (Lux)
Offices:		**Shops/ showrooms**	
Director's office	350	Showrooms showing large objects (such as cars)	500
Work space	350	Bakery and food shop	250
Computer room	350	Flower shop	250
Meeting room	300	Book and stationery store	300
Drawing room	750	Jewellery and watch store	500
File storage	150	Leather goods and shoe store	500
Active file room	300	Clothing store	500
Hotels and Restaurants		Supermarket	500
Lobby, corridors	100	Toy store	500
All purpose room	200	Electronic goods store (TV, Radio/tape, washing machine etc.)	250
Dining room	250	Music and sport store	250
Cafeteria	200	**Industry (General)**	
Bedroom	150	Warehouse	100
Kitchen	300	Rough works	100 ~ 200
Hospital/ clinic		Medium works	200 ~ 500
Treatment room	250	Delicate works	500 ~ 1000
Operating room, maternity ward	300	Extra delicate works	1000 ~ 2000
Laboratory	500	Colour inspection	750
Recreation and rehabilitation room	250		

Source: Indonesia National Standard SNI03-6197-2000

(5) Concrete Measure for Energy Conservation

1) Reduce the Lighting Time

Concrete measure: are:

a) Lights-oat while unnecessary, including lunch breaks
b) Individual lights-out near windows
c) Provide an adequate number of switches for individual lights-out.
d) Lights-out in quiet areas (without personnel)
e) Adopt automatic switches or timer switches for outdoor lamps.
f) Provide a device to detect a vehicle coming in or going out of the unmanned warehouse,

etc. in order to allow a light to be automatically turned on or off. In any case, these countermeasures much depend upon the employees' consciousness and therefore, it is necessary to endeavor to enhance it.

2) Reduce the Distribution Line loss

Since the distribution line loss greatly varies with the distribution system, it is desirable to compare and study well fur determination when establishing new equipment. Besides, to increase voltage level in the distribution line and to improve power factor, etc. must be studied.

3) Keep the Illuminance Proper

Although it is of course important to secure illuminance required for the operation, it is important for energy conservation to reexamine the lighting level and provide local lighting for passages, places where persons do not much enter and outdoor lighting. etc. Also, when establishing a new factory, adoption of natural daylight should be positively considered.

4) Use High-efficient Luminaries

Luminaries here mean ballasts, lamps and light reflectors.

To diminish the distribution line size, the starting current should be smaller, and to reduce the distribution line loss, the power factor should be higher. However, the weight and cost increases in inverse proportion to these and, therefore, it is necessary to study the economical efficiency.

5) Improving Utilization Factor

The utilization factor means the ratio of the luminous flux entering the work area to the total luminous flux going out of the lamp. It varies depending on the installation location of a luminary, the room condition, etc. Room index RI in this table is calculated in the following equation:

$$RI = \frac{(W \times L)}{H(W + L)}$$

Where

W: Width of room (m)

L: Depth of room (m)

H: Height of light source from the working plane (m)

The room index has a higher value when it is a square morn. And the utilization factor will be higher with the higher reflectivity of the inner wall and floor and the higher room index.

6) Improving Maintenance Factor

The maintenance factor means the estimated rate of the initial luminous flux lowering due to dirt on the luminaries with the passage of the working time. To improve the maintenance factor, firstly adopting luminaries with less lowering of luminous flux with the passage of the working time and secondly periodical cleaning of the luminaries and replace the lamps. However, under the actual circumstances of the factory with much expenditure in labor cost, it will be unavoidable to replace the lamps and clean the luminaries when the lamps are burnt out. Therefore, the first countermeasure is to use luminaries with less lowering luminous flux.

Figure 3.1.1-3 and Figure 3.1.1-4 show the lowering tendency of the luminous flux of lamp itself and the lowered luminous flux when dirt accumulates on luminaires respectively.

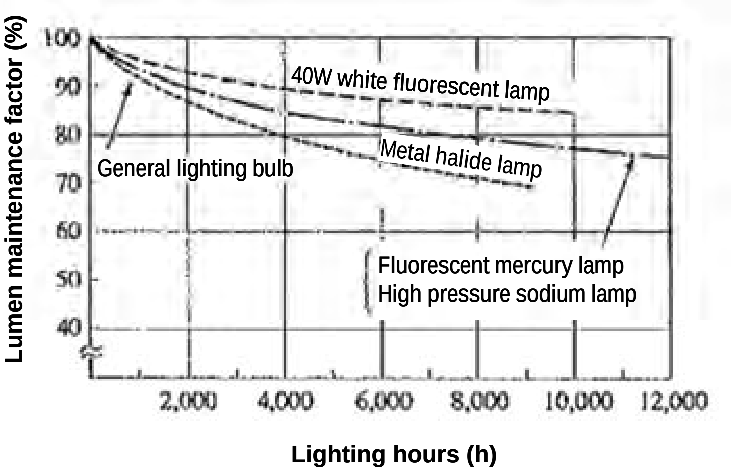


Figure 3.1.1-3 Lumen Maintenance Characteristic of Various Light Source

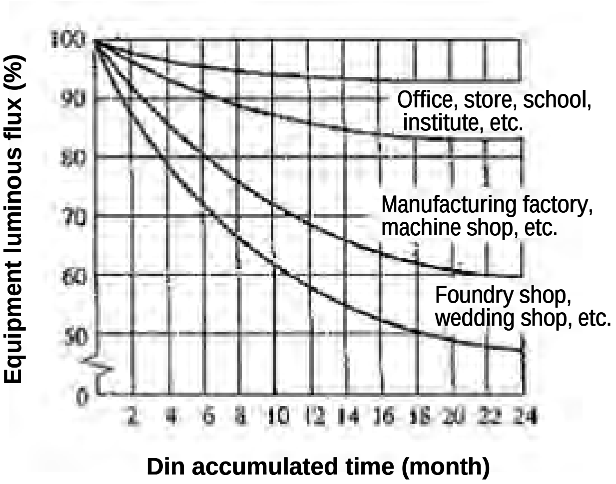


Figure 3.1.1-4 Lumen Maintenance Characteristic of Various Light Sources

3.1.2 Energy Conservation for Air Compressor

(1) Compressed Air System

1) Configuration of Compressed Air System

The compressed air system is a power transmission system that sends the compressed air from a compressor to the actuator through pipes by controlling and adjusting with various control valves. The output is supplied as mechanical power suitable for load side requirements. Figure 3.1.2-1 shows a typical configuration of the compressed air system.

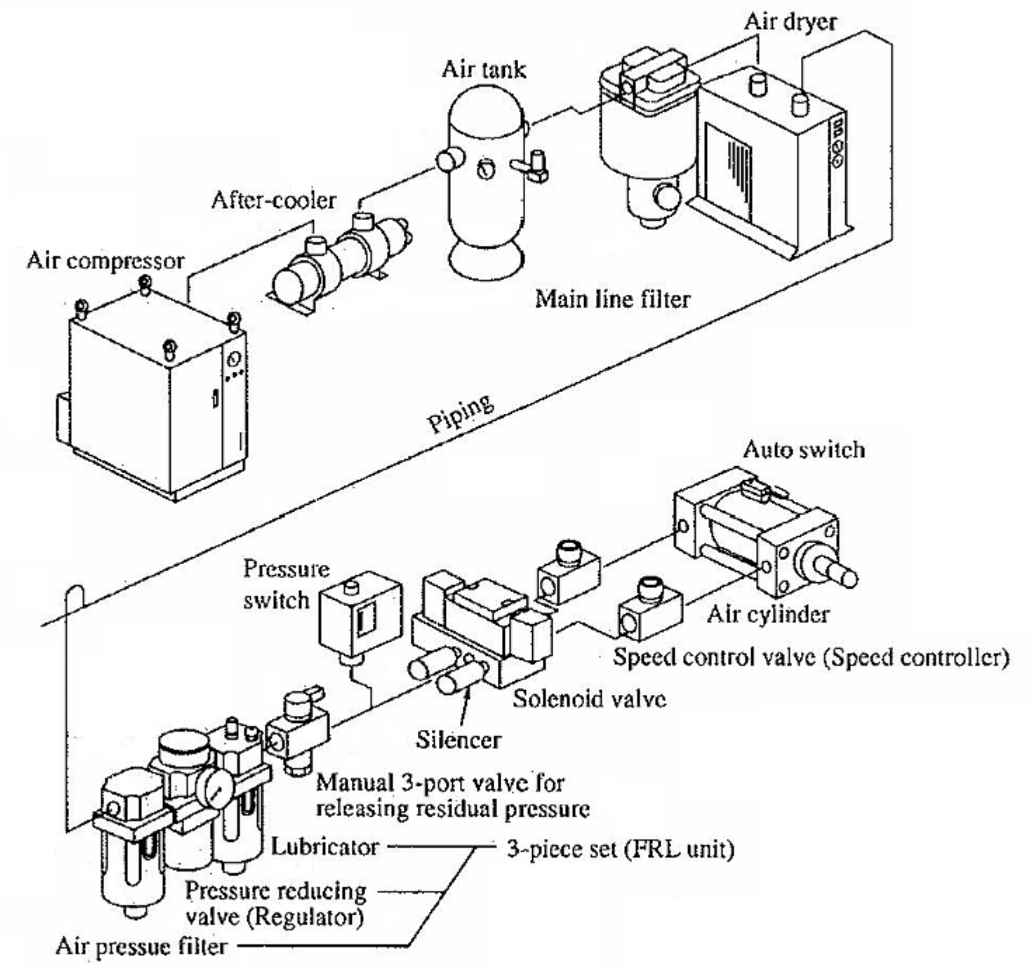


Figure 3.1.2-1 Configuration Example of Compressed Air System

(2) Air Compressor

1) Type and characteristics

The types of air compressors that command a large share of the market in Japan are small size reciprocal type, medium size screw type and large size turbo type.

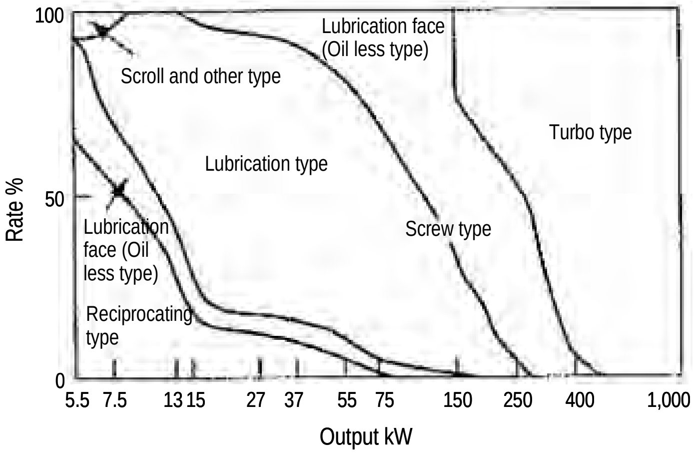


Figure 3.1.2-2 Market Shares of Air Compressors by Type

a) Power required for compressors

Power used for compressors is generally given by the following equation:

$$L = \frac{(a+1)K}{K-1} \bullet \frac{P_s Q_s}{6120} \bullet \left\{ \left(\frac{P_d}{P_s} \right)^{\frac{K-1}{K(a+1)}} - 1 \right\} \bullet \frac{1}{\eta_c \eta_t}$$

L: Required power [kW]

Ps: Absolute pressure of intake air [kg/m^2 abs]

Pd: Absolute pressure of discharge air [kg/m^2 abs]

Qs: Amount of air per unit time converted to a state of intake (m^3/min)

a: Number of intercoolers

K: Adiabatic coefficient of air

η_c: Overall adiabatic efficiency of compressor

η_t: Transfer efficiency

Values of ηc and ηt shall be given by the manufacturer.

The power, provided when $\eta_c \times \eta_t = 1$, is called the theoretical power. Table 3.1.2-1 lists the theoretical power for one-stage compression and two-stage compression.

Table 3.1.2-1 Theoretical Power of Air Compressor (kW)

Compression pressure	One-stage compression	Two-stage compression
0.1	1.261	
0.2	2.129	
0.3	2.811	
0.4	3.380	2.999
0.5	3.874	3.390
0.6	4.312	3.725
0.7	4.707	4.023
0.8	5.069	4.290
0.9	5.404	4.534
1.0	5.715	4.757
1.2		5.163
1.4		5.506
1.6		5.818
1.8		6.100
2.0		6.357

Accordingly, to reduce power for compressors, the following items should be considered.

Select compressors and systems with good efficiency.

Lower temperature of intake air. Also, improve the cooling effect in the intercooler.

Lower the discharge pressure. Also, reduce the amount of air used.

Prevent air leakage from the compressor proper and piping, etc.

Intensify management for the entire system for compressed air.

b) Number of stages for compression

The multi-stage compression type reduces shaft horsepower by cooling the compressed air by intercooler during each stage of the compression stroke. If one-stage compression is changed into two-stage compression, power can be reduced by approximately 15 % when the discharge pressure is 0.7 MPa.

c) Load characteristics

Figure 3.1.2-3 shows an example of the air compressor's load characteristics. If the load rate is smaller than 100 %, the power is small but the relationship is not directly proportional. A no-load shaft horsepower of not less than about 10 % exists even for the reciprocating type. Therefore, operation at a load rate close to 100 % is the most efficient.

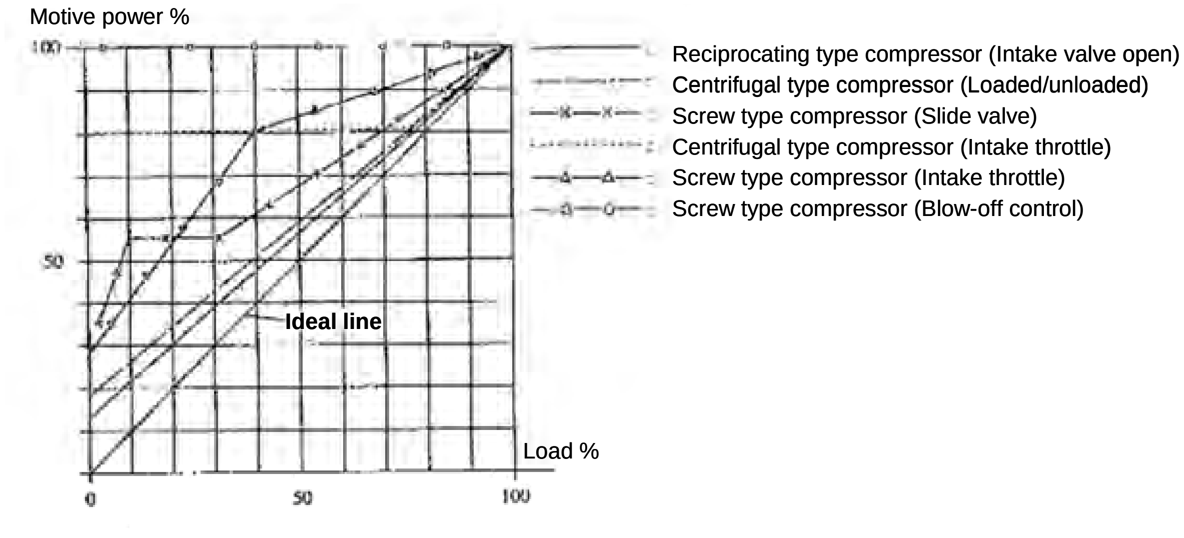


Figure 3.1.2-3 Load Characteristics of Air Compressors

d) Number of running compressors and installation method

Compressors may be installed collectively in a central power room or distributed and installed near the work sites. In any case, layout of the compressors should be determined based on the load variation of the entire factory, risk dispersion, and future plan.

For centralized installation, large models are selected in smaller numbers. Therefore, efficiency of the compressors at 100 % load is improved, while on the other hand the maximum pressure required for equipment in the factory is supplied to all plants. Also, since the piping to the end use point of air is longer, the piping air feed pressure loss increases. Efficiency for minimum use on holidays and partial load efficiency should be also considered.

For distributed installation, one or a few small compressors are selected. Therefore, although the efficiency of the compressors at 100 % load is poorer, the smaller piping pressure loss is a merit. To improve the efficiency for a partial load, use of capacity control should be examined. Also, the backup system in the event of an accident needs to be considered.

2) Capacity Control

a) Pressure switch-driven opening/closing type

This automatic start/stop control system automatically stops the compressor by means of a pressure switch if the air consumption volume decreases and the discharge pressure exceeds the set value. The system automatically starts the compressor again if the pressure drops below the specified value. This system is applied when air consumption is intermittent and pressure variation is large. Although electricity is not consumed while the motor is stopped, the use of this system is limited to small compressors due to the frequency of start/stop operation.

b) Constant control of discharge pressure

This system maintains and controls the discharge pressure within a certain range. The control method varies depending on the type of the compressor.

For the reciprocating type, if the volume of air consumption decreases and the discharge line pressure exceeds the set value, the unloaded piston valve opens the intake valve to continue operation without compressing air. This system is applicable in cases where the air consumption volume varies. Although there is a large fluctuation in pressure, a substantial energy conservation effect is achieved.

For the screw type with lubrication, if the air consumption volume decreases and the discharge pressure increases, the intake throttle valve is closed while the discharge pressure adjusting valve is opened to discharge compressed air and match the intake air volume with the air consumption volume. On the other hand, if air consumption increases and the discharge pressure drops, the pressure adjusting valve gradually closes to open the intake throttle valve and to restore the system to operate with the load. This system is applicable in cases where the load variation is small during continuous air consumption. While the fluctuation in the discharge pressure is small, the energy conservation effect is small as well.

Employing a slide valve that does not drop the intake pressure but shortens the effective part of the screw/rotor when the air consumption volume decrease will eliminate the rise of the pressure ratio, thus enhancing the energy conservation effect.

For the dry screw type, the intake valve throttle control method is rarely used because the energy conservation effect is less significant as mentioned above and the discharge temperature rises. The system using the slide valve is effective, but at the same time involves a problem of oil infiltration because valve operation requires a small volume of oil.

For the turbo type, rise of the discharge pressure is controlled by reducing the intake valve. Although reduction with a butterfly valve is inexpensive, the intake pressure drops when the air consumption declines. There is an inlet guide vane (IGV} system that does not reduce the intake pressure but performs a swing operation on the intake air to reduce the work of the first-stage impeller when the air consumption decreases. Figure 3.1.2-4 gives a comparison between the inlet guide vane system and butterfly valve throttle system. Also available is a system that reduces the discharge-side diffuser. This system, however, is only used for one-stage compressors with a low discharge pressure.

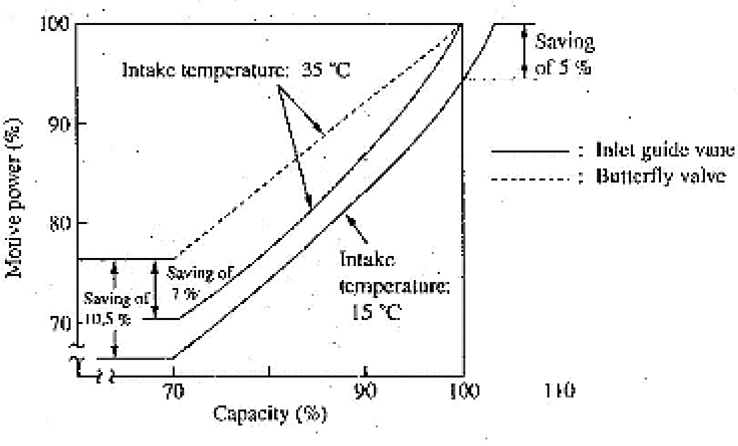


Figure 3.1.2-4 Comparison between Butterfly Valve System and IGV System

c) Inverter system

The rotational speed corresponding to the load is calculated according to the signal from the pressure sensor in the discharge line. Therefore, the compressor is run at the optimum rotational speed to supply air always at a constant discharge pressure. This system flexibly accommodates fluctuations in air consumption, has only a small fluctuation in the discharge pressure and produces a significant energy conservation effect. If the rotational speed is reduced for the turbo type, however, the discharge pressure drops and as a result the required pressure cannot be obtained. Therefore, speed control cannot be applied.

3) Controlling the Number of Operating Compressors

If two or more compressors are installed, the number of running compressors is controlled according to the load fluctuation for the following purposes:

- To minimize the number of running compressors and reduce idling loss
- To minimize the discharge pressure for operation at the proper pressure
- To prevent action delay due to manual operation
- To reduce maintenance man-hours by using centralized management

The number of running compressors should be minimized to match the amount with the air used and all except one compressor should be run on a full-capacity basis provided that one compressor only is run without a load. Figure 3.1.2.-5 shows the load characteristics under control of the number of compressors. It is necessary to bring them to the ideal load characteristic under the widest load range possible.

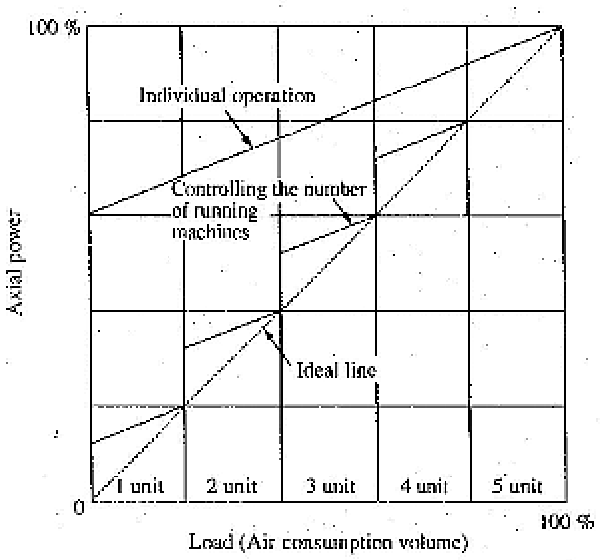


Figure 3.1.2-5 Load Characteristic by Controlling the Number of Operating Machines

(3) Energy Conservation Measures for Compressed Air Equipment

1) Reduction of Intake Temperature

For the displacement type, if the intake temperance drops by 20°C, the shaft horsepower increases by 3 %. Theoretically, however, the actual discharge volume increases in proportion to the absolute temperature of the intake air and therefore it increases by 6.8 %. Thus, a 20°C drop in temperature leads to a 3.8% energy conservation.

For the turbo type, the shaft horsepower does not logically change unless the delivery pressure and intake volume flow rate change. Therefore, a drop in the intake temperature should naturally bring about an energy conservation effect equivalent to the increase in the mass flow rate. On the other hand, if the intake temperature drops, the specific gravity of air increases as well, and this may in turn cause the discharge pressure to increase. This is, however, determined by the toad side. As a result, the discharge pressure does not change and only the intake volume flow rate increases. Thus, operation deviates from the designed point. The efficiency drops and only a 2 to 3 % energy conservation can be achieved with a 20°C temperature drop.

The problem in indoor intake is the need to suppress indoor heat generation and drop the indoor temperature through ventilation. Indoor heat generation can be greatly reduced by exhausting motor heat directly to the outside or cooling the motor with water. For outdoor intake, a cool place not exposed to direct sunlight should be selected for the intake port and reduction of the intake tube pressure loss and silencer installation should be examined.

2) Cooling Effect of Intercooler

Insufficient cooling by the Intercooler takes air compression closer to adiabatic compression, thus increasing the motive power required for compression at the second and subsequent stages.

A possible cause for the drop in efficiency of the intercooler may be reduction of the heat transfer efficiency due to deposits of scale or slime or shortage of the cooling water volume.

Therefore, appropriate countermeasures such as washing the cooler periodically should be planned.

3) Reduction of Discharge Pressure and Air Consumption

As shown in Table 3.1.2-1, reducing the discharge pressure leads to energy conservation. For example, if the Discharge pressure is reduced from 0.7 MPa to 0.6 MPa, power will be reduced by about 8 % for one-stage compression.

Generally, many machines or tools may require different air pressure conditions for the same work even when they have the came capabilities. Therefore, it is important to standardize the operating pressures for the machines or tools in the entire factory to a lower pressure through careful examination in order to reduce the electricity requirements.

If the factory has an equipment such as a press machine which requires high-pressure compressed air, it would be economical to install a dedicated booster.

Since reduction of air consumption leads to an approximately proportionate reduction of the power cost, use of compressed air for personal cooling and cleaning should be inhibited and the nozzle size at each location should be reviewed for a thoroughgoing management of the use conditions.

4) Air Leakage from Clearance, Hole, etc.

a) Air leakage
Flow rate Q when air flows out from a vessel with a pressure of P, inside into a space at pressure of P_2 is given from Bernoulli's equation

$$Q=C*S\sqrt{(2*g*(P1-P2)/\gamma)}\ [\mathrm{m^3/s}]$$

where

g : Acceleration of gravity 9.8 [m/s^2]

y : Specific weight of air [kg/m']

S: Effective cross section [m^2]

P„ P2: Absolute pressure inside and outside vessel [kg/m^2~abs]

C: Discharge coefficient

Since the loss due to this air leakage is very great, it is necessary to check the piping, etc. for leakage and, if any, to repair and correct immediately. The leakage is in proportion to

$\sqrt{(P1\text{-}P2)}$ in equation (3) and, as such, reducing the service pressure surely reduces the leakage. Figure 3.1.2.-6 shows the blow-off air amount from a small diameter orifice.

Figurer 3.1.2-6 is used to determine the blow-off air amount when there is a sufficient large capacity receiver tank and piping as compared with the size of the blow-off nozzle. It is assumed that pressure in the tank and piping remains unchanged during blow-off at normal temperatures. The blow-off air amount is converted to a standard state (20°C, I atmospheric pressure).

To apply practically, use selectively a value multiplied by 0.7 to 0.65 because values in Figure 3.1.2-6 are based when discharge coefficient c = l.

b) Measurement of air leakage

The measurement of leaked air volume in compressed air line is with the following method.

- Listen to air leakage sound and/or soap water test
- Inspection with a ultrasonic leak detector
- Measurement of pressure drop speed of compressed air line after closing air feed valve at production equipment stop

Air leakage is measured by measuring compressor equipment (compressor proper, intercooler, air tank, etc.), piping system, pneumatic machine, control circuit, etc. in the group unit using the sound and the daubed soapy water.

Table 3.1.2-2 shows an example of the results of air leak measurement through sound. The total number of air leaks in the factory is 81. Most leaks occurred at joints followed by auxiliary machines and the like, accounting for 70 % of the total leaks. These, however, do not include drive peripherals such as cylinders for machines.

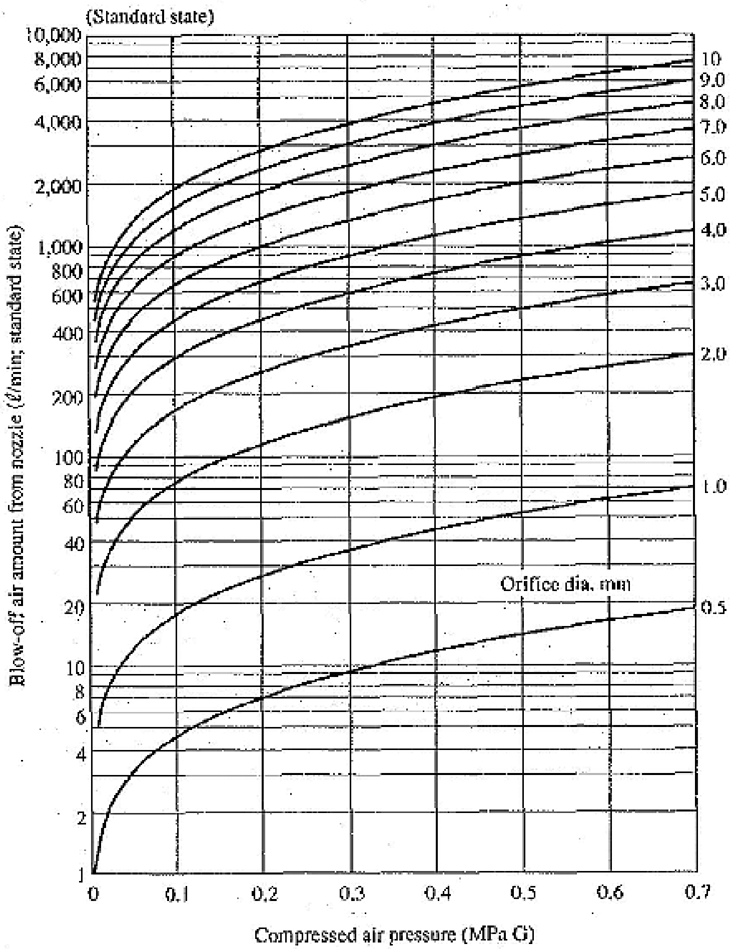


Figure 3.1.2-6 Compressed Air Pressure and Blow-Off Air Amount from Nozzle

Table 3.1.2-2 Results of Air Leakage Survey

Machine category		No. of leakages			
		Leak amount			Total (%)
		Large	Medium	Small	
I.	Piping	0	4	1	5 (6.2)
2.	Joints	0	14	8	22 (27.2)
3.	Auxiliary machines	0	9	6	15 (18.5)
4.	Direction controller	0	3	7	10 (12.4)
5.	Drives	1	0	0	1 (1.0)
6.	Pneumatic tools	0	6	2	8 (10.0)
7.	Others	0	16	4	20 (24.7)
Total		1	52	28	81 (100.0)
Estimated amount of leak (L/min)		@200 200	@50 2,600	@10 280	
		3.080			

3.1.3 Energy Conservation for Motor

(1) Type, Efficiency and Power Factor of Motors

Let us compare the typical DC, induction and synchronous motors with induction motors mostly used in respect to efficiency and power factors.

1) DC and induction motors

The efficiency of the DC motor is 5 to 8% lower than the induction motor for small capacity machines 100 kW or less and 2 to 3% lower for 300 to 100 kW. This DC motor, being of the separately ventilated type, must be essentially evaluated including loss of the blower for cooling. Since, however, this value is omitted, the efficiency actually tends to lower further.

The DC motor is capable of operating in accordance with the load characteristic and also in easily controlling the speed or torque because it can be easily provided with various characteristics by means of excitation systems. On the other hand, the DC motor has the following defects, the efficiency is lower than AC motors such as induction and synchronous motors, etc.; it has difficulties in maintenance and in environment-proof because of a current collecting mechanism.

2) Synchronous and induction motors

The efficiency of synchronous motors is generally higher than that of induction motors and the tendency is remarkable in low-speed motors with larger numbers of poles. For example, in the case of 10 MW class, the efficiency of 4 pole synchronous motors is about 0.5 % higher than induction motors, while 10 pole synchronous motors have an efficiency of about 1 to 1.5 % higher.

Also, the greatest special feature of the synchronous motors is to freely select the power factor, enabling power factor 1.0 or advancing power factor and, at this point, they are quite different from the induction motors. Moreover, it is possible to control the system at a constant power factor by means of the field control, or to restrain voltage fluctuation of the system by performing constant control of the power factor or terminal voltage. Since the power factor considerably lowers with low-speed large capacity induction motors as can be seen from the figure, they are disadvantageous as compared to the synchronous motors in this respect also.

Since, however, the synchronous motors including excitation power source equipment for the field system is expensive, generally selection should be studied, with the following points:

a) For 10 MW or more, study adoption of synchronous motors in respect to efficiency.
b) For low-speed motors with larger numbers of poles even 10 MW or less, study adoption of synchronous motors.
c) When power factor and voltage of the system must be controlled, study adoption of synchronous motors. However, the motor is limited to sufficient enough large capacity to supply the system reactive power (Var).

d) Generally, for 5 MW or less, induction motors arc superior in simple starting and power source composition.

Generally, for salient-pole synchronous motors, the starting torque is not so large as for induction motors; it should be, therefore, noted that they are difficult to start up with large inertia moment or torque loads.

3) Adoption of high-efficiency motors

High-efficiency motors with iron and copper losses reduced by 20 to 30 % have been sold on the market. 'They have been developed by improving the low-voltage squirrel cage type induction motors through adoption of flat rolled high grade magnetic steel plate (silicon steel) and optimization of design with leaving the frame number and external dimensions as the present standard. Although the initial investment will be somewhat higher, they will deserve studying for adoption for long-time operating motors.

Figure 3.1.3-1 and 3.1.3-2 show comparison in efficiency between high-efficiency motors and standard type motors that are being manufactured at present. It should be noted in Figure 3.1.3-2 that the high-efficiency motors are remarkable in the improvement of efficiency at light load.

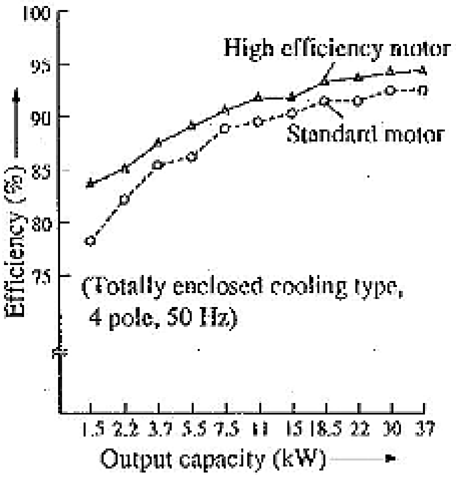


Figure 3.1.3-1 Efficiency Comparison of 3 Phase Squirrel Cage Type Induction Motor (Output Capacity)

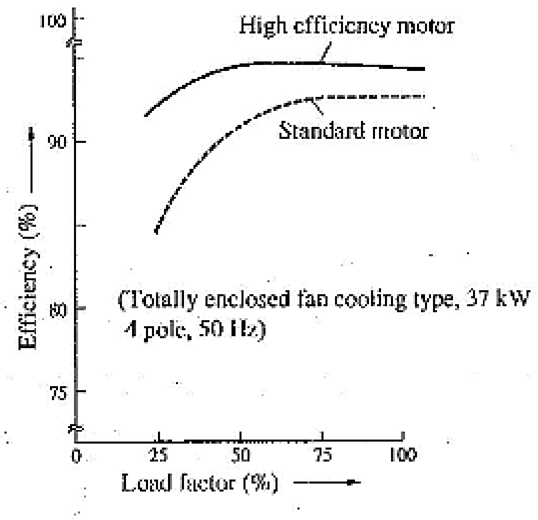


Figure 3.1.3-2 Efficiency Comparison of 3 Phase Squirrel Cage Type Induction Motor (Load factor)

Figure 3.1.3-3 shows an example of achieving an energy conservation effect for high-efficiency induction motors.

Motor specifications: Totally enclosed fan cooled type, 2.2 kW, 4 poles, 200 V, 50 Hz, l00% load

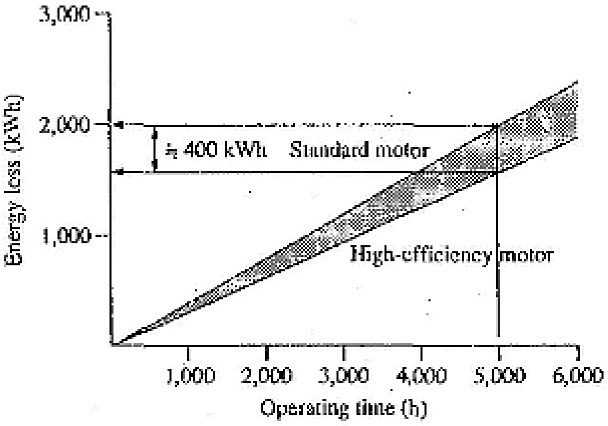


Figure 3.1.3-3 Energy Conservation Effect for High-efficiency Motors

Figure 3.1.3-3 shows that energy conservation of about 400 kWh can be achieved by operating this type of motor, for example, 5,000 hours per year.

4) Variable speed control of induction motors

There are three types of motor loads: the constant-torque load, decreasing-torque load, and constant-output load. Among them, the fluid machine load belongs to the decreasing-torque load. The torque is a function of the angular speed and proportional to the square of the rotating speed, and therefore the power is proportional to the cubic of the rotating speed. Since the flow rate is proportional to the rotating speed, if the flow rate decreases on a fluid machine, the power is reduced in proportion to the cubic of the rotating speed by reducing the rotating speed as a result of rotating speed control. Thus, a substantial energy conservation effect can be expected. Additionally, rotating speed control is also used for the constant-torque load for cranes, etc. Generally, the rotating speed of the induction motor is represented by the following equation:

$N = 120f / P (1 - S)$...................... (1)

As shown above, rotating speed control of the induction motor is attained by changing one of three elements: the number of poles (P), slip (S), or primary frequency (f). Figure 3.1.3-4 shows the rotating speed control methods categorized for these control elements.

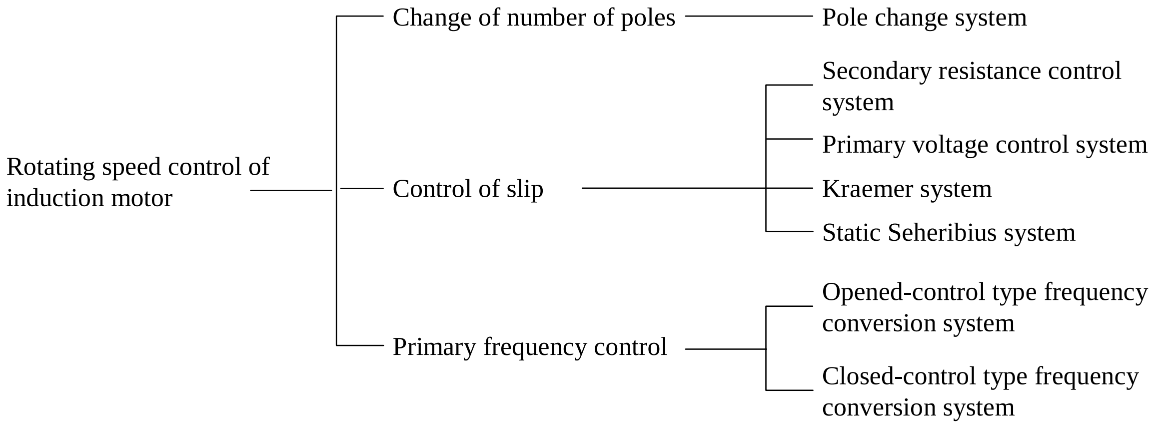


Figure 3.1.3-4 Classification of rotating speed control

a) Changing the number of poles
This speed control method changes the number of poles (P) of the motor step-wise as shown in the equation (1). The rotating speed is changed by changing the number of poles between 2 and 5. The speed change ranges from 1:1.5 to 1:8. This method is used to control the speed step-wise.

b) Secondary resistance control
If the secondary resistance on the wound-rotor type induction motor is changed, torque characteristics change as a result of proportional shifting. By using this feature, the speed control is attained by changing the balance point with the load torque. This method allows the rotating speed to be changed continuously. However, if the rotating speed is reduced by increasing the secondary resistance, heat loss by the secondary resistance increases and efficiency drops.

c) Primary voltage control
This speed control method changes the primary voltage of the motor by combining the induction motor with a thyristor. By using the feature that the toque volume is proportional to the square of the voltage, the rotating speed is changed continuously.

Stable operation at a low speed is possible, while, on the other hand, the efficiency and power factor decrease.

d) Kraemer system

The secondary output of the induction motor is converted into a direct current by a silicon rectifier. By driving the DC motor connected to the induction motor, the direct current is converted into a mechanical output. Since loss is not caused by control, efficiency is high. The variable range is 1:2 or less. This system is suitable for the constant-output operation within a small range.

e) Static Scherbius system

This control method reversely converts the secondary output of the induction motor with an inverter and then returns the resulting power to the power supply. Speed control is attained through inverter phase control. Since loss is not caused by control, efficiency is high. The variable range is 1:2 and said to be economical. This method is used for variable speed control within a small range.

f) Primary frequency control

This speed control method changes the primary frequency (f) of the induction motor. By using an inverter or cyclo-converter, the frequency is changed and the rotating speed is changed continuously. As power devices acquire higher performance, variable speed systems, each using an inverter, are widely used for large industrial machines to small household machines. Since this system is particularly useful for modification of existing equipment, it is described in detail in sub-section 3.1.3.2 (4).

(2) Energy Conservation by Remodeling the Existing Equipment in a Small Scale

1) Induction motors and voltage control

Although generally induction motors are most widely used because they are low cost and simple to handle, it should be noted that supply voltage fluctuation gives the great influence on the efficiency of these motors.

Table 3.1.3-1 Effect of voltage fluctuation on induction motor

		Voltage fluctuation		
		90 % Voltage	Proportional relation	110 % Voltage
Starting torque		−19 %	V^2	+21%
Stalling torque				
Synchronous speed		Remain unchanged	Constant	Remain unchanged
% slip		+23 %	I/V^2	−17 %
Full−load speed		−1.5 %	−	+I %
Efficiency	Full load	−2 %	−	Slightly increased
	3/4 load	Actually no change	−	Achtally no change
	1/2 load	+1 to 2%	−	−1 to −2 %
Power factor	Full load	+I %	−	−3 %
	3/4 load	+2 to 3 %	−	−4 %
	1/2 load	+4 to 5 %	−	−_5 to −6 %
Full−load current		11 %	−	−7 %
Starling current		−10 to −12 %	V	+10 to 12 %
Full−load temperature rise		+6 to 7 C	−	−1 to −2 %
Magnetic noise		Slightly decreased	−	Slightly increased

a) Study when the supply voltage is lowered

To operate with the supply voltage lowered below the rated voltage, it is necessary to check accelerating torque during starting and the value of the peak load because the starting torque and maximum torque decrease at a rate of the square of the voltage as shown in Table 3.1.3-1.

Since the load current increases in inverse proportion to the voltage even if the total loss decreases, the motor copper loss increases, thus increasing the winding temperature, the line loss of distribution line, etc. Care should be taken. Therefore, the lower limit of the supply voltage should be determined within a range not to exceed the motor rated current.

b) Study when the supply voltage is raised

When operated with the supply voltage raised above the rated voltage, saturation of the magnetic flux increases the exciting current remarkably, causing lowered power factor, unusual magnetic noise and an unusually heated iron core due to increased iron loss, etc. Also, since the motor output torque increases at a rate of the square of the voltage, it is necessary to check whether the machine is damaged by excessive torque.

2) Prevention of idle running and reduced starting loss

Since a motor is sure to be connected to the opposite machine, electric power consumed at no-load running will be about two to three times that of the motor itself. Accordingly, it is important for electric power conservation to stop the motor when unnecessary. Also, in this case, it is desirable to stop the motor cooling fan and field system for the DC motor. At this time, the precautions are as follows:

a) Deterioration and output drop of motors due to multi-frequency starting should be restricted within a range so that they can be used as usual
   In the case of large-capacity motors 100 kW or more and motors with high GD^2 as a load such as blower, etc., it is recommended to consult with the motor manufacturer.
b) Electric power during starting should not exceed the electric energy during idle running.
   Generally, to re-start a motor; care should be taken, because certain starting methods cause a considerable amount of loss.

3) Reducing method of starting loss

The following will reduce the starting loss.

a) Start with a higher motor generated torque.
   From the standpoint of operation efficiency, it is desirable to start with the motor torque as high as possible. Starting with reduced voltage or with reduced current to restrain the starting current lowers the motor torque thus increasing the loss. Therefore, it is desirable to directly start as far as the power source circumstances permit.

b) Increase the secondary resistance when starting.
   When a wound-rotor type induction motor is used, inserting a high external resistance when starting will not only greatly reduce the entire motor loss including the external resistance, but also restrain rotor heat and starting current.

c) Change the synchronous angular velocity ω_o.
   Changing the synchronous angular velocity ω_o of induction motor together with a rise in the motor speed greatly reduces the loss during starting.

   The following measures are effective in preventing idle running.

   - Installation of an idle running alarm device
   - Automatic control of the process and equipment
   - Reduction of the waiting time for handling the treated matter by improving the equipment layout and jigs and tools

4) Control of induction motor rotating speed

As mentioned earlier, control of induction motor rotating speed is widely used for energy conservation of pump, fan, blower and motor for crane.

Of the rotating speed control systems shown in Figure 3.1.3-4, the primary frequency control system (VVVF) can be materialized from the standpoint of remodeling the existing equipment and as such it will be described.

The primary frequency control system controls the primary voltage and frequency of the motor at the same time, by means of a frequency converter, to change the synchronous speed.

Inverters are usually used for the VVVF system. Characteristics of rotation control by an inverter are shown below.

a) Can easily control a squirrel-cage induction motor without any additions except VVVF
b) Can apply step-less rotation control effectively in a wide range.
c) Power factor is high. Power capacity can be small for starting up.
d) Can reverse rotation direction electronically.
e) Can start and stop high-frequently.
f) Can apply breaking control electrically.
g) Suitable for rotation control of a motor placed in a severe environment.
h) Can control rotation of multiple motors at a time.
i) Can easily obtain constant torque characteristics and constant output characteristics.

As problems raised from introduction of an inverter, the following can be named: troubles by harmonic waves, troubles by speed control of general purpose motors, and troubles by operation switching between direct and inverter operations. Table 3.1.3-2 shows troubles and measures accompanied with the introduction of an inverter.

Table 3.1.3-2 Troubles and Measures Accompanied with Introduction of Inverter

No.	Trouble	Measures
I	**Trouble by harmonic waves**	
1	• Metallic sound is generated from motor.	• Insert an AC reactor between inverter and motor.
2	• Condensive capacitor of fluorescent lamp is heated.	• Insert an AC reactor to the receiving side.
3	• Input transformer generates heat or causes vibration.	
4	• AM broadcast on radio cannot be heard due to noise.	• Install a noise filter.
5	• Electronic devices such as measuring instruments cause error.	• Place an inverter in an iron case and earth the case. • Earth the motor frames. • Place input/output cables in an iron pipe and earth the pipe.
6	• Earth leakage breaker operates erroneously.	• Shorten connecting wire between inverter and motor. • Use breaker dedicated to inverters.
II	**Troubles by speed control of general purpose motors**	
7	• Resonance occurs between motor and the other machine. As a result vibration and noise are generated.	• Use tire-type coupling between motor and the other machine.
8	• Self-cooling efficiency of motor lowers. Temperature rises.	• Fit a forced cooling fan.
III	**Troubles by operation switch between direct and inverter operations**	
9	• Life of relay shortens due to frequent switching.	• Review control method.
10	• The device stops due to instantaneous power cut when switching.	• Check sequence control circuit.
11	• Adjust time of motor after switching is too long.	• Increase the capacity of inverter.

5) Calculation example for variable speed control

As an example of actual calculation, Table 3.1.3-3 shows a comparison between the power-saving effect achieved by discharge valve control and that achieved by primary frequency control when the present discharge volume is reduced from 9.3 m^3/min to 4.2 m^3/min for a pump of which the discharge volume is 10.3 m^3/min, the pump head is 62 m, and the motor output is 230 kW.

Table 3.1.3-3 Comparative Example for Calculating Energy Conservation Effects

Method	Discharge volume [m^3/min]	Pump head [m]	Rotating speed [rpm]	Pump efficiency [%]	Shaft power [kW]	Power consumption [kW]	Power saving [kW]
Actual state	9.3	67	1,485	61	167	175	
Discharge valve control	4.2	75	1,485	39	132	139	-36
Primary frequency control	4.2	47	1,114	47	61	68	-107

In this example, the effect of electricity conservation by primary frequency control is three times larger than that by discharge valve control although reduction in the discharge volume is same. Thus, rotating speed control is superior in terms of the electricity conservation effect, but the investment cost for discharge valve control is much smaller. Based on the investment effect derived from these, the best electricity conservation method should be selected.

3.1.4 Management of Electrical Facility

(1) Power-Receiving/Transforming Facilities

Electricity supply management (electric power management) for power-receiving and distributing facilities starts with collecting data on the actual conditions of electric power usage as shown in Figure 3.1.4-1. This management can be categorized into the following: load control, voltage control, power factor control, distribution loss control, and demand factor control.

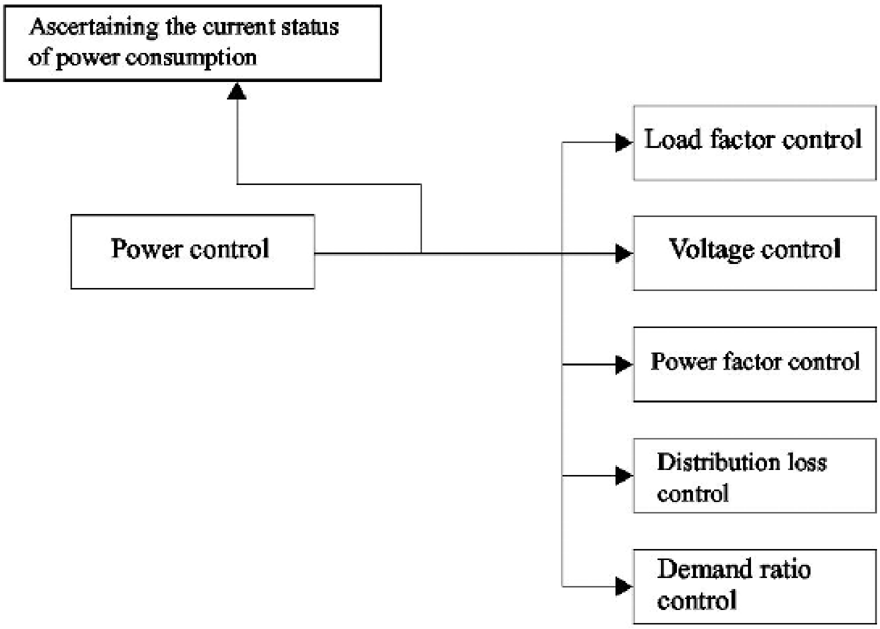


Figure 3.1.4-1 Categorization of Power Management

1) Collecting data on the actual conditions of electric power usage

The basic requirement for saving electric power is to monitor and understand the actual conditions of electric power usage in the present situation.

a) Measurement items
The items to be measured are power consumption (KWh), electric power (kW), voltage (V), current (A), and power factor (%). An electronic portable measuring instrument that can measure all of these items at once is commercially available.

b) Measuring location and measurement interval
The extent of the measurements to be performed must be determined in accordance with the size of a factory or a building and target for power saving. Special knowledge and techniques are required for this measurement. Conduct the measurement after consulting with an expert.

c) Analysis of measurement results
- Extract the information required for energy conservation from the trend data and compile it into an easy-to-understand format. Prepare a graph for the data as shown in Figure 3.1.4-2 and use it as a basis for setting targets and planning measures.

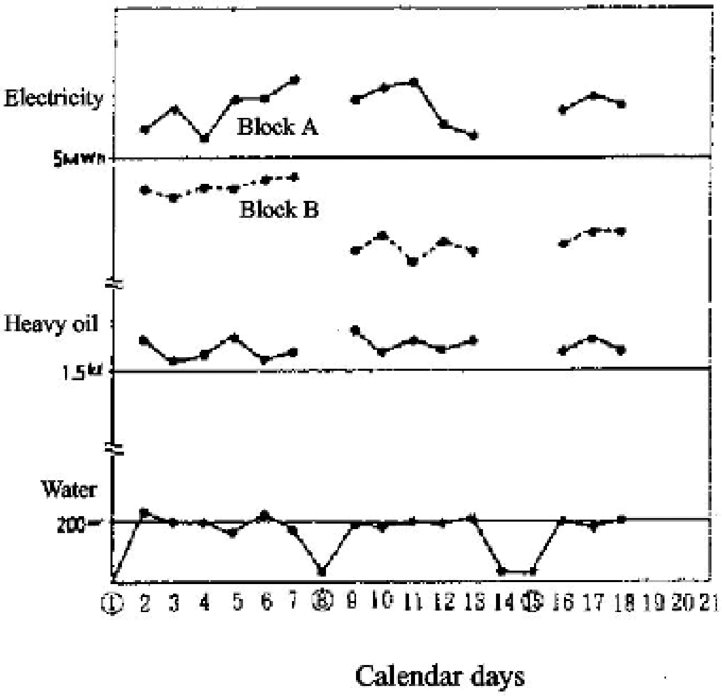


Figure 3.1.4-2 Daily Changes in Consumption of Power, Heavy Oil and Water

- Load curve
The basic electricity charges are decided by the maximum electric power. Therefore, it is necessary to perform an analysis using the so-called load curve showing data on the changes in electric power consumption dependent on the hour of day as shown in Figure 3.1.4 -3. The monthly and annual load curves can be obtained from the monthly and annual changes in electric power consumption.

2) Load factor control

The "(Average electric power (kW) / Maximum electric power (kW) x 100 (%)" calculated from a load curve is called the "load factor". The daily load factor for the case shown in Figure 3.1.4-3 is 49.6%. The monthly and annual load factors are calculated in accordance with the selected period.

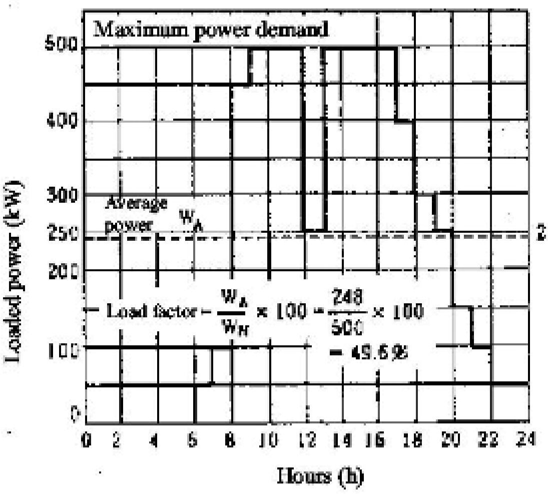


Figure 3.1.4-3 Example of Daily Load Curve

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

or,

$$\text{Load factor} = \frac{\text{Electric power kWh used during a certain period}}{\text{Maximum electric power kW} \times \text{Period (days/hours)}} \times 100\ (\%)$$

The load factor indicates the availability of electrical facilities. For example, when the load factor is low, the contracted electric power is used fully in the peaktime but there is a large allowance during the night.

3) Voltage control

The rated voltage (for example, 100V, 200V or 380V) is always stipulated for electric equipment which is designed so that the equipment operates at peak efficiency when it is used at this voltage. Therefore, check the voltage of each unit of a power distribution system from the power receiving facility up to the end facility, and adjust the voltage so that the terminal voltage of each facility is close to the rated voltage.

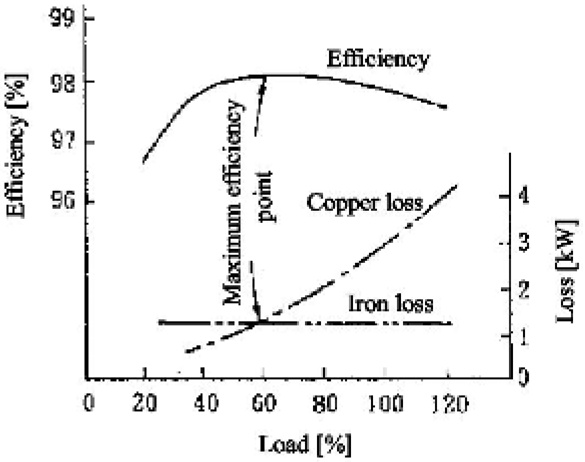
Normally voltage is adjusted by adjusting the tap of a transformer. In this case, the voltage changes slightly depending on the load conditions in factories and buildings. Therefore, it is important to adjust the tap of the transformer using the voltage value measured during full operation.

It should also be noted that the voltage-efficiency characteristics of electric equipment such as a motor change in accordance with the applied load condition. For example, the efficiency of an induction motor is the highest at the rated voltage for a 100% load. It becomes the highest at a lower voltage than the rated voltage for a 50% load.

a) Selecting a transformer

Latest transformers are so designed that maximum efficiency is achieved at 50 to 70% of load against the rated value as shown in Figure 3.1.4-4. Select a transformer in the following manner.

- Select a transformer with high efficiency.
- When the capacity is the same, a self-cooling type transformer has the better efficiency than that of oil filling air cooling type of transformer.
- Select a transformer in accordance with load curve.



(3 φ 200KVA, 6600V/210V, 50Hz)

Figure 3.1.4-4 Relationship between Load, Efficiency and Loss of Transformer

4) Power factor control

There is a portion that functions both effectively and non-effectively in the electric power consumed by AC equipment such as an induction motor. "Power factor" is the percentage of effective electric power to the total electric power consumption.

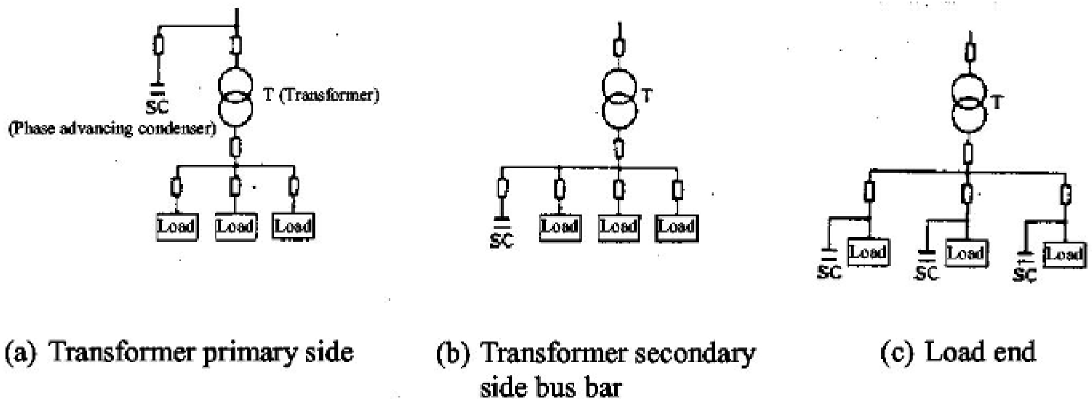
If the power factor is explained, there is less waste and electric power is effectively used when the power factor is closer to 100%. The power factor of a general-purpose motor is normally about 85%.

According to the judgment criteria of the Energy Conservation Law in Japan, the power factor at a power receiving terminal shall be 90% or higher (target value is 95% or higher). It also defines that the power factor should be improved by installing a phase-advanced condenser if the specified capacity is exceeded.

a) Effects of power factor improvement
   - Reduction of power distribution loss (= I2R) of a transformer and power distribution route due to a decrease in load current.
   - Reduction of voltage drop of a transformer and power distribution route due to decrease in load current.
   - The real increase in the capacity of an electrical device, such as a transformer.(Produces surplus electricity due to a decrease in apparent power.)
   - Discount of electricity charges: The power factor at maximum load is called the "commercial power factor". When this power factor exceeds 85%, the electricity charge is discounted by 1% of the basic charge according to 1% increase of power factor. On the other hand, when it drops below 85%, 1 % of the basic charge is added to the fare according to 1% drop of power factor.

b) Power factor improvement method
The power factor can be improved by installing a condenser as shown in Figure 3.1.4-5. The effect and charges vary depending on the installation position of the condenser as follows.

Installation cost: (a) < (b) ≦ (c)
Controllability for follow-up: (a) < (b) < (c)



(a) Transformer primary side
(b) Transformer secondary side bus bar
(c) Load end

Source: "Power Factor Adjustment Techniques"; Denkishoin Publishers

Figure 3.1.4-5 Condenser Installation Places

5) Distribution loss control

The magnitude of the current flowing in an electric wire route and the electric wire resistance will cause distribution loss.

Points for reducing distribution loss:

a) Install a large-voltage load facility as close as possible to a power supply transformer.
b) Apply high voltage (for example, 440V).
c) Improve the power factor of load and reduce the loss caused by a decrease in the load current.

d) The resistance of an electric wire route is proportional to the length of an electric wire and is inversely proportional to the cross-sectional area. Select the appropriate size of electric wire to reduce the resistance loss.
e) Install a transformer as close as possible to the center point of load.

6) Demand factor control

The "demand factor" indicates the ratio of the required maximum electric power (kW) against facility capacity (kW). It indicates the magnitude of a load imposed upon equipment.

It is recommendable to perform the demand factor control by setting a control standard for the appropriate demand factor according to the type of demands with considerations for the operating conditions of an entire factory or building.

Demand factor = Maximum demand electric power kW / Facility capacity kW × 100 (%)

The demand factor can be indicated for a single electric facility/equipment and also for an entire factory or building. Although it varies depending on type of operation and business, the demand factor is approximately from65 to 80%.

7) Checking points of daily management

a) Level a load balance by reviewing it and streamlining the systems. Check whether or not there is a transformer that can be shut down always, during the night, or on holidays. Shut down those transformers if any.
b) Prepare the daily load curves of midsummer. If the curve has a sharp peak, it is possible to reduce the maximum electric power by revising the operation of the electrical facilities/equipment. Therefore, study the matter and conduct the revised operation to reduce the contracted electric power.
c) Make arrangements for the facility (phase-advanced condenser) and revise its operation method so that the power factor at the power receiving end becomes 100%.
d) Ensure that the security cooling of a power room is not too cold.
e) Review methods as follows taking the seasonal factors into considerations. Cooling by an air conditioner or ventilation cooling by outside air intake to find out which one is advantageous for the security cooling of a power room. Implement the most advantageous method.

3.1.5 Energy conservation for transformer

For transformer energy conservation, it is necessary to pay attention to the following:

1) Transformer efficiency
2) When there are two or more transformers, operation with an efficient number of transformers.
3) Selection of transformer taps

(1) Selection of Transformers

1) Transformer efficiency is expressed by the following equation:

$$\eta = \frac{n \times p \times cos\theta}{n \times p \times cos\theta - W_i + n^2 W_c} \times 100 \; [\%]$$

W here

η : Efficiency (%)
n: Load factor
p: Rated capacity (kVA)
cosθ: Power factor
Wi: Iron loss
Wc: Copper loss

Although a transformer has dielectric and stray-load losses, in addition to the above iron and copper losses, they are difficult to measure and are minute, and as such will be ignored. Also, the ratio of copper loss Wc to iron loss Wi at rated load is called "Loss ratio α".

A = Wc / Wi

The loss ratio is generally from 2 to 5 as shown in Table 3.1.5-1. However, it may exceed 10 in the energy conservation type transformers as described later.

The efficiency of transformer is Maximum at 50% to 70% as shown in Figure 3.1.5-1.

Also, the transformer efficiency varies with the power factor of load and lowering the power factor reduces the efficiency as shown in Figure 3.1.5-2.

Table 3.1.5-1 Efficiency of 3 Phase High Voltage Medium Capacity Transformer

Primary 6.6/3.3 kV, Secondary 400/200 V

	Company A				Company B			
Rated capacity kVA	**Efficiency** (%)	**Iron loss** (kW)	**Copper loss** (kW)	**Loss ratio**	**Efficiency** (%)	**Iron loss** (kW)	**Copper loss** (kW)	**Loss ratio**
300	98.2	0.9	4.6	5.1	97.9	2.2	4.2	1.9
500	98.27	1.3	7.5	5.8	98.1	2.7	7.0	2.6
750	98.36	2.0	10.5	5.3	98.2	3.2	10.6	3.3
1,000	98.52	2.5	12.5	5.0	98.2	3.5	14.8	4.2
1,500	98.62	4.5	16.5	3.7	-	-	-	-
2,000	98.69	6.0	20.5	3.4	98.3	7.3	27.3	3.7

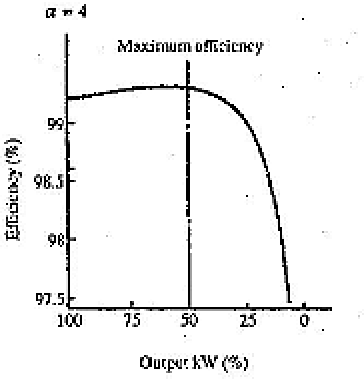
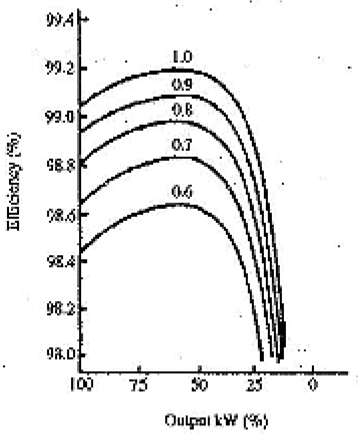


Figure 3.1.5-1 Transformer Efficiency (Example)



Note: Figure indicates power factor.

Figure 3.1.5-2 Relationships between Power Factor and Efficiency (Example)

2) All day efficiency of transformers

Although it is of course important to purchase and operate transformers considering the transformer maximum efficiency point, daily efficiency also must not be neglected because the transformer load varies every hour. The equation below is called "all day efficiency".

$$\text{All day efficiency} = \frac{\text{Output energy per day (kWh)}}{\text{Output enemy per day (kWh)} + \text{Loss energy per day (kWh)}} \times 100\%$$

If the daily load fluctuation is not so big, it would be better to operate transformers so that the all day efficiency becomes better.

3) Energy Conservation Type Transformers

a) Low-loss type magnetic steel plate transformer

This type of transformer uses a flat rolled magnetic steel plate that has a smaller iron loss than the conventional flat rolled silicon steel plate and whose magnetic field is further sub-divided by laser irradiation, and makes the current density still lower in order to reduce the load loss. Table 3.1.5-2 shows comparison with a conventional general-purpose transformer with respect to losses, etc. The magnetic steel type transformer is competitive with amorphous iron core transformer in terms of the total of the fixed and operating costs unless the load factor is especially low, and thus if is employed as a medium or larger transformer. According to recent research result, a magnetic steel plate transformers with iron loss of nearly the same level as amorphous magnetic body has been developed, and thus its application for industrial use is made.

Table 3.1.5-2 Comparisons between a Low Loss Type Transformer and a General-purpose Transformer in Various Specifications (Three-phase, 60 Hz, 500 kVA)

Item	Unit	Low-loss type transformer	General-purpose transformer
No-load loss	W	750	1,090
Load loss	W	5,540	7,000
Efficiency	%	98.75	98.40
Outside dimensions	mm	1,250 × 800 × 1,360	1,280 × 810 × 1,365
Oil amount	L	360	290
Weight	kg	1,540	1,210

4) Amorphous iron core transformer

Performance tests on the amorphous magnetic material were conducted in 1980's with regard to its possible use as the iron core for power transformers. As a result, it was verified that the amorphous magnetic body has a reliability equivalent to that of a conventional silicon steel plate transformer. Following are the characteristics of the amorphous magnetic body when it is to be used as the iron core for transformers.

(Advantages)

- Small iron loss: Approximately one-sixth that of a silicon steel plate transformer
- Small no-load current
- High permeability
- Superior in high-frequency characteristics

(Disadvantages)

- Low in saturation magnetic flux density
- Poor space factor: Approximately one-tenth that of a silicon steel plate
- Annealing conditions are complicated and also annealing makes it fragile.

These characteristics make the material and processing costs higher as compared with those of the silicon steel plate transformer in spite of smaller iron loss, thus limiting the manufacture of amorphous transformers only as small-l and medium-size mass production type transformers.

Table 3.1.5-3 shows comparisons in losses with a silicon steel plate transformer under the same specifications (single-phase, 50 Hz, 30 kVA, and 4f5 V/210 - 105 V). Figure 3.1.5-3 and Figure 3.1.5-4 show a relationship between load factor and loss/efficiency for each of the two types of transformers, respectively.

Table 3.1.5-3 Comparison of Losses due to Iron Core Material

	Amorphous iron core transformer	**Silicon steel plate iron core transformer**
No-load loss (W)	21	124
Load loss (W)	427	440
Total loss (W)	448	564

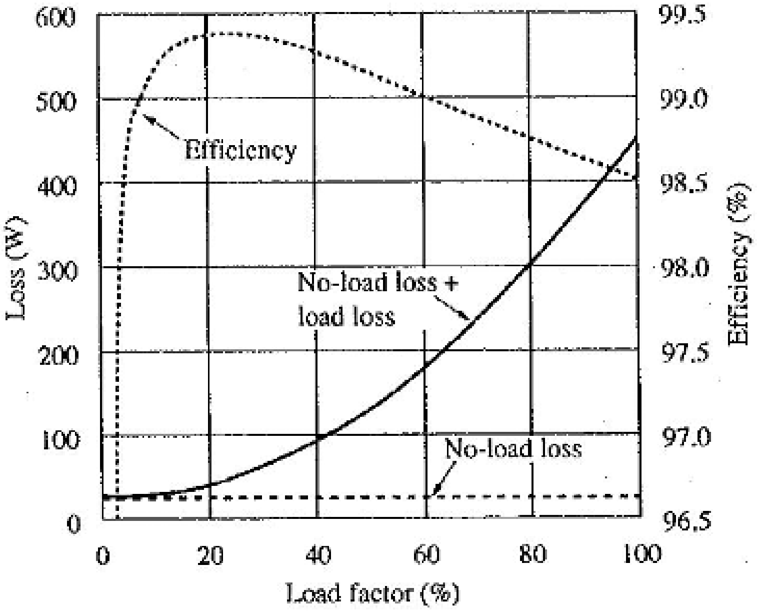


Figure 3.1.5-3 Load Factor and Loss/Efficiency of Amorphous Iron Core Transformer

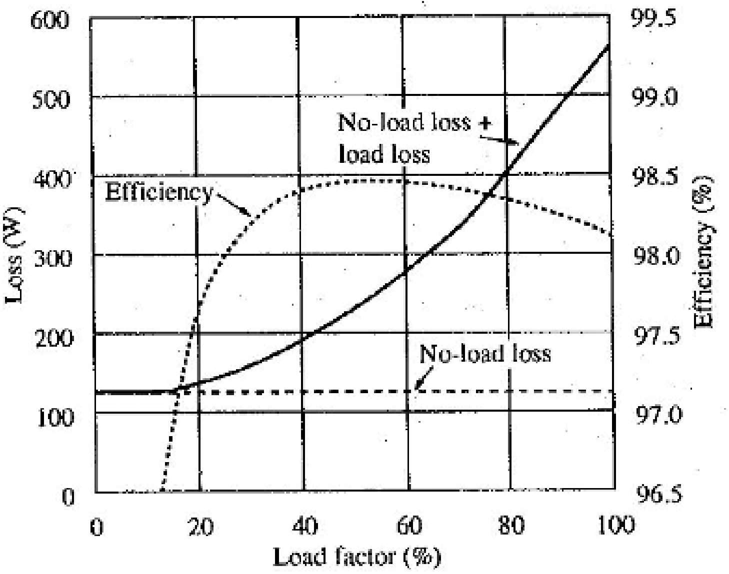


Figure 3.1.5-4 Load Factor and Loss/Efficiency of a Silicon Steel Plate Transformer

(2) Efficient Operation of Transformers

1) Stopping of light-load transformers

Generally speaking, when there are two or more transformers and each of them has a low load factor, electric power can be saved by stopping low load factor transformers to integrate the load. However, in some cases, loss of transformers with increased load may exceed reduced loss of stopped transformers, causing an adverse effect. Therefore, it is always necessary to confirm by calculating, as shown in the following example.

(Example) When there are two 500 kVA transformers

In the case where each transformer has a load factor of 40 % as shown in Figure 3.1.5-5, the merit when one transformer is stopped is calculated. The transformer's characteristics are presumed to be of company A, specified in Table 3.1.5-1.

At present, for both transformer No. 1 and transformer No. 2,

Iron loss = 1.3 (kW)

Copper loss = Full-load copper loss x $(\text{Load factor}/100)^2 = 7.5 \times (40/100)^2 = 1.2$ (kW)

Hence,

Total loss = 2 x (1.3 + 1.2) = 5 (kW)

After stop of transformer No. 1,

Iron loss of transformer No. 2 = 1.3 (kW)

Copper loss of transformer No.2 = Fill-load copper loss x $(\text{Load factor})^2 \times 100$

$= 7.5 \times (100)^2 = 4.8$ (kW)

Total loss = 1.3 + 4.8 = 6.1 (kW)

Stopping one transformer increases the loss by 1.1 kW.

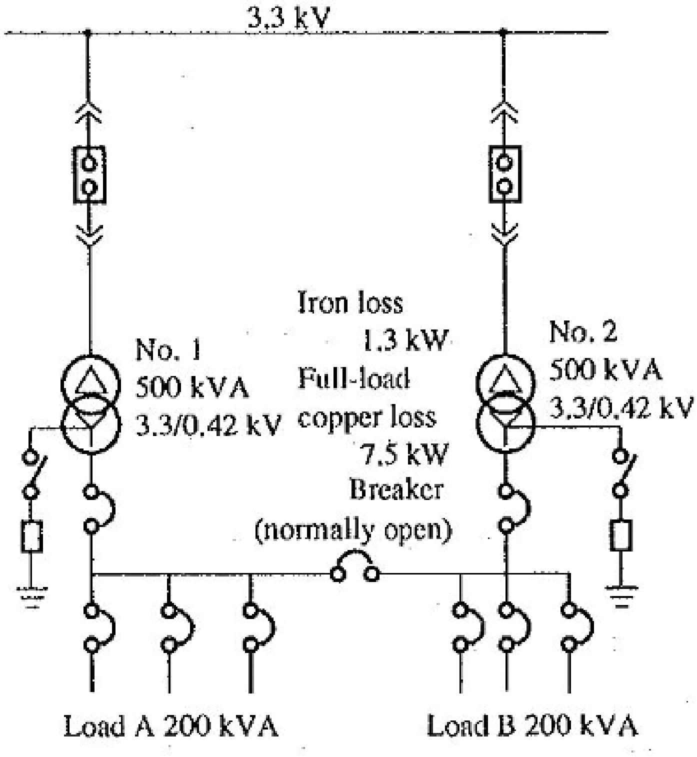


Figure 3.1.5-5 Method to Use 500 kVA Transformer

2) Control of the number of transformers

When transformers with the same rating are operated in parallel, the total loss can be reduced by increasing or decreasing the number of transformers.

Comparison of Overall loss when N units of transformers are operated in parallel and (N-1) units of transformers are operated in parallel:

For example, when three 500 kVA transformers whose loss ratio α is 3 are operated

$$\sqrt{(N\times(N-1)/\alpha}\times Q=\sqrt{(3\times 2)/3}\times 500=707kVA$$

That is, when the load is 707 kVA or below, the energy can be saved by reducing one of the operated transformers to two units.

3) Stopping of transformers at night and on holidays

In equipment and factories where operation is not performed at night and on holidays, the electric power can be saved by concentrating only loads for which electricity supply cannot be stopped even at night and on holidays, to certain transformers and stopping unnecessary transformers. However, when there is not so much difference in electric power between the peaktime and at night, there exists no merit.

3.1.6 Energy Conservation for Blower (Fan and Blower)

(1) Characteristics of Blowers

Although blowers and compressors have the same principles, below 1 mAq, 1 mAq to below 10 mAq (1 kg/cm^2) and 10 mAq, or the above in discharge pressure are usually called "Fan", "Blower” and "Compression” respectively.

For classification, they are mainly divided into turbo types and displacement types according to the operating principle, and the turbo type is further classified into an axial-flow type and centrifugal type.

Table 3.1.6-1 and Figure 3.1.6-1 show characteristics of blowers and the characteristic curves respectively.

1) Turbo Types

The turbo types have two types: centrifugal type, and axial-flow type.

In the former, centrifugal force is involved in rotation of impellers housed in the casing which provides the gas with speed energy, while in the latter, pressure and speed energy are provided while the gas is being flowed in the direction of rotation by rotating impeller blades with the blade section in the straight pipe. "Turbo type blowers" is a general term for this type.

2) Displacement type

In the displacement types, the gas is sucked in a chamber with a specified volume, the inlet port is closed and the gas is pressed out to the discharge opening separately provided while the chamber is being pushed, lessened and compressed. This operation is repeated. The gas is pushed out by means of piston reciprocating operation or rotary operation of cocoon type (roots type) rotor.

Table 3.1.6-1 Characteristic comparison of blowers

System Item	Axiat flow system	Turbo system	Multilane system	Radial system
Range of use	Air capacity 1 – 10,000 m^3/min Static pressure 1 mmAq – 1 kg/cm^2	Air capacity 1 – 10,000 m^3/min Static pressure 1 mmAq – 1 kg/cm^2	Air capacity 1 – 10,000 m^3/min Static pressure 1 mmAq – 1 kg/cm^2	Air capacity 1 – 10,000 m^3/min Static pressure 1 mmAq – 1 kg/cm^2
Efficiency (%)	80 – 92	70 – 85	50 – 60	60 – 70
Efficiency curve	When varied from the planned air capacity, rapidly decreases	Shows no rapid decrease	Comparatively smooth	Shows no rapid decrease
Starting	Fully open damper	Fully close damper	Fully close damper	Fully close damper
Noise (JB)	39 – 55	32 – 44	22 – 41	28 – 42
Limit surging air capacity (%) (against air capacity at maximum efficiency point)	70 – 80	30 – 60	60 – 80	50 – 70
Applications example	For ventilation fan (buildings, architecture, tunnel), for boiler forced draft, for induced exhaust, for mine blower.	For various blowers for steel mills, for dust collecting tunnel ventilation, for boiler forced draft, for induced exhaust, for cement kiln exhaust.	For various blow and exhaust for steel mills, for boiler forced draft, for building and runnel ventilation	For various blow and dust collection for steel mills, for boiler induced draft, exhaust for gas re-circulation, for cement kiln exhaust.

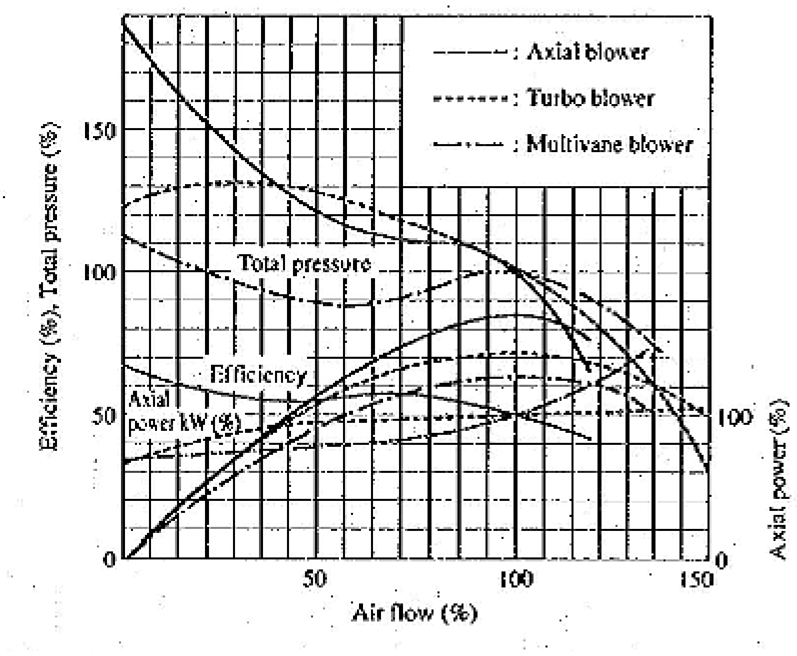


Figure 3.1.6-1 Characteristic curve for various blowers

(2) Required Power of Blowers

I) Air power (L_T)

Air power means effective energy given to air by a blower in unit time.

$$Lt = \frac{K-1}{K} \bullet \frac{Pt2 \cdot Q}{6{,}120} \left\{ \left(\frac{Pt2}{Pt1} \right)^{(K-1)/K} - 1 \right\} \text{ [kW]}$$

Where

Pt1: Absolute pressure on suction side (kg/m^2 abs)

Pt2: Absolute pressure on discharge side (kg/m^2 abs)

Q: Air flow (m^3/min)

K: Specific heat ratio {1.4 for air}

When the pressure ratio is 1.03 or below, it may be calculated by the following equation:

$L_T = Q * P_t/6120$ [kW].

Where

P_t: Total pressure of blower (mmAq)

2) Shaft horsepower (L)

Shaft horsepower is obtained by dividing the air power by the blower efficiency (η r).

L = Lt / ηr [kW]

The efficiency varies with the air flow as shown in Figure 3.1.6-1, but is generally displayed by that during rated air flow.

3) Motor output

Induction motors with simple construction and low-cost are generally used for blowers. Squirrel cage type induction motors are used for comparatively small-capacity blowers. In this case, since the inertia (GD^2) of the blower impeller is great, it is necessary to select after due consideration. The motor output (L_M) is determined by the following equation.

$LM = L * \phi / \eta t$

where

ϕ = Allowance rate

ηt = Transfer efficiency

Values of ϕ and ηt are from Table 3.1.6-2 and Table 3.1.6-3.

Table 3.1.6-2 Value of ηt

1 stage parallel shaft type gear reducer with transfer power of 55 kW or less	1 stage parallel shaft type gear reducer with transfer power of 55 kW or more	Constant speed type fluid coupling with transfer power of 100 kW or less	Constant speed type fluid coupling with transfer power of 100 kW or more
0.95	0.96	0.94	0.95

V-belt	Flat belt	Direct-coupled
0.95	0.90	1.00

Table 3.1.6-3 Value of ϕ

Propeller fan	Disk fan	Mull vane fan	Turbo fan	Plate fan	Profile type fan
1.30	1.50	1.30	1.15	1.25	1.15

(3) Electric Power Conservation for Blowers

Factors for blower electric power conservation are shown in Figure 3.1.6-2.

Namely, the fundamental conception of the electric power conservation is:

- Reduce the operating time,
- adopt high-efficient equipment
- Reduce air power

These will be described as follows:

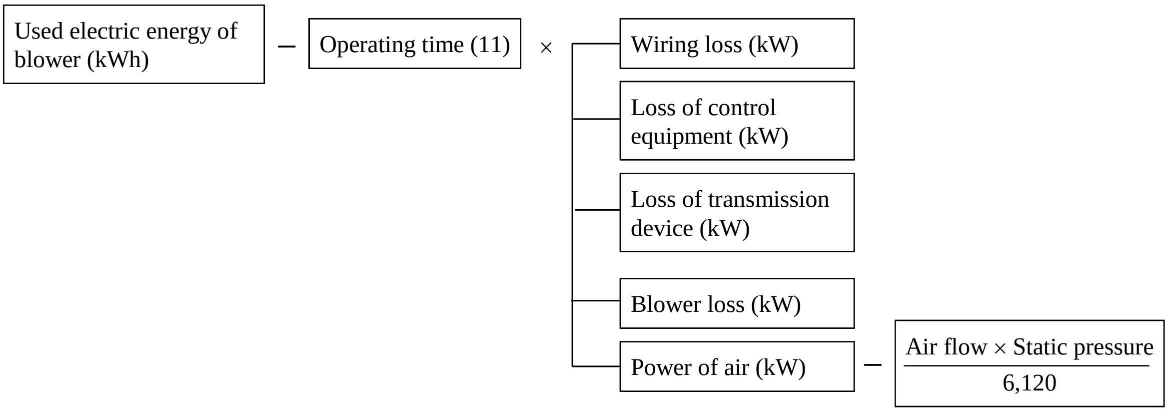


Figure 3.1.6-2 Factors for Blower Electric Power Conservation

1) Reduce the operating time

Too early start of blowers before the factory operation starts, or very late stop of blowers after close of the factory is often seen in factories. Also, blowers in operation, although the entire factory is at a stop because of some troubles, are often seen in general factories. Since such useless operation of blowers is a significant adverse factor for energy conservation, it is necessary for the factory manager to give special attention.

The most direct method to eliminate this useless operation of blower is ON-OFF operation of blowers. Countermeasures and precautions for prevention of general idle operation for motors were described in the section for motors. However, blowers generally have great GD2 and special precautions for ON-OFF operation are as follows:

a) Check the motor for mechanical and electric life
b) Voltage drop of power source
c) Life of starting equipment
d) Others: generated heat for power source cable and life of switches, etc.

2) Adopt high-efficiency equipment

Remarkable points are:

a) Efficiency of blowers
b) Efficiency of power transmission equipment
c) Efficiency of motors

Especially for blowers, it is necessary to select the optimum type according to fluctuation range for air flow, pressure and temperature.

Recently, new products with higher efficiency by improving shape of blade, even of the same type, have been developed

3) Reduce air power

As described in the section for compressors, lowering the air flow, pressure and intake temperature reduces the required power. In the case of a blower, it is generally used with an excessive air flow. For example, when dust collecting effect insufficient at reduced air flow, the blower is operated at full capacity because the proper air flow is not decided. Also, when a blower for cooling has no problems, even if the air flow is reduced according to the season, it is operated at full capacity. These examples are often seen.

That is, to reduce the air flow, it is necessary to study the following:

- What is the proper air flow?
- To acquire this proper air flow, what is the most efficient method?
- Does not air leak from piping and at the place for use?

a) Reduction in units

In case two blowers with the same specifications are operated in parallel, operation mode is changed to one blower operation in consideration with overload to reduce the required air flow rate.

b) Replacement of impellers

When the blower output becomes too high and the damper is exceedingly closed after the required air flow rate is reduced, it is desirable to replace the impellers. Diminishing the diameter of the impeller as requited will bring very great energy conservation.

c) Damper, vane opening adjustment

The damper is installed vertically to the air duct shaft direction to change the opening and when installed on the discharge side, the opening changes the resistance curve and, when installed on the suction side; the opening changes the static pressure curve.

The vane means a movable blade that is installed at the suction side of the blower and provides the gas entering the blower impeller with swirl in the direction of rotation. Accordingly, adjusting the vane changes the wind pressure-air flow curve.

d) Change in rotating speed

Assuming the rotating speed of blower as N,

$Q \propto N$
$P \propto N^2$
$L \propto N^3$

Since there is the above relation, energy can be greatly saved by reducing rotating speed of a motor.

The methods of reduction of rotating speed of a motor are as follows:

- Changing the diameter of the pulley in the case of belt-drive
- Replacing with a motor with lower rotating speed
- Variable speed control with an inverter

Relationship of performance with rotating speed change of a motor is shown in paragraph 3.1.7 “energy conservation of pumps”

Figure 3.1.6-3 shows motor input (%) of various variable air flow control methods

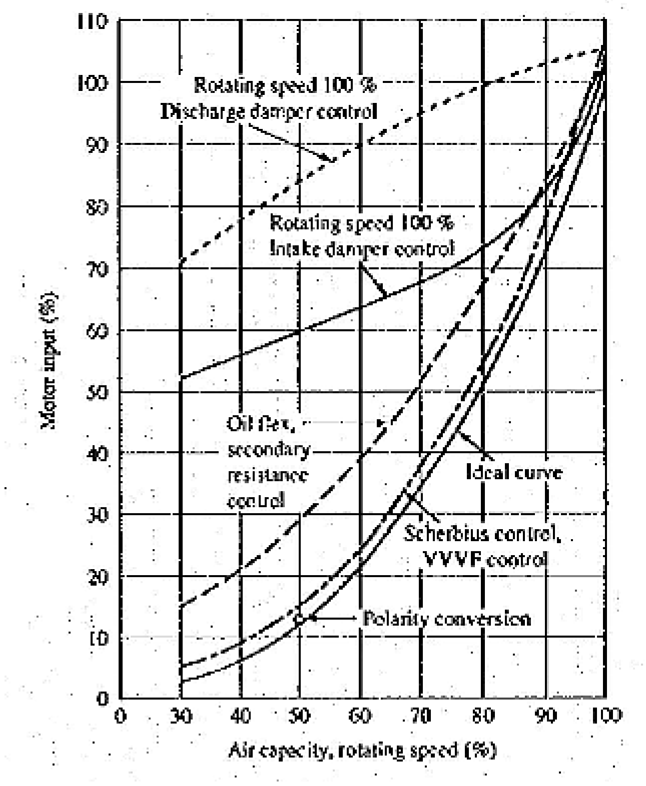


Figure 3.1.6-3 Comparison of Blower Motor's Input

3.1.7 Energy Conservation for Pump

As electric power consumed by pumps in various facilities is huge, improvement of their efficiency is one of the most important concerns for electric power conservation. So far the head of pumps was designed to allow considerable excess on account of the secular increase of line resistance of piping facilities. Also, many of these pumps have excess capacity in prospect of future increase of supply or drainage quantity, so the flow rate is adjusted by valves.

In these cases, while pump efficiency itself is high, efficiency of the pump facilities as a whole is low, resulting in wasteful consumption of electric power.

(1) Type and Construction of Pumps

Pumps are classified into turbo pumps, positive displacement pumps and other pumps, as shown in Figure 3.1.7-1. The turbo pump rotates the impeller in the casing to give fluid energy.

Centrifugal pumps, mixed flow pumps and axial flow pumps belong to this category. As there is no seal between the impeller and casing in the pump body, the discharge varies largely by pressure.

Whereas the positive displacement pump is that which delivers fluid front the section side to the discharge side by means of displacement or change of enclosed space which is generated between the casing and inscribed movable members. Reciprocating pumps and rotary pumps belong to this category. As there is a seat line provided between the casing and the movable members, keeping leakage at a minimum, discharge is hardly affected even when the discharge pressure is varied.

Other pumps include jet pumps and air lift pumps, both of which are used for pumping of water.

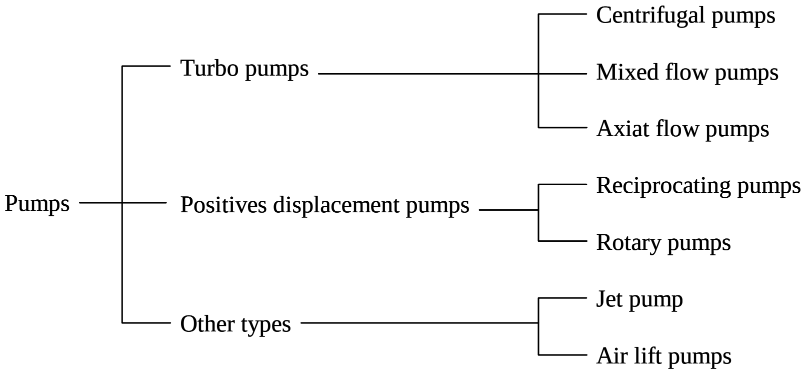


Figure 3.1.7-1 Types of pumps

However, as pumps, turbo pumps are used for the most. So, the following descriptions mainly refer to turbo pumps.

Shapes of these pumps are shown in Figure 3.1.7.1-2

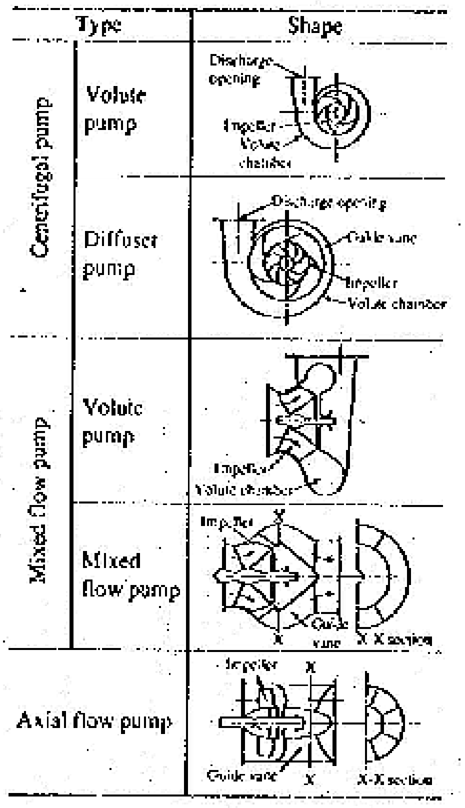


Figure 3.1.7-2 Pump shapes

(2) Characteristic Curves and Operating Points of Pumps

Pumps are not always operated under constantly fixed conditions. However, in each operating state, stable operation is performed at that point of time. This indicates that the state of pipe connected before and after a pump, and of the whole pump system including the water level condition at the suction side and discharge side are in a balanced state. Factors that determine the operating point are pressure loss of the line itself, the closing of valves in the line, and difference of water level between the suction side and discharge side, etc. which are not related to the pump characteristics.

Generally, performance of volute pumps is shown in Figure 3.1.7-3.

Each pump uses a feed pipe to supply water, and the resistance increases almost proportionately to the velocity squared inside the pipe. A resistance curve R, of Figure 3.1.7-3 is the addition of the line resistance of the feed pipe to the actual head of the pump and a pressure required at the end of the feed pipe, and the pump operates with the flow rate Q1 and head H1, at a point of intersection A1 of this resistance curve R, and performance curve of the pump. In this case, the shaft horsepower of pump is a point of intersection L1 of a vertical line drawn from the point A1 with the power curve, and the pumping efficiency is a point of intersection E1 of the same vertical line with the efficiency curve.

Admitting that the actual head and the pressure at the end of the feed pipe are necessary, electric power can be saved by minimizing the resistance of the feed pipe, since the total head

H1 of the pump can be reduced accordingly.

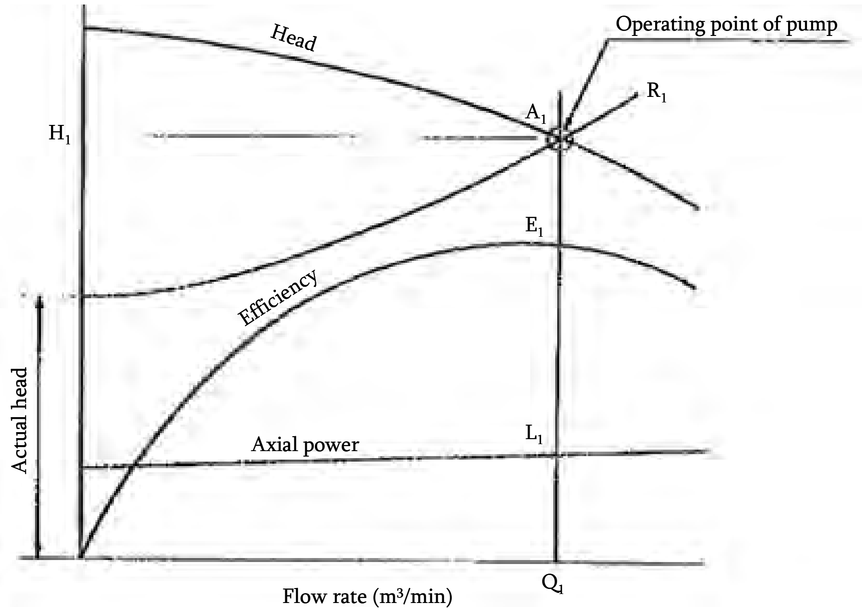


Figure 3.1.7-3 Required power and pump drive motor

(3) Required Power and Pump Drive Motor

1) Required power

The theoretical power of a pump is given by the following formula:

$P = 0.163 * \gamma * Q * H$[kW] ·· (1)

γ: Weight of fluid per capacity (kg/L)
Q: Discharge of the pump (m3/min)
H: Total head of the pump (m)

An output (shaft horsepower) that is required of the motor is given by the following formula:

$P = 0.163 * \gamma * Q * H/\eta * (1+\alpha)$[kW] ························· (2)

η: Efficiency of the pump (%)
α: Tolerance

The approximate values of η and α are shown in Figure 3.1.7-4 and Table 3.1.7-1.

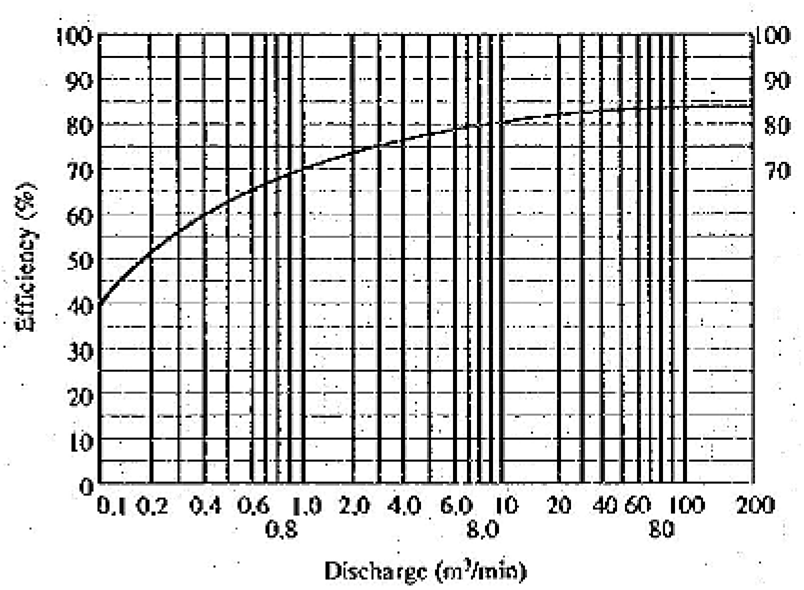


Figure 3.1.7-4 Standard efficiency of general-purpose pumps

Table 3.1.7-1 Tolerance of pumps

Pump type		**Tolerance (%)**	
		Fluctuation of head is relatively small.	**Fluctuation of head is relatively large.**
Volute pump	High head	15	20
	Medium, low head	10	15
Mixed flow pump		15	20
Axial flow pump		20	25

(4) Resistance of Feed Pipe

Generally, resistance of feed pipes is calculated by Darcy's formula (formula (3)when the feed pipe is rather short.

Hf =λ * L / D * v2 / (2g) ·· (3)

Hf: Resistance of feed pipe (m)

λ: Loss factor

L: Length of feed pipe (m)

D: Inside diameter of pipe (m)

v: Velocity in pipe (m/s)

g: Gravity acceleration (9.8 m/s2)

The value of λ is normally set as λ = 0.02 + 1/2,000D, which is multiplied by a modules determined by the smoothness of the internal face of the feed pipe. For this calculation, the loss factor by Colebrook's experimental formula, as shown in Figure 3.1.7-5, will facilitate the procedure.

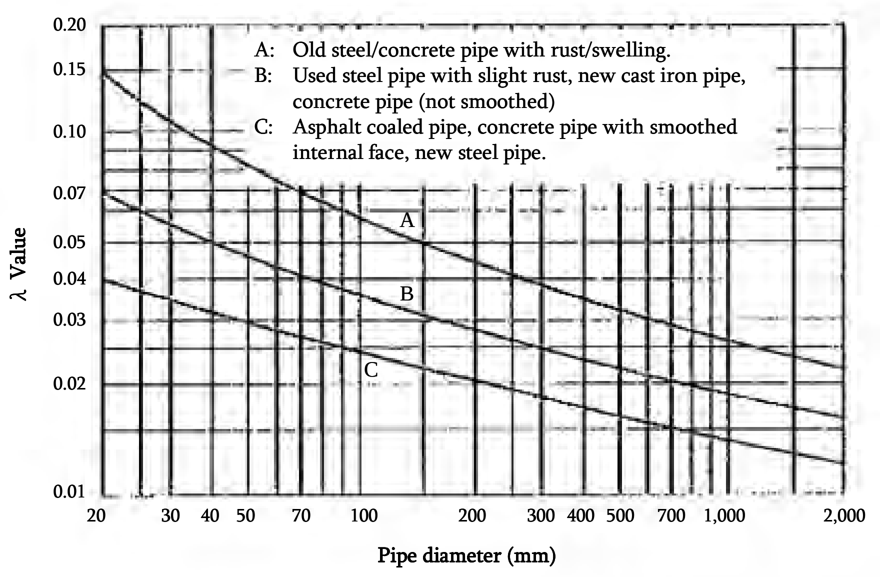


Figure 3.1.7-5 λ value by Colebrook

(5) Variable speed control of pump

Rotating speed control may be adopted for purposes as process control, flow rate control of pumps, or energy conservation, As methods of variable speed control for pump drive motors, there are various methods. To perform rotating speed control, relations of the equations (4), (5), (6) are established by supposing the rotating speed of the pump to be N_0 and N_1 the flow rate Qo and Q_1, the pump head Ho and H_1, and the shaft horsepower Lo and L_1:

$Q_1/Q_0 = N_1/N_0$··(4)

$H_1/H_0 = (N_1/N_0)^2$···(5)

$L_1/L_0 = (N_1/N_0)^3$··(6)

Figure 3.1.7-6 shows changes in characteristics of the pump when the rotating speed is changed, where the flow rate, head and shaft horsepower are changed in a manner so that the expressions (4), (5) and (6) show their relations to the rotating speed. When the resistance curve of the feed pipe is R_3, in Figure 3.1.7-6, and when the rotating speed of the pump is changed from N_0 to N_1 and N_2, the operating point of the pump is changed from A_3 to A_3 and C_3 and the flow rate from Q_3 to Q_2 and Q_1.

If the rotating speed of the pump is left as N_1 when the necessary flow rate is Q_1 the resistance curve must be changed from R3 to R1 by closing the valve, when he operating point of the pump is A1 and the shaft horsepower is L_1. When the rotating speed is changed to N_2, it will change the operating point to C_3 and shaft horsepower to L_1 while leaving the resistance curve as R_3.

Therefore, a considerable amount of electric power can be saved.

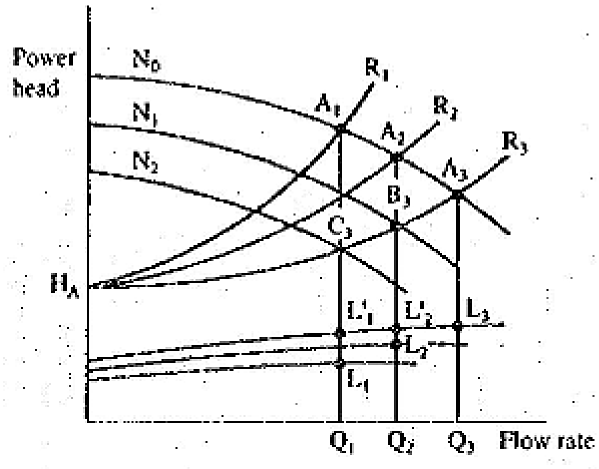


Figure 3.1.7-6 Changes of Characteristics by Change of Rotating Speed

Provided, however, it should be noted that, as the above description applies only when the actual head is small like HA and the line resistance is large as shown in Figure 3.1.7-8, rotating speed would not result in a significant electric power conservation if made when the line resistance is small and the actual head is as large as HB.

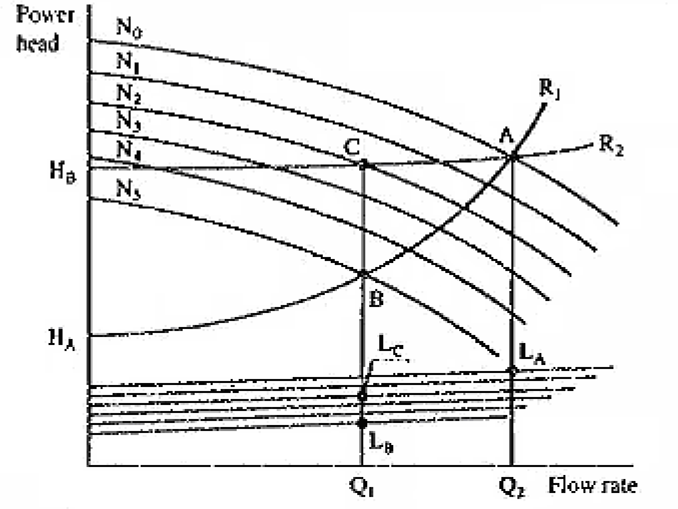


Figure 3.1.7-7 Difference of shaft horsepower by actual head power

- Method to determine rotating speed to change flow rate from Q_0 to Q_2

Suppose that the pump is operating on the operating point A of Figure 3.1.7-8. The resistance curve can be determined from the actual head H3 and the total head H0. On the resistance curve, the total head is H2 and operating point C when the discharge is Q_2.

A curve CB is a quadratic curve passing the origin, obtained as follows:

Supposing the quadratic curve to be,

$H = a * Q^2$

The modulus a is obtained from the point C,

$a = H_2 / Q_2^2$

When factors of Figure 3.1.7.7 are substituted,

$a = 22.5 / (1.5)^2 = 10$

Therefore, curve CB is expressed as,

$H = 10 * Q^2$

The point of intersection of this curve with the pump performance curve at the rotating speed N1 would be point B. From the figure, the discharge $Q_1 = 1.7 m^3/min$, total head H1 = 28.2m, and shaft horsepower L1 = 10.8 kW.

To determine a rotating speed of the pump for reaching the operating point C required by facility, it is calculated by equation (5), as,

$N_2 = N_1 / (H_1/H_2)^{0.5} = 1450 / (28.2/22.5)^{0.5} = 1,295$ rpm

Here, the shaft horsepower is obtained from equation (6), as

$L_2 = L_1 * (N_l / N_0)^3 = 10.8 * (1295/1450)^3 = 7.7$ kW

As the shaft horsepower is 11.0 kW at point A of Figure 3.1.7-8, it is reduced to 7.7 kW by changing the rotating speed.

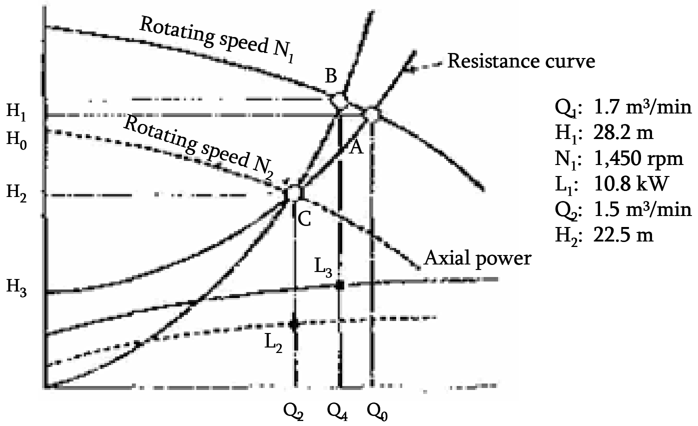


Figure 3.1.7-8 Change of pump performance by rotating speed

(6) Pump Unit Control

When flow control is performed by operating the valve of one large-capacity pump when the required volume of water varies seasonally or by time, i.e. by day or by night, or when the rotation number of the variable speed motor is controlled, the pump efficiency will be low in zones with small flow rates as shown in Figure 3.1.7-9. In such a case as shown in Figure 3.1.7.-9, the number of pumps may he made multiple to perform parallel operation for cases requiring a large volume of water and use only one pump in cases requiring a small volume of water, so that operation can always be performed in zones with high pump efficiency, resulting in electric power conservation. However, it is necessary to make sure of the operating point in order to avoid overload of motor.

If the actual head is HB and the resistance curve of the feed pipe is R2 the f1ow rate is Q_3 when 3 pumps are in operation. Therefore, if only one pump is used, the pump must be operated at the flow rate $Q_3/3$. However, since the flow rate is smaller and resistance of the feed pipe smaller when only one pump is used, the operating point of the pump is B, consequently resulting in a flow rate Q_1 larger than $Q_3/3$. Therefore, study should be made so the motor is free of overloading even when the pump is operated at the flow rate Q_1.

Also, for pumps with small actual head HA, and the resistance curve of the feed pipe R, the flow rate of a pump, when only one pump is to be operated, will exceed the maximum flow rate of the pump, requiring an additional resistance by closing the discharge valve.

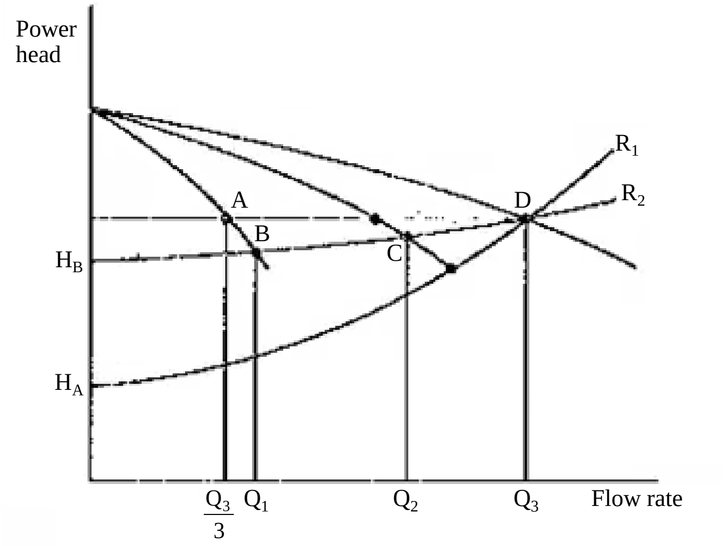


Figure 3.1.7-9 Parallel Operation Characteristics of Pump

(7) Electric Power Conservation Measures of Pump

Since both gas and liquid are fluid and the basic theories are the same, the method that was discussed about the blower thus applies similarly. However, an exception is that the valve control is performed only on the discharge side and not on the suction side. Valve control on the discharge side is the worst method for power conservation purpose.

The 3 factors of electric power conservation of pumps are

- Reduction of required flow rate,
- Reduction of pipe resistance, and
- Efficient flow rate control:

1) Reduction of required flow rate

The first to be done is to reduce the required flow rate. Pumps should be those that meet the required flow rate, however actually in most cases the pump performance are larger than the actually required head and flow rate, because of the following reasons.

a) In many cases pumps having considerable excess capacity in their total head are installed in prospect of an increase of secular loss of piping.
b) Many facilities are installed with excess capacity of flow rate in prospect of a future increase of supply and drainage quantities.
c) Because of the current JIS test standard that states that the actual flow rate-head curve should not be below the prescribed head by means of the flow rate as decided by pump specifications, most pumps have capacities above the flow rate and head as set by the specifications.

2) Reduction of pipe resistance

Although pipe resistance is mostly fixed at construction and rebuilding of existing facilities are difficult, factors that form the resistance may be described as follows:

a) Friction loss of straight pipe
According to Darcy's formula (formula (3)), friction loss of a straight pipe is proportionate to (resistance modules of pipe) * (velocity)^2 * (pipe length)/(pipe diameter).

b) Loss at piping elements
Suction port, bends, acute expanded portions, acute shrinked portions, orifices, diverting points, confluent points, effluent outlet, etc.

c) Loss at valve
In short, piping should be arranged closest to the straight pipe with large diameter and short length, excluding unnecessary accessories from the piping for practical purposes in order to reduce the resistance.

3) Efficient flow rate controlWhen the required flow rate is reducible, methods of electric power conservation of pumps are discussed as follows:

a) Intermittent operation
When water use is clearly distinct between periods of need and no need, pumps may be stopped during unnecessary periods

That is, pumps may be run by intermittent operation. It is a simple method, but turning on and off within short cycles too frequently should be refrained to avoid water-hammer effects.

b) Pump unit control
A method varying the number of pumps according to the fluctuation of flow rate aims at reducing the shaft horsepower of pumps so they can be operated with relatively favorable efficiency meeting the fluctuation range of flow rate.

The control system is simple and risks can be avoided by increasing the number of pumps, but discharge changes by stages. Therefore, when the resistance curve is steep, there exist many problems such as discharge does not in crease so much even when there are more pumps, and so on.

c) Variable speed control
In spite of high initial investment cost, this method offers several such advantages as great reduction in electric power costs and smooth pump operation even at low flow rate. This method is effective for pumps with large capacities, and for cases with large head fluctuation ranges.

d) Replacement of pumps
Replacing pumps with those meeting the required flow rate when the discharge load is stable but the flow rate has dropped lower than before, or when the flow rate fluctuates seasonally, is simple method but has some problems such that flow control is not available, and it takes much time for replacement.

Additionally, someti

mes only motors are replaced for the purpose of reducing the flow rate by changing the revolution.

e) Replacement of the impeller
It is applicable for volute pumps operated under fixed discharge load, and affords efficient changes of pump performance. However, disassembling and assembling of pumps are necessary.

3.1.8 Energy Conservation for Boiler

(1) Classification

Boilers used generally can be classified by structure as shown in Table 3.1.8-1.

Table 3.1.8-1 Classification of Boiler

Type	Model
Cylindrica1 boiler	Vertical boiler
	Flue boiler
	Smoke tube boiler
	Flue smoke tube boiler
Water. tube boiler	Natural circulation water boiler
	Forced circulation water tube boiler
Compact once-through steam boiler	
Once-through boiler	

1) Flue smoke tube boiler

As shown in Figure 3.1.8-1, a flue smoke tube boiler is an internally fired boiler equipped with both of flue and smoke tubes in the shell. The boiler is generally used as a package boiler with characteristics of a relatively larger heating surface area of high efficiency even in a small capacity and has easy installation and handling. The boiler is generally limited to 1.5 MPa (15 kg/cm^2 (G)) in pressure and 25 t/h in capacity. An efficiency of 85 of 92 % is obtainable. On the other hand, the structure is complex, check and cleaning of the inside are difficult and feed water is required to be high quality.

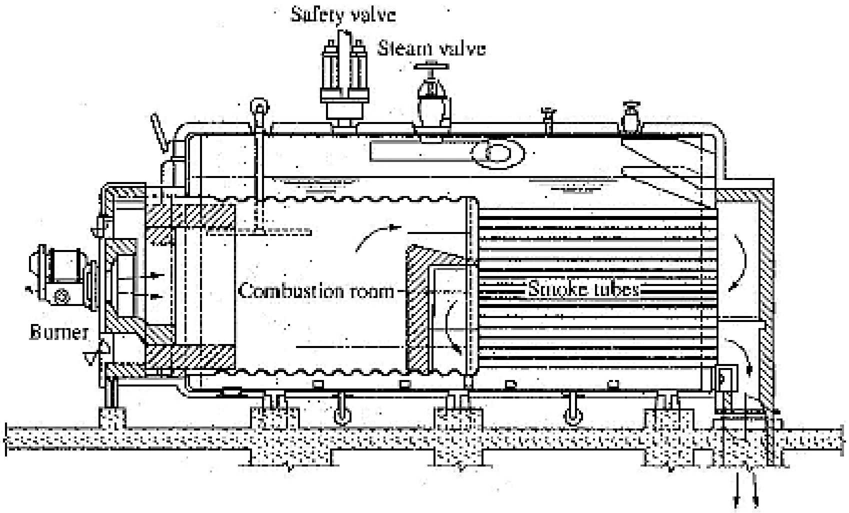


Figure 3.1.8-1 Flue Smoke Tube Boiler

2) Water-Tube Boiler

As shown in Figure 3.1.8-2, a water-tube boiler is composed of a drum for steam and water separation and a number of water tubes formed with a heating surface, and is designed to make feed water evaporate in the water tubes. Accordingly, since the heating surface can be made larger through increasing the number of water tubes, the boiler is suitable even for a large capacity and is capable of obtaining a high pressure easily. The features of water-tube boilers are as follows:

a) Because the combustion chamber can be made in any size, the combustion is in good condition and various fuels can be adapted easily.
b) The thermal efficiency is higher because of a larger heating surface area.
c) The start-up time is shorter because of the small amount of retaining water per heating surface area. While a fine regulation is required since the pressure and water levels are prone to fluctuate with a loading variation:
d) Consideration should be given to feed water and boiler water treatment.
The water-tube boiler has two systems: a natural circulation system, which utilizes the differences of the specific gravities between steam and water, and forced circulation, which uses a pump. A high-pressure boiler is required to adopt a forced circulation system because of the density difference between steam and water is small.

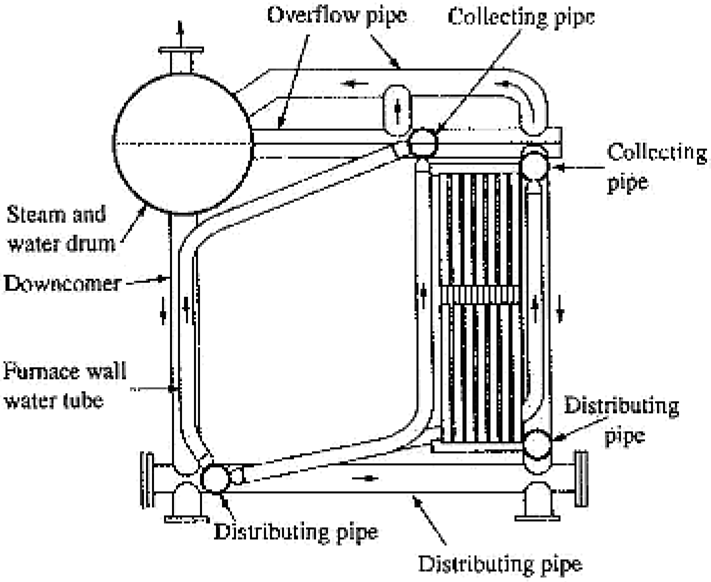


Figure 3.1.8-2 Oil or Gas Firing Water Tube Boiler

A coal firing water tube boiler has coal preparation equipment and highly efficient dust collector as shown in Figure 3.1.8-3. Most of combustion equipment of coal is a traveling type stoker and a spreader stoker.

In spreader stocker combustion, coal is supplied by a feeder, flown by spraying machine of rotor, and equally sprinkled all over a stoker top, which is a reverse traveling type. Large-sized coal is sprinkled to the stoker rear, small-sized coal is sprinkled at the front part by the gravity action, and fine coal carries out floating combustion.

Spreader stocker combustion turns into middle combustion of traveling type stalker combustion and pulverized coal combustion.

The equipment flow of a coal firing water tube boiler is shown in Figure 3.1.8-3, and spreader stalker combustion equipment is shown in Figure 3.1.8-4.

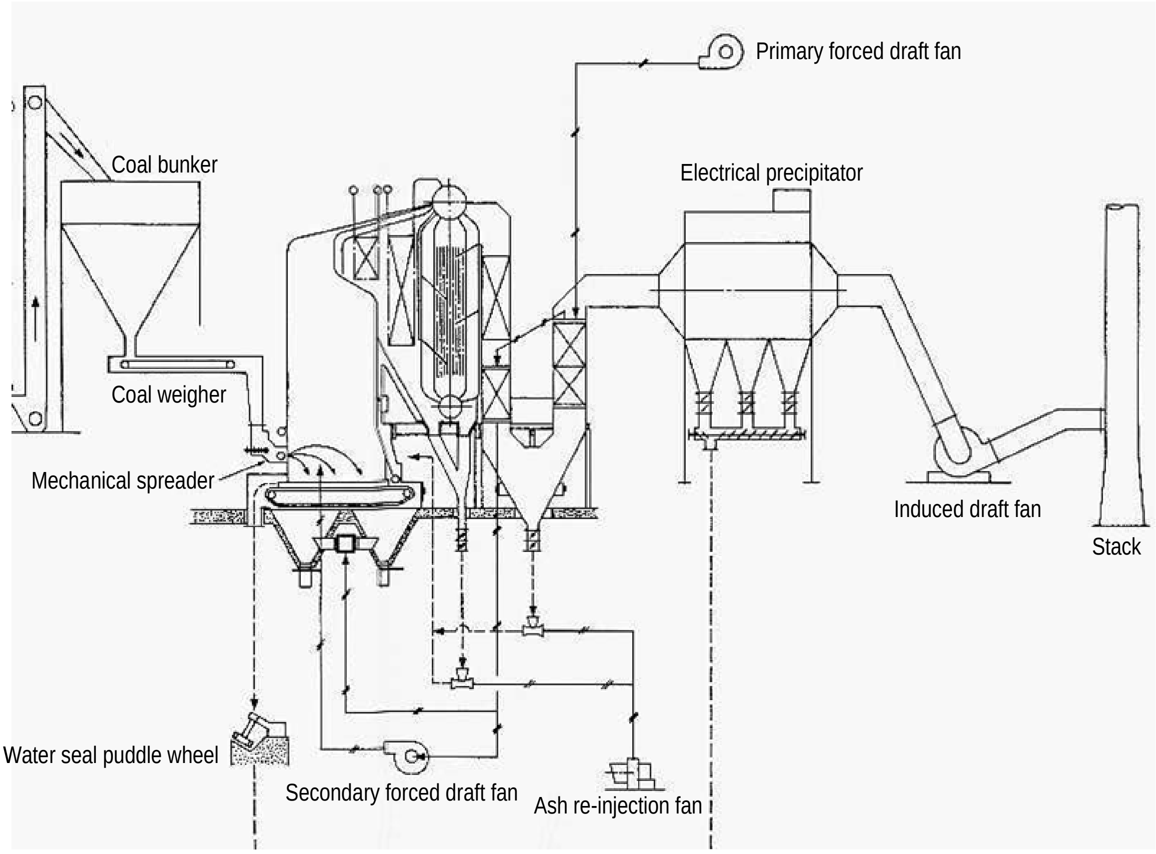


Figure 3.1.8-3 Flow Diagram of Coal Firing water Tube Boiler

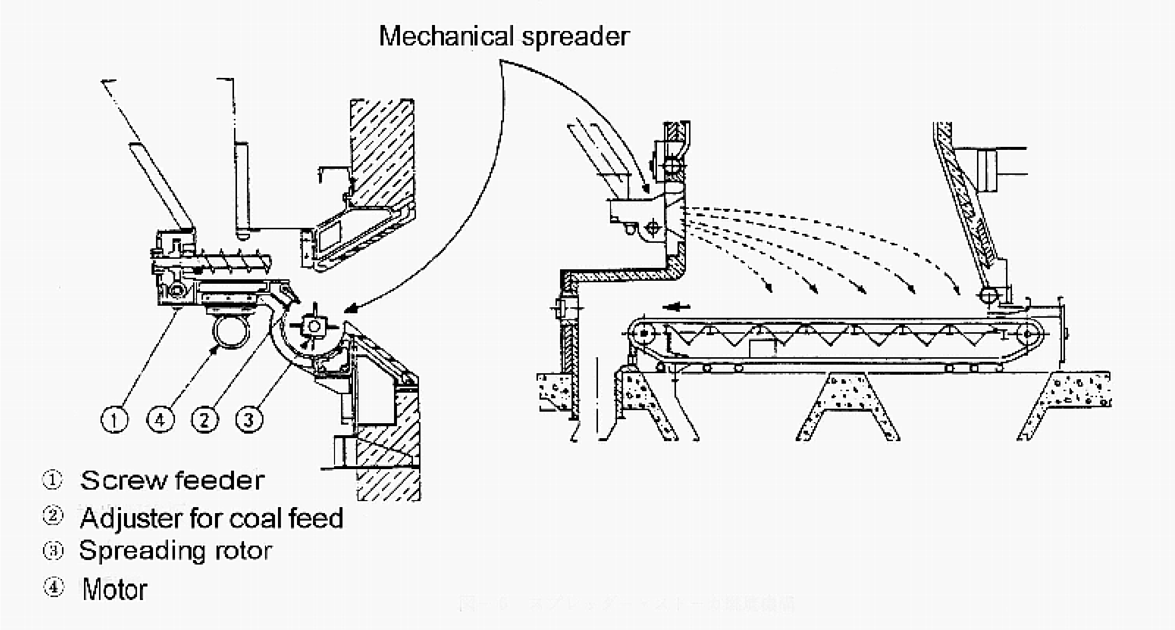


Figure 3.1.8-4 Spreader Stoker

3) Compact once-through steam boiler

As shown in Figure 3.1.8-5, a compact once-through steam boiler is the structure which connected between upper header and lower header with two or more perpendicular water tube. Water is supplied to lower header, is heated to steam mixture state while water goes up water tube, is sent into a steam separation header or upper header, and is sent as steam. Since small-sizing and high efficient conditions of this boiler are attained, this boiler is advantageous on an installation space. Although the maximum capacity is 2 t/h, two or more units of boilers can be installed, and the running number control according to load can be performed.

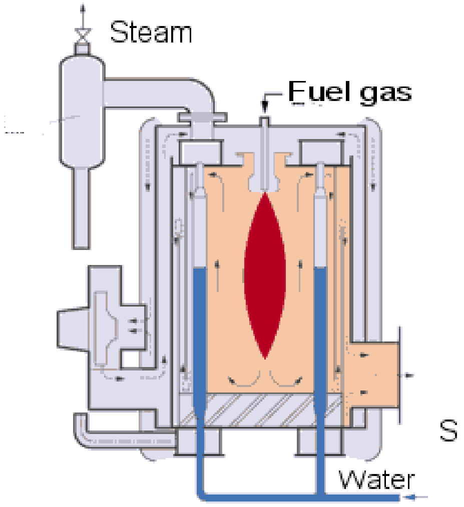


Figure 3.1.8-5 Once-through Steam boiler

(2) Heat Balance of Boilers

In Japan, heat balance method of a boiler is specified by Japanese Industrial Standard (JIS B8222). Its outline is described below.

The heat balance is carried out as the result of an operation in one or more hours under a steady- state on consideration of atmospheric temperature as a reference temperature. In this operation, no blow or no soot blow is done.

At the start, range of heat balance should be fixed as shown in Figure 3.1.8-6. The heat balance shall be performed on heat output and heat input across the battery limit. If equipped with waste heat recovery equipment, take care not to mistake the measuring points.

The specification of equipment for a subject boiler should be examined and the operation record should be described.

The results of the heat balance should be entered into the format of Table 3.1.8-2. The important items and referred items for calculation are picked up and indicated hereinafter.

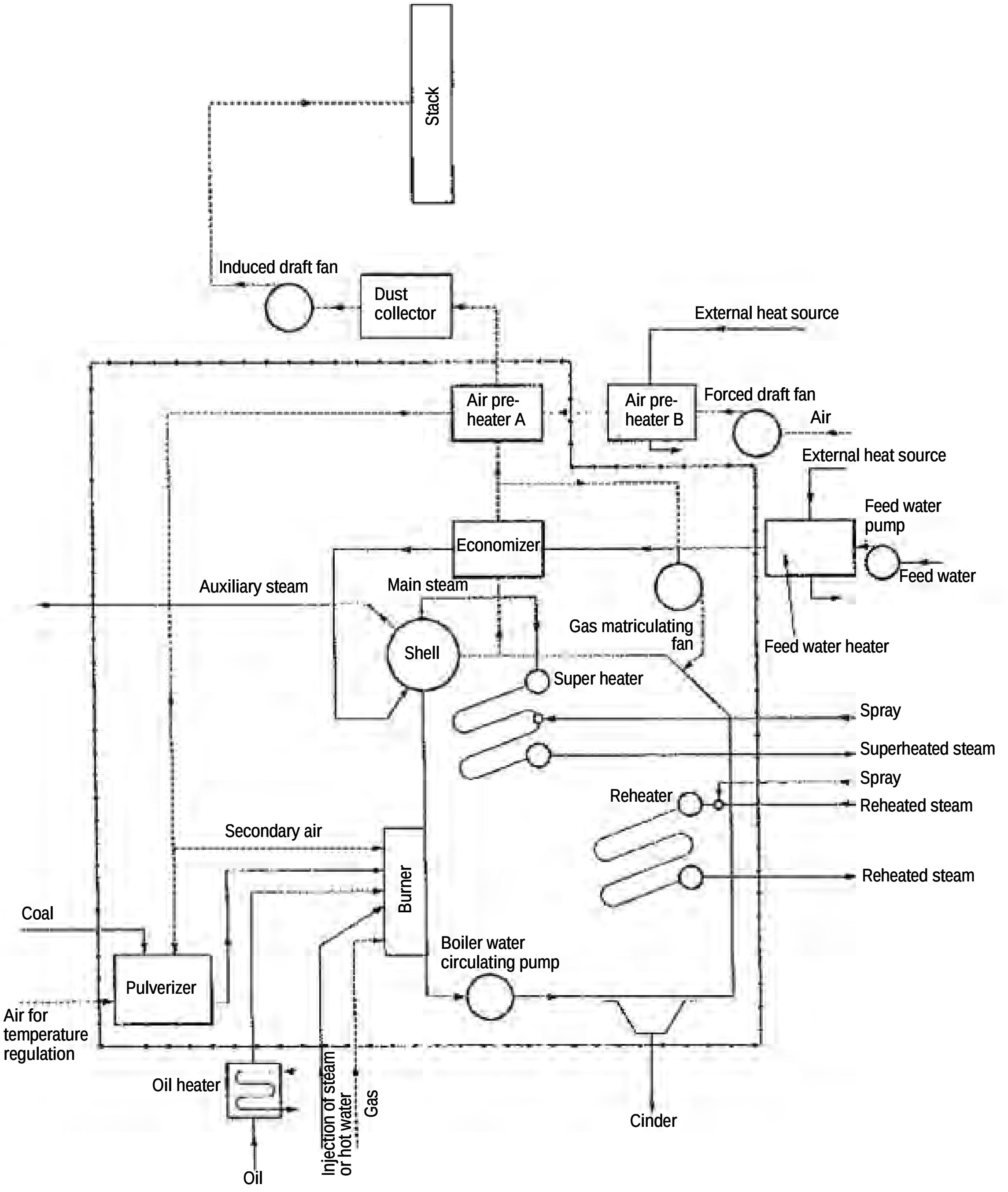


Figure 3.1.8-6 Standard Range of Boiler Heat Balance

Table 3.1.8-2 Heat Balance Table

	Heat input	**kJ/kg (m^3N)**	**%**
(1)	Calorific value of fuel	H_J(2)	
(2)(')	Sensible heat of fuel	Q_1	
(3)(')	Sensible heat of air	Q_2	
(4)(')	Carrying heat of furnace injection steam	Q_3	
(5)(')	Heat corresponding to the work of auxiliary devices	Q_4	
	Total	**H_J(2)+Q**	**100**

		Heat input	**kJ/kg (m^3N)**	**%**
Effective heat	(1)	Heat of generated steam	Q_S	
	(2)	Heat of blow water	(Q_d)	
	(3)	Others		
		Subtotal	**Q_S**	
Heat loss	(1)	Heat loss in exhaust gas	L_H(3)	
	(2)	Heal loss due to furnace injection steam	L_2	
	(3)	Heat loss due to incomplete burning exhaust gas	L_3	
	(4)	Heat loss due to combustible in refuse	L_4	
	(5)	Heat loss due to dissipation	L_5	
	(6)	Heat loss due to others	L_6	
		Subtotal	**L_1(3)**	
		Total		**100**

	Boiler efficiency	**%**
(1)	Input and output heat method $\eta_1 = \frac{Qs}{H_1+Q} \times 100$	
(2)	Heat loss method $\eta_2 = (1 - \frac{L_1}{H_1+Q}) \times 100$	

Note (1) (2), (3) and (4) are due to the external heat source,
(2) In case of a high heating value basis, it shall be taken as $H_{h,}$
(3) In case of a high heating value basis L_1 shall be taken as L_{1h} and L_1 be taken as shall be taken as L_h.

1) Exhaust gas loss

The average specific heat of combustion exhaust gas is 1.38 kJ/ (m^3N°C) (0.33 kcal/ m^3NºC) from the result obtained in the range of 0 to 300ºC in a temperature and from 1.0 to 1.3 in an air ratio (1.5 for a solid fuel).

The theoretical wet combustion exhaust gas quantity is calculated from the material balance similar to the theoretical air or can be obtained from the fuel heat value according to Boie's approximate expression.

- Case of coal
  G_1 = 0.216 * Hf/1,000 + 1.67［m^3N/kg−fuel］ 和文では*が入っているが？
- Case of fuel oil
  G_1 = 3.762 * Hf/10,000 - 3.91［m^3N/kg−fuel］
- Case of gaseous fuel (Case of hydrocarbon-mixed gas)
  G_1 = 2.926 * Hf/10,000［m^3N/m^3N−fuel］

Where

H_f: Heat value of fuel (kJ/kg) or (kJ/ m^3N)

Actual exhaust gas quantity is as the following equation.

$G = G_1 + (m - 1) A_0$ + water vapor quantity due to moisture in air

The water vapor quantity due to moisture in the air may usually be neglected.

Where

m: Air ratio

A_0: Theoretical air volume (m^3N/kg-fuel) or (m^3N/m^3N-fuel)

Exhaust gas loss is the following equation.

$LH = G * Cp * (tg-ta)$ [kJ/kg] or [kJ/m^3N]

Where

Cp: Average specific heat of exhaust gas [1.38 kJ/m^3N]

tg: Temperature of exhaust gas [K]

ta: Ambient temperature [K]

(3) Energy Conservation Measures for Boiler

There are various items for the energy conservation measures for boiler as shown in Figure 3.1.8-7 cause and effect diagram. The energy conservation measures for boilers are shown in Table 3.1.8-3. a little bit in detail.

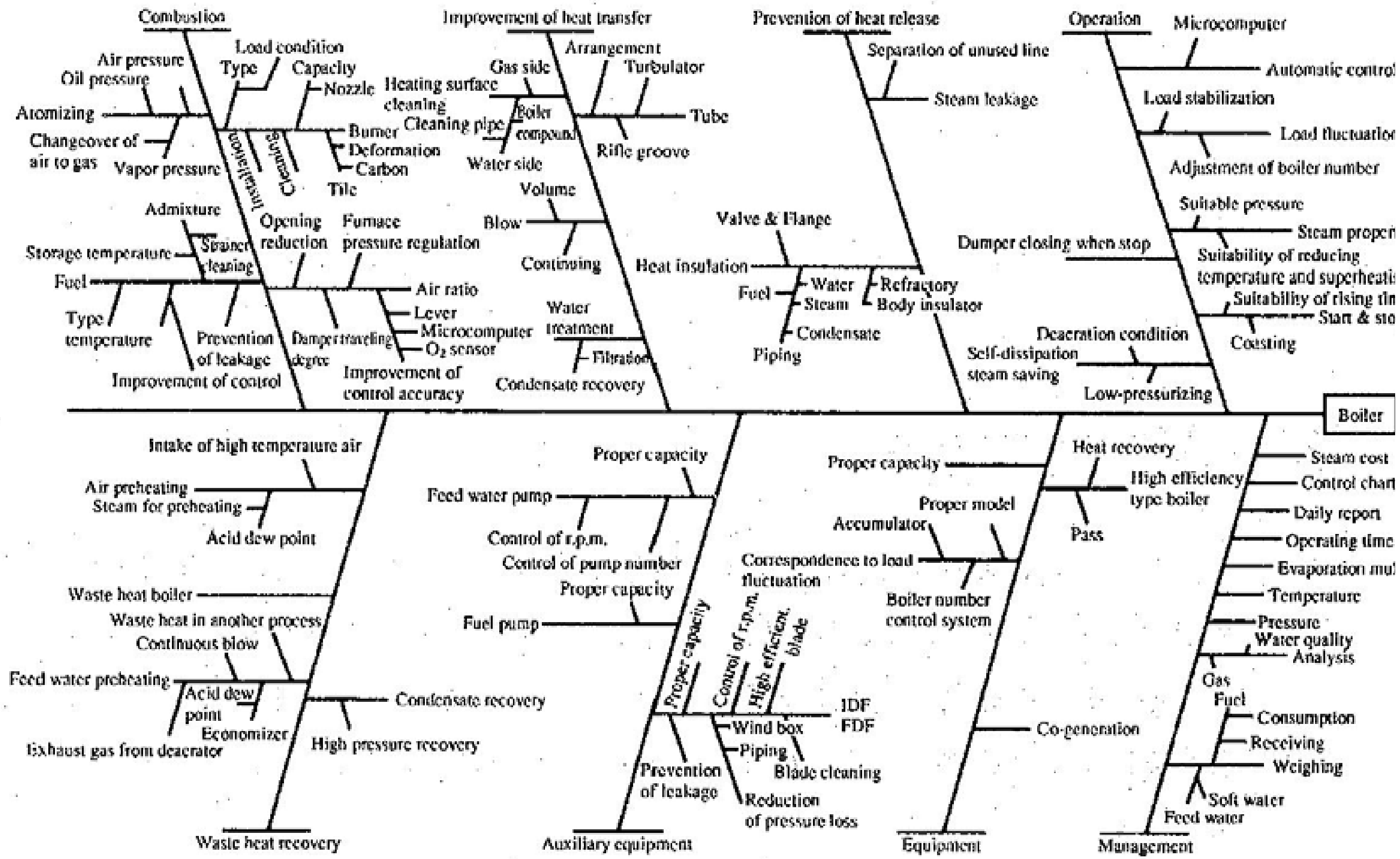


Figure 3.1.8-7 Cause and Effect Diagram of Energy Conservation Measures for Boiler

Table 3.1.8-3 Energy Conservation Measures for Boiler

No.	Category	Energy conservation measures	Energy saving effects	Investment cost	Remarks
1	Combustion	Improvement of air ratio	Exhaust gas 600^0C, Base temp 20 ^{0}C, heavy oil firing, Air ratio 1.6 to 1.2、 Waste heat loss: 37% ⇒ 28% Improvement of fuel saving: 9%	Installation cost of oxygen analyzer for exhaust gas	
2	Combustion	Keeping of fuel oil temperature Preheated temperature is 80 to 100 ^{0}C		No investment cost	
3	Combustion	Inspection and maintenance of burner: Oil strainer, Burner chip, Burner direction, Burner tile, Oil leakage of valves and piping		No investment cost	
4	Combustion	Keeping of steam pressure for atomizing at the value indicated by manufacturer		No investment cost	
5	Combustion	Preventions of infiltrating air: Keeping of inner pressure of combustion chamber, Closing of opening area		No investment cost	
6	Combustion	Adjustment of combustion air volume: Monitoring of combustion flame and smoke		No investment cost	
7	Combustion	Introduction of automatic combustion control unit: Damper control of combustion air fan by feedback of oxygen content in exhaust gas		Installation cost of oxygen analyzer for exhaust gas and automatic control unit	
8	Heat transfer	Removal of heat transfer surface and water tube: Soot blow work, Periodical cleaning every 1 to 3 months	Remove thickness of soot 2mm to 0.5mm, Fuel consumption: 30% ⇒ 5% Fuel saving effects: 25%		

No.	Category	Energy conservation measures	Energy saving effects	Investment cost	Remarks
9	Heat transfer	Removal and prevention of scale in water tube: Water treatment, Boiler water blowing, Periodical cleaning or acid cleaning a year,	Remove scale of thickness of 1mm, Fuel saving: 2%	Installation cost of economizer, Insulation cost of feed water piping	
10	Heat transfer	Removal of dissolved oxygen in feed water: Introduction of membrane unit	Saving of agent of deoxygenize	Installation cost of deoxygenize unit with membrane type	
11	Waste heat recovery	Preheating of combustion air by waste heat recovery	Air ratio: 1.2、Exhaust gas temp.: 900^0C, Preheated air temp.:200 ^{0}C, Fuel saving: 12%。	Installation cost of air preheater, Insulation cost of air piping	
12	Waste heat recovery	Preheating of feed water by waste heat recovery	Base feed water: 20^0C, Boiler pressure: 1MPa, Feed water temp.:20^0C to 80 ^{0}C preheated, Fuel saving: 9%	Installation cost of economizer, Insulation cost of feed water piping	
13	Waste heat recovery	Recovery of steam condensate	At boiler efficiency: 85%, Recovery of condensate: 80%, Apparent boiler efficiency : 95% Efficiency improvement: 10%	Installation cost of condensate tank, piping and steam trap	
14	Heat dispersing	Prevention of steam leakage from steam piping		No investment cost	
15	Heat dispersing	Repairing of insulation material of boiler body		No investment cost	

No.	Category	Energy conservation measures	Energy saving effects	Investment cost	Remarks
16	Heat dispersing	Reinforcement of insulation of steam piping and steam valve	Steam pressure: 4 MPa, Steam temperature: 250^{0}C, No-insulated piping of diameter: 5inch（125A） and length: 10m, After insulation of 30mm thick, dispersion heat from surface of piping: 20,000kcal/h ⇒1,690 kcal/h Heat saving: 18,310kcal/h	Insulation cost of piping	
17	Anxiety equipment	Variable speed control of induced draft fan Rotating speed control by inverter due to load		Insulation cost of inverter control unit	
18	Operation	Preparation of graph of steam evaporation volume and fuel consumption: Check the trend of data	Prevention of damage and loss by early finding of extraordinary	No investment cost	
19	Operation	Preparation of daily operation record: Evaporation volume, fuel consumption, Feed temperature, Exhaust gas temperature, Oxygen content in exhaust gas, Record every 1 hour	Prevention of damage and loss by early finding of extraordinary。	No investment cost	

1) Air ratio

The largest heat loss of boilers is an exhaust gas loss (see Figure 3.1.8-8). The exhaust gas loss is determined by an exhaust gas volume and an exhaust gas temperature. A proper air ratio must be kept to minimize the exhaust gas volume.

Considerable points to maintain the proper air ratio are as follows:

a) Maintaining of proper fuel oil temperature
Fuel oil should be preheated to 80 - 100°C to maintain the viscosity of fuel oil within the range from 20 to 45 cSt.

b) Inspection and tuning up of oil burner
  - Clogging of oil strainer
  - Clogging, abrasion and assembling of burner tip
  - The mounting direction of the burner and distance to the burner file
  - Damage of and deposit of carbon on the burner file
  - Oil leakage from the oil valves and the pipe connections

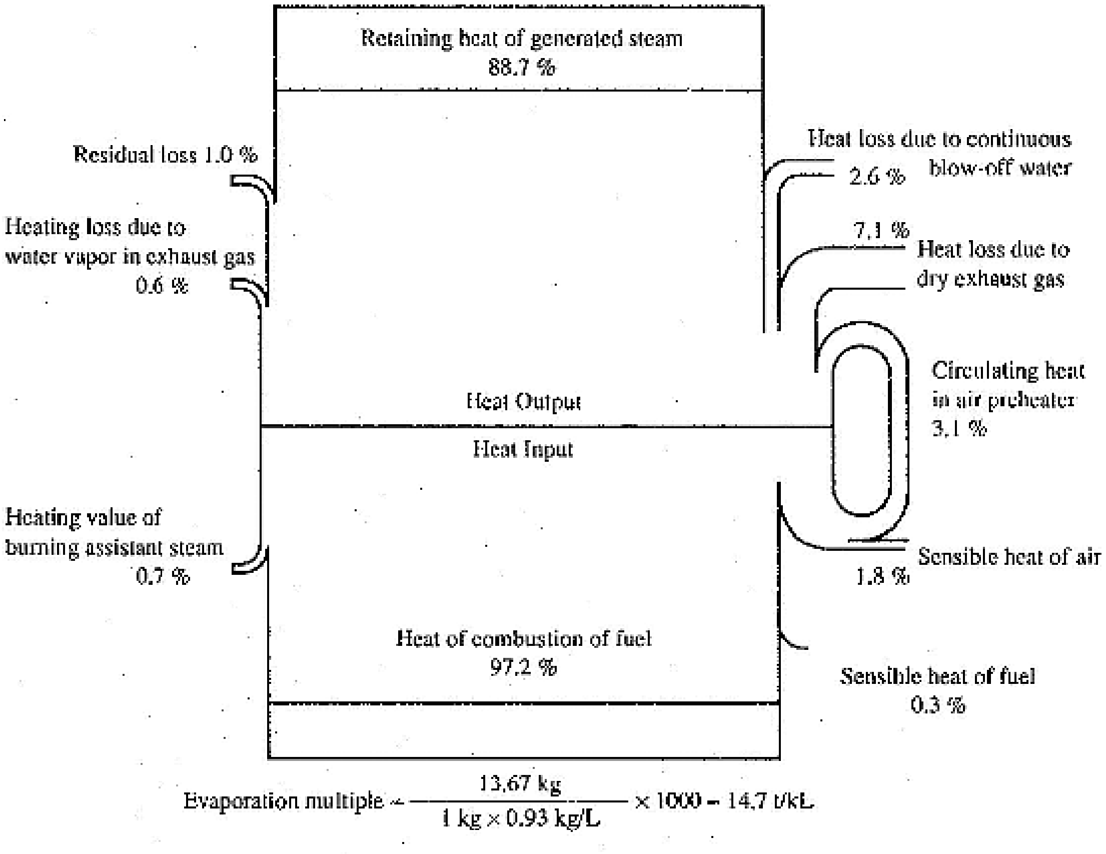


Figure 3.1.8-8 Example of Heat Balance of 20 t/h Steam Boiler

c) Maintaining of steam pressure for atomization in oil burner
The steam pressure, air pressure or fuel oil pressure should be maintained to the specified value by the manufacturer to be atomized sufficiently. For the characteristics of oil burners,

d) Prevention of air invasion
Prevent air invasion by keeping the boiler combustion chamber pressure properly and reducing the area of the opening parts.

e) Regulation of air
The air ratio can be checked for its appropriateness by an oxygen or CO_2 analysis in the exhaust gas but air must be adjusted by observation of flame and smoke in daily operation. The air amount is adjusted with observation of the smoke sent forth from the stack and should be a little more than that under which a slightly black smoke will be emitted.

The fuel oil or kerosene burning, through observation of the flame from the front inspection hole, the combustion under conditions that the center of flame is a slightly dark shade and a dazzling flame around it is stable is near to the proper air ratio. If the air amount decreases a little shorter than the proper value, the tip part of the flame has a tinge of black and soot generates. On the other hand, if the air is excessive, the flame shortens extremely and becomes like a branch swaying violently. The color of the flame becomes yellow closer to white.

f) Automatic control
It is the simplest method when the fuel control valve is interconnected mechanically with the air damper and the lever is driven by the control motor of the automatic combustion. But this method is difficult to change the setting of the air ratio during the operation and the air ratio is more likely to be set at a1ittle higher level not to generate black smoke even at lower load.

Therefore, a partially improved method is the following.
The example shown in Figure 3.1.8-9 has a ratio setting mechanism in the linkage and the O_2 content in the exhaust gas is fed back to adjust the air damper to the O_2 setting by fine adjustment.

For a large capacity boiler, a flow controller should be installed for fuel and air respectively to perform a parallel or series cascade control by the steam pressure signal as shown in Figure 3.1.8-10.

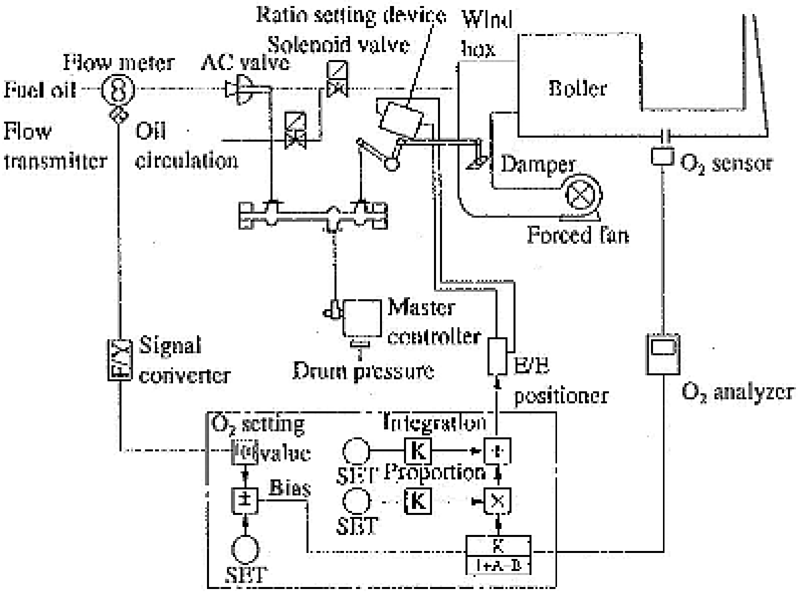


Figure 3.1.8-9 Boiler Air Ratio Controllers

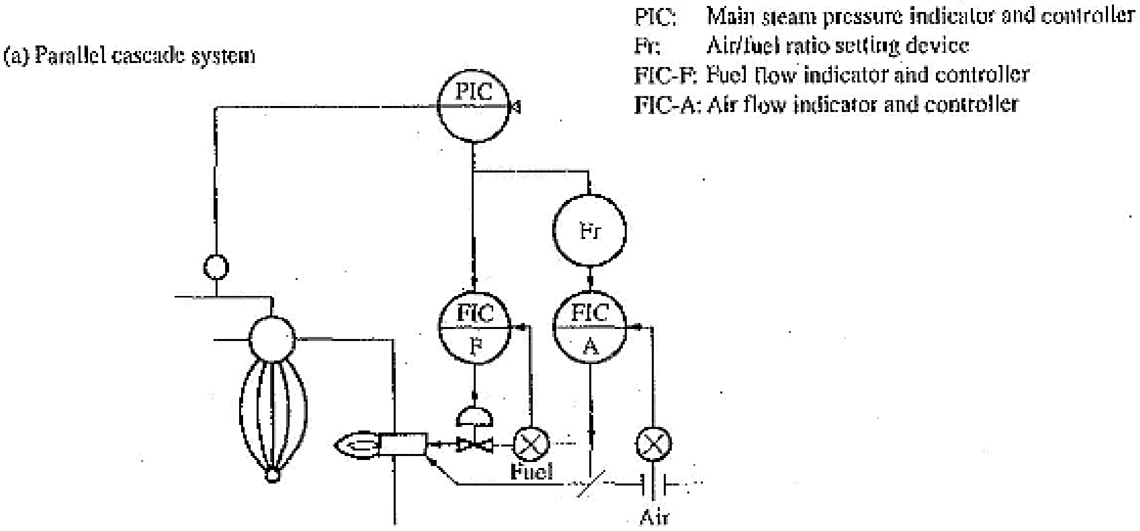


Figure 3.1.8-10 Basic Combustion Control System

g) Standard of air ratio

Since the air ratio is influenced by the type of fuel, the load factor and the composition of control devices, these points must be considered for setting of the standard. The target values of air ratio of Japanese standard in the energy conservation law for boilers are shown in Table 3.1.8-4 and the values for industrial furnaces are shown in Table 3.1.8-5 as reference.

Table 3.1.8-4 Target Value of Air Ratio in Boiler

Classification	Load factor (%)	Solid fuel			Liquid fuel	Gas fuel	Blast furnace gas and other by-product gases
		Fixed bed		Fluidized bed			
		Coal	Pulverized coal				
Large-sized boiler for electric utilities	75 - 100	-	1.15-1.25	-	1.05 - 1.1	1.05 - 1.1	1.15 - 1.2
Other boilers							
30 t/h or more	50 - 100	1.2 - 1.3	1.2-1.25	1.2- 1.25	1.05 - 1.15	1.05 - 1.15	1.2 - 1.3
10 to 30 t/h	50 - 100	1.2 - 1.3	1.2-1.25	1.2- 1.25	1.15 - 1.25	1.15 - 1.25	-
5 to 10 t/h	50 - 100	-	-	-	1.15 - 1.3	1.15 - 1.25	-
<10 t/h	50 - 100	-	-	-	1.15 - 1.3	1.15 - 1.25	-

Applicable for Incluprl cuune 20 liter/h oil coupmpler

Table 3.1.8-5 Target Value of Air Ratio in Industrial Furnace

(Applicable for Industrial Furnace over 20liter/h oil equivalent consumption)

Applicable for Industrial Furnaces of 20 Liter/H

Item	Gas fuel		Liquid fuel	
	Continuous type	Intermittent type	Continuous type	Intermittent type
Metal melting furnace for casting	1.05-1.20	1.05-1.25	1.05-1.25	1.05-1.30
Continuous billet reheating furnace	1.05-1.15	-	1.05-1.20	-
Metal heating furnace other than the above	1.05-1.20	1.05-1.30	1.05-1.20	1.05-1.30
Metal heat treatment furnace	1.05-1.15	1.05-1.25	1.05-1.20	1.05-1.30
Petroleum heating furnace	1.05-1.20	-	1.05-1.25	-
Thermal cracking furnace and reforming furnace	1.05-1.20	-	1.05-1.25	-
Cement kiln (*1)	1.05-1.25	-	1.05-1.25	-
Lime kiln (*1)	1.05-1.25	1.05-1.35	1.05-1.25	1.05-1.35
Drying oven (only the combustion chamber)	1.05-1.25	1.05-1.45	1.05-1.30	1.05-1.50

Note: (*1) value of liquid fuel in case pulverized coal firing

2) Exhaust Gas Temperature

a) Recovery of waste heat in exhaust gas

In boilers, it is basic that the exhaust gas temperature does not rise by keeping air ratio in proper values by lessening contamination on the heating surface, If the exhaust gas temperature is higher, the waste heat in the exhaust gas is recovered to preheat the feed water or the air for combustion and the thermal efficiency as a whole should be improved. In general, a large size boiler is often equipped with both an air preheater and a feed water preheater (economizer). A middle or small size boiler is often provided with either of them.

- Corrosion by sulfuric acid

The point to be given attention for recovery of waste heat in the exhaust gas, is corrosion in low temperatures due to sulfuric acid mist in the exhaust gas.

When a fuel containing sulfur is burned, SO_2 is formed and a part of it is converted to SO_3. Accordingly, the temperature of exhaust gas comes to the dew point or less by contact to the low temperature wall of the heat exchanger, SO_3 reacts with water to produce sulfuric acid (H_2SO_4) in a high concentration, which provides corrosion to the heat exchanger or the duct.

- Saving rate of fuel by air preheating

The saving rate of fuel due to air preheating is as follows:

Where,
Q: Carrying-away heat of exhaust gas kJ/kg-fuel
Y: Carrying-in heat of preheated air kJ/kg-fuel
F: Heat value of fuel kJ/kg-fuel
H: Available heat and required heat = F - Q kJ/kg-fuel
In a case, where air is not preheated
HA = F-Q
In a case of preheating air
HB =F-Q+P=HA+P
Taking the required heat of furnace as X kJ/h, the fuel consumption when air is not preheated:
X/HA [kg-fuel/h]
When air is preheated:
X / HB = X/(HA+P) [kg-fuel/h]
Accordingly, the fuel saving rate is as follows:

$$\frac{X/HA - H/(HA+P)}{X/HA} = \frac{P}{HA+P}$$

The fuel saving rate in case of the air ratio 1.2 is shown in Figure 3.1.8-11.

The preheating of air brings an energy conservation effect by increasing of the carrying-in heat, a reduction of the air ratio through an improvement of the ignition and stability of the flame and an acceleration of combustion and a rising of the flame temperature.

In the case of an air preheating, however, care must be used to the increasing of NOx generation due to the rising of flame temperature and the heat resistance of the burner.

When an installation of an economizer is planned, it should be overall investigated in comparison with the recovery of condensate, the heat recovery in a continuous blow and the feed water preheating effect by solar energy or utilization of waste heat in other processes. If the feed water temperature has already risen by other heat sources, the economy of an economizer may sometimes drop to a lower level,

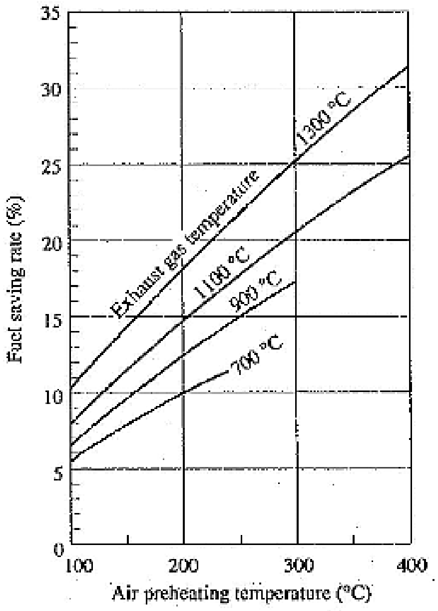


Figure 3.1.8-11 The fuel saving rate in case of the air ratio 1.2

b) Exhaust gas temperature standard

The heat efficiency of boilers is generally at a higher level compared with an industrial furnace and the exhaust gas temperature is also at a relatively lower level. A large size boiler is in a favorable economical condition to equip with a waste heat recovery unit and has the exhaust gas at a lower temperature. A gaseous fuel generally has lower sulfur content and heat recovery from the exhaust gas comes to extent of lower exit temperature.

In the Japanese exhaust gas temperature standard of a boiler of the energy conservation law, the standard of an exhaust gas temperature by capacity and by fuel is determined in consideration of these points as shown in Table 3.1.8-6. This standard value is a temperature in a condition of 20°C in an ambient temperature and 100 % in a load factor just after the periodical maintenance.

Japanese target waste heat recovery rate of industrial furnace is shown in Table 3.1.8.-7.

Table 3.1.8-6 Standard Exhaust Gas Temperature of Boiler (unit: ºC)

(Load factor: 100 % at the outer temperature of 20ºC)

Class	Target exhaust gas temperature (°C)				
	Solid fuel		Liquid fuel	Gas fuel	BF gas and other by-product gas
	Fixed bed	Fluidized bed			
Large-sized boiler for electric utilities	―	―	135	110	190
Others					
30 t/h or more	180	170	160	140	190
10 to 30 t/h	180	170	160	140	―
5 to 10 t/h	―	300	180	160	―
Below 10 t/h	―	320	200	180	―

Table 3.1.8-7 Target Waste Heat Recovery Rate of Industrial Furnace

Waste gas temperature (°C)	Capacity category	Target waste heat recovery ratio (%)	Reference	
			Waste gas temperature (°C)	Preheated air temperature (°C)
below 500	A･B	35	275	190
500 to 600	A･B	35	335	230
600 to 700	A	40	365	305
	B	35	400	270
	C	30	435	230
700 to 800	A	40	420	350
	B	35	460	310
	C	30	505	265
800 to 900	A	45	435	440
	B	40	480	395
	C	35	525	345
900 to 1,000	A	55	385	595
	B	45	485	490
	C	40	535	440
1,000 and over	A	55	―	―
	B	45		
	C	40		

Note: Capacity category A, B and C
Category A: Furnace with rated capacity of 84,000 MJ/h or more
Category B: Furnace with rated capacity of 21,000 to 84,000 MJ/h
Category C: Furnace with rated capacity of 840 to 21,000 MJ/h

3) Prevention of heat Release

Boilers are designed to restrict heat release as much as possible under consideration that most of the heat radiation surface is water or steam part and heat insulation is also generally sufficiently provided. However, the feed water tubes, valves and flanges around the boiler are sometimes not provided with that insulation.

In the event that hot water such as condensate is recovered into a feed water tank, some examples allow the hot water recovered with much effort to overflow in vain owing to poor level control if overflow is required, piping should be arranged to allow the low temperature water at the bottom to overflow.

The heat insulation reference of boilers is not shown in the Japanese standard but it is taken to be according to the Japanese Industrial Standards (JIS A9501).

Surface temperature standard of Japanese industrial furnace in the energy conservation law is shown in Table 3.1.8-8.

Table 3.1.8-8 Surface temperature standard of industrial furnace in Japan

Furnace temperature (ºC)	Target furnace wall outer surface temperature (ºC)		
	Roof	Side wall	Bottom in contact with open air
1,300 and over	120	110	160
1,100 to 1,300	110	100	135
900 to 1,100	100	90	110
below 900	80	70	90

4) Examples of energy conservation improvement case of boilers

a) Feed water preheating with waste heat in other processes (Petrochemical plane
In an ethylene manufacturing process, the water used for cooling of the process fluid has been discharged at a temperature of 63ºC with 1,500 t/h. The water has been cooled to 35ºC in a cooling tower and has been used again for cooling.

On the other hand, the boiler in the adjoining plant has preheated air to 60ºC in a preheater with steam to prevent a low temperature corrosion of the air preheater.

The persons in charge of both plants have taken notice of this point, arranged a pipe between both plants, installed a hot water system air preheater and stopped to use the steam system preheater.

The results saved the steam for preheating of 13 t/h. The investment cost was 70 million yen. The saved cost of fuel was 330 million yen a year. The investment recovery period was 3 months.

b) Improvement of boiler air ratio (Building material manufacturer)
The heat balance of a boiler (30 t/h) that burns fuel oil was as follows:

- Boiler efficiency:	87%
- Exhaust gas loss:	8%
- Steam loss for atomization	1%
- Heat release and others	4 %

Various tests were carried out by changing the air ratio automatic controller to a manual operation in order to try to reduce the exhaust gas loss. The result proved to be possible to reduce from 5.0% of the lower limit of oxygen content (O_2) to 3.0%. As a result, oxygen content has been reduced to 3.0%

- by replacing to a microcomputer control system which can cope with a load fluctuation and
- by installation of a zirconia system O_2 analyzer which is low time delay.

Since the opening of the damper for the forced draft fan was a low degree of 10 to 20 %, the revolution control by inverter was carried out.

As a result, fuel oil was reduced by 37.5 kL/year, power was reduced by 145,000 kWh/year, the merit was 5.15 million yen/year and the investment cost was recovered in about one year.