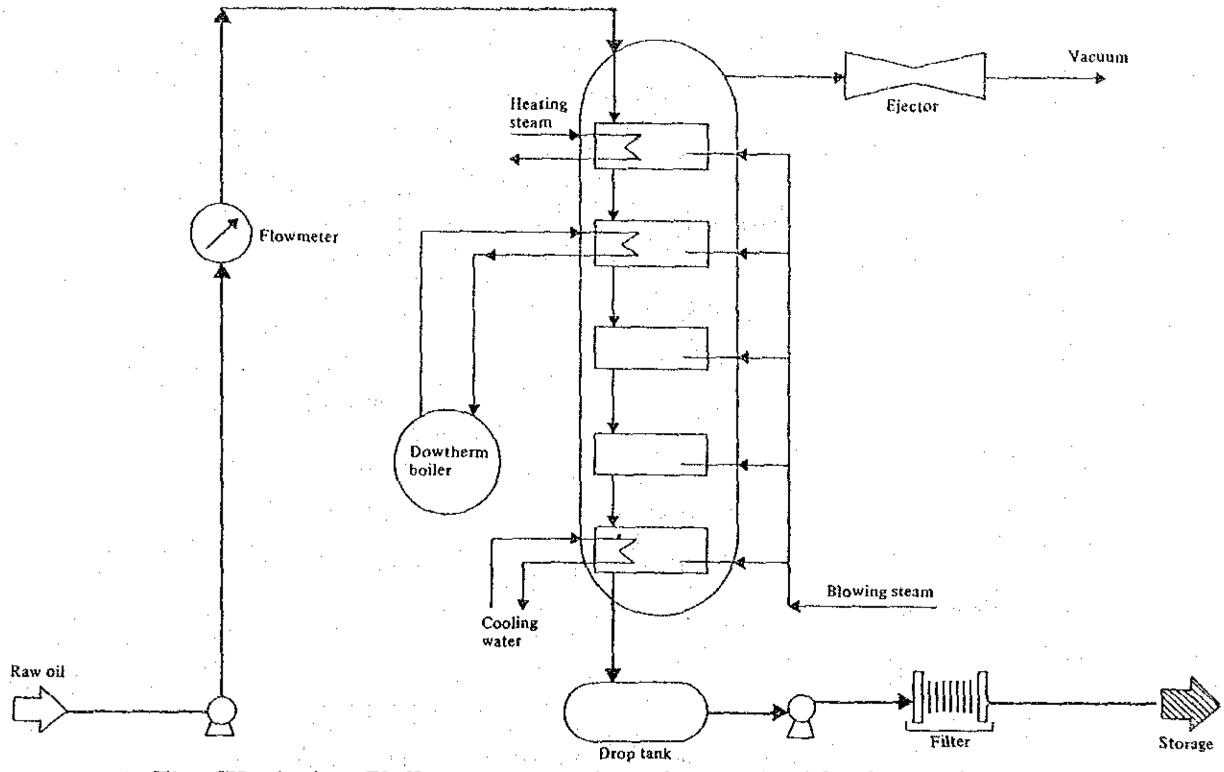


Fig. III—6—4 Girdler system semi-continuous deodrization equipment

The equipment has the following advantages: an even pressure distribution in the column, a good deodorizing effect, an easy changeover to other kinds of oils and no contamination due to leaked air.

The consumption of utilities are as follows:

In the treatment capacity of 50 t/d, steam is 200 kg/h, power is 25 kWh, and process water (hot water and cooling water) is 900 to 1200 kg/h.

The deodorizing equipment has been considerably improved for energy conservation, each improved equipment in various ways at every factory has made remarkable achievements.

2.2 Energy consumption

2.2.1 Canning factories

The energy used in fish canning factories is shown in Table III-6-1.

The consumption ratio of energy in Thailand's marine product canning factories is as Fig. III-6-5 and the energy ratio (calory) of fuel and power is approximately 75%:25%. The fuel is a heavy oil and has been used in the boiler for steam generation. Most of the steam is used for cooking and sterilization.

Table III-6-2 is the result of 133 factories researched by the Japan Canning Association in 1980. Table III-6-3 is the estimated values of output in Thailand's diagnosed factories.

Table III-6-6 shows these results as a histogram.

Table III–6–1

Purpose	Equipment	Energy source
Cooking	Cooker	Steam
	Exhaust box	Steam
Seasoning mix	Rice boiler	Steam
Sterilization	Retort	Steam
Degassing	Seamer	Steam & Electric power (vacuum pump)
Rolling	Seamer	Electric power
Refrigeration	Refrigerator	Electric power
Air compression	Compressor	Electric power
Waste water treatment	Lagoon pump	Electric power

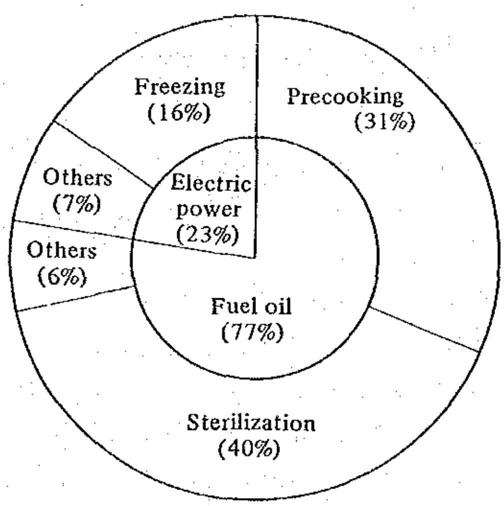


Fig. III–6–5 Energy proportion in marine products canning factory in Thailand

(1) Fuel unit consumption

In the Japanese example, the fuel unit consumption shows a higher value where tuna and bonito are precooked than in the case of sardines. In the Thailand example, the fuel unit consumption preferably shows a lower value in the case of only tuna and bonito. This may be due to a small n number, a small ratio of sardines and a reflection of the kind of fish depending on the season.

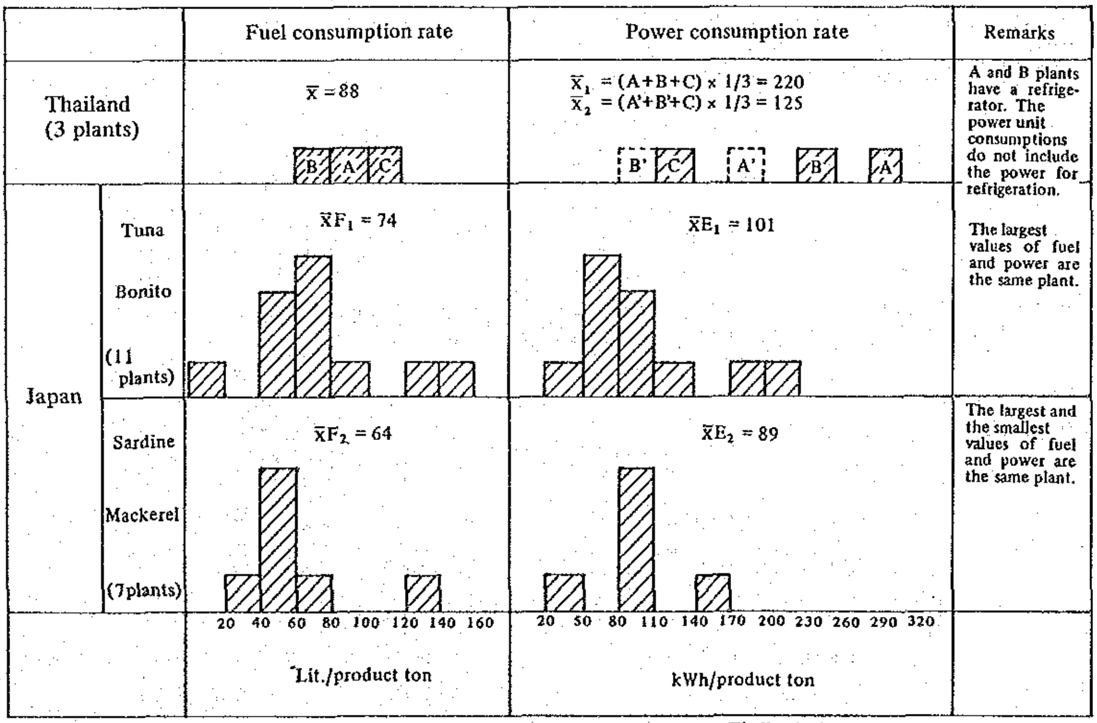
Table III–6–2 Energy consumption rate of marine products plant in Japan

Item	Output t	Fuel consumption rate (fuel oil)		Electric power consumption rate		Water consumption rate		Total energy Kcal/kg of product	Remarks
		Kl/t of product	Kl/t of raw material	Kwh/t of product	Kwh/ of war material	m³/t of product	m³/t of raw material		
Tuna, Bonito (Oil soaking, Boiling in water)	~ 500	0.010	0.180	78	128	20	32	1,151	Tuna
	1,000~2,000	0.075	0.062	94	77	13	10	823	Bonito
	2,000~3,000	0.086	0.069	174	121	190	132	1,002	Bonito
	"	0.075	0.050	94	63	13	8.4	572	Tuna
	"	0.128	0.106	47	43	–	–	1,311	Tuna, Bonito
	4,000~6,000	0.046	0.050	73	81	–	–	513	" "
	"	0.071	0.070	80	79	18	17	780	" "
	"	0.155	0.105	217	156	39	33	1,637	" "
	"	0.052	0.053	74	74	–	–	513	Tuna
	8,000~11,000	0.065	0.050	65	50	41	32	700	Tuna
		0.056	0.040	115	83	41	30	651	Tuna
	Average	0.074	0.076	101	89	47	35	878	
	Range	0.010~ 0.155	0.040~ 0.106	47~ 217	43~ 156	13~ 190	8.4~ 132	513~ 1,627	
Sardine, Mackerel, (Boiling in water, Boiling with tomato)	1,000~2,000	0.055	0.047	62	52	7.7	6.5	601	Mackerel
	"	0.051	0.015	99	29	14	4.2	595	Sardine
	2,000~3,000	0.052	0.044	100	84	15	6.5	600	Mackerel
	6,000~7,000	0.028	–	24	–	5.7	–	306	"
	"	0.080	0.060	82	63	14	11	843	Mackerel, Sardine, Bonito
	10,000~14,000	0.130	0.117	159	174	0.8	0.7	1,423	Mackerel Sardine
	"	0.052	0.048	99	24	14	9.9	521	Mackerel
	Average	0.064	0.055	89	71	10.2	6.5	699	
	Range	0.028~ 0.130	0.015~ 0.117	24~ 159	29~ 174	0.8~ 1.4	0.7~ 11	306~ 1,424	

Source: (Foundation) Energy Conservation Center, Energy Using Rationalization Diagonosis Instruction Manual, Canned and bottled marline products volume, Statistical values in 1978.

Table III-6-3 Energy consumption rate of marine products in the third research of Thailand

	A Co.	B Co.	C Co.	Japan
Main raw materials	Tuna, Sardin	Tuna	Tuna, Sardin	Tuna, Sardin, etc.
Quantity of raw material t/y	25,000	9,000	3,500	
Product output t/y	12,000	5,000	2,000	
Fuel oil consumption Kℓ/y	960	340	210	
Fuel oil consumption Kℓ/t of product	0.080	0.068	0.105	0.067
Electric power consumption Kwh/y	3,608 x 10^3	1,180 x 10^3	250 x 10^3	
(Breakdown)	(Refrigerating system) 1,562 x 10^3	(Refrigerating system) 774 x 10^3	(No refrigerator) —	
	(Can manufacture) 2,046 x 10^3	(Can manufacture) 406 x 10^3	250 x 10^3	
Electric power consumption Kwh/t of product	301	236	125	95
(Refrigerating system)	130	155	—	—
(Can manufacture)	170	81	125	95
Quantity of water t/y	1,200 x 10^3	90 x 10^3	118 x 10^3	
Water consumption m^3/t of product	100	18	59	10 ~ 50



Thailand: Results in 1983
Japan: Results in 1978

Fig. III-6-6

From these data, it is difficult to see a significant difference in the fuel unit consumption between both countries. The histogram shows a higher value of 10 to 20 l/t in Thailand. There is a climactical difference between Thailand and Japan. The average water temperature of Thailand is 27° C and that of Japan is 16° C. Thus, the difference between the two units is about 11° C. Supposing that water of $10m^3$/ton of the product out of the total water used in the canning process is required to be heated, the following difference of fuel consumption is caused between both countries.

$$\frac{10{,}000\ l/t \times 11°C}{9{,}500\ kcal/l \times 0.85} = 14\ l/t \text{ of the product}$$

In consideration of the difference, the fuel unit consumption in Thailand has room for improvement.

(2) Electric power unit consumption

The electric power unit consumption is in a larger ratio for refrigerators. It varies remarkably with the arrival condition of the raw materials. The electric power unit consumption other than that for refrigeration seems to be in proportion to the process water unit consumption. The greater water consumption compared to Japan may be due to a poor electric power unit consumption. In the case of Japan, since the difference of atmospheric temperatures by season is larger and the raw materials vary with marine products or farm products, the margin of the waste water treatment facility is a factor to allow the electric power consumption to increase. In Thailand, the use of water and electricity leaves room for improvement with consideration to these points.

2.2.2 Vegetable oil industries

Most of the fuel is used to generate steam and a part of it is used to heat a heating medium for high temperature heating.

Heat energy is used in the processes of drying and heating of the raw material, heating of the extract, desolvent and drying of the grounds, separation of the solvent and the crude oil, maintaining temperatures in the refining process, and deodorizing. Particularly, most of the heat energy is consumed in the expression and extraction processes.

Fig. III-6-7 shows the consumption of steam and electric power by processes in the factories in Japan. The expression and extraction processes and the refining process consume a steam of 86% and an electric power of 58%.

The utility unit consumption of several typical oil factories in Japan, according to the research of the Japan Fat and Oil Association, is shown in Table III-6-4. The unit consumptions vary largely from the types of raw materials. The ratio of steam consumption in the expression and extraction processes by a treating scale is shown in Fig. III-6-8. In Thailand, although the unit consumption is not broken down by processes, the total consumption is 590 to 700 kg/t of product in steam and 70 kWh/t of product in electric power. This is almost equivalent to Japan.

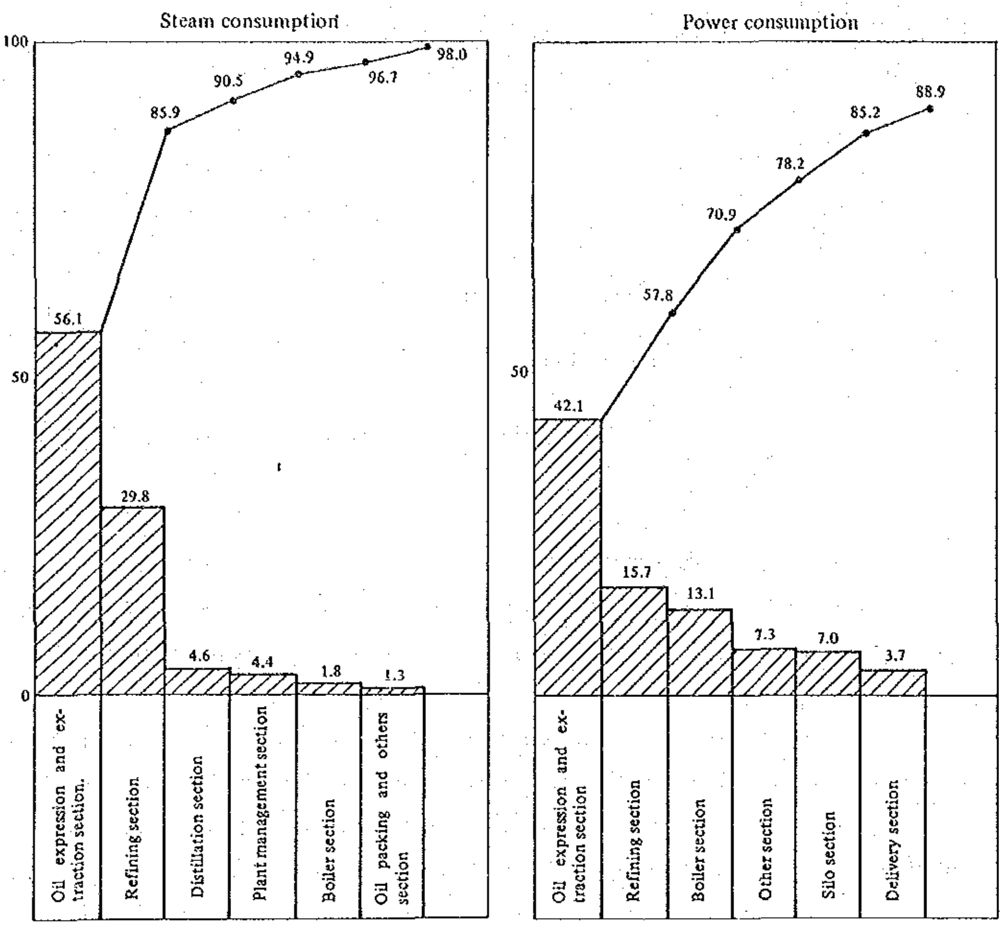


Fig. III–6–7

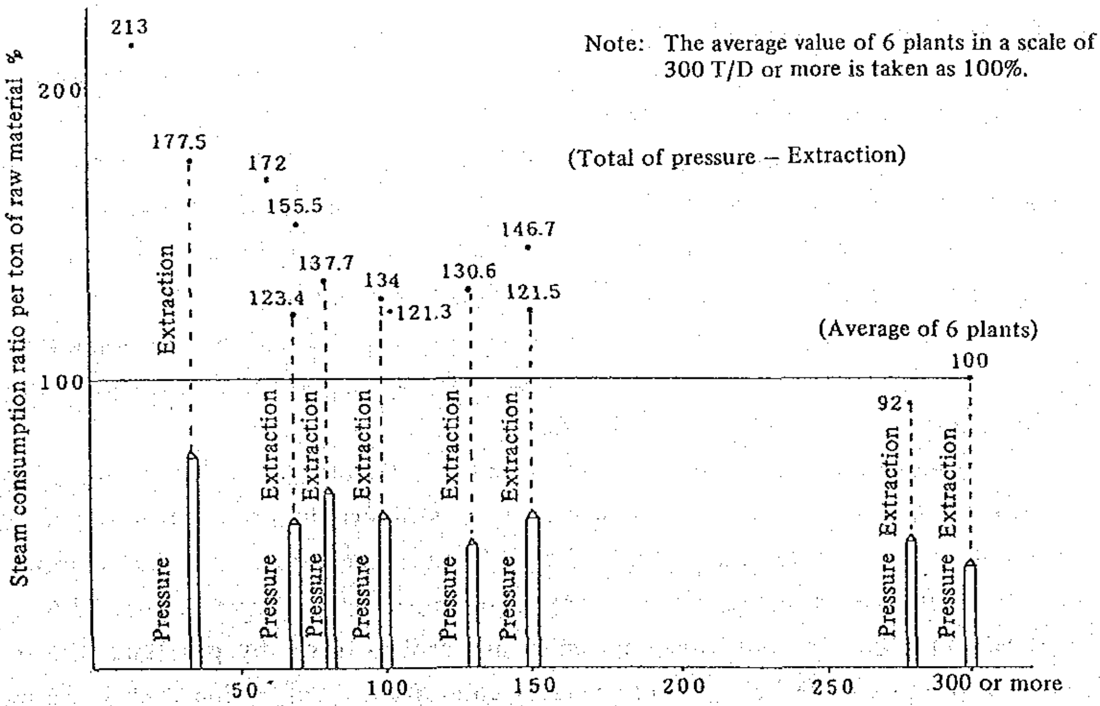


Fig. III–6–8 Comparison of steam consumption per ton of raw material by plant scale

Table III–6–4 *Standard energy consumption rate* (1979 base)

1. Steam · Fuel oil

	Steam		Fuel oil	Remarks
	Expression (Kg/t of raw material)	Refining (Kg/t of crude oil)	Refining (lit./t of oil)	
Soybean	350 ~ 450	400 ~ 580	10 ~ 12	
Rape	400 ~ 500	400 ~ 580	10 ~ 12	
Corn jam	400 ~ 500	400 ~ 580	10 ~ 12	
Rice bran	450 ~ 790	1,400 ~ 2,500	13 ~ 18	
Palm	—	1,500	Include steam for refining	
Palm core	400	1,400		
Coconut	360	1,400		

2. Electric power

	Expression (Kwh/t of raw material)	Refining (Kwh/t of crude oil)	Remarks
Soybean	30 ~ 40	30 ~ 40	*1 Expression and extraction method *2 Dewaxing 30 ~ 45 *3 Include solvent dewaxing
Rape	40 ~ 50 *1	30 ~ 40	
Corn jam	80 ~ 90	40 ~ 45 *2	
Rice bran	Batch 30 ~ 50 Continuous expression 40 ~ 50	80*3	
Palm	—	70	
Palm core	90	60	
Coconut	70	60	
Range	From silo taking out to crude oil	From Degum and deoxidizing to deodorizing oil	

3. How to Manage Energy

In order to improve the efficiency of energy consumption, productivity and product quality as well as raise their overall level, it is essential first to use facilities well adjusted and maintained to the purpose and to operate them correctly. It is most effective for energy conservation to reduce the incidence of equipment failure and increase product yield. Secondly, it is required that those engaged in energy management study the possibilities of further improving the existing facilities and operating method and pursue better means through repeated surveys and factory experiments.

Accordingly, it is not exaggerating to mention that the consciousness and willingness of the total factory employees would influence the actual performance of the factory. And it is important to raise the level of factory management which encourages the employees to have such consciousness and willingness. It is defined that energy management is a systematic effort to achieve energy conservation.

3.1 Clarification of Management Policy

Following the soaring of energy prices, the factory owner and manager have grown more concerned about energy conservation. In order to promote this tendency on a company level instead of letting it merely stay within the frame of the owner's mind as a desire, it needs to be clarified toward all the employees that the top management has the intention to tackle the energy conservation problem seriously as a company policy. In positive terms, the target should be clarified quantitatively; such as what percentage of energy consumption per ton of finished product should be reduced. Simultaneously the restrictions such as the ceiling of annual investment and deadline for pay back time should be clarified.

As explained above, the top management should clearly show the way to proceed on to the employees. Then in turn, the latter become confident about their jobs meeting the direction set by the former. Further, both can develop a smooth collaborative relationship because everybody involved is spiritually aligned in a unified direction.

Since the target of the top management is shown as a comprehensive one for the whole factory, each section and department should set concrete subtargets which do not require too much time and try their best effort to achieve these subtargets. These subtargets should be set concerning items for which any counter-measures can be taken by section and department personnel within their own responsibility range to attain the target set by the top management. As the said target is shown in a familiar and understandable form, it is easy to expect even employees of the lowest rank to fully understand the subtargets and extend their cooperation in attaining them.

When setting subtargets for each section and department, it is suggested that the committee described later or others study if such subtargets would be appropriate for achieving the overall target.

3.2 Arrangement of System for Promotion

In a campaign, for energy conservation where various classes of people take part, persons who play a part to promote the activities of all as a nucleus. If the factory is small, an individual person may be a promoter, but if the factory is large, a section for promotion is sometimes established.

This position should be occupied by a top-notch person and he should always be careful about a progress in energy conservation status and look into a cause, if there is a delay, then try to treat problem.

In concrete terms, the assignments of the position are as follows: the grasping of actual energy consumption, comparison of actual energy consumption with plans, invitation and checking of ideas about improvement, budgetary distribution, management of work progress and evaluation of actual works, mapping-out of education programs, preparations for committee meetings, etc.

The committee is effective for adjustment so that inter-disciplinary understanding may be realized among sections and departments such as manufacturing, sales, raw material purchasing, equipment maintenance and servicing, and accounting, and countermeasures may be put into practice smoothly. At the committee meeting, any possible influence of energy conservation measures to be performed on each section and department should be studied to make sure that no profit is reduced on an entire factory basis.

It is important that a general manager of the factory or a person next to the former in rank who has responsibility and authority in production assume the chairmanship of the committee. Otherwise, no decision would be made, neither would such a decision be implemented.

Even if certain energy measures were based on an excellent idea, any fruitful results would not be expected unless the operator fully understands what the measures mean and applies them to the actual work. There are many cases where the QC (quality control) circle which is effective for quality control is utilized successfully for energy conservation with noteworthy results. The QC circle is an activity of improving human relationship in the job, stimulating people to become more conscious about independence endowed intrinsically to humans and providing them with the pleasure of working actively. However, it is necessary to prepare conditions which make the operator find it easier to conduct activities such as education and incentive granting before he can recognize the advantages and necessity of the circle activities. It is the operator on the front line that is always in touch with energy consuming equipment and sensitive enough to grasp any phenomenon appearing according to a change in the operating conditions. It is extremely effective for energy conservation to make the best of information obtained by the operator and to squeeze out a good idea for improvement.

3.3 Scientific and Systematic Activities

It is an indispensable condition to obtain an exact status of energy consumption when energy conservation is carried out. If data such as change of the unit consumption rate per production, difference in the unit, variation of product grade and difference in raw materials are not available, it would be impossible to formulate plans which guide you toward an area requiring the implementation of immediate procedures. In other words, it is factory data that provide numerous ideas for improvement. If studies are made of these data with a consciousness about problems, it would be able to find something leading to such ideas. Therefore, it is suggested that a measuring instrument be installed at necessary spots, record its readings and obtain information through their periodical arrangement. In this case, such data should be processed from the viewpoint of mathematical statistics to determine if the difference is significant.

Next, it should be made sure that the results are followed up, if improvement plans were implemented. Efforts should be made to enhance the quality of operations according to the PDCA circle advocated by Dr. Deming. The function of the PDCA circle is such as explained below as shown in Fig. III-6-9:

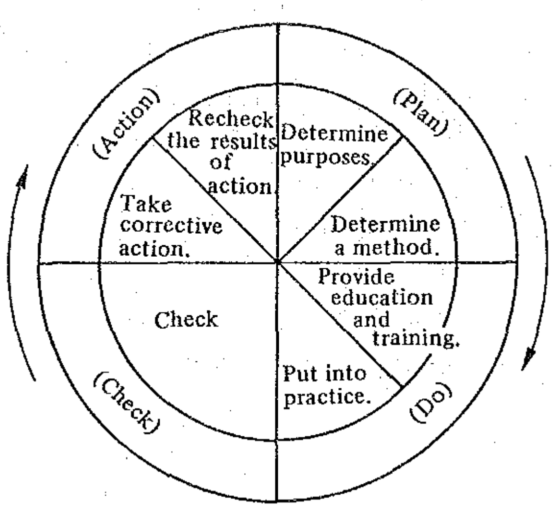


Fig. III–6–9 Deming circle

First, plans should be formulated; that is, a purpose will be set for a certain theme and means decided. This represents "P" for PDCA. People will be trained concerning how to perform these means and given an opportunity to actually do them. This represents "D". The results of the performance will be checked. This represents "C." Results of the check will be evaluated to determine if they are satisfactory. Action will be to standardize the results, if they are satisfactory and to take corrective measures if there is still a problem yet to be resolved. If one step was completed, the function of "PDCA" will be set to work towards a target of higher level. In this way, people proceed with their assignments. This method will be helpful for not only energy conservation but also heightening the quality of jobs in every field.

With regard to the part concerned with "Plan," it is recommended that "improvement plans invitation system" be actively utilized because items to propose can be found rather easily during an early stage. It should be so arranged that proposals may be made by whosoever he may be, an individual or a member of a working place, the QC circle or staff. Proposals presented should not be left alone, but should be examined promptly by the committee and others. The proposals presented should be adopted as far as circumstances allow after being modified on advice depending on the occasion. It is also suggested that a prize be presented to people for their proposals and further, a commendation be given to those whose proposals brought about fruitful results. These measures will be an incentive for people to deepen their consciousness about participation. For proponents whose proposals were not adopted, it is suggested that they be explained about the reasons why the proposals were not taken up and at the same time, be properly guided over better ideas.

In the stage of "D", it is suggested that satisfactory explanation be provided to employees of the lowest rank regarding an intention for improvement, and their cooperation in an effort toward the improvement be solicited. They are also encouraged to report even on minor abnormalities during operation so that they may be able to make scrupulous adjustments. This consideration is necessary to eliminate any possible cause for error.

"Check" should be conducted periodically and at the same time, the results be reported to the committee and the senior official. Along with this procedure, the results also should be made known to the operator so that he may deepen his concern. In this case, it is important to clarify an evaluation criterion from the beginning; it is not desirable to change it easily halfway.

If satisfactory results can be expected following the implementation of an improvement plan, they should be incorporated into the operation standard. Simultaneously necessary measures for the improvement of equipment should be taken so that any extra load may not be brought to bear on the operator. This is a condition for continued favorable results of energy conservation.

In case considerable results have been accomplished continuously as a result of the above, their summarized processes should be published as references. At the same time, those concerned should be officially commended so that they may be motivated for next activities.

3.4 Furnishing of Education and Information

Even if employees are willing to cooperate, any improvement can hardly be expected, unless they have knowledge as to how they should do it. They would become more positive to participate in the energy conservation campaign, if they are capable of presenting their own improvement proposal without being limited to merely pointing out problems. In order to realize this target, an internal education program sponsored by the company itself is important; that is, programs such as seminars and distribution of guide books should be provided. In the Kingdom of Thailand, a considerable number of companies are enthusiastic about education and also numerous cases where their staffers are sent for participation into external seminars are noticed. To our regret, however, such staffers sent for the external seminar tend to keep their acquired knowledge only to themselves instead of passing it on to other staffers or general operators. If it is arranged so that those who received external seminar training become lecturers for internal education and provide training to other people based on their acquired knowledge, it is expected that the entire level of employees' professional quality will be raised and staffers participating in the external seminars will be able to make sure that their obtained knowledge is practically useful.

Next, it is desired that information exchange with other companies of the same industry or raw material suppliers or finished product buyers be activated. Although it is naturally important that competition should take place among different companies of the same industry, it is recommended that technical information be exchanged to some extent on a give and take basis. This is because the technical level of the entire company can be heightened resulting in stronger international competing power and subsequent mutual benefit. For instance, the publishing of actual unit consumption rates will be instrumental for the motivation of commercial competition.

4. Rationalization in the Utilization of Thermal Energy

4.1 Canning industries

4.1.1 Steam pressure

The steam consumption of marine products canning factories in Thailand, according to our research, is shown in Table III-6-5.

Table III–6–5 Steam consumption in main producing processes

	Internal temperature °C	Internal pressure kg/cm² G	Retention time Min.	Servicing steam pressure kg/cm² G
Cooker	100 ~ 103	1.2 ~ 1.3	60 ~ 120	3 ~ 5
Exhaust box	90 ~ 100	–	15 ~ 20	"
Retort	110 ~ 120	1.6 ~ 1.8	50 ~ 100	"

More than 90% of the steam generated by a boiler is consumed in the cooker and the retort. The required temperature is 90 to 120° C. A higher temperature is not required. For a sterilization temperature of 120°C, the servicing steam pressure should be sufficient at 2.0 $kg/cm^2 \cdot G$.

Use of too high a steam pressure results in an increase of heat dissipation out of the equipment and the piping. If there is some margin in the pipe diamenter, a reduction of the steam pressure generated in the boiler is able to decrease the heat dissipation and the blow loss.

But, according to the canning industry in Japan, the higher steam pressure shortens the come-up time and the operation rate of the retort increases. Accordingly, the best point of energy efficiency should be found in the whole, in compliance with the conditions of the production and the facilities.

4.1.2 Air vents

When a product is treated and processed by steam in an autoclave without air vents, a required temperature is not reached and the heat treatment becomes imperfect. Particularly, for the sterilization of food, a perfect vent of air is important.

To avoid such obstacles in the steam heating of a retort, it is the real state of things that a prevention of trouble is taken by excess vents. When energy conservation in a retort is carried out positively, you should know exactly the interference of air.

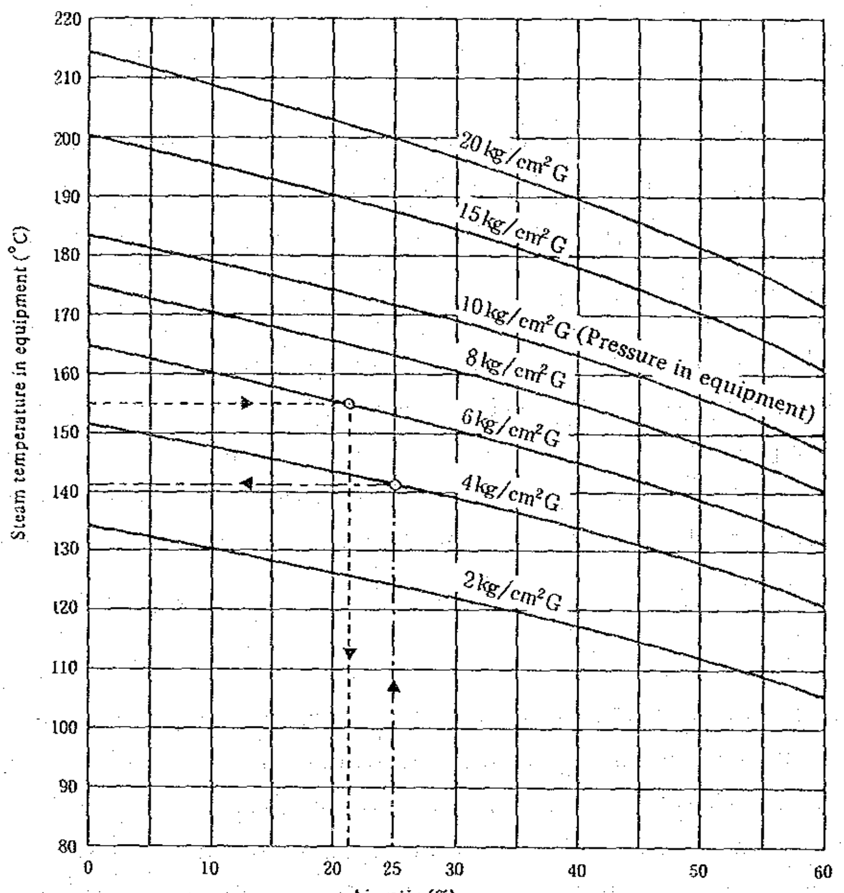
(1) Bad influence of air

Steam entered into a closed vessel forms a mixture of steam and air mixed with the air in the vessel. The temperature of the mixture is lower than the temperature of pure steam according to Dalton's law. For an explanation in an example, the temperature of a retort filled with a saturated steam in the absolute pressure of 2.4 kg/cm^2 is 120° C. If a mixture of steam and air in the mixing rate (volume) of 3:1 is present in the retort, the partial steam pressure is 0.75×2.4 kg/cm^2 and the absolute pressure is 1.8 kg/cm^2.

Since the absolute pressure is 1.8 kg/cm^2 and the saturated temperature of the steam in 0.8 kg/cm^2·G is 117°C, the temperature of the content in the retort is a temperature equivalent to 1.4 kg/cm^2·G indicated by the pressure guage. The temperature should practically be lower by 9°C than the saturated temperature. A lower temperature causes the heating speed to be slow and a longer heating time is necessary, and a right treatment is not performed.

The relation between the air ratio and the steam temperature in the retort is shown in Fig. III-6-10.

Since the specific gravity of air differs from that of steam, part of the air in the retort remains as a thin layer on the retort and this obstructs the stream of heat. This can not be solved only by pressurizing in the retort or by a longer time of the heating.



How to use the graph

When the air ratio is 25% in the gage pressure of 4 kg/cm^2, draw perpendicularly a line from the point of 25% in the air ratio, get an intersection of the curve of 4 kg/cm^2 G, draw horizontally a line in a left direction from the intersection and obtain a steam temperature. The temperature is 141°C but the steam pressure is 2.75 kg/cm^2 in the steam chart. When the temperature inan equipment is 155°C and the pressure is 6 kg/cm^2 G, the air ratio is 21%.

Fig. III–6–10 Temperature change chart due to air pressure in steam equipment

(2) Steam flow

In a retort for sterilization of cans, the retort is packed so as to obstruct the free flow of steam and air and the flow is apt to form turbulence. Accordingly, steam should be passed in at a slow rate as possible and so as to spread evenly over the whole space. The matter that allows the steam to pass from the upper part of retort or from the lower is a problem that causes a discussion. Theoretically, the air stays in the lower part because of a larger specific gravity than that of steam and the temperature of air is lower than that of steam. Accordingly, passing steam from the lower results in an unreasonableness.

The experiment to investigate this influence was performed by the equipment shown in Fig. III-6-11. Two steam diffusers were provided on the upper part, the equipment was operated by an automatic value in a condition of 115° C, 60 minutes and 4 kg/cm^2 of a steam pressure.

The steam consumption of the method results in the following compared with the conventional method which passes steam from the lower part:

One steam diffuser: 97.3%

Two steam diffusers: 93.2%

It is proven that this method can reduce the steam consumption. The inside of a retort is packed with cans and the flow of steam is very complicated. An improvement should be carried out through trial by various means.

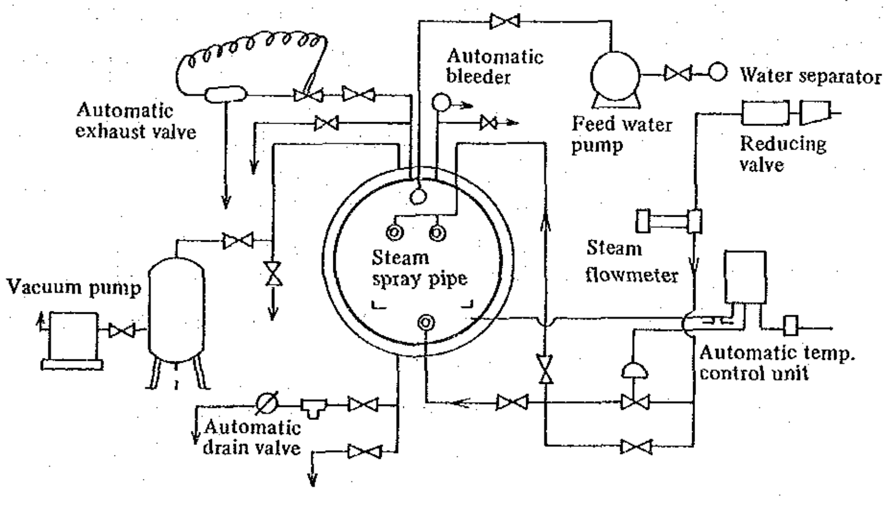


Fig. III-6-11

Even in an example of passing steam from the lower part, the diameter of the steam supply pipe in the lower part of the retort is almost $1\frac{1}{2}''\phi$. However, to prevent an uneven flow of steam and maintain an adequate rate, two $2''\phi$ pipes should be arranged in parallel. The steam blow hole provided in the pipe is an upward direction. But, to cause a non-turbulent flow and gently expell air in an upper direction, the direction of nozzle should be facing downward and the diameter of steam blow hole is better to be 3mmϕ.

The air exits for air vents located in the upper part are required with two at least or three if possible to form a linear flow of gas stream in the retort. For a long drum retort, multi-air exits should be provided for air vents according to the length.

Although these are based on an accumulation of practical experiments, a pipe suitable to a productivity, quality, and energy conservation should be mounted in a full investigation through an observation such as how to turn on the steam.

(3) Automation of air vents

Air vents are operated briskly by a manual vent cock. At the starting time, there is no problem, but it is difficult to judge how all air is vented. An early close of the cock allows air to remain and the product quality is affected. To prevent this, air vents are apt to open too much and it leads to a steam loss.

An exact judgment of the existence of air and use of a temperature sensing type automatic air vent conteo device brings about the following effects.

a. Consumption of steam is reduced. No waste consumption of steam is realized since an inclusion condition of air and steam in the vent can be detected and the cock can be closed when air is taken away.

b. The short vent time is related to a short come-up time and leads to a good operating rate of the retort.

c. The inferior goods due to air obstacle can be very reduced.

An automatic air vent device should be selected to a good accuracy and a large capacity for a retort. For a cooker, a small size automatic air vent valve is effective for steam saving since the cooker is operated in a condition of a temperature of 90 - 100° C for 100 to 120 minutes and it is not necessary to take into consideration the way it is in the retort.

A slight quantity of the inferior goods affects the company's confidence and a mistake is not permitted. At this point, the meaning of automation is large and it is effective for energy conservation.

The experiment in automation was carried out by the equipment as shown in Fig. III-6-11. The temperature recorder is provided to judge the interior condition. The discharged heat in exhaust gas, air vent and drain discharge is recovered through condensation respectively and the discharge quantity is obtained. The result is shown in Table III-6-6. The automation is clear to reduce the steam consumption and the reduction rate is more than 10%.

4.1.3 Initial temperature of retort

According to the experimental result in Japan, the case of the start from 30-40° C in the retort temperature reduced the fuel consumption by about 15% compared to the case of the start from 10-20° C. (See Table III-6-6)

The cooling of cans after the sterilization is generally carried out by pouring of water in the retort but consideration is necessary to not lower them below the required temperature.

4.1.4 Heat insulation of retort

A heat insulation of the retort is a most direct energy conservation measure. When the external surface of retort is insulated by a glass wool of 50m/m thickness, according to the experimental example, the steam consumption was reduced to about 88% compared to the case of no insulation and the come-up time was shortened. The results of measuring and calculation are as shown in Table III-6-7.

Table III–6–6 Discharge steam and drain due to the differences of cooking initial temperature and automatic and manual operation

Initial temp.	Control valve / Process	Exhaust gas		Air vent		Drain		Typical value	
		Automatic	Manual	Automatic	Manual	Automatic (Trap)	Manual (Valve)	Automatic	Manual
115°C 60 min. Initial temp. 20°C	Come-up process	(kg) 3.07~4.92	(kg) 2.26~2.49	(kg) 0.02~0.06	(kg) 0.19~0.95	(kg) 74.97~96.5	(kg) 80.00~88.08	123 kg	137 kg
	Sterilization process	0.75~3.08	0	0.05~0.90	2.54~12.34	18.20~42.7	34.32~49.50		
115°C 60 min. Initial temp. 30~40°C	Come-up process	2.39~4.38	2.07~3.14	0.02~0.06	0.18~0.82	54.9~72.95	67.59~75.03	104 kg	121 kg
	Sterilization process	0.65~1.98	0	0.07~0.1	2.53~12.25	22.18~48.15	32.42~46.57		
Equipment		Thermostat 1", Temp. control range 93~127°C	1 1/2"	Temp. sensitive system, bellows type 1/2"	1/8"	Float type steam trap 1"	1/2"	227	258
								$\frac{258-227}{258} \times 100$ = 11.2%	

Table III–6–7 Results of measurement of retort surface temp. and calculation of heat radiation

Sterilization temp. (°C)	Heat insulation	Retort surface temp. (°C)	Heat radiation from retort surface (Kcal/m²·h)		
			Radiation Qr	Convection Qc	Total
113	No	107	263.1	584.6	847.7
113	Yes	28	36.9	29.6	66.5
115	No	109	271.7	601.4	873.1
115	Yes	29	41.9	34.3	76.2
120	No	113	289.5	635.4	924.9
120	Yes	30	46.6	39.1	85.7

Note 1) Room temp.: 20°C

2) ε : Reflection coefficient of no insulation (Painted with aluminium paint): 0.40
Reflection coefficient of insulation with glass wool: 0.90
Thickness of insulation: 50 mm

The heat dissipation from the heating equipment is due to radiation and convection. The heat dissipation quantity (Qr) of unit area and unit time due to the heat dissipation can be obtained.

$$Qr = 4.88\varepsilon\{(\frac{T_1}{100})^4 - (\frac{T_2}{100})^4\}\ (\text{kcal/m}^2\text{h}) \quad \cdots\cdots (1)$$

T_1: Absolute temperature (K°) of equipment surface

T_2: Absolute temperature of room temperature

ε: Reflection factor of equipment surface

The heat dissipation quantity (Q_c) of unit area and unit time due to the convection can be obtained by the following equation.

$$Qc = hc(T_1 - T_2)\ (\text{kcal/m}^2\text{/h}) \quad \cdots\cdots (2)$$

hc: Heat transfer rate

For a retort: $hc = 2.2\ (T_1 - T_2)^{0.25}$

4.1.5 Steam and hot water heatings of retort

The sterilization heating of cans in Thailand and Japan is almost always a steam heating system due to an origination of American technology. It seems to be based on the idea which takes a serious view toward productivity, that is, it is an idea that the higher temperature the shorter the treating time.

The most common sterilization system in Europe is a liquid heating system. Since automatic control of valve operation is easy and the prevention of an air obstruction is more easy compared to the steam heating, an occurence of the sterilization mistake is very rare. The heat of the hot water can be used repeatedly.

The steam heating and the hot water heating have advantages and disadvantages in sterilization effeciecncy and product quality. This should be investigated, in comparison, including energy consumption.

4.1.6 Saving of electric power for refrigeration.

(1) Improvement of the efficiency of refrigerator operation

For the principle of a refrigerator refer to III-5 of Chemical Industry.

The check points not to increase the power consumption of a refrigerator are as follows.

a. Not contaminate the heat transfer surface of a condenser Take care the quality of cooling water and clean periodically the heat transfer surfaces

b. Prevent a decrease in the cooling water quantity

Clean periodically to prevent a clogging of the strainer and the nozzle

c. Maintain the temperature of cooling water

Check periodically the cooling tower and the packing and arrange a normal distribution of water

d. Prevent an inclusion of non-condensating gas

Take care to include at the time of vacuum operation and overall

e. Prevent an efficiency decreasing of the cooler

Prevent frost and short pass of cooled air

f. Check the heat transfer area of the cooler

g. Check the capacity of a refrigerator

h. Clean the strainer of the refrigeration system

Check for clogging of the suction strainer of the refrigerator and the protective strainer of the automatic valve

i. Check the pipe diameter of a refrigerant piping system

In an expansion of equipment, the refrigerant piping may remain as it is and the stream may be not enough

j. Check the quantity of refrigerant

(2) Decreasing refrigeration load of the refrigerator

a. Heat entering from the wall surface should be reduced

The entrance heat Q (kcal/h) is expressed by the following equation.

$Q = AK\ \Delta t$

A (m^2): The external wall area of the building

K(kcal/m^2·h·°C): The heat transfer rate determined by type of insulator and its thickness

Δt(°C): The temperature difference between the temperature in the room and the temperature of the external wall

Accordingly, it is important for the K value to be small through an intensification of the heat insulation. Check sufficiently the insulator because the insulator saturated with moisture loses the insulating effect and replace the insulator saturated with moisture.

b. Decreased heat loss due to ventilation

In the opening and closing of a door, a quantity of heat loss caused by entrance of hot air in the atmosphere into the refrigerator may reach 40 kcal in a −30°C refrigerator and 35 kcal in a −20°C refrigerator through an external air of 1 m^3 in 32°C of the atmospheric temperature and 70% of the humidity is replaced with the cooled air in the refrigerator.

If the cooler is located in a position near door, the efficiency is reduced by a frost of the moisture in the atmospheric air on the cooling pipe. An installation of an air curtain, or a free door or a drop curtain in the front chamber is an effective means to prevent the heat loss due to ventilation, if possible, a drop curtain should be installed also on the inside of the main door.

c. Decreased heat in cooled goods

The pan or the palette taken out of the refrigerator should be applied to the next goods cooled in the refrigerator as early as possible.

d. Decreased heat generated from the fan

The heat of the electric power input by the fan installed in the refrigerator is 860 kcal per kWh. A smaller capacity of fan can not only directly save the electric power but also can reduce the refrigeration load to eliminate this heat.

Table III-6-8 is the practical measured example of the refrigeration load rate. It is proven that the rate of the heat generated from the fan is larger than 12.7%.

Table III–6–8 Refrigeration load factor in refrigerating equipment

Type of load	Load factor %
1. Heat coming from wall	1.4
2. Cooling heat of building etc., veneer plate, floor concrete, heat insulator, cooler frame etc.	6.6
3. Cooling heat of refrigerating pan	0.9
4. Cooling of residual moisture and air in refrigerator	0.7
5. Cooling and refrigerating heat of products	77.7
6. Heat generated from cooler fan	12.7

Batch refrigeration: 15 hours. Temperature when fishes are put in it: 10° C.
Source: Maekawa Seisakusho Data.

During the stop of the refrigerator, the fan should stop without fail.

e. Decreased heat loss due to lighting in the refrigerator

The light and the floor heater for working in the refrigerator should be turned off when they are not used and the unnecessary ones should be removed.

f. Utilization of the waste heat in the refrigerator for defrost

(3) Room temperature and electrical quantity of refrigerator

Entrance rate of refrigerator: 2.5% per day

Atmospheric temperature: 40° C in the ceiling surface,
30° C in the external wall
20° C in the floor surface.

Atmospheric temperature: 27° C

Insulator: Ceiling of 225 mm, external wall of 200 mm and floor of 175 mm.

Heat transfer rate: 0.025 kcal/m^2·h·° C

If the refrigeration load rate of the refrigerator in the above condition is obtained to −20° C, −25° C, and −30° C of the temperature in the refrigerator respectively, these values are as shown in Table III-6-9.

The electric power (kW) corresponding to one refrigeration ton of the refrigerator for various evaporating temperature of refrigerant is shown in table III-6-10 as follows:

The change of the temperature in the refrigerator allows the refrigeration load to change and also the electrical quantity per ton of the refrigerator changes. If the ratio of the power quantity by the temperature in the refrigerator is obtained is as shown in Table III-6-11. That is, if the temperatures in the refrigerator are −30° C and −20° C, the power of the refrigerator increases by 2 times.

If the load required to refrigerate the 10° C fish to −20° C is obtained, it is as follows:

Table III–6–9 Refrigeration load (Example)

Temperature in refrigerator	–20°C	–25°C	–30°C
Heat coming from wall Kcal/h	43,818	48,291	52,764
Heat loss due to ventilation Kcal/h	21,945	23,826	25,080
Cooling heat of product in refrigerator Kcal/h	37,500	56,250	75,000
Heat generated from fan Kcal/h	19,800	26,400	33,000
Heat loss from lighting and others Kcal/h	1,785	1,785	1,785
Safety factor 10% Kcal/h	12,485	15,655	18,763
Total load Kcal/h	137,333	172,207	206,392
Refrigeration ton JRT	41.4	51.9	62.2
Load factor in –20°C: 100%	100%	125.4%	150.3%

Table III–6–10

condensation temperature +35°C, Fron 22

Refrigerant evaporation temp. °C	–28	–33	–38
Refrigerating capacity JRT	40.3	32.8	25.6
Required power kW	64.3	59.7	54.5
kW required to 1 JRT (kW/JRT)	1,596	1,843	2,129
kW/JRT ratio (as 100% the ratio in –28°C)	100%	115.5%	133.4%

Table III–6–11

Temperature in refrigerator °C	–20	–25	–30
Load factor	100	125.4	150.3
Refrigerator kW/JRT ratio	100	115.5	133.4
Required power ratio	100	144.8	200.5

Load required to refrigerate until –2° C:

$(10 + 2) \times 0.85 + 58 = 68$ kcal/kg

Load required to refrigerate from –2° C to –20° C:

$(20 - 2) \times 0.47 = 8$ kcal/kg

Thus, the load is larger in a relatively high temperature until freezing and much more energy is required to refrigerate to a lower temperature. Particular attention must be given to lower temperatures in the refrigerator.

(4) Refrigeration speed-up

To increase the refrigeration speed, it is required to increase the wind speed which touches the fish and to increase the heat transfer rate. In a higher wind speed place and a lower wind speed place, the time to freeze is different by several hours. There are some equipments where the refrigeration is not complete to the temperature of −4° C and which refrigerate sufficiently at −30° C. This is due to the difference in the touch of the wind and to the wind speed. Care must be taken to evenly pass the wind over the whole.

4.1.7 Saving of process water

A large amount of process water requires an electric power for supply and increases electric power for the waste water treatment facility.

The main method of process water saving is in a prevention of some waste use in each process. The following matter is necessary to carry out this;

a. Train the employees to make the purpose understood.

b. Install a flowmeter at every main process to indicate the flow every day.

c. Utilize the automatic stop valve depending upon the application.

d. Make sure of re-utilization of the process water. Reuse the waste water of little contamination with installation of a pit such as cooling water for the retort and washing water of the sterilized cans. It is not only possible to recover the process water, but also to recover the heat. An example of the process water reutilization plan is shown in Fig. III-6-12.

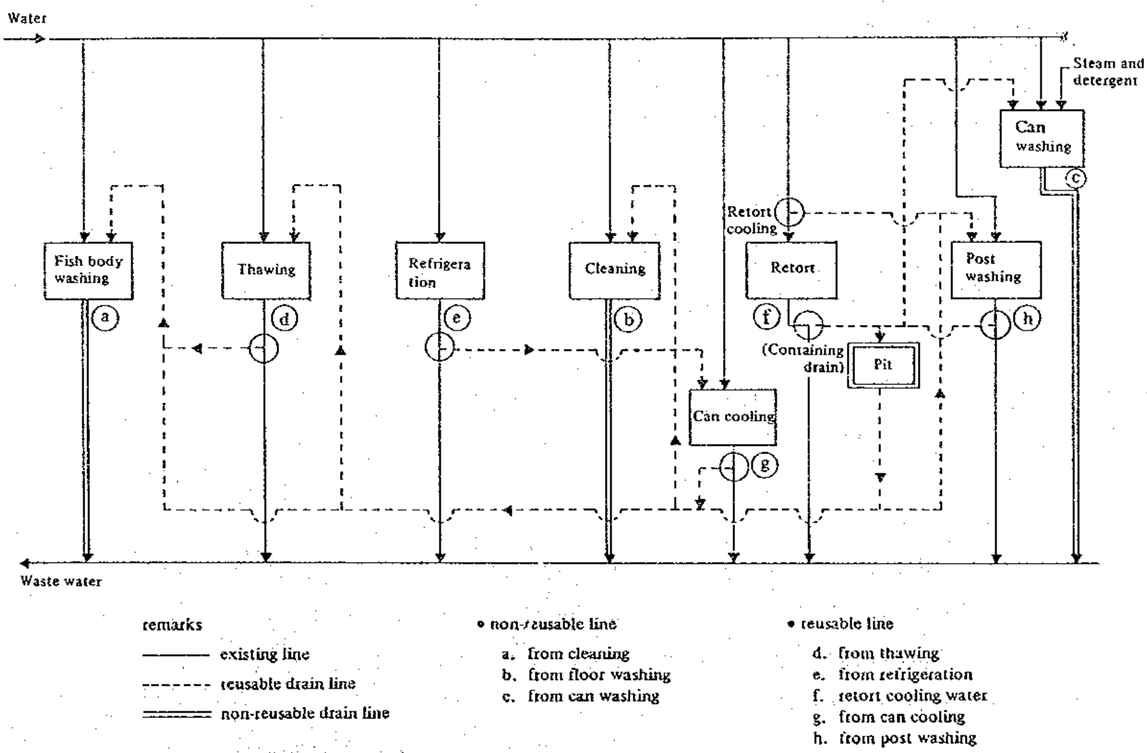


Fig. III–6–12 Drain practical use plan flow diagram – Draft

4.2 Vegetable oil industries

4.2.1 Energy conservation in expression process

(1) Relation with expression process

When energy conservation in the expression process is investigated, the whole of energy conservation related to the extraction process shall be always considered. There are some cases related to an increase in the expression process to make energy conservation by making grounds for an easy extraction, but these should be wholly considered.

The expressed grounds for an easy extraction are to be (a) a low oil content, (b) a low moisture content, (c) a uniform granule without a fine powder and (d) a porous granule with a high penetrability of liquid. Fig. III-6-13 shows a relation between the residual oil content in the expressed grounds and the steam consumption by a process of expression and extraction.

If heat treatment is sufficiently carried out in the expression process, although steam consumption increases somewhat, it shows to move to an energy conservation as a whole in the processes of expression and extraction.

(2) Relation with refining process

The refining process seems to be at the same condition as the expression process. It is desirable to continuously feed a crude oil containing little impurities and refined easily in the refining process. Therefore, proper cooking and drying in the expression process is an important factor.

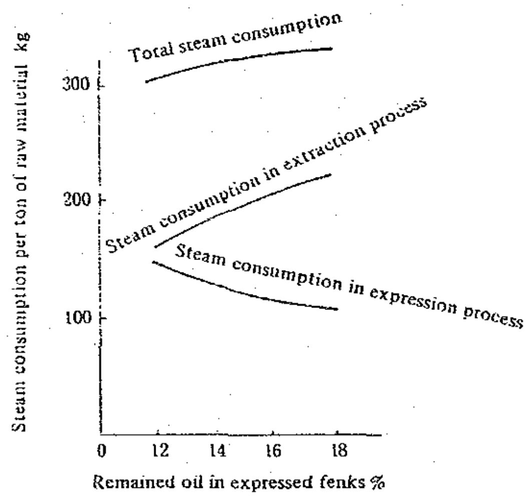


Fig. III-6-13 **Relation between the remained oil in the expressed fenks and the steam consumption by expression and extraction**

(3) Condition for making good expressed fenks

a. Influence of moisture in raw materials at the inlet of an expeller

Fig. III-6-14 shows the relation between the moisture content in the expressed fenks and the oil content by a graph. It is recognized that the moisture content is in proportion in some degree to the oil content. Accordingly, particular attention should be given to the moisture content in the expression.

b. Influence of raw material temperature at the inlet of an Expeller

It is well known that the higher the temperature of raw materials in the Expeller inlet has a tendency of a lower oil content in the fenks. But, to make the fenks suitable for extraction, the interrelationship between the temperature and the *moisture content in raw materials at the Expeller inlet is important.*

Fig. III-6-15 shows the optimum zone graph of the temperature and the moisture content in the expression process. Although the optimum condition may change more or less depending upon the expeller type and size, a finding of the optimum condition with a comprehension of the routine expression condition (temperature, moisture content, and fenks state) can lead to a large energy conservation.

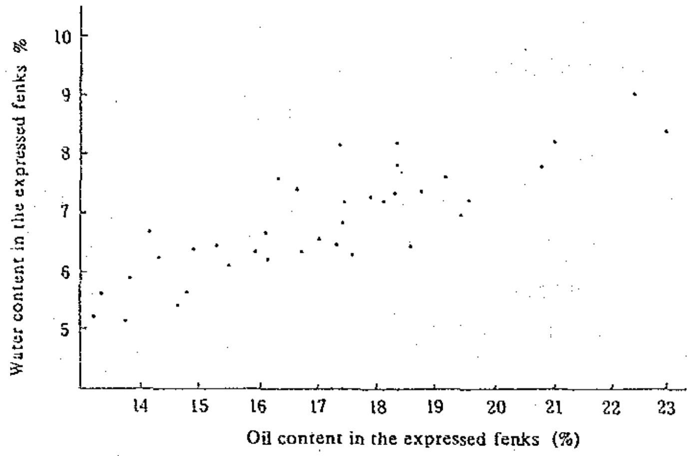


Fig. III–6–14 Relation between the expressed fenks conponent and the oil content

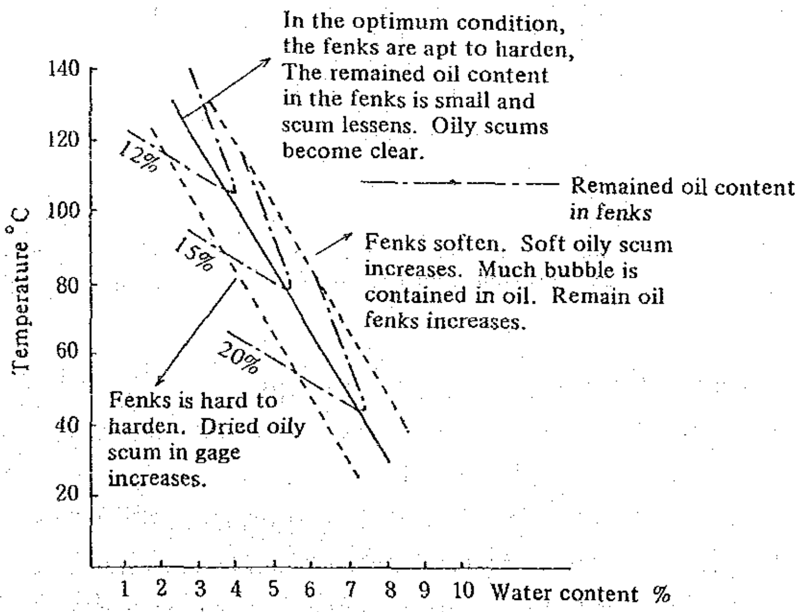


Fig. III–6–15 Optimum condition zone of water content and temperature in expression process

c. Flat press

The raw material is normally flat pressed, though some raw materials may not need to be flat pressed. The quality of flat press is related to the efficiency of the extraction process rather than the expression process.

d. Treatment of expressed fenks

(1) Arrangement of the fenks' granular size. The expressed fenks are crushed roughly to a proper size. If required, the crushed grounds are sifted to eliminate fine powder.

(2) Cooling of fenks. It is effective that the grounds are cooled by air near the extraction temperature and is fed to the extraction process. The air cooling allows the moisture in the fenks to evaporate, the grounds surface to solidify and formation of a fine powder is prevented.

(4) Drying

The heat energy consumption in the drier of the expression is considerable larger.

In the example of C company in Thailand, the quantity of steam consumed in the belt conveyer called "hot air conditioner" has reached about 20% of all consumption in the factory.

There are several types of a raw material driers such as a direct fire type, a heat transfer type, a horizontal disk type and a vertical cooker type. The primary measures are to prevent hot air leakage, to reuse the hot air by circulation, and to intensify the heat insulation of the external wall.

Also an introduction of an automatic control system is effective. If the quantity of steam is automatically adjusted by measuring the most important factors from the temperature of a subject heating material, the temperatures and the humidity of hot air and moisture in the inlet and the outlet, a larger result can be obtained at a relatively lower cost.

4.2.2 Energy conservation in the extraction process

(1) Pretreatment

In the solvent extraction of rice bran, a decreasing of the heat consumption and an improvement of the extraction rate are closely related to pretreatment. In pretreatment, the granule is prepared on the optimum surface area to lessen the attached quantity of solvent. The pretreatment reduces the quantity of heat required to expel the solvent after the extraction, bring about a proper penetration pressure loss of rice bran, reduce an ineffectual pass ofsteam and be related to energy conservation.

The heating pretreatment of rice bran is roughly divided into three operations of cooking, pressurized steaming and drying. A good combination of these operations makes possible to prepare the optimum granule surface area.

A) Cooking

Cooking means the operation to add a proper quantity of moisture to rice bran and to heat it in a vessel. The operation allows the expression rate to improve, the decoloring to improve, the plasticity of rice bran to decrease, and the coagulation effect of granules to be obtained (granulation by association of fine powder). The cooking condition is generally 10 to 20% of moisture content, 90 to 95°C of temperature and for 5 to 10 minutes of time.

Rice bran causes a large difference in granular size distribution depending upon type of the rice sweeper. There are two types of pressure system rice sweeper: cylindrical friction type, and mortar and pestle type. The granule is generally rough. In the speed system sweeper, grinder type, the granule is generally fine.

The granular size of rice bran affects considerably the extraction and the desolvent processes, and relates deeply to energy conservation. An example of the granular size distribution by pretreatment (cooking, pressurized steaming and drying) is shown in Table III-6-12. It is proven that a fine granular size decreases the pretreatment.

B) Pressurized steaming

Pressurized steaming means a light and mechanical expression of the cooked rice bran and has an effect of decreasing the surface area, the fine powder, and the attached solvent at the time of the solvent extraction. Since this operation lessens the pressure loss and reaches the proper attached quantity of solvent, the residual micella quantity is lowered and the expelling of solvent is favorable. This can increase the proper charging quantity per vessel by 20 to 30%. This corresponds to approximately 130 kg/t of the steam reduction.

Table III–6–12 Particle size distribution by rice sweeper and pretreatment

Type of rice sweeper	Mesh / Kind of rice bran	~20	20~30	30~40	40~50	50~60	60~80	80~
Speed system	Raw bran	7.8	4.3	8.9	7.8	5.5	36.3	29.4
	Cooking	9.1	7.3	8.0	15.3	5.9	36.8	17.4
	Pressurized steaming bran	7.4	11.4	18.8	14.4	4.4	36.1	7.5
Press system	Raw bran	5.4	16.1	51.5	1.1	22.5	2.9	0.5
	Pressurized steaming bran	7.4	24.9	50.7	0	17.0	0	0

C) Drying

In a batch type solvent extraction, the optimum moisture content of the rice bran charged into the extraction equipment is 5 to 6%. The solvent content in the micella is a sum of the internal penetrating quantity and the surface absorption quantity of the rice bran layer in the extraction equipment. The decreasing of moisture content and the micella concentration largely affect the solvent content, indicated in some reports. The resistance of penetration of the rice bran layer becomes larger with the smaller granular size of bran and the greater moisture content. The optimum resistance of penetration on the bran layer lessens the ineffectual pass of steam to create energy conservation.

The above pretreatment operation allows the following energy conservation to be attained in the extraction process.

a. The result that the ineffectual pass of steam was decreased in the solvent elimination process came into the steam saving of 40 kg/ton of the raw material.

b. The improvement of micella concentration causes energy for micella distillation to decrease and the charging quantity to increase by 20 to 30% in the same solvent quantity. The residual oil is unchangeable.

c. The drying of fenks after the elimination of solvent is unnecessary. When the solvent is expelled, steaming for a long time makes moisture adhere to the fenks by more than 15%. The fenks must be dried again to decrease less than 13%. If the expelling time is adequate, the steaming time is shortened and the fenks are only cooled without drying.

(2) Utilization of the waste heat in DT tower

In a continuous extraction factory of rice bran, some examples obtained better results by a utilization of the latent heat of steam in the DT tower for micella distillation.

Fig. III-6-16 is the flow diagram of the conventional desolvent process of the extracted oil micella and Fig. III-6-17 is an improved flow diagram.

- Before improvement: As shown in Fig. III-6-16, the distillation of micella is a double effect system, the 1st evaporator was heated with the steam generated in the second evaporator.
- After improvement: As shown in Fig. III-6-17, it was reconstructed to use the desolvent vapor in the fenks desolvent equipment as a heat source of the first evaporator.

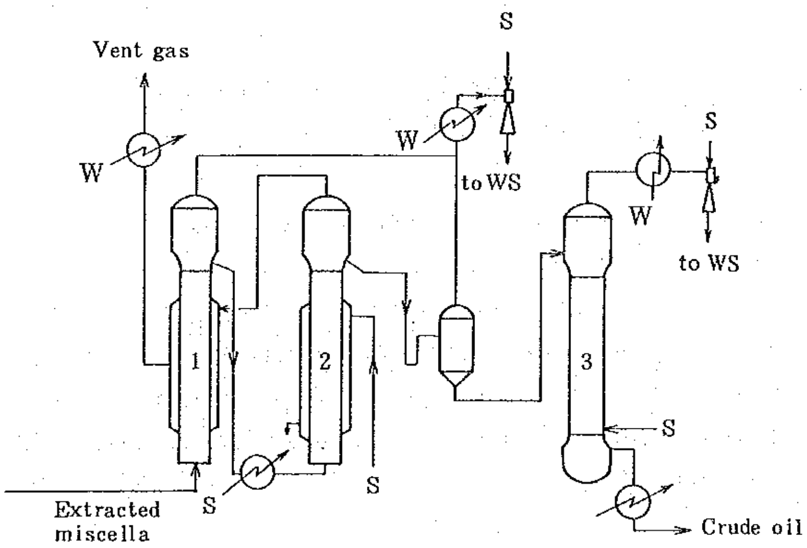
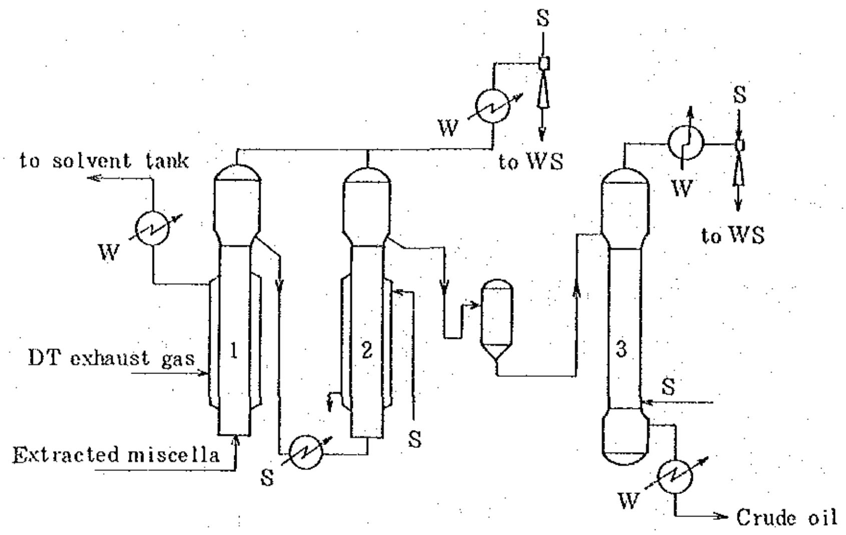


Fig. III–6–16 Before improvement



1 : Primary evaporator   2 : Secondary evaporator   3 : Stripper

W : Cooling water   S : Steam   WS: Waste sewer

Fig. III–6–17 After improvement

As a result of the reconstruction, the quantity of heat supplied to the first evaporator increased by a larger extent compared to before the reconstruction and the concentration of micella became higher. The operating pressure of the second evaporator before the reconstruction was atmospheric pressure, but this was reconstructed to operate in a reduced pressure (250 to 300 Torr) similar to the pressure in the first evaporator. Thus, the quantity of steam required in the second evaporator decreased substantially and energy conservation was realized. The concentration of the concentrated micella fed from the second evaporator to the stripper was about 93% both before, and after the reconstruction. Accordingly, the decreased quantity of steam in the second evaporator resulted in energy conservation.

- Effect: The servicing quantity of steam in the second evaporator before reconstruction was 596 kg/h, but after the reconstruction it was reduced to 296 kg/h. Since the quantity of raw material treatment is 6,500 kg/h, the steam was saved by 46 kg/t of raw material.
- Saved money = ¥5,000/t of steam × 0.3 t/h × 7,200 h/year
  = ¥10,800,000/year (ca.1 million Bt/year)

While, the investment cost totaled ¥15,000,000 of ¥10,300,000 in the main equipment cost and ¥4,700,000 in the construction cost. The investment cost was recovered in about 1.4 years.

- Caution: When a reconstruction is performed to feed the discharged vapor in the desolvent equipment to the condenser through the first evaporator in comparison to the case where the vapor was fed directly to the condenser, it is important to be reconstructed so that a pressure is not applied to the desolvent equipment with attention to the resistance of piping.

(3) Waste heat recovery in drying of fenks

Since the degreased fenks contain a considerable quantity of moisture by the steaming in the D-T tower, it is usually dried in a rotary drier in order to meet the moisture standard.

There are many examples to utilize through recovery of the heat energy in the waste gas of the drier by heat exchange with a low temperature air supplied to the drier.

If a plate type counterflow heat exchanger is applied, the heat recovery rate can be obtained by 60 to 90% because of the high temperature of the waste gas, dust in the waste gas is hard to attach to the wall of heat exchanger because of a plate type element layer structure and a cleaning effect with drain can be also expected.

Some example are shown below:

A) Improvement

< Example-1 >

- Before improvement

The intake air of the meal drier shown in Fig. III-6-18 directly induced fresh air through an open damper and the waste gas was discharged by a suction blower to the atmosphere.

- After improvement

The intake air of the meal drier shown in Fig. III-6-19 forced fresh air by a forced blower to be induced to the inlet of the drier through a heat exchange with the waste gas in the drier. The waste gas is discharged to the atmosphere after the heat exchange.

Although the temperature depends on the waste gas temperature of the meal drier, the intake air temperature after the heat exchange becomes 50 to 60° C, the servicing quantity of indirect steam in the drier is decreased, and the drier capacity is also improved.

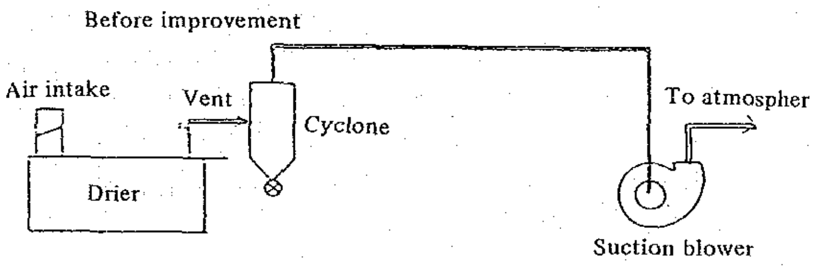


Fig. III–6–18

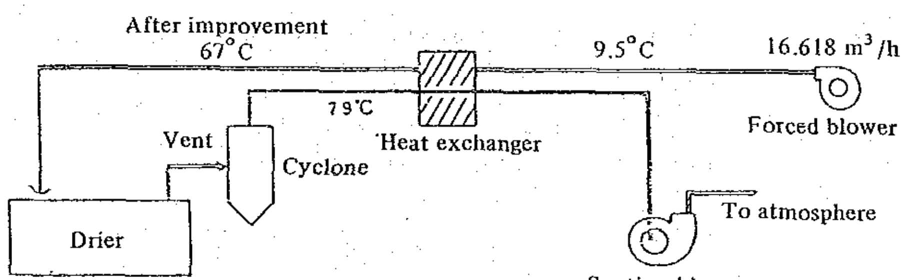


Fig. III–6–19

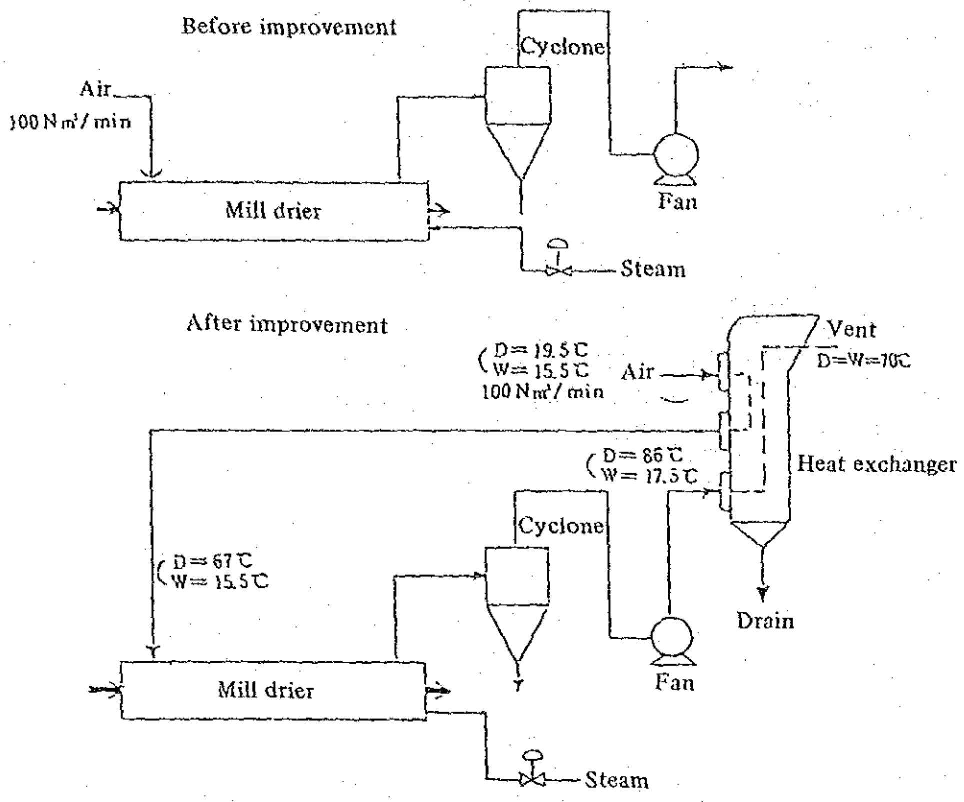


Fig. III-6-20

< Example-2 >

- Before improvement

  The fenks fed to the drier are heated to a predetermined temperature. The evaporated moisture is expelled by the air intake from the inlet of the fan and discharged through a cyclone to the atmosphere.

- After improvement

  Air in the inlet is heat-exchanged with the discharged gas fed from the drier in the heat exchanger shown in Fig. III-6-20. When the heat exchanger is operated in the way similar to before the improvement, a steam equivalent to the increased temperature of air in the heat exchanger can be saved. The higher temperature of air in the inlet allows the drying effect to improve, and the drier capacity to improve.

B) Energy conservation effect

< Example-1 >

a. As shown in Table III-6-13, the conditions of intake air and discharge gas in the installed heat exchanger were measured (the measured value in winter season).

b. Heat exchange efficiency f

$$f = \frac{\text{Intake air outlet temp.} - \text{Intake air inlet temp.}}{\text{Discharge inlet temp.} - \text{Intake air inlet temp.}} \times 100 = \frac{67 - 9.5}{79 - 9.5} \times 100 \fallingdotseq 83\%$$

Table III-6-13

Suction side	Result	Exhaust side	Result
Heat exchanger inlet temp.	9.5°C	Inlet temp.	79°C
Heat exchanger outlet temp.	67°C		
Absolute humidity	0.0036 kg/kg'		
Drier inlet air volume	17,618 m^3/H		

c. Specific volume of air in the intake v

$$v = 0.4555 \times (\text{Absolute humidity} + 0.622) \times (\text{Absolute temp. in the intake outlet}) \times 10^{-2}$$
$$= 0.4555 \times (0.0036 + 0.622) \times (67.0 + 273.15) \times 10^{-2}$$
$$= 0.969$$

d. Intake air weight G

$$G = \frac{\text{Air volume in inlet } (m^3/h)}{\text{specific volume}} \times (1 + \text{Absolute humidity})$$
$$\fallingdotseq \frac{17.618\ m^3/h}{0.969} \times (1 + 0.0036) = 18{,}247\ kg/h$$

e. Calculation of recovered heat quantity Q

If the specific heat of air is taken as 0.243 kcal/kg°C,

$$Q = \text{Intake air weight} \times 0.243 \times (\text{Intake outlet temp.} - \text{Intake inlet temp.})$$
$$= 18{,}247 \times 0.243 \times (67 - 9.5) = 254{,}956\ kcal/h$$

f. If the latent heat of steam is taken as 500 kcal/kg, the year taken as 300 days and 7200 hours operation, and the unit cost of steam as ¥5,000/t, the merit M is:

$$M = \frac{\text{Recovered heat quantity}}{\text{Steam latent heat}} \times 7{,}200\ h \times \frac{¥5{,}000/t}{1{,}000\ kg/t}$$
$$= \frac{254{,}956\ kcal/h}{500\ kcal/kg} \times 7{,}200 \times \frac{¥5{,}000}{1{,}000} = ¥18{,}357{,}000/year$$

g. The operating cost of the intake blower (320 m^3/h, 11 kW) is calculated as the demerit (D). If the unit cost of electric power is taken as ¥20/kWh and the actual load is taken as 80%, the demerit (D) is:

$$D = 11\ kW \times 0.80 \times ¥20/kWh \times 7{,}200\ h = ¥1{,}267{,}000/year$$

h. Accordingly, the total merit (M_T) is:

$$M_T = 18{,}357 - 1{,}267 = ¥17{,}090{,}000/year$$

< Example-2 >

a. The measured values are shown in Table III-6-14.

Table III–6–14

Suction side	Result	Exhaust side	Result
Heat exchanger inlet temp.	19.5°C	Inlet temp.	86 °C
Heat exchanger outlet temp.	67°C		
Absolute humidity	0.0089 kg/kg'		
Drier inlet air volume	7,472 m^3/H		

b. Heat exchange efficiency f

$$f = \frac{67 - 19.5}{86 - 19.5} \times 100 = 71\%$$

c. Specific volume of air in the intake side v

$$v = 0.4555 \times (0.0089 + 0.622) \times (67 + 273.15) \times 10^{-2}$$
$$= 0.978\ m^3/kg$$

d. Intake air weight G

$$G = \frac{7,472}{0.978} \times (1 + 0.0089) = 7,708\ kg/h$$

e. Recovered heat quantity Q

$$Q = 7,708\ kg/h \times 0.243 \times (67.0 - 19.5) = 88,970\ kcal/h$$

f. Merit M

$$M = \frac{88,970}{500} \times \frac{5,000}{1,000} \times 7,200 = ¥6,0406,000/year$$

Provided that the latent heat of steam is taken as 500 kcal/kg and the unit cost of steam is taken as ¥5,000/t.

C) Spillover effects

a. Scatter of moisture content in the products due to the change of atmospheric temperature was reduced and it was available for process control.

b. The capacity of the drier was increased by rising of the temperature of the intake air.

c. Condensation of moisture formed a damp wall in the heat exchanger, prevented a fly of the fine powder, and cleaned the waste gas.

d. The improvement of the drying efficiency reduced the load of the fan (decreasing of the air quantity of the inlet).

e. The exhaust of gas in the drier has been carried out as an odor measure. The cases of a cleaning system and an absorption system are required to lower the exhaust gas temperature. However, the installation of this heat exchanger allowed the deodorizing to be carried out smoothly.

D) Investment profitability

- Investment cost (See Table III-6-15)

Example-1. Swiss·Landisgear Co. Type: Economea 100RR/B × 2
Example-2. Swiss·Landisgear Co. Type: Economea 150RR/B × 1

- Profitability (See Table III-6-16)

E) Precaution for the equipment

a. Material

The material of the heat exchanger has three types of fins: SUS-external plate: SUS, fin: Al-external plate: SUS and fin: Al-external plate: steel. Because the exhaust gas discharged from the drier is of high temperature and higher humidity, the material is desirable to be all SUS though it is of higher cost. Also, for the chamber as a connection of the upper and lower ducts, the material should be selected to SUS.

Table III–6–15

Item	Example–1	Example–2
1) Heat exchanger	10,000 thousand yen	6,600 thousand yen
2) Fan	1,575 thousand yen	—
3) Erection and others	11,530 thousand yen	4,500 thousand yen
Total	23,105 thousand yen	11,100 thousand yen

Table III–6–16

	Example–1	Example–2
Investment cost	23,105 thousand yen	11,100 thousand yen
Saving cost	17,090 thousand yen	6,406 thousand yen
Pay back time (year)	1.35	1.73

b. Discharge of drain

If a discharge of drain generated in the heat exchanger is not enough, the exhaust of gas is disturbed, drain is accumulated in the heat exchanger, the duct and the fan have troubles.

The performance of the heat exchanger should be maintained through a usual maintenance to 100% or more of the humidity in the exhaust gas, a continuous generation of drain, a damp wall in the discharge side of the heat exchanger and a prevention of attachment of fine powder.

c. Installation of cleaning equipment

Although the element laminating structure of this heat exchanger is hard to have dust attach, if the duct and chamber are made of a steel material, an attachment of iron dust to the inside of the heat exchanger may cause electrolytic corrosion. Accordingly, a periodic cleaning is required to eliminate these dusts.

d. Adjustment of intake air quantity

To adjust the intake air quantity in a degree not to apply internal pressure to the meal drier, a damper should be provided in the inlet of the air intake of the heat exchanger or the forced fan.

e. Fin in heat exchanger

Because the exhaust gas of a meal drier contains a fine powder, a flat heat exchange surface of the heat exchanger can prevent a reduction of heat exchange due to the attachment of fine powder.

f. Heat insulation

Heat insulation on the duct for exhaust gas and on the heat exchanger body improves heat efficiency.

4.2.3 Energy conservation of refining processes

The oil in refining processes is subject to repeated heating and cooling. Accordingly, it leaves some room for application of the heat through a mutual heat exchange. The points taken into account for a plan of heat recovery are as follows:

- Consider the whole plant.
- Is it possible to lower the present heating temperature?
- Does it affect to the following process? If affected, some measures should be taken.
- The physical properties of a fluid subject to a heat exchange should be exactly comprehended.
- Proper equipment should be applied with a good understanding of the characteristics of the heat exchanger.

(1) Rationalization in the neutralizing and decoloring processes

In the neutralizing process, the material is heated to 60 to 90° C for neutralization and it has to be allowed to stand as it is after the seperation of foots. In the decoloring process, the material has to be heated to 100° C, but in the following dewaxing process it has to be cooled by cooling water or coolant and has to be stored as it is.

In each process of the neutralizing, decoloring and dewaxing, and heating, cooling and heat dissipation have been operated separately. But if the heat in these operations is transfered mutually and systematically, an effective energy conservation can be carried out. The example is shown below (See Fig. III-6-21).

A) Before improvement

The raw oil in a neutralizing process is heated by the No. 2 heat exchanger, and the decolorized oil at high temperatures through the processes of dewaxing and decolorizing has been fed to the decolorized oil tank as it is. The decolorized oil in the dewaxing process has been cooled preliminarily in the No. 3 heat exchanger, then has been cooled to the wintering condition temperature by a refrigerator. The cooled oil through a filter has been fed to the dewaxed oil tank as it is.

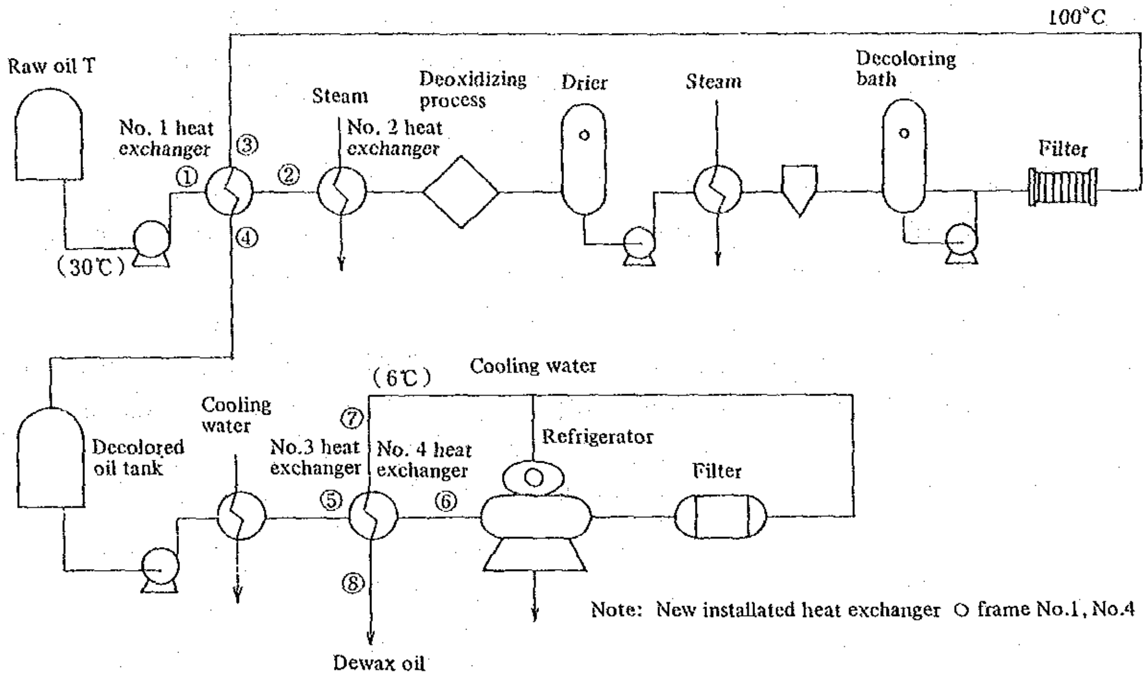


Fig. III–6–21 Improved process flow

B) After improvement

The oil heated in the processes of neutralizing and decolorizing is heat-exchanged in the No. 1 heat exchanger (a new construction) to cool to 50° C and is fed to the decolorized oil tank. At the same time, the cooled, neutralized oil is heat-exchanged to 80° C and is heated to a neutralization condition in the No. 2 heat exchanger.

While, the dewaxed oil in the dewaxing process is cooled and filtered it is heat-exchanged in the No. 4 heat exchanger (a new construction) with the decolorized oil precooled in the No. 3 heat exchanger and is fed to the dewaxed oil tank. At the same time, the decolorized oil precooled in the No. 3 heat exchanger is cooled to 10° C in the heat exchanger and then is cooled again to a dewaxing temperature by the refrigerator. The energy conservation effects by the above improvement are the following two points.

a. Reduction of steam consumption for neutralization due to the new construction of the No. 1 heat exchanger.

b. Reduction of power load for wintering cooling due to the new construction of the No. 1 and No. 4 heat exchangers.

C) Selection of heat exchangers

It is important for the heat exchanger to meet the process conditions, to be economical, and have high workability.

The example is a liquid-to-liquid heat exchanger of an equal quantity at low pressure. The plate type raises the workability and the profitability.

The heat exchanger size can be obtained by the heating area shown in the catalogues of each company.

$A = Q/U.\Delta tm$

A: Heating area (m^2)

Q: Heat exchange quantity (kcal/h)

U: Overall heat transfer coefficient

Δtm: Average temperature difference

The overall heat transfer coefficient is determined by the type of heat exchanger and the subject liquid or gas, in general, an experimental value is used.

D) Result

In the example, the result as shown in Table III-6-17 was obtained (the average is taken as 5,000 kg/h, though a little variation exists depending upon the flow).

Table III–6–17

Item		No. 1 heat exchanger	No. 4 heat exchanger
Plate type heat exchanger		24 m^3	48 m^3
Inlet temp.	①, ⑤	30°C	30°C
Outlet temp.	②, ⑥	80°C	10°C
Heating and cooling oil	③, ⑦	100°C	6°C
Heating and cooling outlet oil	④, ⑧	50°C	26°C

E) Effect

Although the process flow varies from the kind of treating oil the experiment was taken as 5,000 kg/h of a medical kind of oil and the measured value was confirmed. The data just after the installation could be satisfied by 100% of the design value. Since the efficiency may be reduced by an attachment of scale with age, a periodical cleaning is required.

a. Energy conservation effect

① Steam in the deoxidizing process

5,000 kg/h × 0.55 kcal/kg·°C × (80°C − 30°C)
× 7,200 h/year ÷ 500 kcal/kg = 1,980 t/year

② Power in the wintering process

5,000 kg/h × 0.55 kcal/kg·°C × (30°C − 10°C)
× 7,200 h/year ÷ 2,400 kcal/kW = 165,000 kWh/year

(Note) Refrigerator (R-22)

b. Spillover effect

The expansion of the heat exchanger resulted in a reduction of the temperature of decolorized oil and the load of the refrigerator, and the loads of process water and cooling tower were decreased by a large degree. However, this is not included in the energy conservation effect.

F) Investment profitability

a. Investment cost for equipment

Heat exchanger:	$24m^2$	one set	¥1,000,000
Heat exchanger:	$48m^2$	one set	¥1,500,000
Construction cost:	Piping	one set	¥1,500,000
Total			¥4,000,000

Note) The construction cost differs from process layouts.

b. Merit of energy conservation

Steam: 1,980 t/year × ¥5,000/t = ¥9,900,000/year

Electric power: 165,000 kWh/year × ¥20/kWh

= ¥3,300,000/year

Total ¥13,200,000/year

c. Profitability

Investment cost/energy conservation merit =

¥4,000,000/¥13,200,000 = 0.30 years

G) Precaution

a. Generation of Δp accompanied with the expansion of heat exchanger and check of the specification of the existing pump.

b. Check the balance of the whole system accompanied with the generation of Δp

(2) Rationalization by heat exchange of decolorized oil and wintering oil

The wintering oil was heated by the heat exchange of a high temperature decolorized oil and a low temperature dewaxed oil (a wintering oil), and the steam consumption was reduced in the following deodorizing process. This example is shown below.

A) Before improvement

As shown in Fig. III-6-22, the decolorized oil was cooled to around 40° C by a cooler and was fed to a decolorized oil tank.

While the winter oil was fed to the deodorizing process through the winter oil tank.

B) After improvement

As shown in Fig. III-6-23, the winter oil was pre-heated by the heat exchange of the decolorized oil and the winter oil, and the steam consumption of the preheater in the deodorizing process was reduced.

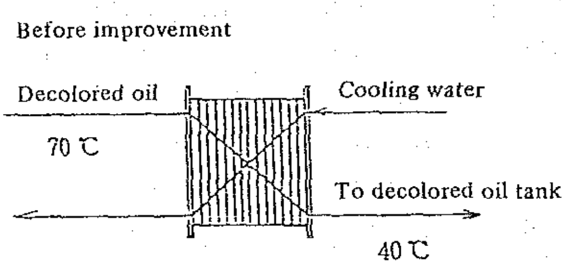


Fig. III-6-22

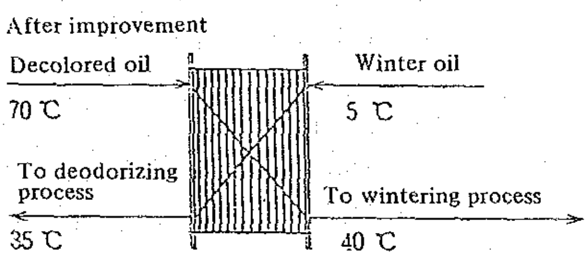


Fig. III-6-23

C) Effect

a. Energy conservation effect

The calculation was made as deodorized just after the wintering process.

Saved quantity of heat: $1{,}000\ kg \times 0.55 \times (35 - 5) = 16.5 \times 10^3\ kcal/t$ of oil

Specific gravity of oil: $C = 0.55\ kcal/kg°C$

If oil of 40,000 t/year is wintered, the saved quantity of steam is;

$16.5 \times 10^3 \times 40{,}000/500 = 1{,}320 \times 10^3\ kg/year$

Saved money: $1{,}320 \times 10^3 \times$ ¥5/kg = ¥6,600,000/year

b. Spillover effect

- If the decoloring and wintering was operated by a direct connection, the cooling water of the cooler for the decolorized oil was not used.
- Dewing on the receiving bath of winter oil in the summer season disappeared.

D) Investment profitability

a. Investment cost

Plate type heat exchanger: 18.6m^2	¥1,500,000
Erection and piping work: One set	¥1,200,000
Total	¥2,700,000

b. Profitability

¥2,700,000/¥6,600,000 = 0.41 years

E) Precaution

a. Since the optimum value depending upon the kind of oil exists in the oil temperature in the inlet of the wintering process, a control of the outlet temperature of the heat exchanger is required. Particular attention must be given to not overcool.

b. The production schedule should be designed to improve energy conservation and to maintain as longer a time of the operation in a direct connection of each process (deoxidizing, decoloring, wintering and deodorizing) as possible.

c. The heat insulation in both high and low temperature sections should be intensified.

(3) Rationalization by heat recovery in deodorizing process

There are many examples in the deodorizing process. Deodorizing is the process which consumes the most energy in the oil production factory and there is great interest in energy conservation.

However, since the process produces the final product, particular attention to the product quality must be given. The heat recovery in the deodorizing equipment is based on the heat exchange of the high temperature of the product oil in the outlet and the feed oil in the inlet.

Heat recovery method

- Direct heat exchange of oil-oil.
- Indirect heat exchange through a medium

< Example of a direct heat exchange of oil-oil >

Up to now, the oil was heated to a predetermined temperature by the external heater and was fed to the deodorizing columun. The deodorized oil was cooled by water in the tray. The cooling water was discharged as a hot waste water.

To heat-exchange the crude oil with the high temperature oil of the final step in the deodorizing process, the external heat exchanger was connected to the coil in the tray, the cooling (heat exchange) in a high temperature part was carried out with reduced pressure and the cooling (heat exchange), since that step where no deterioration of the product quality was applied to the external exchanger.

A) Before improvement

As shown in Fig. III-6-24, oil was heated in the deaerator, then heated to 160° C by steam of 10 kg/cm^2 in the No. 1 tray and heated to a predetermined temperature by a high pressure steam in the No. 2 tray.

B) After improvement

As shown in Fig. III-6-25, the inlet oil after the deaeration is heated by passing into the coils of the No. 8 and No. 7 and heated to 230° C by a spiral type heat exchanger in order to improve the heat recovery rate, then fed to No. 1 tray.

The high temperature oil is discharged continuously from the No. 6 tray, cooled by the spiral type heat exchanger, and fed to the No. 7 tray.

In the No. 7 and 8 trays, the oil is cooled by steaming and fed out of the column at a temperature of 110° C.

The oil fed out, at a temperature of 110° C, is heat-exchanged with an oil in the inlet of the deoxidizing process by a plate type heat exchanger and is heat-exchanged again with industrial water. The hot water produced is utilized in the deoxidizing process.

C) Effect (Measured value)

Capacity	Oil flow	8,500 kg/h
	Steam pressure	10 kg/cm^2, 56 kg/cm^2

a. Saved steam quantity (γ = 478 kcal/kg, 380 kcal/kg)

- Heat recovery in the deodorizing process

Temperature of inlet oil (decolored oil)	90° C
Feed temperature to No. 1	230° C
Equivalent to 10 kg/cm^2 steam (90° C → 160° C)	620 kg/h
Equivalent to 56 kg/cm^2 steam (160° C → 230° C)	860 kg/h

- Heat recovery in the neutralizing process

Temperature of oil in the outlet of the deodorizing column	110° C
Temperature after the heat exchange of raw oil and industrial water	55° C
Equivalent to 10 kg/cm^2 steam (110° C → 55° C)	440 kg/h

b. Increased electric power

Power for three pumps 35 kW

c. Saved money (See Table III-6-18)

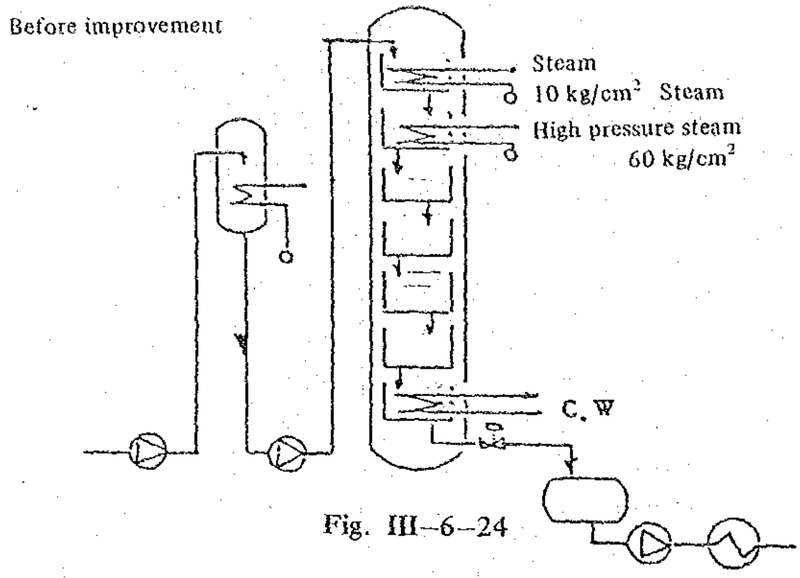


Fig. III–6–24

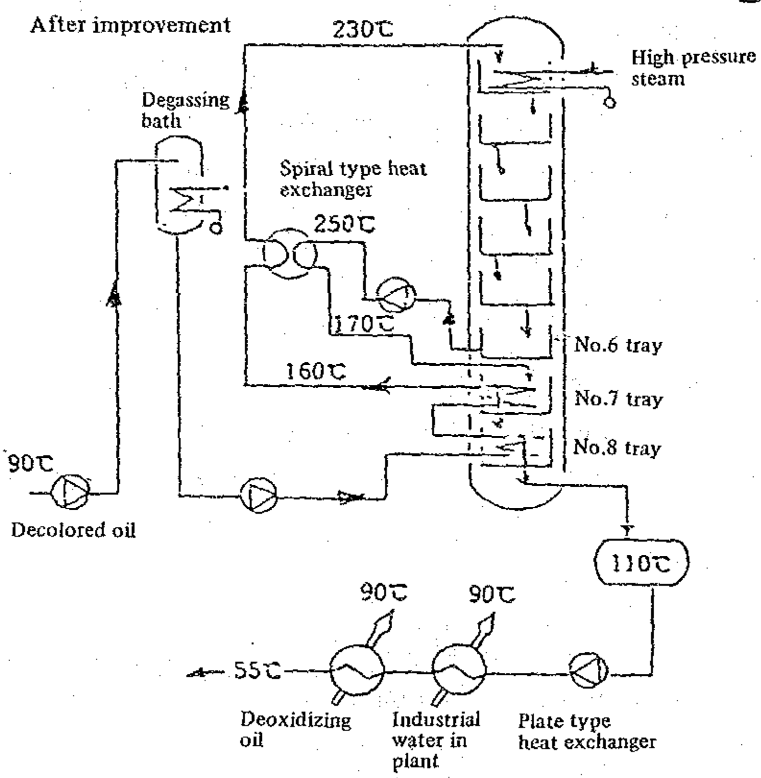


Fig. III–6–25

Table III–6–18

	10K steam	56K steam	Electricity	
1	620 kg/h	860 kg/h		
2	440 kg/h			
3			35 kW	
Total	1,060 kg/h	860 kg/h	35 kW	
Saving quantity (year)	7,632 t	6,192 t	252,000 kWh	Operating time 7,200h
Saving sum (year)	38 million yen	34 million yen	Δ 5 million yen	

Unit cost of steam ¥5,000/t, Unit cost of power ¥20/kWh Total saved money per year ¥67,000,000

D) Investment profitability

a. Investment cost

Reconstruction of deodorizing column (increase and reconstruction of tray)	¥30,000,000
Spiral and plate type heat exchangers	¥7,000,000
Instrument and controller	¥10,000,000
Erection, piping and electrical works	¥55,000,000
Miscellaneous expenses	¥3,000,000
Total	¥105,000,000

b. Saved money ¥67,000,000

c. Profitability 105,000/67,000 = 1.6 years

E) Precaution

- Deaerate prior to be fed into the coil for heat exchange in order to prevent contamination on the inside of the coil.
- Speed up the flow rate in the coil as far as pressure permits.
- Take the coil at one pass as far as the heat transfer area is permitted.
- Not leave a dead space for a branched coil.

< Example of indirect heat exchange >

For a heat recovery with no damage of the deodorized oil quality, it is best in the heat exchange with steam distillation in the deodorizing column. It is desirable to carry out heat recovery by a steam medium in order not to attach any scale on the heat exchanging part.

A) Before improvement

The crude oil was heated by steam to the temperature required for deodorizing and the deodorized oil was cooled by water.

B) After improvement

As shown in Fig. III-6-26, the coil of the No. 1 preheating tray is connected to the coil of the No. 6 cooling tray and the coils are filled with pure water to form a kind of heat pipe and the oil can be preheated. Therefore, a preheating steam is not necessary.

One step of a cooling tray was increased in order to drop the oil temperature to 60° C or less under a reduced pressure.

C) Effect

a. Energy conservation effect

If the oil temperature in the inlet of the No. 1 tray is 70° C, the oil temperature in the outlet of No. 1 tray is 160 to 170° C (average 165° C).

The saved quantity of heat:

1,000 kg × (165° C − 70° C) × 0.55 kcal/kg·° C

$= 52.3 \times 10^3$ kcal/t of oil

The quantity of steam saved in the case of deodorized oil of 54,000t annually is;

$52.3 \times 10^3 \times 54{,}000/500 = 5.65 \times 10^3$ kg/year

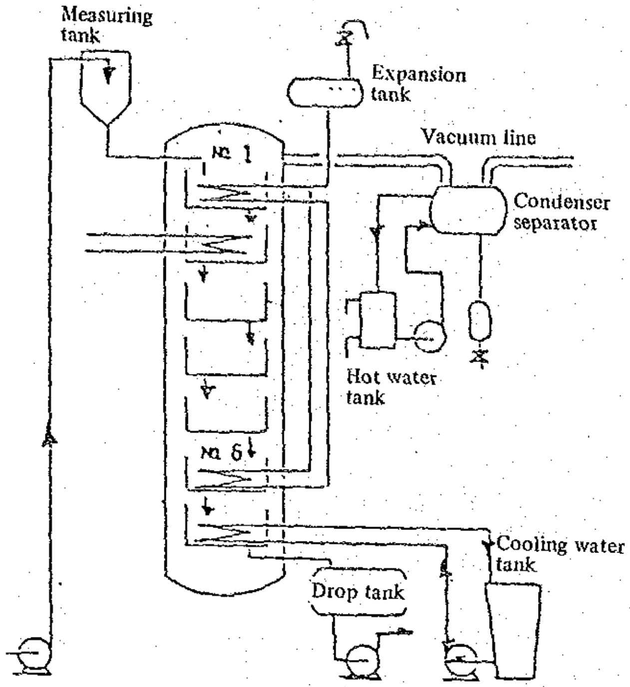


Fig. III–6–26

Saved money: 5.65 × 10³ × ¥5/kg = ¥28,250,000/year

b. Spillover effect

- The servicing quantity of cooling water for oil cooling was reduced.
- The load of the high pressure boiler was reduced (the temperature in the outlet of the No.1 tray before improvement was 150°C).

D) Investment profitability

a. Investment cost

The revamping cost in the 180 t/day capacity:

Revamping of No.1, No.6 trays and tray increasing . . . one set ¥24,000,000

b. Profitability

¥24,000,000/¥28,250,000 = 0.85 years

E) Precaution

- The pressure in the coil must be taken into consideration because the pure water filled in the coil is heated up to around 200°C.
- Care must be taken not to empty the No. 1 tray at the time of the operation end.

III. Guideline for Rationalization of Energy Use

7. Boiler and Steam

Contents

1. Boilers

1.1 Classification

Now, boilers used universally can be classified by structure as shown in Table III-7-1.

Table III-7-1 Classification of boiler

Type	Model
Cylindrical boiler	Vertical boiler Flue boiler Smoke tube boiler Flue smoke tube boiler
Water tube boiler	Natural circulation water tube boiler Forced circulation water tube boiler Once-through boiler
Others	Sectional boiler etc.

1.1.1 Cylindrical boiler

Cylindrical boiler is mainly composed of a large diameter cylinder and unsuitable for a high pressure and a larger capacity due to its structure. It has been used as a boiler of less than 10 kg/cm^2 and 8 t/h in evaporation.

Since the cylindrical boiler has a larger water retaining volume per capacity compared with water-tube boiler, it demands much time to start-up but a pressure fluctuation due to loading change is small.

a. Vertical boiler

As shown in Fig. III-7-1, vertical boiler has a vertical cylinder and a combustion chamber in the bottom section. There are two systems of horizontal tube type and multi-tube type. Because it can not be provided with large heating surface area, the capacity is limited to 1 t/h or less.

It can do with a small floor area and can be set simply up, but it is hard to check and clean because of its small size. Because of the small surface area, entrainment contained in the generated steam tends to be too much.

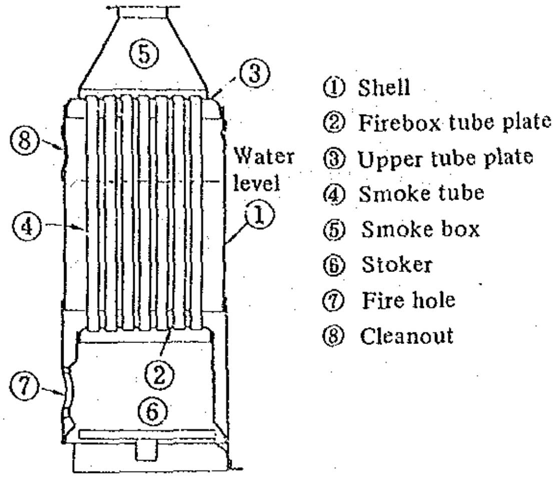


Fig. III-7-1 Vertical boiler (multitublar type)

b. Flue boiler

The flue boiler is provided with one or two flues through shell and the burners are equipped in the flue. One flue type is called a Cornish boiler and two flues type is referred to as a Lancashire boiler. Since the boiler has a small heating surface area and has lower efficiency, recently it has been scarcely manufactured.

c. Smoke tube boiler

As shown in Fig. III-7-2, a smoke tube boiler is equipped with a combustion chamber formed with brick laying beneath the cylinder and arranged with a number of smoke tubes in the shell. The combustion gas heats the lower section of shell and then heats again the side surface of shell after passing the smoke tubes. As the heat loss through the brick wall is large in case of outside combustion chamber,some boiler is equipped with the combustion chamber in a part of the flue.

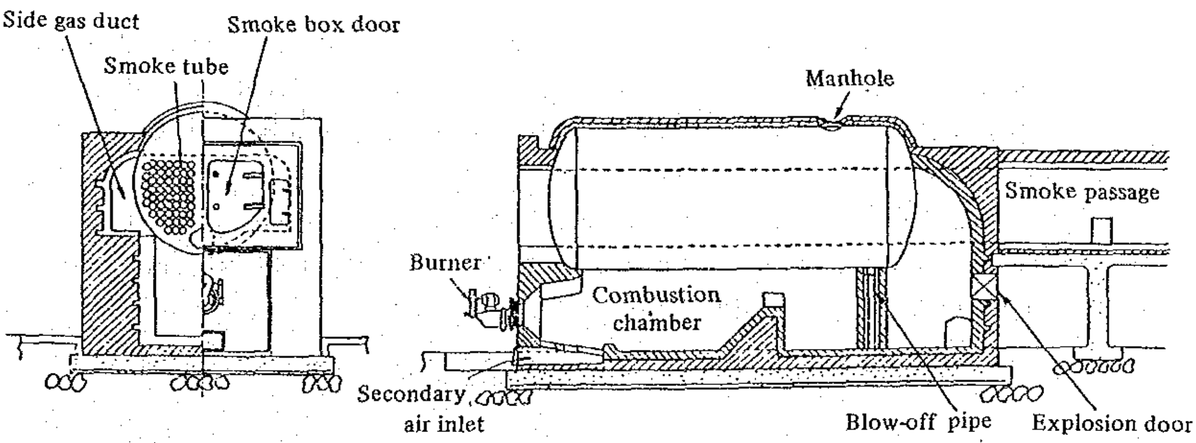


Fig. III-7-2 Externally fired horizontal smoke boiler

d. Flue smoke tube boiler

As shown in Fig. III-7-3, 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 limited to 15 kg/cm^2 in pressure and 25 t/h in capacity. An efficiency of 85 to 92% is obtainable. On the other hand, the structure is complex, check and cleaning in the inside are difficult and feed water is required to be high quality.

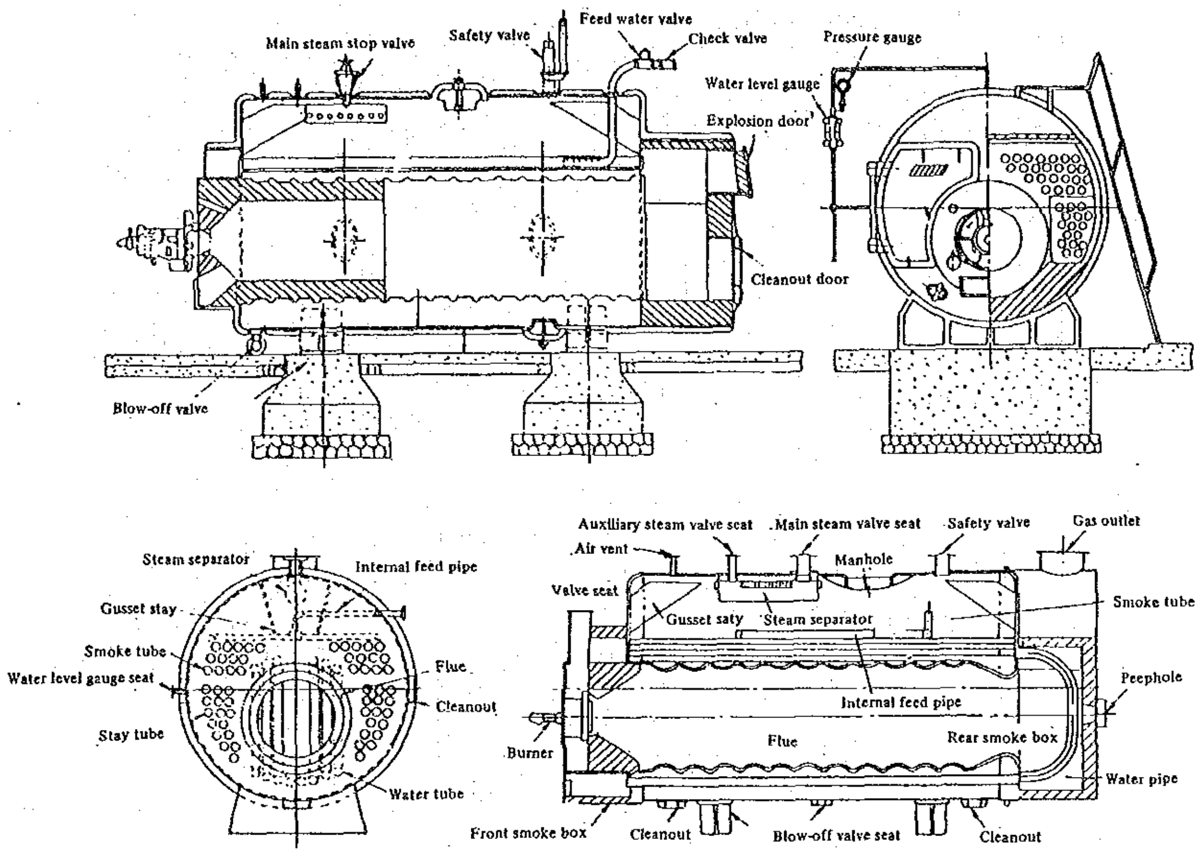


Fig. III-7-3 Flue smoke tube boiler

1.1.2 Water-tube boiler

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 evaporate feed water 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 able to obtain easily a high pressure. The features of water-tube boilers are as follows:

a. Because the combustion chamber is able to 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 (see Fig. III-7-5). A high pressure boiler is required to adopt a forced circulation system because of the density difference between steam and water is small.

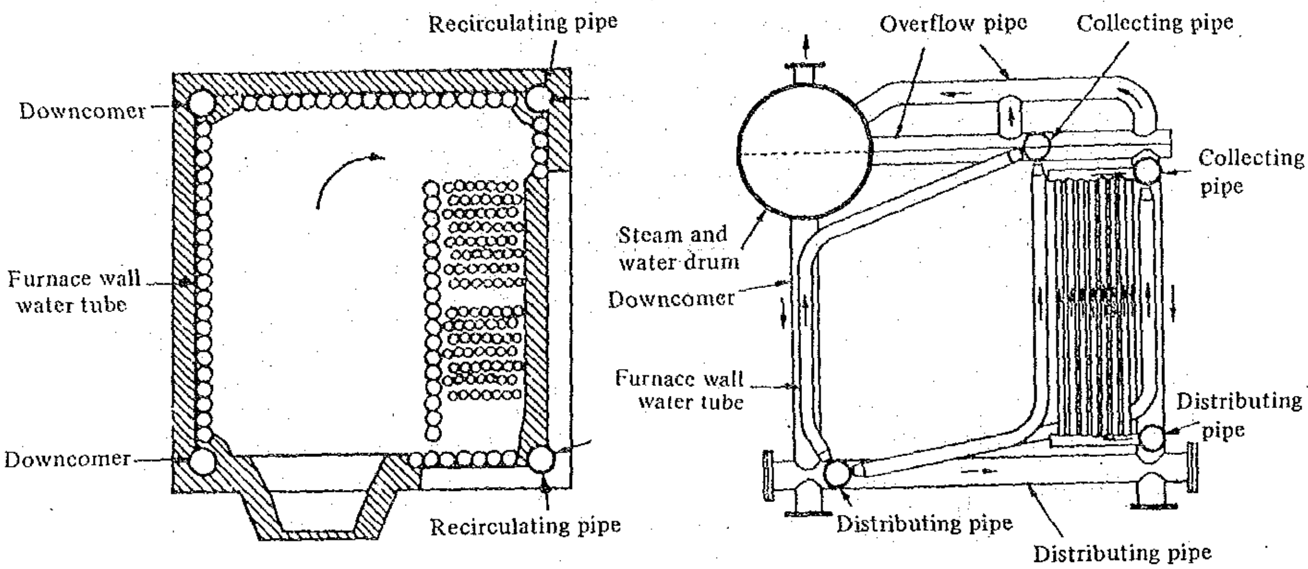


Fig. III-7-4 Bending water tube boiler

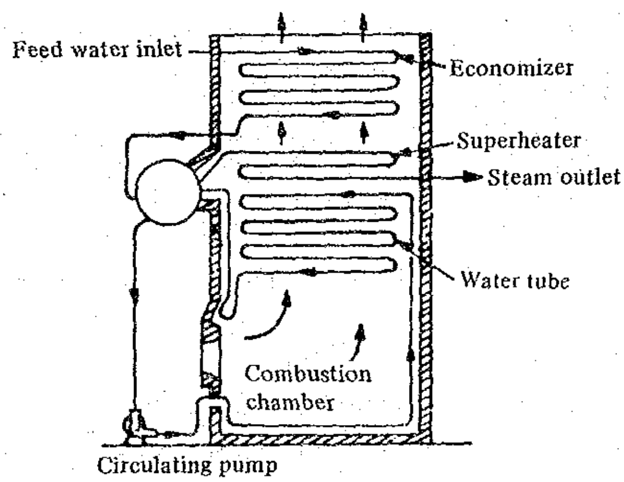


Fig. III-7-5 Forced circulation boiler

An one-through boiler only composed of a series of long water tubes is designed so that feed water is pushed into the tube by a pump from the end of the tube, by turn temperature is raised, evaporated, superheated and taken out as superheated steam from another end of the tube. Accordingly boiler water is not circulated (see Fig. III-7-6). The features of this one-through boiler are as follows:

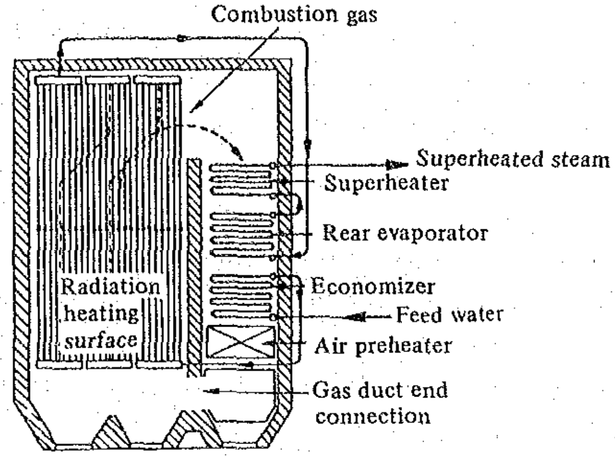


Fig. III-7-6 Schematic flow diagram of Benson boiler

- Suit a high pressure boiler because there is no steam drum.
- Able to be designed compactly.
- Start-up time is short because the retaining water is extremely small amount per heating surface area.
- Require an automatic control device with good response since a loading change is prone to cause large pressure fluctuation.
- Require a feed water of good quality because all the feed water evaporates in the tube.

With such characteristics, the one-through boiler has been applied in a wide variety from a supercritical pressure boiler to a small scale boiler.

1.1.3 Other boilers

There is a boiler combined with a cast iron section which is used as a low pressure or hot water boiler, a waste heat boiler or a boiler for special fuel and so on.

1.2 Boiler trouble prevention

A boiler is an equipment which deals with a high temperature and a high pressure steam. If trouble occurs, the human body and the facilities may suffer damage on a large scale and it is related to a long-term production stop. Then, the continuing effort for energy conservation may be rendered futile. To take prudential measures for boiler trouble is essential for energy conservation.

The operation necessary to prevent boiler trouble is closely related with energy conservation. For example, a feed water treatment prevents damage due to local heating and also serves for improvement of heat transfer.

Most boiler troubles are caused by a lower water level (no load combustion), explosion in combustion chamber, crack of cast iron boiler or burst due to local overheating.

The points remarked to prevent trouble are as follows:

1.2.1 Preparation of operation and inspection manuals and training.

The standards on boiler operation and check-and-servicing should be prepared and be observed by the employee through sufficient training.

1.2.2 Safety device

The boilers should pass a predetermined inspection and be equipped with a relief valve, a high and low water level alarm, a flame detector as a necessary instrument and a safety device. Furthermore, the boilers should be designed to operate failsafely against miss operation through automation. These must be inspected periodically. Table III-7-2 shows the routine check items for boilers.

1.2.3 Consideration on operation

(1) Igniting operation

If fire is put in the furnace under a mixture of air and gas or oil vapor, combustion occurs explosively. It is a danger of accident occurrence. Prior to ignition, prepurge must be done for five minutes or more in Cold Start or for about one minute in Hot Start to send completely out combustible gases of the combustion chamber and flue. If ignition becomes a failure, the operation should be halted without hesitation and done over again from the prepurge step.

Heating just after ignition is done to make temperature raise gently over about two hours to prevent differential expansion of the body and leakage from the joint parts.

(2) Monitor of water level

Keeping the water level in a boiler to a certain range is the most important task of a boiler operator and should be monitored at all times.

Therefore, the water level gauge should be cleaned usually so that observation is easily made. For the following cases, a function test should be performed and a check should be done to indicate a regular water level.

a. After the boiler is started.

b. When the operators are shifted.

c. When the reads of two or more water level gauges are different.

d. When some foaming is occurred in the boiler water.

Where an automatic feed water control device is equipped, its performance should be checked periodically by lowering the water level in the boiler.

(3) Water treatment and blow

The purposes of water treatment to boiler feed water are classified in the following three items:

a. Prevention of corrosion due to dissolved oxygen and corrosive substances.

b. Prevention of scale formation due to deposition of hardness components and dissolved solids in the feed water.

c. Prevention of foaming due to accumulation of dissolved solid and oily matter in the boiler water.

Table III 7–2 Daily inspection of boiler

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Constantly inspection	1. Pressure of boiler	O				1. Reading. Pointer movement	1. Smooth moving without catching.
					O	2. Surface temperature. Leakage.	
				O		3. Initial and stop temperatures of pressure controller.	3. No disorder. See item 9.
					O	4. Particularly take care to popping pressure at operation of the safety valve.	4. Check disorder by comparison with pressure gages of three or more
	2. Water level of boiler	O				1. Movement of water level of a water gage.	1. A little movement of the water level is normal. If the hole is clogged, the movement becomes dull. Compare the water levels of two water gage which the height changes.
			O			2. Normality of water level at start and stop of the feed water pump.	2. A detection by bellows vary with the level and the operation range by fluctuation of pressure. When the pressure goes to higher, the level goes to down and the operation range come to wider. Check the operation level and range in an average pressure.
					O	3. Special care must be taken to the working at a lower and higher level alarm.	3. Find out the cause and take a countermeasure. (See items 5 and 6.)
	3. Combustion state	O				1. Change of burning sound.	1. Take care to abnormal sound at the start of combustion and during the switching from low to high.
			O			2. Shape and color of flame.	2. Proper flame without touch to furnace and with no rough particle.
		O				3. Generation of smoke and its time.	3. Check the internal pressure of furnace, exhaust gas analysis and the quantity of air and oil. Care must be used to a long time operation under a low load.
Daily inspection	4. Gage glass	O				Check of gage glass. Open a drain cock, close a steam cock and blow out boiler water sufficiently. And then close the water cock, open the steam cock, check the steam side, then close the drain cock, open the water cock and watch forcible rising of water level.	1. Make sure the open and close condition and any leakage of each cock. Clean the inside.
					O		2. Repair to any leakage from the out of glasses. Check a disorder of the mounting core of the upper and lower cocks and the length of glass.
			O				3. Clean the glass. Use a predetermined length of glass if exchanged. Use care not to tighten too much the glass. Namely, first, open the drain cock to warm with steam and close the drain cock. Open the water cock and open fully the steam cock. After use a little, do retightening.
	5. Water column (floatless)		O			1. Drain water in the column and remove sludge and scale.	1. Make sure the open and close condition of the interconnecting line and clean the inside.
					O	2. Build-in water level detector. Inspect the electric wiring terminal, any contamination of the insulation of the electrode holder, contamination and crack of the electrode.	2. Check the electric wiring (heat resistance wiring). Measuring of insulation resistance—remove the wiring for the electrode holder and the resistance between the electrode and the earth shall be more than 100MΩ. Cleaning of electrode. Clean contamination of the electrode holder, check any crack or exchange it.

(T. III-7-2②)

Type of inspection	Place of inspection		Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessary of the body)	6. Automatic feed water adjustable device. McDonnel floatless. Low level breaker. High and low water level alarm.		O			1. Change each valve and purge scale and sludge in the inter-connecting pipe.	1. Make sure the open and close condition of the interconnecting line. Clean the inside (blow enough) in a condition of lower pressure if possible.
				O			2. Make sure the operation with lowering of the water level by blowing.	2. Make sure the operation with blowing. If impossible to blow, remove the electric wire to make sure the operation (burner cut).
						O	3. Check the internal mercury switch and bellows.	3. Check a scattering of mercury and balance. Check leakage from the bellows.
						O	4. Check the electric wiring.	4. Check damage due to heat. Rewire with a heat resistance wire.
						O	5. Check a wrong operation due to vibration.	5. Mount a stay in a change orientation.
						O	6. Check contamination, crack and leakage of the electrode holder.	6. Replace the cracked and leaking insulator with a new one and clean the electrode. Insulation shall be more than 100MΩ and a defective shall be replaced.
		7. Copes type Automatic feed water adjustable device (single element type)			O		1. Discharge scale and sludge in the interconnecting pipe of the thermostat.	1. Make sure the open and close condition of the valve in the connecting pipe and clean the inside at the start.
					O		2. Make sure and adjust each interconnecting place.	2. Make sure the specified position of the slide sprocket weight. The weight shall be positioned at 3 inch from the slide rotation shaft, 3½ inch from the sprocket lever shaft and about 9 inch from the weight valve lever shaft.
				O			3. Adjust the water level due to a boiler load.	3. The level lowers by loosening the adjustable nut of the heel piece of thermostat until the valve lever comes to horizontal position by the boiler load.
		8. Flame detector			O		1. Make sure fire going-out, no ignition and burner cut in a closing state of the fuel valve.	1. Stop an ignition fuel for detection of the pilot and make sure not to transfer to the main. For detection of the main, remove the cap or the detector and make sure no ignition. A flame response delayes for 2 to 4 seconds.
						O	2. Check the degree of fatigue of a detector.	2. Measure the current by a microammeter, test by a false flame and replace any defective.
						O	3. Defect of electric wiring. Influence of induced current of power.	3. Change to the schield wire or a single wire.
						O	4. Detection of false flame. Self-discharge. Check by a protect relay, no ignition.	4. Check mistake to detect red heat refractory and change the position of installation. Inferior tube shall be replaced.
					O		5. Contamination of lens and glass tube and mounting position.	5. Cleaning of contamination. Stop down it when excessive current is detected (the life be shortened.).
						O	6. Check + or – phase of the electric wiring and loosening of connection.	6. Change the wiring and tighten it.
						O	7. Check the amplifier and the flame relay.	7. Replace the defective. If current is normal in measuring current by a microammeter but fire is not ignited, the amplifier or the flame relay are defective.

(T. III-7-2③)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection	Automatic equipment (accessary of the body)	9. Pressure restriction device.				O	1. Check the operation stop pressure and the setting of differential gap.	1. If the detecting part is clogged, the relief valve may blow. Clean and check the siphone pipe, meter cock and the detective part of the bellows. Change the setting of differential gap.
						O	2. Check leakage and concave in the bellows of the detector. Check the mounted position and orientation.	2. Install and remove at the hexagone part if required. The bellows may puncture by rising temperature. Make longer the siphone pipe if rising temperature. The mercury switch changes the orientation to install in an opposite direction to the movement.
						O	3. Check the two step setting values for control of high and low-off.	3. When the load is heavier due to too much wide to be set in response to the load, the pressure droppes.
						O	4. Check damage of the electric wire.	4. Check and replacement. Tighten the terminal.
		10. Pressure controller				O	1. Check the width of proportional band.	1. Change the width of proportional band according to load.
						O	2. Check inferior contact, contamination and disconnection of resistance of the potentiometer.	2. Check, clean and replace it.
						O	3. Check clogging of the detecting part.	3. See item 9-2.
		11. Wind pressure switch				O	1. Check the setting value.	1. Set to a proper value of the fan static pressure.
						O	2. Check clogging and leakage of the pipe.	2. Disassembly, check and cleaning.
		12. Oil temperature switch				O	1. Check the setting value.	1. Set to a proper oil temperature of the burner.
						O	2. Check contamination and installing dimension of the heat sensitive cylinder and the detecting part.	2. Clean contamination. Investigate the length and replace. Investigate the installing location.
						O	3. Check the configuration of detecting part.	3. Check any damage. Check opening to the atmosphere and install a cork stopper.
		13. Latch switch. Low and high interlock, damper lock and burner lock				O	1. Check the settings of each latch switch.	1. Check that it is set in a proper position.
						O	2. Check loosening of the setting of installed position.	2. Check and adjustment.
						O	3. Check a normal operation of the interlock.	3. Check the operation, inspect and repair.
		14. Control motor			O		1. Check the movement.	1. Check a smooth movement in the angles of rotation of 90° and 160°.
						O	2. Check an inferior contact of the balancing relay and an influence of vibration.	2. Check arc and clean the contact. Investigate the installing position not to be influenced by vibration of the oil pump, the fan and the burner and repair the vibration source.
						O	3. Check contamination and contact defect of the potentiometer.	3. Inspection and cleaning.
		15. Pilot burner.			O		1. Check the gas pressure.	1. Check the gas pressure and charge the cylinder and adjust to the required pressure of burner.
						O	2. Check a deterioration of the ignition transformer.	2. Check a spark between the electrode and the earth to be 7 to 8mm in atomosphere.

(T. III–7–2 ④)

Type of inspection	Place of inspection	Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection / Firing equipment					O	3. Check a deposit of carbon.	3. Clean the carbon between the nozzle and the electrode and clean the insulator.
					O	4. Check a backfire at the ignition.	4. Set an air-fuel ratio in a proper low combustion. Check a backfire at the ignition if the ignition burner insulator is very often contaminated.
					O	5. Check the clearance between the nozzle and the electrode	5. Adjust an interval suitable to the voltage and the pilot burner.
	16. Electric pilot firing device				O	1. Check an electric spark state.	1. Blue color is normal. If redish, cleaning is necessary. Short spark is a narrow interval.
					O	2. When a frequent cleaning is required. Inferior electrode setting.	2. If the electrode is set within the jetting angle, the electrode is wetted with oil and don't spark. The electrode should be set to the setting value.
					O	3. Transformer insulation defect. Deteriorated lead	3. Check the transformer and clean the insulator. Check any damage of the lead.
	17. Burner			O		1. Remove carbon and sludge.	1. Check the air outlet of air nozzle. Check and Repair of burner tile.
				O		2. Check the atomizing cap and the shape of tip bleeding part. Clean contamination.	2. Keep roundness not to be damaged. Repair by a file and remove contamination.
					O	3. Clean the shaft and the lubricating pipe.	3. Remove sludge and oil.
					O	4. Apply grease the bearing. Check seal leakage.	4. Apply grease and check the bearing.
				O		5. Check any damage of the diffuser and carbon deposit.	5. Cleaning and adjustment of the interval.
					O	6. Gun type burner. Check and clean the chip and strainer.	6. Disassembly and cleaning. Check the chip hole.
					O	7. Check the gun type electrode insulator.	7. Clean and set the specified dimension.
				O		8. Check abnormal sound and overcurrent.	8. Research of its cause and assembly servicing. Replace the bearing.
					O	9. Oil leakage	9. Repair leaking place.
					O	10. Burner belt	10. Replace cracked burner.
	18. Fuel cutout valve (main valve)			O		1. Check leakage of the cutout valve.	1. A fire is extinguished entirely after cutout.
				O		2. Make sure cutout due to a low level and no ignition.	2. Make sure to cutout completely. Make sure a low cutout level.
					O	3. Check the electric wiring.	3. Check damage due to heat.
	19. Oil pump			O		1. Check the oil pressure.	1. Set to a proper oil pressure.
					O	2. Clean the strainer.	2. Drain and remove sludge.
					O	3. Check oil leakage. Leakage of oil seal.	3. Repair the leaking place. Replace the oil seal.
					O	4. Check over heat and overcurrent.	4. Research the cause and replace the bearing.
	20. Oil preheater			O		1. Check a proper oil temperature.	1. Adjustment of the thermostat. Check a gasification by the air chamber.
					O	2. Drain	2. Drain and remove sludge.
					O	3. Check oil leakage.	3. Repair the leaking place.
					O	4. Check the shieth heater.	4. Disassemble and check the sludge removing.

(T. III–7–2⑤)

Type of inspection		Place of inspection	Cycle: Constantly monitoring	One hour	A week or a day	At any time	Inspection item	Procedure
Daily inspection	Firing equipment	21. Service tank. Storage tank.			O		1. Make sure the oil level control. Low and high oil level operation.	1. Make sure the operation of the float switch and other controller. Check a low and high operation by manual.
						O	2. Temperature control. Operation of the control valve and the steam solenoid valve.	2. Check leakage and operation.
						O	3. Clean the oil strainer.	3. Clean the element.
					O		4. Check the receiving quantity and the residual quantity.	4. Check and record.
						O	5. Check a leakage and the piping line.	5. Repair the leaking place of the tank. Repair the pipe leakage of the oil line.
						O	6. Drain and remove sludge.	6. Check periodically.
		22. Oil meter		O			1. Check the oil meter indication record	1. For abnormality, disassemble and clean the meter and replace the parts.
						O	2. Grasp the oil temperature passing through the meter.	2. Since the efficiency calculation is based on the specific gravity at passing through the meter, the oil temperature should be roughly grasped.
		23. Oil quantity controller.			O		1. Check the link mechanism to the controller.	1. Adjust the link mechanism compared with the air volume, check loosening and play.
						O	2. Check the oil quantity by a meter measurement. (Every load) Take out drain and sludge.	2. Check by operation and oil quantity and disassemble and clean it.
		24. Oil strainer			O		1. In autocleaner, turn the handle. In an change type strainer, a prepared one should be always cleaned.	1. Cleaning of strainer. Use in a periodical changeover.
						O	2. Remove drain and sludge. Graspe a good rating of cleaning by a differential pressure between the inlet and the outlet.	2. Sludge should be discharged from the bottom of autocleaner, which is disassembled and cleaned periodically.
		25. Forced draft fan			O		1. Check abnormal sound and overcurrent.	1. If abnormal, disassemble and service it, and replace the bearing.
						O	2. Check foreign matter in the suction port.	2. Mount a wire gauze not to suck foreign matter.
						O	3. Check vibration. Check and replace the belt. If it is three belts type, all three belts are replaced at the same time and the deflection should be 2 to 3cm.	3. Loosening of installed bolts. Loosening of the runner. Remove any deposit to the runner. Replace the bearing.
		26. Damper. Primary damper. Main damper. Outlet damper.			O		1. Check the link mechanisms of the primary and main dampers.	1. The damper should be adjusted to be opened slowly.
					O		2. Check the opening of damper.	2. Check distortion or loosening.
						O	3. Adjust the damper draft in the outlet of boiler.	3. 0 ± 2 mmAq in a pressurized combustion of rated operation.
						O	4. Adjust the dampers of boilers which use a stack in common.	4. A great fluctuation between the operations in all boilers and the operation in one boiler. The adjustment of draft is required according to the number of operating boiler.
						O	5. Leakage from the damper. Poor opening.	5. Repair a leaked place. Check periodically the inner parts.
		27. Internal pressure gage of boiler.			O		1. Make sure the indication of internal pressure gage of boiler. Check value.	1. Check a clogging in lead pipe. Check the opening and closing of valve cock. Check and repair a leaking point due to corrosion.

(T. III–7–2⑥)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	28. Smoke indicator.			O		1. Check a difference between the indication and the smoke concentration.	1. Cleaning of glass. Adjust a floodlamp and a light receiver. Blow air from a compressor.
						2. Adjust the Zero point.	2. Set the zero point.
	29. Exhaust gas analyser.			O		1. Make sure the operation of pointer.	1. Check a clogging and leakage in the lead. Cleaning or replacement of the filter and tightness test of the lead (check of leakage due to corrosion).
					O	2. Adjustment. O_2 meter. by air.	2. Adjustment of the water quantity in aspirator. More than .5 lit./min. Comparison of a normal operation through passing air (O_2 21%) to the transmitter with the Orsat analyzed value.
	30. Flue and stack				O	1. Check leakage and corrosion.	1. Inspection and repairing.
					O	2. Remove soot in the flue and the stack.	2. Inspection and cleaning once per year.
					O	3. Discharge of rain water.	3. Make sure to remove and discharge soot.
	31. Water softening equipment.			O		1. Check of the water pressure. 1.5 to 2 kg/cm².	1. No solenoid valve in 0.7 kg/cm² or less allows to leak. Regeneration is possible in 1 kg/cm² or more.
					O	2. Check of hardness. Check in the secondary side.	2. Check from 70 to 80% of cycle.
					O	3. Leakage from the perforated valve.	3. Use care to leak from the fitting part of the packing (short pass).
					O	4. Care must be taken to leak during a stop of the pump operation. The water pressure of 0.5 to 0.7 kg/cm² should link to the solenoid valve.	4. The raw water pump shall link to the solenoid valve.
	32. Feed water tank		O			1. Check of the level gage.	1. Make sure the water level.
			O			2. Make sure the operation of low level alarm lamp.	2. Test in an actual level drop or test by an electric wiring.
			O			3. Make sure the level control.	3. Make sure a manual operation of controller.
			O			4. Check of temperature.	4. Check of abnormality of trap.
					O	5. Check the painting on the tank inside and corrosion. Clean the inside.	5. Check, repair and cleaning.
	33. Chemicals pouring device.			O		1. Check a proper chemicals pouring.	1. Check contamination in the tank and the flow rate.
				O		2. Check a linkage to the feed water pump.	2. Check the operation.
					O	3. Check leakage or clogging.	3. Inspection and repair.
	34. Feed water pump			O		1. Check overcurrent.	1. Adjust the valve to come into a proper flow.
					O	2. Check leakage from the ground.	2. Replace and tighten a packing.
					O	3. Check an oil servicing.	3. Apply oil and grease.
					O	4. Check play in the coupling.	4. Repair and replacement.
	35. Injector.				O	1. Check a normal operation.	1. Impossible to feed when the steam pressure lowers, the feed water temperature rises, air is sucked, the feed water pressure is too much higher (5 to 7m) and steam drain is mixed in.
					O	2. Check the check valve. Attachment of scale.	2. Check, disassemble and clean.
					O	3. High, raw water pressure.	3. Check the valve, disassemble and clean. Install a reducing valve.

(T. III-7-2⑦)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	36. Water flow meter strainer		O		O	1. Check the operation. 2. Check clogging in the strainer.	1. Record, check operation. 2. Disassemble and clean.
	37. Feed water check valve.				O	1. Check back flow (leakage).	1. Water hammer. Hand touch feels hot to the feed water pipe. Overhaul or replacement.
	38. Feed water internal pipe.				O O	1. Check clogging in the internal pipe. 2. Inferior or falling of the gasket for installation of the internal pipe.	1. Insufficient feed water quantity. Overhaul. 2. Water hammer. Even though the feed water stop valve is closed, the water hammer remains. Replace the gasket. When the check valve for the feed water pipe is good operation, hand touch does not feel hot.
	39. Relief valve			O	O O O	1. Check leakage of steam. 2. Check the popping and blowdown pressures in operation. 3. Check the popping volume. 4. Check before- and after-leakage.	1. Repair the leaked place and overhaul. 2. Adjust the blowdown pressure to approximately 0.5 kg/cm^2 (LP=10 kg/cm^2). 3. When the pressure rising in a rated combustion is 6% or more, it is not acceptable. 4. Overhaul in too much leakage. Some relief valve may leak.
	40. Blowoff valve.			O O		1. Check leakage. Check heat by hand touch. 2. Blow off as a quick opening valve in the body side and as a slow opening valve in the secondary side. 3. Check the discharge port.	1. To leakage, overhaul or replacement. 2. For 10 kg/cm^2 or more, two valves. Body side valve should be used carefully. 3. Check the size of pit. Should arresting measure and water control.
	41. Manhole			O	O	1. Check leakage from the manhole. 2. Keep a mating surface of the gasket in no contamination.	1. Tightening, replacement of gasket, tightening accompanied with temperature rising or pressure rising and tighten not to leak from the initial. 2. Apply graphite to facilitate a replacement.
	42. Casing for insulation					1. Check gas leakage. 2. Check discolored place.	1. Gas leakage should be checked and repaired as soon as possible. 2. Find out the cause of overheat, check and repair.
	43. Refractory material.				O O	1. Check damage, falling and abnormality. 2. Check gas leakage and short pass.	1. Repair the refractory material as soon as possible. 2. Repairing.
	44. Inspection port. Cleaning port. Mounting part of accessary.				O	1. Check leakage of steam and water.	1. Repair the leaked place. Tightening, replacement of gasket and replacement.
	45. Explosion door.			O	O	1. Check gas leakage. 2. Check the spring.	1. Repair the leaking place. 2. Inferior springs due to leakage or heat should be replaced. Check an impossible opening and closing due to rust.
	46. Magnet switch and contactor.				O O O	1. Check the contact of relay. 2. Check loosening of the terminal. 3. The oil preheater feed pump is apt to damage.	1. Replace the contact and relay. 2. Tighten the terminal. 3. Replace the contact and relay.

(T. III–7–2⑧)

Type of inspection	Place of inspection	Cycle: Constantly monitoring	Cycle: One hour	Cycle: A week or a day	Cycle: At any time	Inspection item	Procedure
	47. Timer. Time limit relay.				O O	1. Check the setting of the timer. 2. Check the setting of the cam mechanism.	1. Y-Δ starting. Starting current. Change to Δ after dropping to rated value by Y. 2. Check by sequence.
	48. Actuation lamp.			O	 O	1. Check a disconnection and luminosity. 2. Inferior contact.	1. Replace the lamp. 2. Tightening.
	49. Spare. Fuse lamp.				O	1. Check the spare parts.	1. Supplement of fuse and lamp spare.
	50. Protect relay (Timer motor).			O	 O O	1. Check the operation. 2. Check the fixing and tightening of relay and the contact. 3. Check voltage drop.	1. Check the sequence. Replace if inferior. 2. Check the operation. 3. Check the voltage in the operating circuit.
	51. Terminal.				O O	1. Check loosening of the terminal. 2. Cleaning.	1. Tightening. Apply a detent paint if possible. 2. Suck dust by a vacuum cleaner.
	52. Insulation resistance				O	1. Measuring by 500V megger. Measure in a removing condition of a low voltage equipment, for example, low voltage breaker relay, timer or protect relay.	1. If newly build panel and secondary side has resistance less than 5MΩ, inspection or repair are required.
	53. Electric wiring				O O O	1. Check overheat, damage and discoloration. 2. Check damage of coating. 3. Check of phase. Hot line Ground line	1. Check the wiring. 2. Use care to a discolorization of the wiring around the terminal. 3. Make sure the hot line or the ground line if designated. Unexpected accident may cause. It is very important on safety.

Since the thermal conductivity of scale is only 1/100 of mild steel, the thermal efficiency becomes extremely worse due to adhesion of scale and the local heating decreases the mechanical strength of the heating tube which leads to bursting trouble not standing against the boiler pressure. The steel surface, on which scale occurs, is more easily corroded.

For prevention of the trouble mentioned above, Japanese Industrial Standard (JIS) has provided the standard value for water quality as shown in Table III-7-3 and Table III-7-4.

Table III 7–3 Quality of feed water and boiler water for circulating boiler

Classification	Type of boiler	Cylindrical boiler			Water-tube boiler													
Classification	Max. servicing pressure kgf/cm2				Below 10		From 10 to 20	From 20 to 30	From 30 to 50	From 50 to 75	From 75 to 100		From 100 to 125		From 125 to 150		From 150 to 200	
Classification	Max. servicing pressure (MPa)				Below 1		From 1 to 2	From 2 to 3	From 3 to 5	From 5 to 7.5	From 7.5 to 10		From 10 to 12.5		From 12.5 to 15		From 15 to 20	
Classification	Rate of evaporation of heating surface (kg/m²·h)	Below 30(1)	From 30 to 60	Over 60	Below 50	Over 50	–	–	–	–	–		–		–		–	
Feed water	pH (25°C)	7~9	7~9	7~9	7~9	7~9	7~9	7~9	8~9.5	8.5~9.5(9)	8.5~9.5(9)		8.5~9.5(9)		8.5~9.5(9)		8.5~9.5(9)	
Feed water	Hardness ($mgCaCO_3/\ell$)	Below 60	Below 2	Below 1	Below 1	Below 1	Below 1	0	0	0	0		0		0		0	
Feed water	Fat and oil(2) (mg/ℓ)	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible.	Maintain zero as much as possible		Maintain zero as much as possible		Maintain zero as much as possible		Maintain zero as much as possible	
Feed water	Dissolved oxygen (mgO/ℓ)	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Maintain in low level	Below 0.5	Below 0.1	Below 0.03	Below 0.007	Below 0.007		Below 0.007		Below 0.007		Below 0.007	
Feed water	Total iron ($mgFe/\ell$)	–	–	–	–	–	–	–	Below 0.1	Below 0.05	Below 0.03(10)		Below 0.03(10)		Below 0.02(11)		Below 0.02(11)	
Feed water	Total copper ($mgCu/\ell$)	–	–	–	–	–	–	–	Below 0.05	Below 0.03	Below 0.02		Below 0.01		Below 0.01		Below 0.005	
Feed water	Hydrazine(3) (mgN_2H_4/ℓ)	–	–	–	–	–	–	Over 0.2	Over 0.06	Over 0.01	Over 0.01		Over 0.01		Over 0.01		Over 0.01	
Feed water	Electrical conductivity (25°C)(μS/cm)	–	–	–	–	–	–	–	–	–	–		–		Below 0.3(12)		Below 0.3(12)	
Boiler water	Treatment method	Alkali treatment							Alkali treatment or phosphating		Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment	Phosphating	Volatile matter treatment
Boiler water	pH (25°C)	11.0~11.8	11.0~11.8	11.0~11.8	11.0~11.8	11.0~11.8	10.8~11.3	10.5~11.0	9.4~11.0(13)	9.2~10.8(13)	9.0~9.8	8.5~9.5	8.7~9.7	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5
Boiler water	M-Alkalinity(4) ($mgCaCO_3/\ell$)	100~800	100~800	100~800	100~800	100~800	Below 600	Below 150	–	–	–	–	–	–	–	–	–	–
Boiler water	Alkalinity(5) ($mgCaCO_3/\ell$)	80~600	80~600	80~600	80~600	80~600	Below 500	Below 120	–	–	–	–	–	–	–	–	–	–
Boiler water	Total solids (mg/ℓ)	Below 4000	Below 3000	Below 2500	Below 3000	Below 2500	Below 2000	Below 700	Below 500	Below 300	Below 100	Below 20	Below 30	Below 5	Below 20	Below 3	Below 10	Below 2
Boiler water	Electrical conductivity (μS/cm)	Below 6000	Below 4500	Below 4000	Below 4500	Below 4000	Below 3000	Below 1000	Below 800	Below 500	Below 150	Below 60(12)	Below 60	Below 20(12)	–	–	–	–
Boiler water	Chloride ion ($mgCl^-/\ell$)	Below 600	Below 500	Below 400	Below 500	Below 400	Below 300	Below 100	Below 80	Below 50	Below 10	–	Below 3	–	–	–	–	–
Boiler water	Phosphate ion(6) ($mgPO_4^{3-}/\ell$)	20~40	20~40	20~40	20~40	20~40	20~40	5~15	5~15	3~10	2~6	(11)	1~5	(11)	0.5~3	(11)	0.5~3	(11)
Boiler water	Sulfite ion(7) ($mgSO_3^{2-}/\ell$)	10~20	10~20	10~20	10~20	10~20	10~20	5~10	5~10	–	–	–	–	–	–	–	–	–
Boiler water	Hydrazine(8) (mgN_2H_4/ℓ)	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	0.1~0.5	–	–	–	–	–	–	–	–	–	–	–
Boiler water	Silica ($mgSiO_2/\ell$)	–	–	–	–	–	–	Below 50	Below 20	Below 5	Below 2		Below 0.5		Below 0.3		Below 0.2	

Notes
(1) Apply it when use live steam and use constantly make-up water in a cast iron boiler.
(2) It means hexane extract (see JIS B 8224).
(3) Apply it when hydrazine may be poured in the feed water as an oxygen scavenger.
(4) It means an acid consumption (pH 4.8)
(5) It means an acid consumption (pH 8.3)
(6) Apply it when phosphate may be poured in water.
(7) Apply it when sulfite may be poured in water as an oxygen scavenger.
(8) Apply it when hydrazine may be poured as an oxygen scavenger in a cyrindrical boiler or a water-tube boiler in a pressure less than 20 kgf/cm² [2MPa] of the maximum servicing pressure.
(9) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.
(10) It is desirable to maintain below 0.02 mgFe/lit.
(11) It is desirable to maintain below 0.01 mgFe/lit.
(12) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.
(13) The pH lower limit indicates a lower limit when a phosphating is applied and shall be taken as a pH corresponding to the lower limit of the PO_4^{3-} concentration of boiler water. (See paragraph 1.3.1 of the description).
(14) If hardness components and pH lowering components are leaked in the boiler water due to sea water leakage from the sample vessel, some type and quantity of phosphate required to the emergency treatment against the leaked components and quantity should be poured.

Remarks.
1. The concentration unit of mg/lit. shall be regarded as the same as ppm.
2. For a make-up water to a water-tube boiler of the maximum servicing pressure of 20 kgf/cm², desalted water shall be applied.
3. Hydrazine or sulfite as an oxygen scavenger, as a rule, either one of them shall be poured.

Table III 7–4. Quality of feed water for once-through boiler

Classification	Max. serving pressure							
		kgf/cm²	Below 25	From 75 to 100	From 100 to 125	From 125 to 150	From 150 to 200	Over 200
		(MPa)	Below 2.5	From 7.5 to 10	From 10 to 12.5	From 12.5 to 15	From 15 to 20	Over 20
Feed water	pH (25°C)		10.5~11.0	8.5~9.5(2)	8.5~9.5(2)	8.5~9.5(2)	8.5~9.5(2)	9.0~9.5
	Hardness ($mgCaCO_3/ℓ$)		Below 1*	0	0	0	0	0
	Dissolved oxygen (mgO/ℓ)		Below 0.5	Below 0.007	Below 0.007	Below 0.007	Below 0.007	Below 0.007
	Total iron (mgFe/ℓ)		–	Below 0.03(3)	Below 0.03(3)	Below 0.02(4)	Below 0.02(4)	Below 0.01
	Total copper (mgCu/ℓ)		–	Below 0.01	Below 0.01	Below 0.005	Below 0.003	Below 0.002
	Hydrazine(1) ($mgN_2H_4/ℓ$)		–	Below 0.01	Below 0.01	Below 0.01	Below 0.01	Below 0.01
	Silica ($mgSiO_2/ℓ$)		–	Below 0.04(5) Below 0.02(6)	Below 0.04(5) Below 0.02(6)	Below 0.03(5) Below 0.02(6)	Below 0.02	Below 0.02
	Total solids (mg/ℓ)		Below 700	–	–	–	–	–
	Electrical conductivity (25°C)(μS/cm)		Below 1000	Below 0.3(7)	Below 0.3(7)	Below 0.3(7)	Below 0.3(7)	Below 0.25(7)
	Phosphate ion ($mgPO_4^{3-}/ℓ$)		20~40	–	–	–	–	–

Note (1) The concentration of hydrazine shall be limited with a concentration not exceeded the upper limit of pH.
(2) Where the pipe material in the heater for a high pressure feed water is steel pipe, pH is desirable to be adjusted to a higher.
(3) It is desirable to maintain below 0.02 mgFe/lit.
(4) It is desirable to maintain below 0.01 mgFe/lit.
(5) It is applied to a boiler with separator.
(6) It is applied to a boiler without separator.
(7) A subject water passed through a hydrogen form strong acidity cation exchange resin should be measured.

Remarks
1. Since the concentration of the total solids in the feed water for a high pressure once-through boiler is very low and can not be nearly measured, the measured value of electrical conductivity should be used to estimate a concentration of soluble solids in the total solids.
2. The maximum servicing pressure of 25 kgf/cm² [2.5 MPa] or less shall be applied to an once-through boiler returned by 30% of the boiler water into the feed water. Since the water returned from the boiler is added into the feed water is again fed to the boiler with addition of some chemicals, the water quantity shall be controlled by the method similar to it for a circulating boiler.
The mark of * shall be applied to the feed water prior to addition of a returned water.

The treatment methods of boiler water are classified in a boiler external treatment and a boiler internal treatment.

In the boiler external treatment, there is elimination of suspended solid by sedimentation and filtration and salt elimination by ion exchange resin and a deaeration. For a low pressure boiler of 20 kg/cm^2 or less, a simple softener using Cation exchange resin—a lower investment cost and an easy operation—is often applied. On the operation of the softener, extreme caution should be exercised to the impurity elimination in the salt for regeneration, establishment and its observation of the standard for flow rate, regeneration time and back washing amount, based on analysis of water, and a supplement or replacement of resin once a year.

The recovery of condensate is a reasonable method to make the load on the softener reduce and to plan an effective use of the heat. But, on the way of recovery, O_2, CO_2 or iron produced by corrosion may sometimes be contained into the condensate. In such a case, the condensate should be passed through a filter and a deaerator prior to return to feed water and thus. Care must be used not to cause new corrosion due to an accumulation of these impurities.

The boiler internal treatment is a method which treats water by addition of a conditioner, a softening agent, a scale inhibitor and a foaming inhibitor. The compound contained with these components is on the market.

To prevent an accumulation of the impurities in the boiler water, the blow is an important operation. A continuous blow with linking an amount of feed water is preferably economical owing to an easier adjustment of the amount and possibility of heat recovery compared with a periodic blow-down. The blow amount can be obtained by the following equation from the feed water quantity and the boiler water standard shown in Table III-7-4.

y: Blow amount

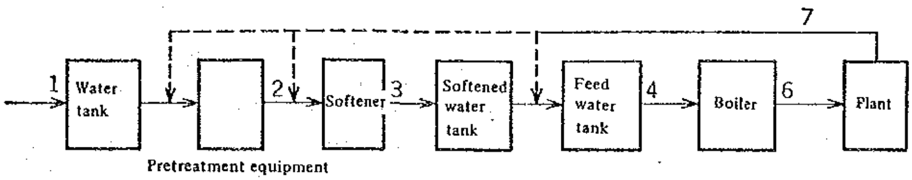
k: Blow rate (%)

x: Evaporation

a: Impurity concentration in feed water

b: Impurity concentration standard in boiler water

Table III-7-5 Standard for water quality measuring frequency



Sampling location / Check division / Item	1		2		3		4		5		6		7	
	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals	Iregular intervals	Periodical intervals
Appearance		D		D				D		D				D
pH	n		n		n			D		D	n			D
P-alkalinity										D				
M-alkalinity	n				n					D				
Chloride ion	n							W		D				D
Free chlorine	n		n											
Phosphate ion										D				
Electric conductivity		D						D		D				
Hydrazine								2 W						
Sulfite ion								2 W						
Total solid	n				n				n		n		n	
Silica										M				
Total hardness	n		n			D		D	n				n	
Total iron									n					
Turbidity	n				n				n				n	
Organic matter (COD)	n												n	

Remarks: D: Once per day, W: Once per week, 2W: Twice per week, M: Once per month,
n: According to demand

$$a(x + y) = b\,y$$

$$\therefore y = \frac{a}{b - a} x$$

$$k = \frac{a}{b - a} x\ 100$$

Although a total dissolved salt or a chloride ion in the impurities are taken as the control subject, the analyses of those are not easy in practice and the electrical conductivity is sometimes taken as a good measure. It is desirable to control through premeasurement of a relation between the total salt concentration and the electrical conductivity.

Table III-7-5 is a standard of the water quality measuring frequency shown as reference in JIS.

1.3 Expression of boiler capacity

An expression of boiler capacity has two ways of rated evaporation and an equivalent evaporation.

1.3.1 Rated evaporation

The rated evaporation is expressed as an evaporation per unit hour under the maximum load possible to operate continuously and should be described together with evaporation pressure, evaporation temperature and feed water temperature.

1.3.2 Equivalent evaporation

The equivalent evaporation facilitates comparison of capacity through conversion of the above-mentioned condition to a certain reference. This value is that net heat per hour required to generae a steam from feed water is divided by a heat of vaporization of 539 kcal/kg at temperature of 100° C.

If G is taken as an actual evaporation kg/h, h_1, h_2 as a specific enthalpy of the feed water and the produced steam, the equivalent evaporation G_e can be obtained by the following equation:

$$G_e = \frac{G(h_2 - h_1)}{539} \quad (kg/h)$$

In addition, the boiler capacity may sometimes be expressed by a heating surface area (m^2) based on the combustion side. A small sized boiler in U.S. and British has been often expressed by boiler horse power. This expression was established in 1876 and was based on the value which was taken as one horse power per 30 lb/h of saturated steam in 70 lb/in^2 of gauge pressure. Nowadays this is not familiar with the actual specification. The equivalent evaporation of 15.65 kg/h corresponds to one horse power.

1.4 Heat balance of boilers

In Japan, a heat balance system of boilers is specified by Japanese Industrial Standard (JIS B8222). Its outline will be 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, a limit of heat balance should be fixed as shown in Fig. III-7-7. 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 according to the items shown in Table III-7-6 and the operation record should be described on the items of Table III-7-7. The results of the heat balance should be entered into the formula of Table III-7-8. Referred items are indicated for calculation below.

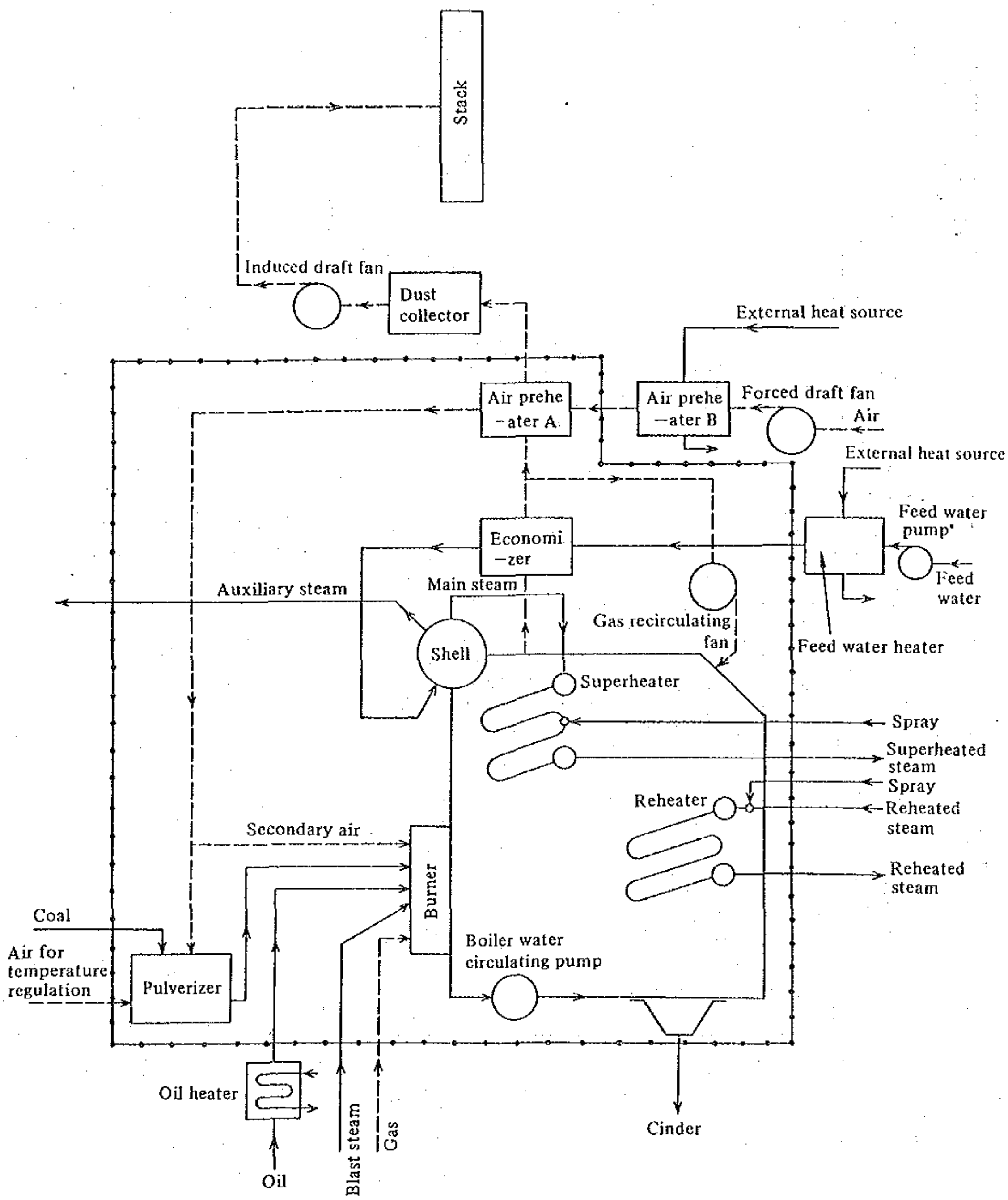


Fig. III-7-7 Standard scope of boiler heat balance

Table III-7-6 Outline of Installation

Outlines of the installation shall be indicated as follows.

Name of plant, Address				
Name of boiler maker				
Number of boiler, date of manufacture				
Boiler proper	Kind · Type			
	Maximum continuous evaporation		t/h	
	Maximum working pressure (1)		kg/cm^2	
	Normal operating pressure (1)		kg/cm^2	
	Superheated (reheated) temperature		°C	
	Calorific value of standard fuel		$kcal/kg(m_n^3)[kJ/kg(m_n^3)]$	
	Heating surface area	Boiler	m^2	
		Water wall	m^2	
		Total	m^2	
Superheater	Type			
	Heating surface area		m^2	
Reheater	Type			
	Heating surface area		m^2	
Economizer	Type			
	Heating surface area		m^2	
Airpreheater	Type			
	Heating surface area		m^2	
Firing equipment	Type (1)			
	Burner capacity, number and grate area		$kg(m_n^3)/h$, m^2	
Combustion chamber	Furnace volume		m^3	
	Standard heat generation		$kcal/m^3h$	
Control device	Pressure			
	Water level			
	Superheating temp.			
	Others			
Drafting equipment	Drafting			
	Forced fan	Type		
		Capacity	$m^3/min(°C)$	
		pressure	mmAq	
	Induced fan	Type		
		Capacity	$m^3/min(°C)$	
		pressure	mmAq	
	Other fan	Type		
		Capacity	$m^3/min(°C)$	
		pressure	mmAq	
	Chimney	Size (diameter x height)	m x m	
		Name and number of common use		
Water feeding equipment	Kind			
	Capacity, number		t/h	
	Kind and capacity of feed water treating device			
	quality of feed water			
	Name and quantity of chemical use			
Preparing condition at test starting				

Note (1) The pressure is a gage pressure.

Table III-7-7 Test Results

The test results shall be indicated as follows.

	Date and time of test			
	Personnel in charge			
	Weather, atmospheric pressure, wind velocity		°C	
	Ambient temperature, dry bulb and wet bulb temperatures		°C	
	Duration of test		h	
	Load factor		%	
Fuel	Brand and characteristic of fuel			
Fuel	Mixing ratio			
Fuel	Temperature as used		°C	
Fuel	Total moisture		%	
Fuel	Proximate analysis	Analysed value	%	
Fuel		As used	%	Correct by moisture.
Fuel	Ultimate analysis	Analysed value	%	
Fuel		As used	%	Correct by moisture.
Fuel	Lower calorific value of fuel used (high)	Analysed value	kcal/kg(m_n^3)	Measure a high combustion heat by a calorimeter and obtain a low combustion heat by calculation.
Fuel		As used	kcal/kg(m_n^3)	Correct by moisture.
Fuel	Fuel consumption Total		kg(m_n^3)	
Fuel	Fuel consumption Per hour		kg(m_n^3)/h	
Fuel	Firing quantity per burner		kg(m_n^3)/h	
Fuel	Combustion chamber heat generation		kcal/m³ h	
	Condition of firing equipment			
	Condition of control device			
	Condition of drafting equipment			
	Condition of water feeding equipment			
Feed water	Quantity of feed water	Total (corrected value)	kg	
Feed water		Per hour	kg/h	
Feed water		Per unit volume of fuel	kg/kg(m_n^3)	
Feed water	Temperature	Economizer inlet	°C	
Feed water		Boiler proper inlet	°C	
Feed water	Rate of condensate recovery		%	
Steam generated	Pressure	Boiler drum	kg/cm²	
Steam generated		Superheater outlet	kg/cm²	
Steam generated		Reheater inlet	kg/cm²	
Steam generated		Reheater outlet	kg/cm²	
Steam generated	Temperature	Superheated outlet	°C	
Steam generated		Reheater inlet	°C	
Steam generated		Reheater outlet	°C	
Steam generated	Dryness (in case of no superheater)		%	Measuring by a throttling calorimeter or approximate figures (i.e. 98%)
Steam generated	Evaporation	Total (corrected value)	kg	Obtain from the feed water quantity. Correct the boiler water level and the steam used in itself.
Steam generated		Per hour	kg/h	
Steam generated		Equivalent evaporation per hour	kg/h	
Steam jetting into furnace	Source of steam			
Steam jetting into furnace	Quantity of stem		kg/h	If impossible to measure, use an approximate figures.
Steam jetting into furnace	Pressure and temperature		kg/cm², °C	
Air for combustion	Air quantity per 1 kg of fuel		m_n^3/kg(m_n^3)	Calculate from the composition of fuel and combustion gas.
Air for combustion	Temperature and pressure	Air preheater inlet	°C, mmAq	
Air for combustion		Air preheater outlet	°C, mmAq	
Air for combustion		Outlet of forced draft fan	°C, mmAq	
Air for combustion		Inlet of chamber	°C, mmAq	

(Table III-7-7②)

Air for combustion	Air ratio	Outlet of boiler proper Outlet of economizer Outlet of air preheater	
Exhaust (combustion) gas	Exhaust gas quantity per unit volume of fuel $m_n^3/kg(m_n^3)$		
	Temperature and pressure	Furnace inside °C, mmAq Outlet of boiler proper °C, mmAq Economizer inlet °C, mmAq Economizer outlet °C, mmAq Air preheater inlet °C, mmAq Air preheater outlet °C, mmAq Induced fan suction °C, mmAq Induced fan delivery °C, mmAq	
	Gas analysis	Outlet of boiler proper (CO_2, O_2, CO) % Outlet of economizer (CO_2, O_2, CO) % Outlet of air preheater (CO_2, O_2, CO) %	
	Unburned component % Refuse quantity per unit volume of fuel kg/kg		Calculate from the fuel consumption,ash in fuel, unburned fuel in cinder.
Condition of smoke			
Auxiliary	Steam consumption kg Electric power consumption kWh		
Remark			

Remarks

1. The values entered to this sheet, such as analysis data of the refuse and exhaust gas, pressures, temperatures and etc. of the steam, air and gas shall be the averages.
2. Load factor shall be as follows.

$$\text{Load factor} = \frac{\text{Actual evaporation}}{\text{Maximum continuous evaporation}} \times 100\%$$

3. Condition of firing equipment means as follows.

Hand firing	method and interval of feeding coal, damper opening
Stoker firing	speed of stoker or coal feeder, thickness of coal layer, damper opening, etc.
Pulverizer coal firing	working number and speed of coal feeders, pulverizers, exhausters and fans, damper opening, working number and condition of burners
Oil firing	oil pressure, and working number and condition of burner
Gas combustion	gas pressure. Number and condition of operating burners

4. Condition of water feeding equipment means as follows.

Intermittent feeding	number of feeding per hour, etc.
Continuous feeding	working number, revolution, valve opening and etc. of pumps

5. Condition of drafting equipment means revolution, regulating valve opening, damper opening and etc. of fans.

Table III 7 – 8 Table of Heat Balance [Lower calorific value basis]

Heat input	kcal/kg(m_n^3)	%	
(1) Calorifie value of fuel H_l(3)			(2)Mean specific heat of fuel x (Fuel temp. after heating–ambient temp.)
(2) (2) Sensible heat of fuel Q_1			(3)Air quantity (including moisture) per 1 kg (Nm³) of fuel x Mean specific heat of air x (Air temp. after heating–combient temp.)
(3) (2) Sensible heat of air Q_2			
(4) (2) Carrying heat of furnace blast steam. Q_3			(4)Blast steam quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam–Enthalpy of steam in ambient temp.) (Only in case of steam from another soruce)
Total H_l(3) + Q		100	

Note (2) (2), (3) and (4) are due to the external heat source. (5) is not usually considered.
(3) In case of a high heating value basis, it shall be taken as $H_h(H_h')$.

	Heat output	kcal/kg(m_n^3)	%	
Effective heat	(1) Heat content of generated steam			(1)
	(a) Heat absorbed at the boiler proper Q_b			(a)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of boiler–Enthalpy in outlet of economizer)
	(b) Heat absorbed by economizer Q_{ec}			(b)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of feed water in outlet of economizer–Enthalpy of feed water)
	(c) Heat absorbed by superheater Q_{sh}			(c)Feed water quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of superheater–Enthalpy of steam in outlet of boiler) + Spray quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of superheater–Enthalpy of spray water).
	(2) Heat absorbed by reheater Q_{rh}			(2)Steam quantity in inlet of reheater per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of reheater–Enthalpy of steam in inlet of reheater) + Spray quantity per 1 kg (Nm³) of fuel x (Enthalpy of steam in outlet of reheater–Enthalpy of spray water)
	Subtotal Q_s			
Heat loss	(1) Heat loss due to moisture in exhaust gas L_1(4)			(1)Actual exhasut gas quantity (including moisture) per 1 kg (Nm³) of fuel x Mean specific heat of exhaust gas x (Temp. of exhaust gas–ambient temp.)
	(2) Heat loss due to furnace blast steam L_2			See item (f)
	(3) Heat loss due to incomplete burning exhaust gas L_3			See item (g)
	(4) Heat loss due to combustible in refuse L_4			See item (h)
	(5) Heat loss due to release L_5			See item (i)
	(6) Heat loss due to others L_6			See item (j)
	Subtotal L_ℓ(4)			
	Total		100	

Note (4) In case of a high heating value basis $L_l/\{L_l'\}$ shall be taken as L_{1h} $\{L_{1h}'\}$ and L_ℓ $\{L_\ell'\}$ be taken as shall be taken as L_h $\{L_h'\}$

Boiler efficiency		%	
(1) Input-and-output heat method $\eta_1 = \frac{Q_s}{H_l + Q} \times 100,$			
(2) Heat loss method $\eta_2 = (1 - \frac{L_l}{H_l + Q}) \times 100,$			

a. Method to obtain lower combustion heat from higher combustion heat.

Solid fuel and liquid fuel: $Hl = Hh - 6(9h + w)$ kcal/kg Fuel

Here, h: Hydrogen content in service condition (wt%)

w: Moisture content in service condition (wt%)

When omitting elementary analysis, h shall take the following value.

Kerosene, light oil, crude oil and fuel oil A:	h = 13%
Fuel oil B:	h = 12%
Fuel oil C:	h = 11%

Apart from this, on petroleum fuel, the graph and chart which show the relation between specific gravity and calorific value have been published. (See Fig. III-7-8). When a specific gravity measured at t °C is d_t, the specific gravity d_{15} at 15°C can be obtained by the following equation.

$$d_{15} = d_t + 0.00065(t - 15)$$

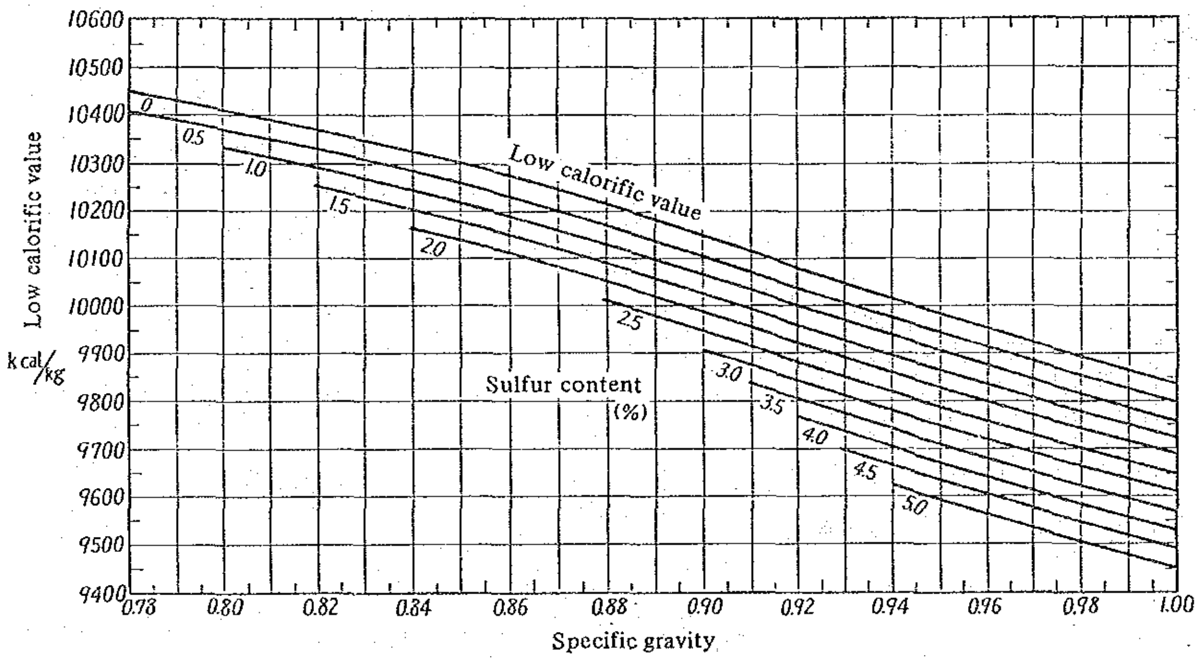


Fig. III-7-8 Relation between calorific value (low) and specific gravity of petroleum fuel

Even if the following equation is applied, error is not so much. (See Table III-7-9)

Gaseous fuel: $Hl = 25.7(H_2) + 30.2(CO) + 85.5(CH_4) + 143(C_2H_4) + 154(C_2H_6) + 211(C_3H_6) + 224(C_3H_8) + 272(C_4H_8) + 295(C_4H_{10})$ kcal/$m^3{}_N$ Fuel

Here, (H_2) etc. are taken as the vol.% of each component.

Table III-7-9 Specific gravity, sulfur content and mean calorific value of petroleum fuel

	Specific gravity	Sulfur content (%)	Mean calorific value (low)
Kerosene	0.79 ~ 0.85	0.5 Below	kcal/kg 10400
Light oil	0.82 ~ 0.86	1.2 以下	10300
Whole fuel oil			9850
A fuel oil	0.84 ~ 0.86	0.5 ~ 1.5	10200
B fuel oil	0.88 ~ 0.92	0.5 ~ 3.0	9900
C fuel oil	0.90 ~ 0.95	1.5 ~ 3.5 (Over)	9750

b. Specific heat of fuel and air

Coal: 0.25 kcal/kg. °C

Fuel oil: 0.45 kcal/kg.°C

Natural gas: 0.38 ~ 0.42 kcal/$m^3{}_N$°C

LPG: 0.7 ~ 1.0 kcal/$m^3{}_N$ °C

Air: 0.31 kcal/$m^3{}_N$°C (Influence of humidity in air can be neglected.)

c. Air amount

The theoretical air (A_o) can be obtained by calculation from the component of fuel. In solid and liquid fuels, if the contents of carbon, hydrogen, oxygen and sulfur in the fuel are taken as c, h, o and s %, respectively, A_o is represented by the following equation.

$$A_o = \frac{1}{100}[8.89\ c + 26.7\ (h - \frac{0}{8}) + 3.33s]\ m^3{}_N/\text{kg Fuel}$$

If an elementary analysis of fuel is not done, A_o is able to calculate using the approximate expression from its calorific value. This standard adopts Boie's equation.

· Case of coal

$$A_o = 1.01 \frac{Hl + 550}{1{,}000} m^3{}_N/\text{kg Fuel}$$

· Case of fuel oil

$$A_o = 12.38 \frac{Hl - 1{,}100}{10{,}000} m^3{}_N/\text{kg Fuel}$$

· Case of gaseous fuel

$$A_o = 11.05 \frac{Hl}{10{,}000} + 0.2\ m^3{}_N/m3_N\ \text{Fuel}$$

(Case of $Hl > 3{,}500$ kcal/$m^3{}_N$)

The actual air input (A) can be obtained by the following equation.

$$A = mA_o\ (1 + 1.61\ z) m^3{}_N/\text{kg Fuel}$$

m: Air ratio

z: Absolute humidity of atmosphere kg/kg Dry air

The value of z can be obtained from Fig. III-7-9.

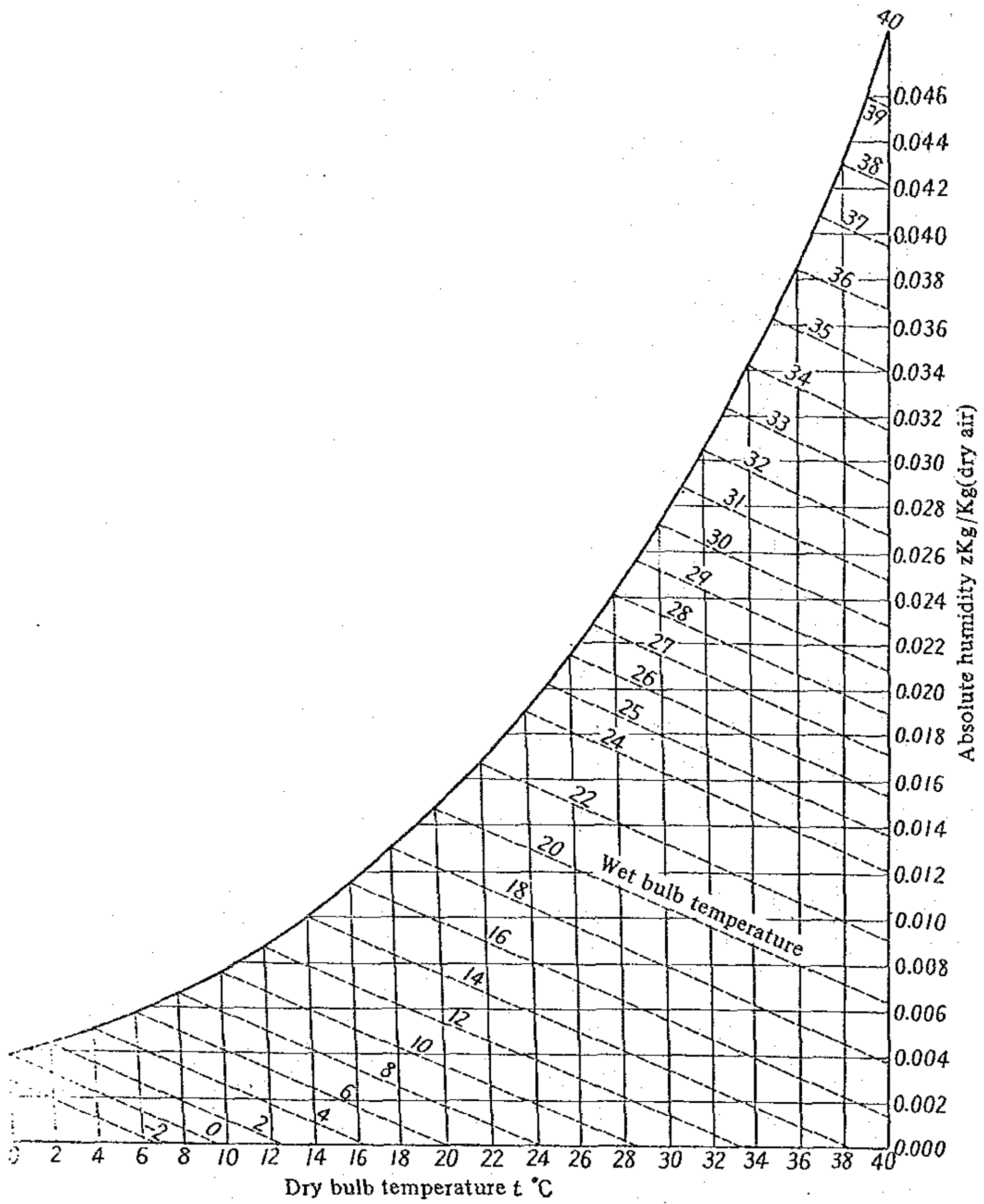


Fig. III-7-9 Absolute humidity of air

Absolute humidity z kg (steam)/kg (dry air)

$$\text{Quantity of steam in air} = \frac{\text{Specific volume of steam } m^3_N/kg}{\text{Specific volume of dry air } m^3_N/kg} \times z = 1.61\, z\ m^3_N/m^3_N(\text{dry air})$$

The air ratio can be obtained by calculating the material balance through measuring the oxygen concentration or CO_2 concentration in the exhaust gas. If the nitrogen content in fuel is small and the nitrogen content in the air for combustion is 79%, and if its combustion is a complete one, the air ratio can be obtained by the following equation.

$$m = \frac{21}{21-(O_2)} = \frac{(CO_2)max}{(CO_2)}$$

(O_2): Oxygen concentration in exhaust gas %

(CO_2): Carbon dioxide concentration in exhaust gas %

$(CO_2)max$: Maximum carbon dioxide concentration in theoretical dry exhaust gas

The value of $(CO_2)max$ may use the following values.

Coal: 18.5%, Fuel oil: 15.7%, Natural gas: 12% and LPG: 14.5%.

d. Heat absorbed by generated steam

The heat absorbed by the generated steam is shown by the value that substracts the sensible heat of feed water from the retaining heat of generated steam. If water is sprayed in a superheater, the heat absorbed by the sprayed water is added to this.

If a reheater is used, the heat obtained by the steam and the sprayed water is added to it. The retaining heat of steam is shown in Table III-7-10 and 11.

e. Exhaust gas loss

The average specific heat of combustion exhaust gas is 0.33 $kcal/m^3{}_N{}^\circ C$ from the result obtained in the range of 0 to 300 °C in a temperature and 1.0 to 1.3 in an air ratio (1.5 for a solid fuel).

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

· Case of coal

$$G_o = \frac{0.905\,(Hl + 550)}{1{,}000} + 1.17\ m^3{}_N/kg\ Fuel$$

· Case of fuel oil

$$G_o = \frac{15.75\,(Hl - 1{,}100)}{10{,}000} - 2.18\ m^3{}_N/kg\ Fuel$$

· Case of gaseous fuel

$$G_o = \frac{11.9Hl}{10{,}000} + 0.5\ m^3{}_N/\ m^3{}_N\ Fuel$$

(Case of $Hl > 3{,}500\ kcal/m^3{}_N$)

Actual exhaust gas quantity isas the following equation

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

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

Table III-7-10 Thermodynamic properties of saturated water and saturated steam (temperature reference)

Temperature		Saturation pressure	Specific volume (m³/kg)		Specific enthalpy (kJ/kg)			Specific entropy (KJ/(kg·K))	
t (℃)	T (K)	P_s (MPa)	v'	v"	h'	h"	r=h"−h'	s'	s"
0.00	273.15	0.0006108	0.0010002	206.3	−0.04	2501.6	2501.6	−0.0002	9.1577
0.01	273.16	0.0006112	0.0010002	206.2	0.00	2501.6	2501.6	0.0000	9.1575
2	275.15	0.0007055	0.0010001	179.9	8.39	2505.2	2496.8	0.0306	9.1047
4	277.15	0.0008129	0.0010000	157.3	16.80	2508.9	2492.1	0.0611	9.0526
6	279.15	0.0009345	0.0010000	137.8	25.21	2512.6	2487.4	0.0913	9.0015
8	281.15	0.0010720	0.0010001	121.0	33.60	2516.2	2482.6	0.1213	8.9513
10	283.15	0.0012270	0.0010003	106.4	41.99	2519.9	2477.9	0.1510	8.9020
12	285.15	0.0014014	0.0010004	93.84	50.38	2523.6	2473.2	0.1805	8.8536
14	287.15	0.0015973	0.0010007	82.90	58.75	2527.2	2468.5	0.2098	8.8060
16	289.15	0.0018168	0.0010010	73.38	67.13	2530.9	2463.8	0.2388	8.7593
18	291.15	0.002062	0.0010013	65.09	75.50	2534.5	2459.0	0.2677	8.7135
20	293.15	0.002337	0.0010017	57.84	83.86	2538.2	2454.3	0.2963	8.6684
22	295.15	0.002642	0.0010022	51.49	92.23	2541.8	2449.6	0.3247	8.6241
24	297.15	0.002982	0.0010026	45.93	100.59	2545.5	2444.9	0.3530	8.5806
26	299.15	0.003360	0.0010032	41.03	108.95	2549.1	2440.2	0.3810	8.5379
28	301.15	0.003778	0.0010037	36.73	117.31	2552.7	2435.4	0.4088	8.4959
30	303.15	0.004241	0.0010043	32.93	125.66	2556.4	2430.7	0.4365	8.4546
32	305.15	0.004753	0.0010049	29.57	134.02	2560.0	2425.9	0.4640	8.4140
34	307.15	0.005318	0.0010056	26.60	142.38	2563.6	2421.2	0.4913	8.3740
36	309.15	0.005940	0.0010063	23.97	150.74	2567.2	2416.4	0.5184	8.3348
38	311.15	0.006624	0.0010070	21.63	159.09	2570.8	2411.7	0.5453	8.2962
40	313.15	0.007375	0.0010078	19.55	167.45	2574.4	2406.9	0.5721	8.2583
42	315.15	0.008198	0.0010086	17.69	175.81	2577.9	2402.1	0.5987	8.2209
44	317.15	0.009100	0.0010094	16.04	184.17	2581.5	2397.3	0.6252	8.1842
46	319.15	0.010086	0.0010103	14.56	192.53	2585.1	2392.5	0.6514	8.1481
48	321.15	0.011162	0.0010112	13.23	200.89	2588.6	2387.7	0.6776	8.1125
50	323.15	0.012335	0.0010121	12.05	209.26	2592.2	2382.9	0.7035	8.0776
55	328.15	0.015741	0.0010145	9.579	230.17	2601.0	2370.8	0.7677	7.9926
60	333.15	0.019920	0.0010171	7.679	251.09	2609.7	2358.6	0.8310	7.9108
65	338.15	0.02501	0.0010199	6.202	272.02	2618.4	2346.3	0.8933	7.8322
70	343.15	0.03116	0.0010228	5.046	292.97	2626.9	2334.0	0.9548	7.7565
75	348.15	0.03855	0.0010259	4.134	313.94	2635.4	2321.5	1.0154	7.6835
80	353.15	0.04736	0.0010292	3.409	334.92	2643.8	2308.8	1.0753	7.6132
85	358.15	0.05780	0.0010326	2.829	355.92	2652.0	2296.5	1.1343	7.5454
90	363.15	0.07011	0.0010361	2.361	376.94	2660.1	2283.2	1.1925	7.4799
95	368.15	0.08453	0.0010399	1.982	397.99	2668.1	2270.2	1.2501	7.4166
100	373.15	0.10133	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
							2230.0		
110	383.15	0.14327	0.0010519	1.210	461.32	2691.3	2230.0	1.4185	7.2388
120	393.15	0.19854	0.0010606	0.8915	503.72	2706.0	2202.2	1.5276	7.1293
130	403.15	0.27013	0.0010700	0.6681	546.31	2719.9	2173.6	1.6344	7.0261
140	413.15	0.3614	0.0010801	0.5085	589.10	2733.1	2144.0	1.7390	6.9284
150	423.15	0.4760	0.0010908	0.3924	632.15	2745.4	2113.2	1.8416	6.8358
160	433.15	0.6181	0.0011022	0.3068	675.47	2756.7	2081.3	1.9425	6.7475
170	443.15	0.7920	0.0011145	0.2426	719.12	2767.1	2047.9	2.0416	6.6630
180	453.15	1.0027	0.0011275	0.1938	763.12	2776.3	2013.1	2.1393	6.5819
190	463.15	1.2551	0.0011415	0.1563	807.52	2784.3	1976.7	2.2356	6.5036
200	473.15	1.5549	0.0011565	0.1272	852.37	2790.9	1938.6	2.3307	6.4278
210	483.15	1.9077	0.0011726	0.1042	897.74	2796.2	1898.5	2.4247	6.3539
220	493.15	2.3198	0.0011900	0.08604	943.67	2799.9	1856.2	2.5178	6.2817
230	503.15	2.7976	0.0012087	0.07145	990.26	2802.0	1811.7	2.6102	6.2107
240	513.15	3.3478	0.0012291	0.05965	1037.6	2802.2	1764.6	2.7020	6.1406
250	523.15	3.9776	0.0012513	0.05004	1085.8	2800.4	1714.6	2.7935	6.0708
260	533.15	4.6943	0.0012756	0.04213	1134.9	2796.4	1661.5	2.8848	6.0010
270	543.15	5.5058	0.0013025	0.03559	1185.2	2789.9	1604.6	2.9763	5.9304
280	553.15	6.4202	0.0013324	0.03013	1236.8	2780.4	1543.6	3.0683	5.8586
290	563.15	7.4461	0.0013659	0.02554	1290.0	2767.6	1477.6	3.1611	5.7848
300	573.15	8.5927	0.0014041	0.02165	1345.0	2751.0	1406.0	3.2552	5.7081
310	583.15	9.8700	0.0014480	0.01833	1402.4	2730.0	1327.6	3.3512	5.6278
320	593.15	11.289	0.0014995	0.01548	1462.6	2703.7	1241.1	3.4500	5.5423
330	603.15	12.863	0.0015615	0.01299	1526.5	2670.2	1143.6	3.5528	5.4490
340	613.15	14.605	0.0016387	0.01078	1595.5	2626.2	1030.7	3.6616	5.3427
350	623.15	16.535	0.0017411	0.008799	1671.9	2567.7	895.7	3.7800	5.2177
360	633.15	18.675	0.0018959	0.006940	1764.2	2485.4	721.3	3.9210	5.0600
370	643.15	21.054	0.0022136	0.004973	1890.2	2342.8	452.6	4.1108	4.8144
374.15	647.30	22.120	0.00317		2107.4		0.0	4.429	

1[Mpa]=10.197kg/cm²　　　1kJ=0.2389 kcal

Table III-7-11 Thermodynamic properties of saturated water and saturated steam (pressure reference)

Pressure	Saturation temperature		Specific volume (m³/kg)		Specific enthalpy (kJ/kg)			Specific entropy	(KJ/(kg·K))
P (MPa)	t_s (℃)	T_s (K)	v'	v''	h'	h''	$r=h''-h'$	s'	s''
0.001	6.9828	280.1328	0.0010001	129.20	29.34	2514.4	2485.0	0.1060	8.9767
0.002	17.513	290.663	0.0010012	67.01	73.46	2533.6	2460.2	0.2607	8.7246
0.003	24.100	297.250	0.0010027	45.67	101.00	2545.6	2444.6	0.3544	8.5785
0.004	28.983	302.133	0.0010040	34.80	121.41	2554.5	2433.1	0.4225	8.4755
0.005	32.898	306.048	0.0010052	28.19	137.77	2561.6	2423.8	0.4763	8.3960
0.006	36.183	309.333	0.0010064	23.74	151.50	2567.5	2416.0	0.5209	8.3312
0.007	39.025	312.175	0.0010074	20.53	163.38	2572.6	2409.2	0.5591	8.2767
0.008	41.534	314.684	0.0010084	18.10	173.86	2577.1	2403.2	0.5925	8.2296
0.009	43.787	316.937	0.0010094	16.20	183.28	2581.1	2397.9	0.6224	8.1881
0.010	45.833	318.983	0.0010102	14.67	191.83	2584.8	2392.9	0.6493	8.1511
0.02	60.086	333.236	0.0010172	7.650	251.45	2609.9	2358.4	0.8321	7.9994
0.03	69.124	342.274	0.0010223	5.229	289.30	2625.4	2336.1	0.9441	7.7695
0.04	75.886	349.036	0.0010265	3.993	317.65	2636.9	2319.2	1.0261	7.6709
0.05	81.345	354.495	0.0010301	3.240	340.56	2646.0	2305.4	1.0912	7.5947
0.06	85.954	359.104	0.0010333	2.732	359.93	2653.6	2293.6	1.1454	7.5327
0.08	93.512	366.662	0.0010387	2.087	391.72	2665.8	2274.0	1.2330	7.4352
0.10	99.632	372.782	0.0010434	1.694	417.51	2675.4	2257.9	1.3027	7.3598
0.101325	100.00	373.15	0.0010437	1.673	419.06	2676.0	2256.9	1.3069	7.3554
0.12	104.81	377.96	0.0010476	1.428	439.36	2683.4	2244.1	1.3609	7.2984
0.14	109.32	382.47	0.0010513	1.236	458.42	2690.3	2231.9	1.4109	7.2465
0.16	113.32	386.47	0.0010547	1.091	475.38	2696.2	2220.9	1.4550	7.2017
0.18	116.93	390.08	0.0010579	0.9772	490.70	2701.5	2210.8	1.4944	7.1622
0.2	120.23	393.38	0.0010608	0.8854	504.70	2706.3	2201.6	1.5301	7.1268
0.3	133.54	406.69	0.0010735	0.6056	561.43	2724.7	2163.2	1.6716	6.9909
0.4	143.62	416.77	0.0010839	0.4622	604.67	2737.6	2133.0	1.7764	6.8943
0.5	151.84	424.99	0.0010928	0.3747	640.12	2747.5	2107.4	1.8604	6.8192
0.6	158.84	431.99	0.0011009	0.3155	670.42	2755.5	2085.0	1.9308	6.7575
0.7	164.96	438.11	0.0011082	0.2727	697.06	2762.0	2064.9	1.9918	6.7052
0.8	170.41	443.56	0.0011150	0.2403	720.94	2767.5	2046.5	2.0457	6.6596
0.9	175.36	448.51	0.0011213	0.2148	724.64	2772.1	2029.5	2.0941	6.6192
1.0	179.88	453.03	0.0011274	0.1943	762.61	2776.2	2013.6	2.1382	6.5828
1.2	187.96	461.11	0.0011386	0.1632	798.43	2782.7	1984.3	2.2161	6.5194
1.4	195.04	468.19	0.0011489	0.1407	830.08	2787.8	1957.7	2.2837	6.4651
1.5	198.29	471.44	0.0011539	0.1317	844.67	2789.9	1945.2	2.3145	6.4406
1.6	201.37	474.52	0.0011586	0.1237	858.56	2791.7	1933.2	2.3436	6.4175
1.8	207.11	480.26	0.0011678	0.1103	884.58	2794.8	1910.3	2.3976	6.3751
2.0	212.37	485.52	0.0011766	0.09954	908.59	2797.2	1888.6	2.4469	6.3367
2.2	217.24	490.39	0.0011850	0.09065	930.95	2799.1	1868.1	2.4922	6.3015
2.4	221.78	494.93	0.0011932	0.08320	951.93	2800.4	1848.5	2.5343	6.2690
2.5	223.94	497.09	0.0011972	0.07991	961.96	2800.9	1839.0	2.5543	6.2536
2.6	226.04	499.19	0.0012011	0.07686	971.72	2801.6	1825.0	2.5831	6.2315
2.8	230.05	503.20	0.0012088	0.07139	990.48	2802.0	1811.5	2.6106	6.2104
3.0	233.84	506.99	0.0012163	0.06663	1008.4	2802.3	1793.9	2.6455	6.1837
3.5	242.54	515.69	0.0012345	0.05703	1049.8	2802.0	1752.2	2.7253	6.1228
4.0	250.33	523.48	0.0012521	0.04975	1087.4	2800.3	1712.9	2.7965	6.0685
4.5	257.41	530.56	0.0012691	0.04409	1122.1	2797.7	1675.6	2.8612	6.0191
5.0	263.91	537.06	0.0012858	0.03943	1154.5	2794.2	1639.7	2.9206	5.9735
5.5	269.93	543.08	0.0013023	0.03563	1184.9	2789.9	1605.0	2.9757	5.9309
6.0	275.55	548.70	0.0013187	0.03244	1213.7	2785.0	1571.3	3.0273	5.8908
6.5	280.82	553.97	0.0013350	0.02972	1241.1	2779.5	1538.4	3.0759	5.8527
7.0	285.79	558.94	0.0013513	0.02737	1267.4	2773.5	1506.0	3.1219	5.8162
7.5	290.50	563.65	0.0013677	0.02533	1292.7	2766.9	1474.2	3.1657	5.7811
8.0	294.97	568.12	0.0013842	0.02353	1317.1	2759.9	1442.8	3.2076	5.7471
9	303.31	576.46	0.0014179	0.02050	1363.7	2744.6	1380.9	3.2867	5.6820
10	310.96	584.11	0.0014526	0.01804	1408.0	2727.7	1319.7	3.3605	5.6198
11	318.05	591.20	0.0014887	0.01601	1450.6	2709.3	1258.7	3.4304	5.5595
12	324.65	597.80	0.0015268	0.01428	1491.8	2689.2	1197.4	3.4972	5.5002
13	330.83	603.98	0.0015672	0.01280	1532.0	2667.0	1135.0	3.5616	5.4408
14	336.64	609.79	0.0016106	0.01150	1571.6	2642.4	1070.7	3.6242	5.3803
15	342.13	615.28	0.0016579	0.01034	1611.0	2615.0	1004.0	3.6859	5.3178
16	347.33	620.48	0.0017103	0.009308	1650.5	2584.9	934.3	3.7471	5.2531
17	352.26	625.41	0.0017696	0.008371	1691.7	2551.6	859.9	3.8107	5.1855
18	356.96	630.11	0.0018399	0.007498	1734.8	2513.9	779.1	3.8765	5.1128
19	361.43	634.58	0.0019260	0.006678	1778.7	2470.6	692.0	3.9429	5.0332
20	365.70	638.85	0.0020370	0.005877	1826.5	2418.4	591.9	4.0149	4.9412
21	369.78	642.93	0.0022015	0.005023	1886.3	2347.6	461.3	4.1048	4.8223
22	373.69	646.84	0.0026714	0.003728	2011.1	2195.6	184.5	4.2947	4.5799
22.12	374.15	647.30	0.00317		2107.4		0.0	4.4429	

f. Steam into boiler

Steam is used to atomize fuel. In use of the steam generated in the boiler, the heat loss is according to the following equation.

Heat loss due to blow-in steam = Blow-in steam quantity per 1 kg of fuel × [(Enthalpy of steam at exhaust gas temperature) − (Enthalpy of feed water)]

In use of steam in another line, the enthalpy of steam at ambient temperature is taken as basis (600 kcal/kg), and an output heat and input heat are calculated in enthalpies in each condition.

g. Heat loss due to unburned gas

It is calculated according to the following equation.

Heat loss = $30.5\,[G_o + (m - 1)\,A_o]\,(CO)$ kcal/kg(m^3_N) Fuel

(CO) is a carbon monoxide content(%) in dry exhaust gas.

h. Heat loss due to combustible refuse in cinder.

A combustible carbon(C)% content can be obtained by the following equation.

$c = au/(100 - u)$

here, a: Ash content % in fuel

u: Average unburned carbon content % in cinder.

Heat loss is 81c kcal/kg Fuel.

i. Heat loss due to heat release

Although it may be obtained by measuring the heat release in each part, in Japanese Industrial Standards, heat loss is taken as a value multiplied by the fuel calorific value by heat release loss %.

The following values are shown as round figures for heat loss. (Table III-7-12)

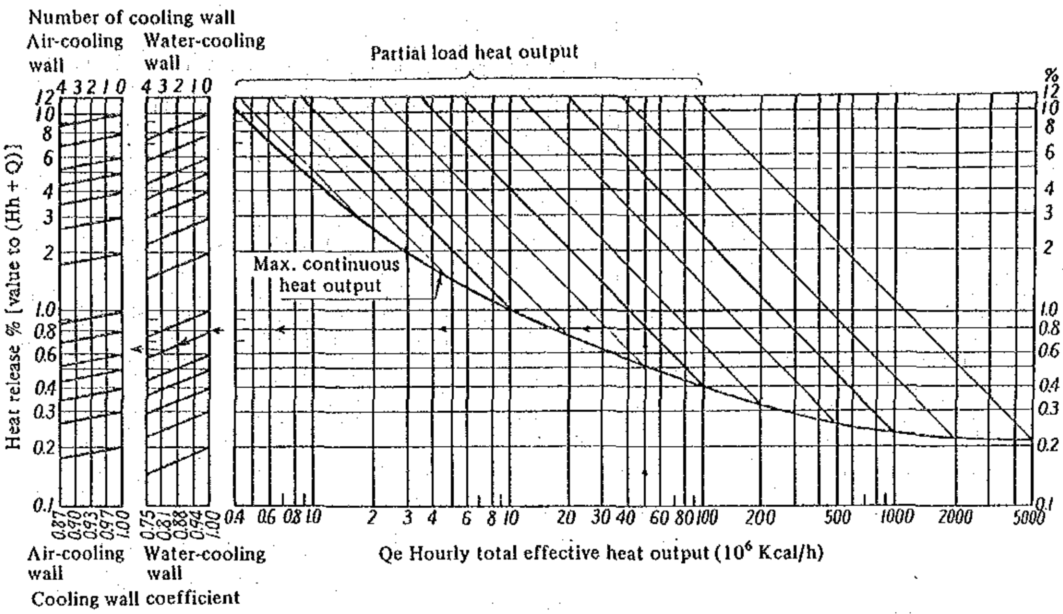
Table III-7-12 Radiant heat loss

Boiler capacity *t/h*	5	10	50	100	500	1000
Radiant heat loss %	2.0	1.4	0.8	0.5	0.3	0.2

For reference, the diagram shown in the Power Test Code of the ASME (American Society of Mechanical Engineering) is shown in Fig. III-7-10. This diagram is a case of the difference between the temperature of the warm surface and the ambient temperature is 28° C and the air flow velocity on the surface is 0.5 m/s. For other conditions, it should be corrected by a multiple of Fig. III-7-11. This diagram is for a high calorific value. For a low calorific value it should be multiplied by Hh/Hl.

j. Other heat losses

They are error terms.



(The figure shows the case that the temperature difference between the heat release surface and the ambient air is 28°C and the wind velocity on the heat release surface is 0.5 m/s. Correction multiples in other condition are based on it of Fig. III-7-11.)

Note: So far as a water-cooling wall occupies 1/3 or more of the projected area in a combustion chamber, reduction of heat loss is permitted to be done. For an air-cooling wall, the reduction of heat loss should be restricted to a case of utilization to combustion of the cooling air.

Example: In a boiler having the maximum continuous load of 100 × 10^6 Kcal/h, when the partial load is 5 × 10^6 Kcal/h and the number of water-cooling wall is 3, the heat loss rate results in 0.65%.

Fig. III-7-10 Heat loss chart (From ABMA chart in Power Test Code of ASME) ASME)

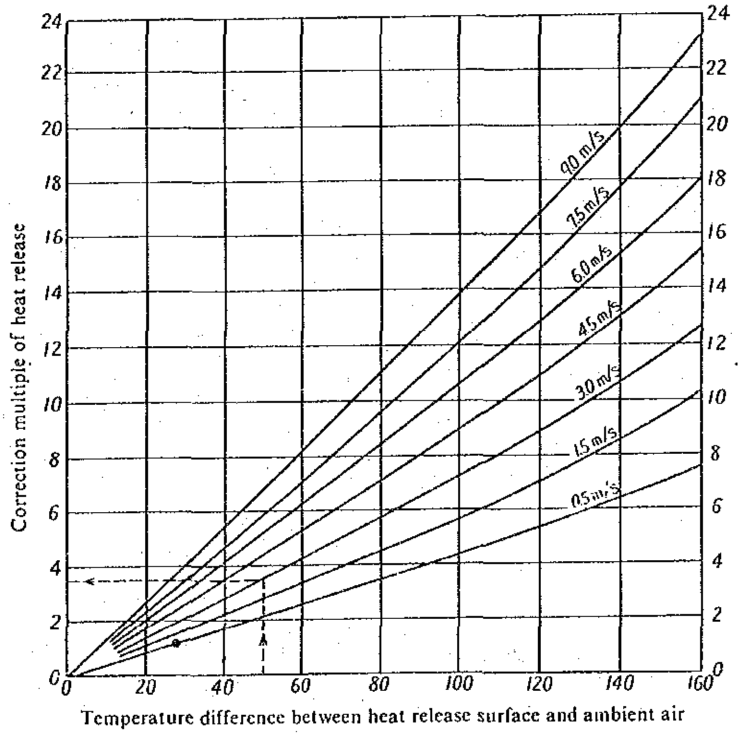


Fig. III-7-11 Correction multiple of temperature difference and air velocity to Fig. III-7-10

1.5 Boiler performance indication

The boiler efficiency is indicated by an input-output method which is represented by a ratio of the available output heat to the total input heat as shown in Table III-7-8 or by a heat loss method which subtracts the heat loss rate. The latter should be applied to a boiler of 10 t/h of more.

Also, to indicate the boiler performance, an equivalent evaporation multiple is often used.

$$\text{Equivalent evaporation multiple} = \frac{\text{Equivalent evaporation}}{\text{Consumed fuel quantity}} \text{ kg steam/kg } (m^3N) \text{ Fuel}$$

In the same boiler, when the vapor pressure and other conditions are almost constant, an evaporation multiple should be obtained as an actual evaporation without conversion. It is sometimes used as a good rating for daily management.

The performance may sometimes be indicated by a rate of evaporation of heating surface (kg/m^2h) which is divided by the equivalent evaporation by the heating surface area (except an economizer and a superheater), or by a rate of heat generation (kcal/m^3h) in the combustion chamber which is divided by the total input heat by the volume of the combustion chamber.

1.6 Consideration in installation steps

1.6.1 CO-generation

When steam is applied to heating, its heating temperature is almost 200°C or less and the temperature of steam is also around the same temperature. While, the flame temperature when fuel is burned, reaches one thousand and several hundred degrees centigrade, but the temperature difference between its temperature and the steam temperature is not utilized effectively.

The basis of a heat engine in which heat is converted to work is the Carnot cycle. When an effective work occurs by the completion of cycle through that of an operating fluid receives heat at the temperature of T_1 K from a high temperature heat source and releases the heat at the temperature of T_2 K to a low temperature heat source, the theoretical efficiency of the Carnot cycle can be represented by the following equation.

$$\eta = 1 - \frac{T_2}{T_1}$$

Accordingly, a higher T_1 is a higher efficiency.

CO-generation gives a work (electric power) by utilization of the higher temperatures when fuel is burned and utilizes the remaining exhaust heat as heat (see Fig. III-7-12). And various systems are considered as follows.

(1) (Gas turbine power generation) + (Steam turbine power generation)

(2) (Diesel or gas engine power generation) + (Hot water supply)

(3) (High pressure steam turbine power generation) + (Steam supply for heating)

In the plants of a steam consumption type, the last system (3) is usually used in such as a petroleum refinery, a paper and pulp plant, or a chemical plant. From the point of view of efficiency, the vapor pressure is desirable in 30 kg/cm^2 or more and it

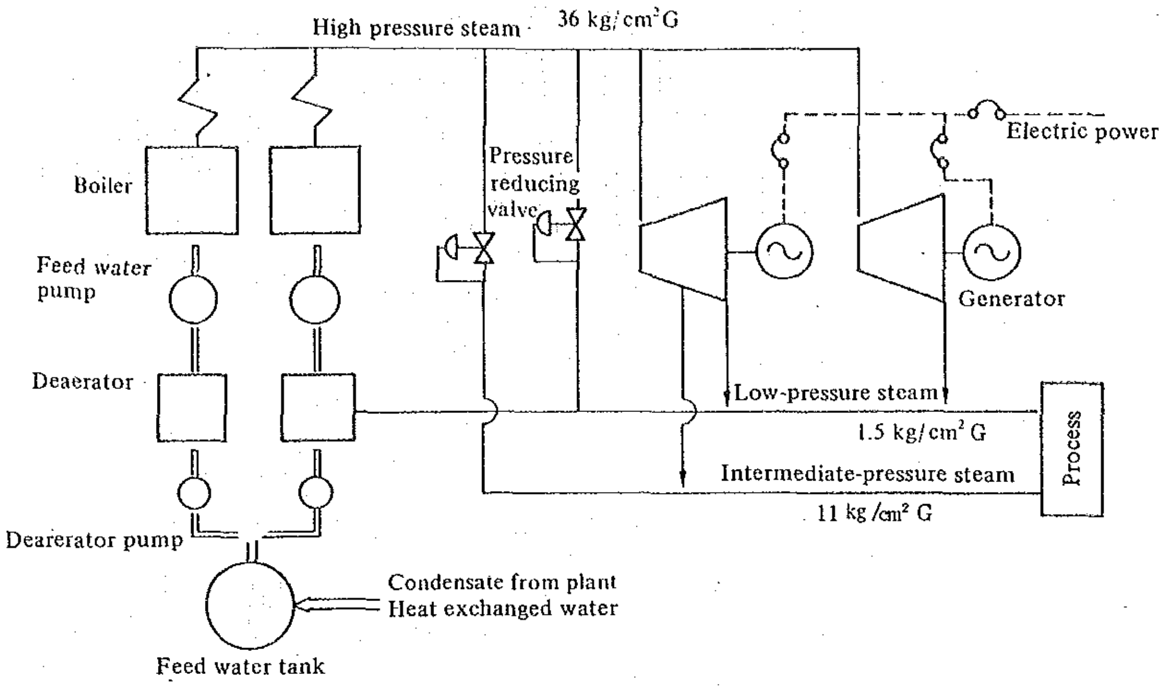


Fig. III-7-12

is almost 100 kg/cm². And the capacity is 50 t/h or more. With the sharp advance of an energy price, the economical efficiency is improved even in further lower pressure and a lower capacity boiler and the case equipped with a generator instead of the pressure reducing valve has increased.

1.6.2 Coping with steam demand variation

When the steam demand fluctuates largely in a short time or a difference in the steam demand between day and night is large, an excessive capacity boiler compared with the average load must be installed and the air ratio must be kept at a higher level to prevent black smoke occurring at the load fluctuation.

To prevent a declining of the boiler efficiency due to those, balancing the demand should be done through managing the manufacturing plants as much as possible and the following measures to the system should be taken.

As a method, the steam accumulator should be equipped to store some excess steam which is used when short of steam (See Fig. III-7-13). If an accumulator is accompanied when the boiler is installed, a boiler of the capacity near to the average load is able to cover sufficiently the demand.

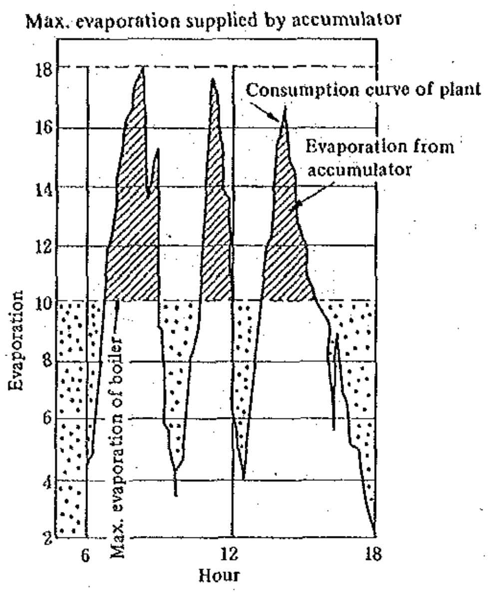


Fig. III-7-13

In another method, several small size one-through boilers which are quick start-up are installed and the operating number of boilers is controlled automatically according to load (see Fig. III-7-14). Since this method increases the efficiency in a lower load compared with the case of a single boiler (see Fig. III-7-15), energy conservation can be taken as a whole with a counterbalance of some loss increase due to the start-up and shut-off operation.

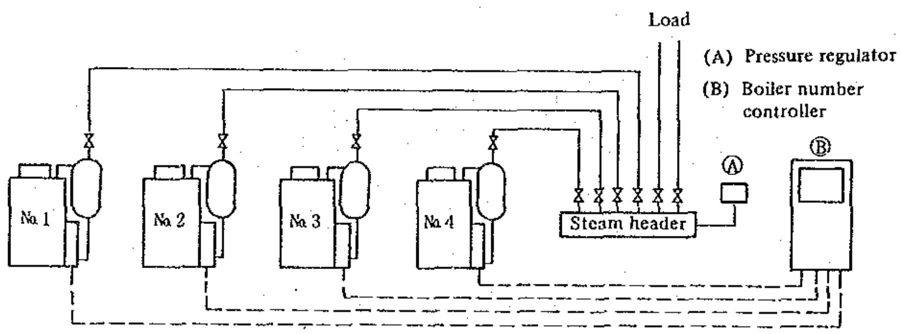


Fig. III-7-14

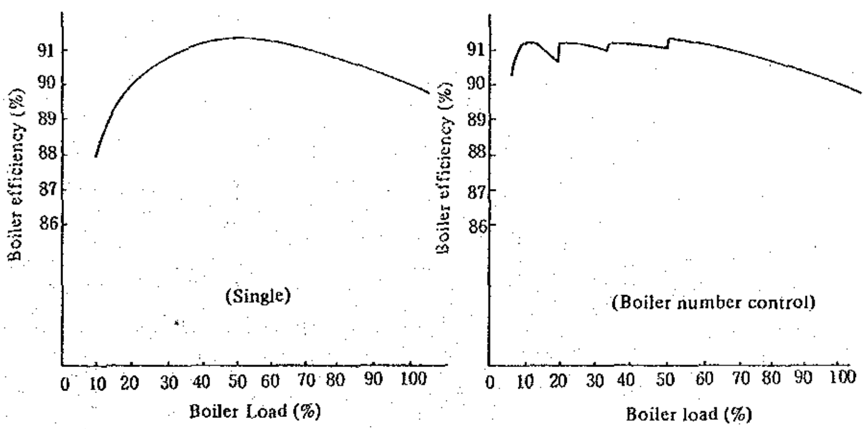


Fig. III-7-15

1.6.3 Installation of proper capacity boiler

Installation of an excess capacity boiler causes not only a higher investment but also requires a relatively longer start-up time to the required steam quantity and for much heat loss. In addition to this, when the number of ON-OFFs in operation is increased, the exhaust gas loss due to purge at each operation is increased. In a high-low combustion changeover system boiler, although a proper air ratio is held at a high combustion, it will often be transformed to a higher value at a lower combustion.

For installation of a boiler, a proper capacity boiler should be installed, after saving of steam consumption and control of fluctuation should be taken.

If the capacity of an existent boiler becomes excessive and if the time of a low combustion is longer, an exchange to a small capacity burner may bring about a better result.

1.7 Energy conservation measure of boilers

There are various items for the energy conservation in the boilers as shown in Fig. III-7-16;, the characteristic factor chart. The important points of these items are described below.

1.7.1 Air ratio

The largest heat loss of boilers is an exhaust gas loss (see Fig. III-7-17). The exhaust gas loss is decided 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:

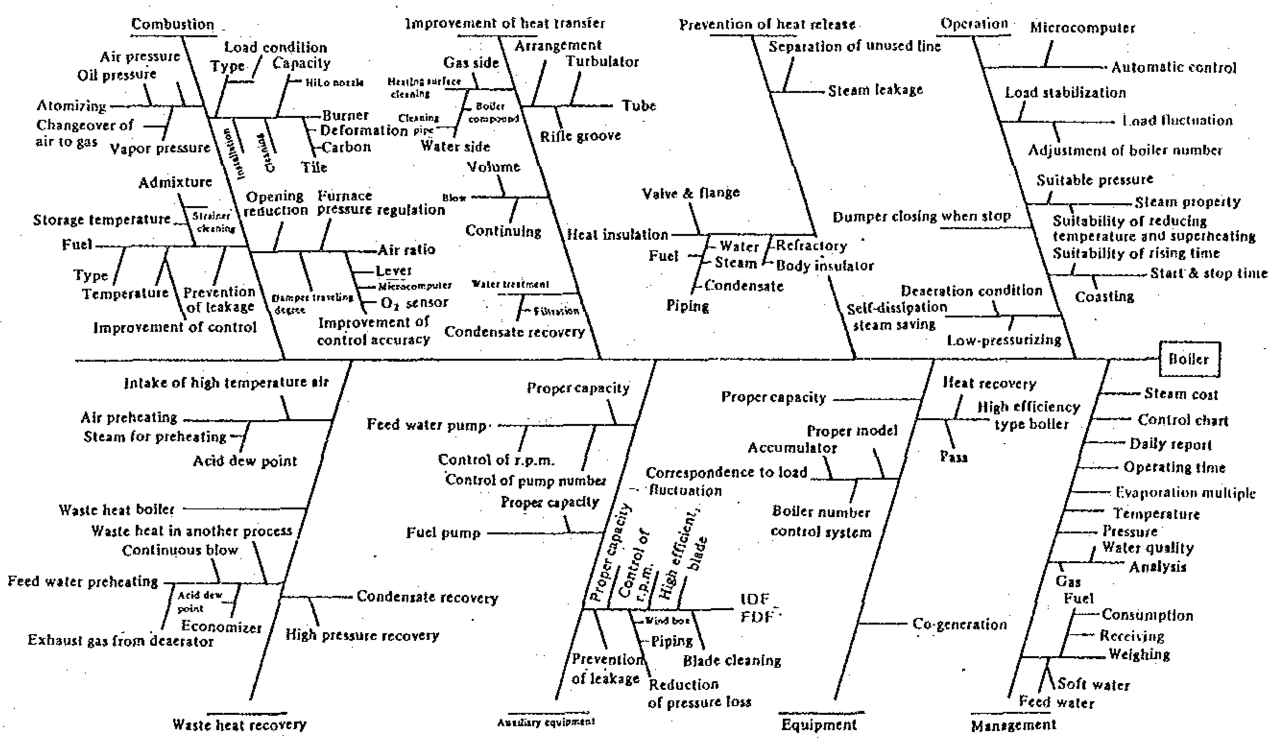
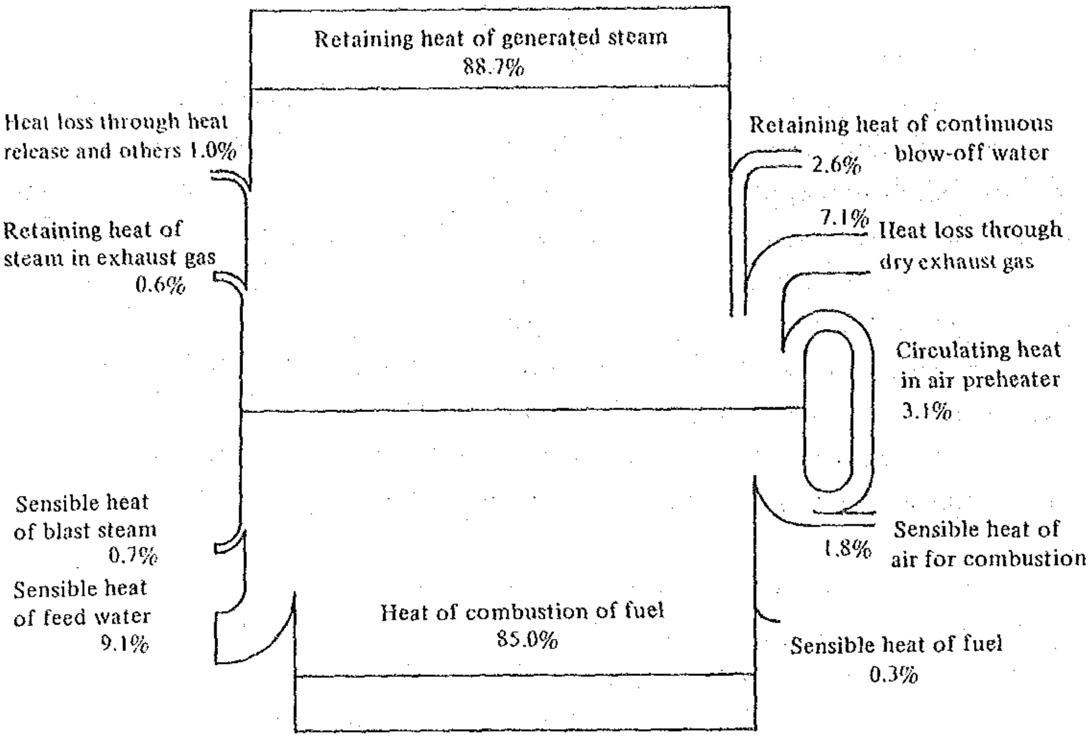


Fig. III-7-16 Energy conservation items of boiler



$$\text{Evaporation multiple} = \frac{13.67\ \text{kg}}{1\ \text{kg} \times 0.93\ \text{kg/lit.}} \times 1000 = 14.7\ \text{ton/k}l.$$

Fig. III-7-17 Example of 20 T/H boiler heat balance

(1) 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 of 20 to 45 cst. (See Fig. III-7-18).

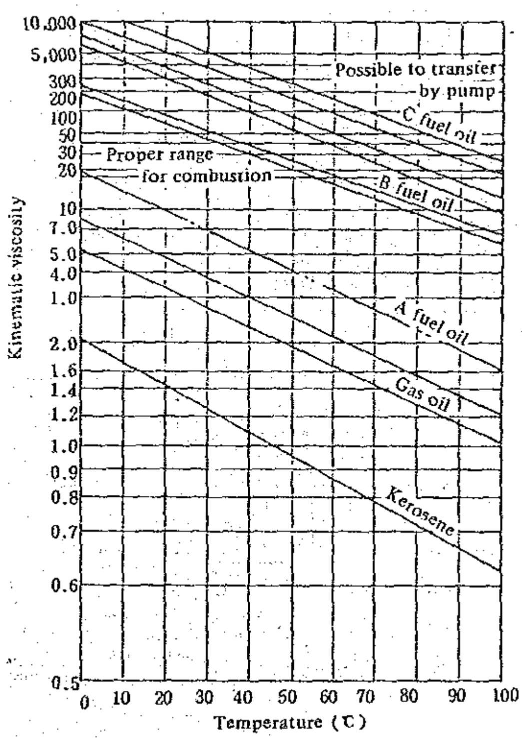


Fig. III-7-18

(2) Inspection and tuning-up of burner

- Clogging of oil strainer
- Clogging, abrasion and assembling of burner tip.
- The mounting direction of the burner and distance to the burner tile.
- Damage of and deposit of carbon on the burner tile.
- Oil leakage from the oil valves and the pipe connections.

(3) Maintaining of Steam Pressure for Atomization

The steam pressure, air pressure or fuel oil pressure should be maintained to the specified value by the manufacturer to be atomized sufficiently. The characteristics of oil burners should be referred to Table III-7-13.

(4) Prevention of air invasion

Prevent air invasion by keeping the furnace pressure properly and reducing the area of the opening parts.

Table III-7-13 Characteristics and application of oil burner

		Low pressure air system		High pressure atomizing system		Oil pressure system		Rotary burner
		Interlocking type	Non-interlocking type	Internal mixing type	External mixing type	Return oil type	Non-return oil type	
Fuel oil amount	ℓ/h	1.5 ~ 120	4 ~ 180	10 ~ 5,000	10 ~ 600	50 ~ 10,000	50 ~ 10,000	10 ~ 300
Oil pressure	kg/cm^2	0.4 ~ 1	0.1 ~ 0.3	2 ~ 9	0.2 ~ 1	5 ~ 40	5 ~ 70	0.5 ~ 10
Atomizing pressure	kg/cm^2 (mmH_2O)	mmH_2O (400 ~ 2,000)	mmH_2O (400 ~ 2,000)	3 ~ 10 kg/cm^2	2 ~ 8 kg/cm^2	—	—	1 ~ 3 kg/cm^2
Atomizing medium amount	A Nm^3/kg, S kg/kg	2 ~ 3 m^3N/kg	1 ~ 3 m^3N/kg	A 0.2 m^3N/kg, S 0.25 kg/kg	A 0.26 m^3N/kg, S 0.33 kg/kg	—	—	
Atomizing medium		*Air*	*Air*	*Air or steam*	*Air or steam*			Air, rotation of cup
Combustion air pressure	mmH_2O	400 ~ 2,000	100 ~ 2,000	0 ~ 250	0 ~ 50	100	100	0 ~ 100
Combustion regulation range		4 ~ 6 : 1	4 ~ 8 : 1	8 : 1	6 : 1	3 : 1	3 : 1	2 ~ 10 : 1
Flame characteristic		Short flame	Slightly short flame, Long flame	Short flame, Long flame	Slightly long flame	Short flame	Short flame	Short flame
Merit		Possible for proportional control by one lever. Low cost of installation and operation	Easy handling. *Same as left*	Good atomizing. Small clogging	Same as left	Low combustion noise. Low cost of operation	*Same as left*	Low cost, *Easy handling*
Weakness		Blower required	Same as left	Power cost required	Power cost required	Not respond to load fluctuation. *High pressure pump required*	Same as left	Result in large size
Boiler application	Flue smoke tube	○	○	○	○	○	○	○
	One-through			○	○	○	○	
	Vertical	○	○		○			○
	Water-tube	○		○	○	○	○	○

(5) Regulation of air

The air ratio is able to make sure by an oxygen analysis in the exhaust gas but air must be adjusted by observation of flame and smoke for daily management. 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.

In fuel oil or kerosene burning, through observation of the flame from the front spy 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 drops a little shorter than the proper value, the neighborhood of the flame tip 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 a yellow closer to white.

(6) Automatic control

It is the most simple 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 a little higher level not to generate black smoke even at a lower loading.

Therefore, there is a method improvement in part of this method.

The example shown in Fig. III-7-19 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.

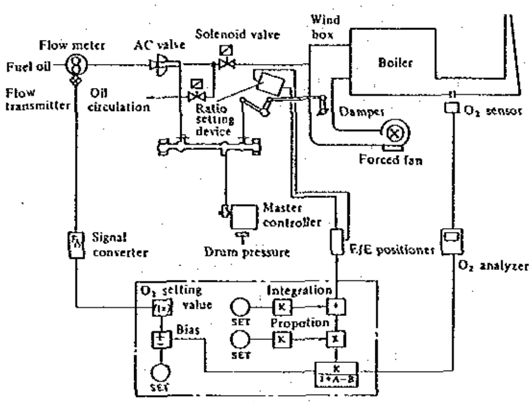


Fig. III-7-19

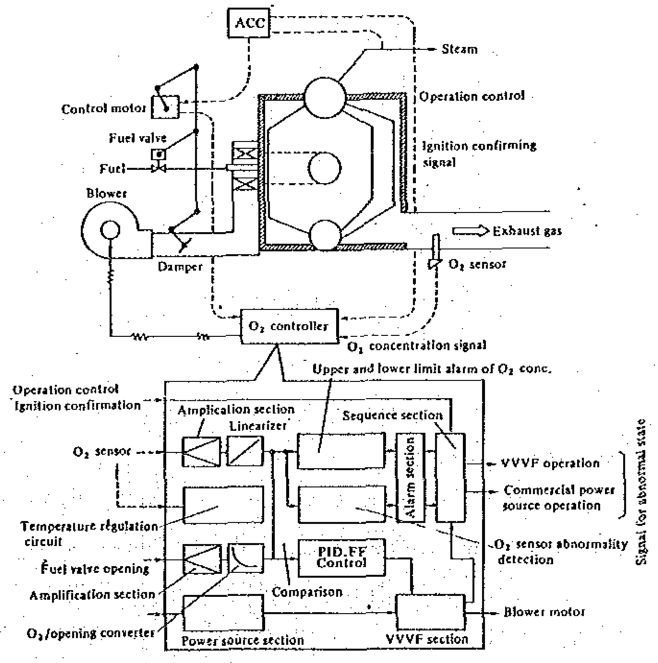


Fig. III-7-20

The example shown in Fig. III-7-20 remains the function of linkage and the controller of the revolution of the blower is added to it to adjust the O_2 concentration in the exhaust gas using a setting value suitable to the load.

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 Fig. III-7-21.

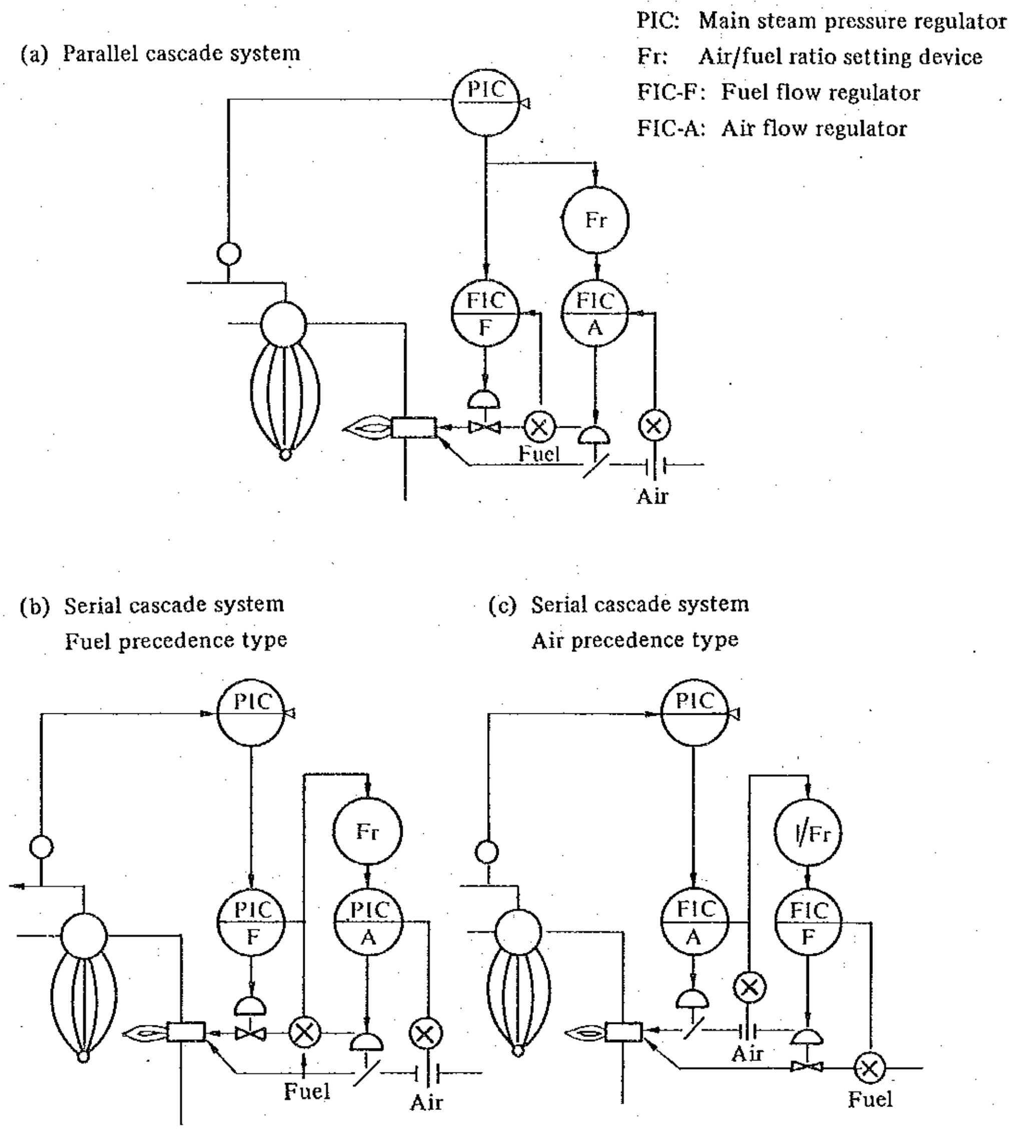


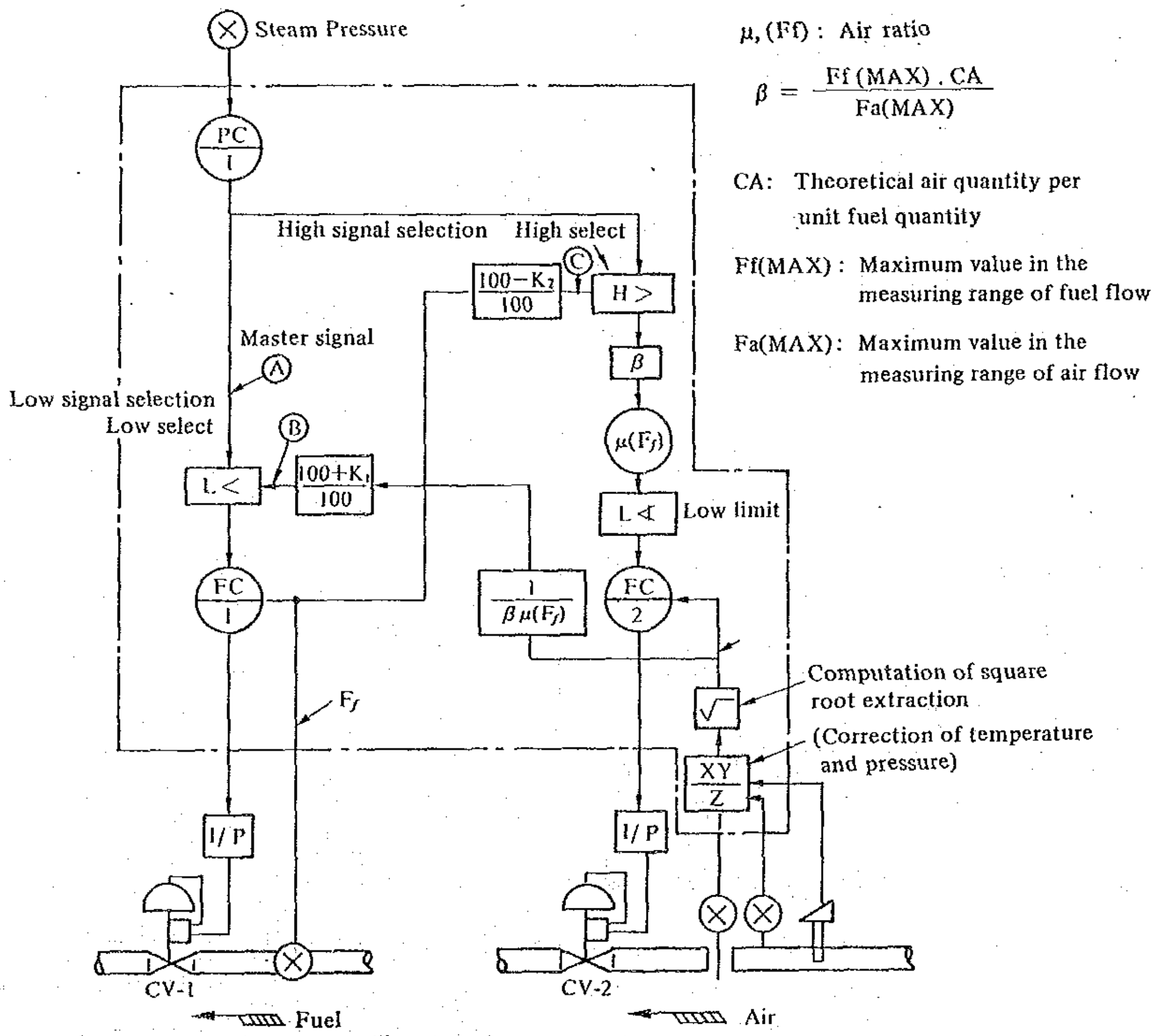
Fig. III-7-21 Basic combustion control system

These controls have little problem under the steady operation, but they do not have a mechanism to prevent black smoke generation which control fuel or air by preceding air when boiler load increases and preceding fuel when boiler load decreases. Accordingly, these controls have the problem that the air ratio must be set at a little higher level not to generate black smoke even in a load fluctuation.

To dissolve this defect, the example in Fig. III-7-22 is applied with a cross limit to check fuel or air flow whether to conform to the actual flow of each other: for fuel, the master signal coming from the steam pressure meter is compared with the smoke limit fuel quantity signal obtained by a calculation from the actual air flow, then smaller value is selected as a fuel value. In the air side, contrary to this, the air flow is set to a larger value between the master signal and the smoke limit air quantity signal obtained from the actual fuel flow. Thus, since a control of the air preceding type is done in a load increasing and a control of the fuel preceding type is done in the load decreasing, the air ratio is not required at a large margin.

Even in this method, however, since, at a load rapid decreasing, the air ratio comes temporarily to a higher level, an upper and lower limit mechanism of the air ratio may be attached.

When the fuel component fluctuates, there are some cases in which air flow is controlled more exactly through transmitting the signal to the controller from the O_2 analyser in exhaust gas.



PC-1 : Main Steam pressure regulation

PC-1 : Fuel oil flow control

PC-2 : Air flow control

Fig. III-7-22 Block diagram of single cross limit combustion control system

(7) 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 values of Japanese standard are shown in Table III-7-14 as reference.

Table III-7-14 Standard air ratio of boiler

Division		Load rate (%)	Standard air ratio			
			Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other byproduced gas
For electric industry		75 ~ 100	1.2 ~ 1.3	1.05 ~ 1.1	1.05 ~ 1.1	1.2
Others	Evaporation: more than 30 t/h.	75 ~ 100	1.2 ~ 1.3	1.1 ~ 1.2	1.1 ~ 1.2	1.3
	Evaporation: 10 to 30 t/h	75 ~ 100	—	1.2 ~ 1.3	1.2 ~ 1.3	—
	Evaporation: Less than 10 t/h	75 ~ 100	—	1.3	1.3	—

These values shall be applied to the operations of load factor in the range shown in the Table and to steady operation. In a solid fuel, this is the case of pulverized coal of $H/ \geqq 5{,}000$ Kcal/kg.

The example in Fig. III-7-23 is the result of Japanese boilers researched by the Energy Conservation Center. The figures shown in the standard correspond to the value in the highest frequency of distribution.

The boilers in Thailand are in the distribution shown in Fig. III-7-24 (Summary of Phase I). The air ratio is of nature not different from each other by each industry and the capacity was 30 t/h or less in any boilers diagnosed. Therefore, a uniform standard setting will be suggested without classification of the industry and capacity until the number of data increases in the future.

About liquid fuel, the air ratio shall be taken as a reference with 1.3 of the highest frequency of distribution. About solid fuel, although the distribution could not be obtained due to the small number of n, it is taken as a reference with 1.5 for the present.

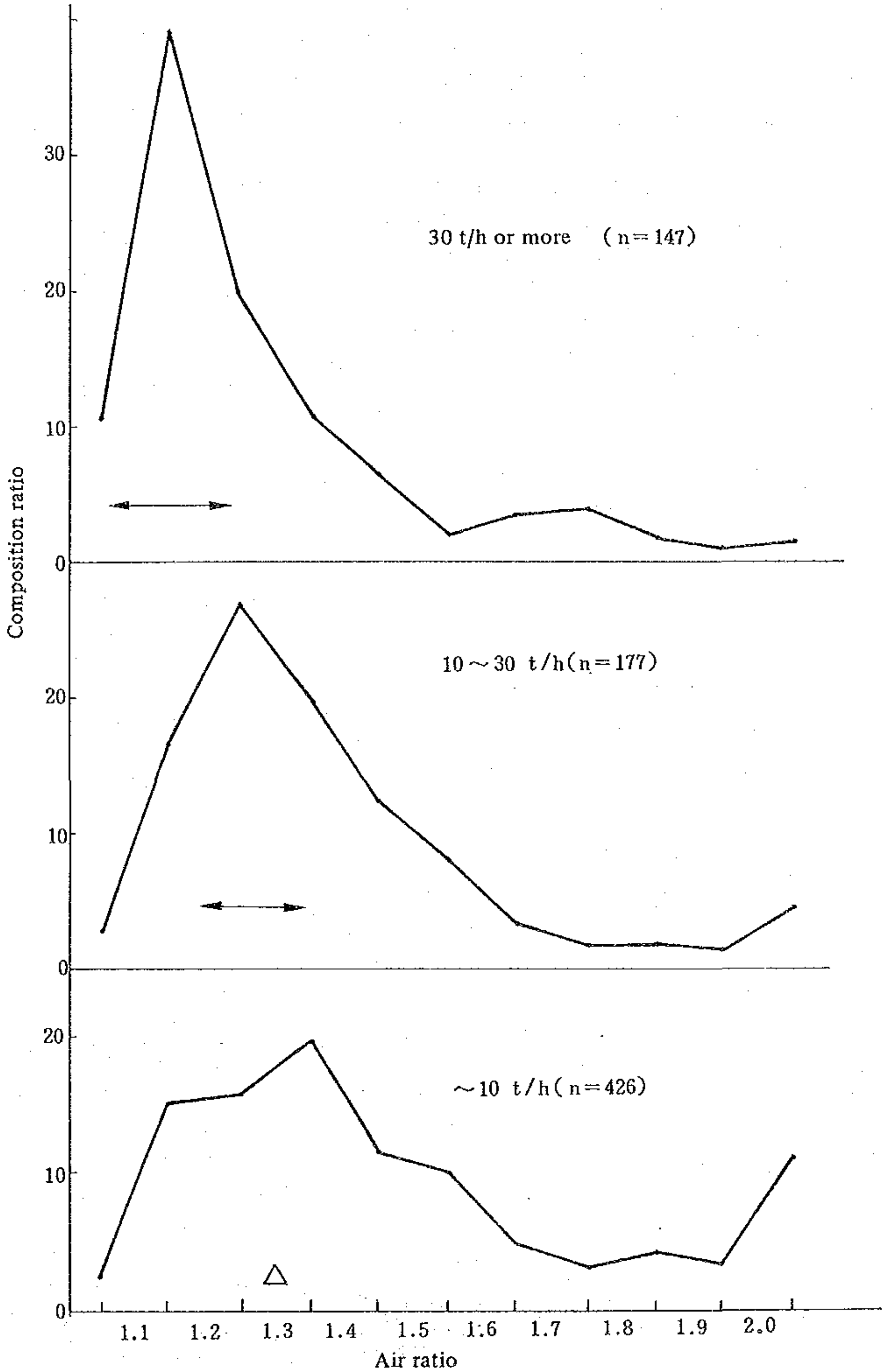


Fig. III-7-23 Boiler air ratio distribution example (1979)

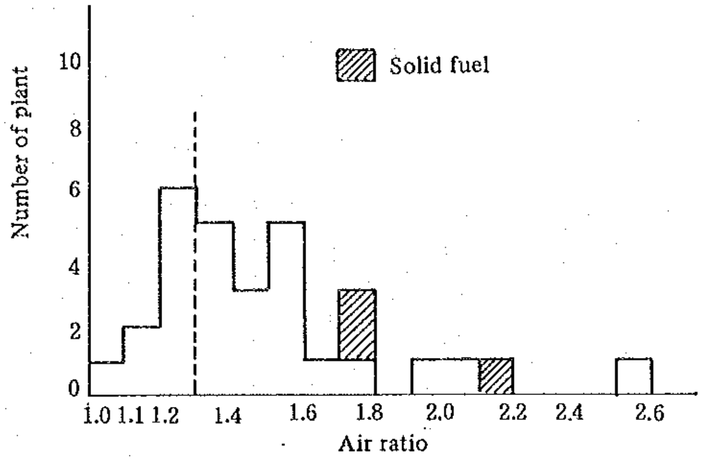


Fig. III-7-24 Boiler air ratio distribution

1.7.2 Exhaust gas temperature

(1) Improvement of heat transfer

The thermal conductivities of soot and scale depend on their composition and the deposit situation, and they are of values of no more than 1/100 to 1/100 of those of mild steel as shown in Table III-7-15. Accordingly, these deposits make the thermal efficiency of boilers decline remarkably similar to some insulation on the heating surface (see Fig. III-7-25 and Fig. III-7-26).

Table III-7-15 Thermal conductivity of scale and other substance

Scale and other substance	Thermal conductivity (kcal/mh°C)
Soot	0.06 ~ 0.1
Oily matter	0.1
Scale as main component of silicate	0.2 ~ 0.4
Scale as main component of carbonate	0.4 ~ 0.6
Scale as main component of sulfate	0.6 ~ 2
Mild steel	40 ~ 60

In order to avoid any hindrance due to the scale, it is required to perform properly a water treatment and a blow and to clean periodically as described in item (3) of paragraph 1.2.3.

Cleaning of the heating surface for the water side should be carried out commonly once per year, though it depends on the degree of the water treatment, by manual cleaning with a brush or by a chemical cleaning of acid containing an inhibitor.

Cleaning of the heating surface for the gas side should be carried out by a brush every month or three months. Even in its period, when the temperature of exhaust gas is higher by 30°C compared with the temperature just after the cleaning, cleaning is again required.

When a flue smoke tube boiler has a enough capacity, a special steel turbulator in the smoke tube is inserted to improve the coefficient of heat transfer by bringing turbulent flow in the gas flow (see item (3) of paragraph 1.7.7).

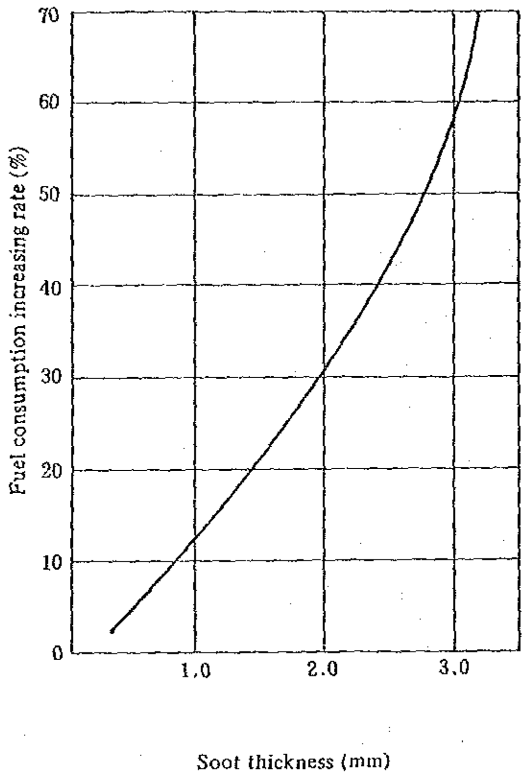


Fig. III-7-25
Example of fuel loss due to soot on heating surface

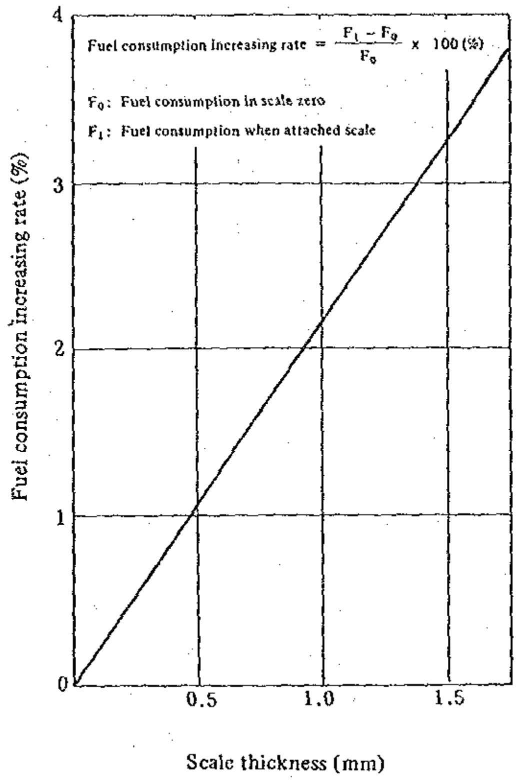


Fig. III-7-26
Example of relation between scale thickness and fuel loss

(2) Recovery of waste heat in exhaust gas

In boilers, it is basic that the exhaust gas temperature does not raise 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.

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 contained with 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.

The relation between the sulfur content in fuel and the SO_2% in exhaust gas is shown in Fig. III-7-27, the conversion of SO_2 to SO_3 is shown in Fig. III-7-28 and the relation between the SO_3 concentration and the dew point of acid is shown in Fig.

III-7-29. In the vicinity of the inlet for a low temperature fluid of the heat exchanger, a low temperature part exists partially. Therefore, the gas temperature must be kept at a higher level than the dew point of acid shown in the figure.

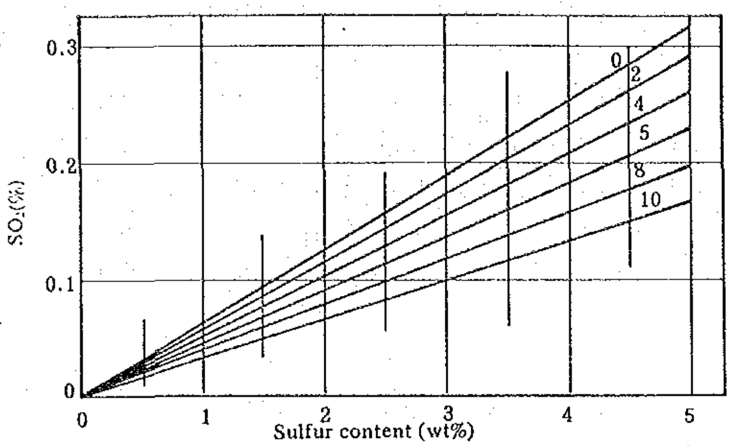


Fig. III-7-27 Relation between sulfur content in fuel and SO_2 content in fuel gas

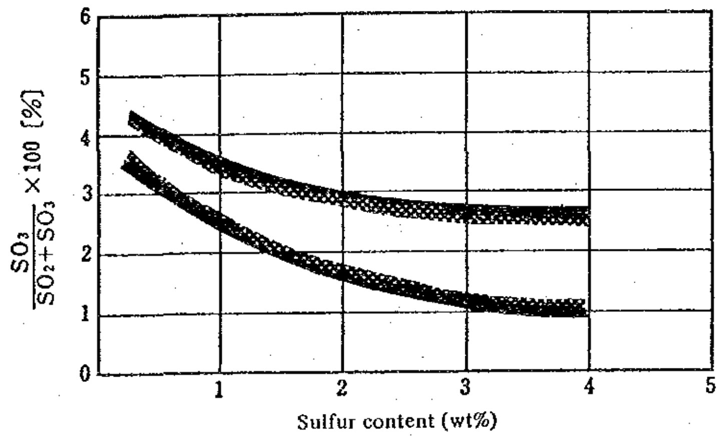


Fig. III-7-28 Relation between sulfur content in fuel and conversion ratio from SO_2 to SO_3

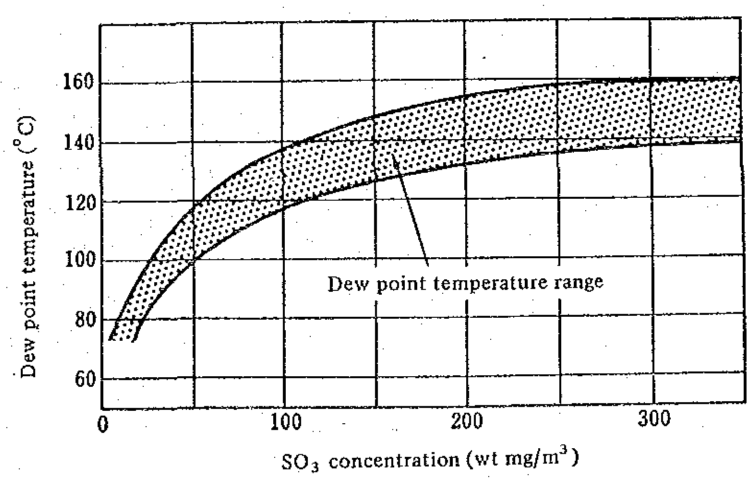


Fig. III-7-29 Relation between SO_3 concentration in exhaust gas and dew point temperature

To avoid this trouble, some heat exchangers are used with a glass tube or a lead coating tube as the material. As shown in Fig. III-7-7 of paragraph of the heat balance, a measure to prevent overdropping of the exhaust gas temperature may sometimes be taken by means of preheating the air with an external heat source prior to feeding the air to the air preheater.

The rising of feed water temperature not only causes a direct increase of the input heat but also it has a merit which make the thermal stress generated in the drum very low by a small temperature difference between the temperatures of feed water and boiler water in the drum.

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

Where,

Q:	Carrying-away heat of the combustion gas	kcal/kg Fuel
P:	Carrying-in heat of the preheated air	kcal/kg Fuel
F:	Calorific value of fuel	kcal/kg Fuel
H:	Available heat and required heat $= F - Q$	kcal/kg Fuel

In a case, where air is not preheated

$H_A = F - Q$

In a case of preheating air

$H_B = F - Q + P = H_A + P$

Taking the required heat of furnace as X kcal/h, the fuel consumption when air is not preheated:

$$\frac{X}{H_A} \quad \text{kg Fuel/h}$$

When air is preheated:

$$\frac{X}{H_B} = \frac{X}{H_A + P} \quad \text{kg Fuel/h}$$

Accordingly, the fuel saving rate is as follows:

$$\frac{\dfrac{X}{H_A} - \dfrac{X}{H_A + P}}{\dfrac{X}{H_A}} = \frac{P}{H_A + P}$$

The fuel saving rate in case of 1.2 in the air ratio is shown in Fig. III-7-30.

The preheating of air brings an energy conservation effect by increasing of the carrying-in heat, an 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 NO_x 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.

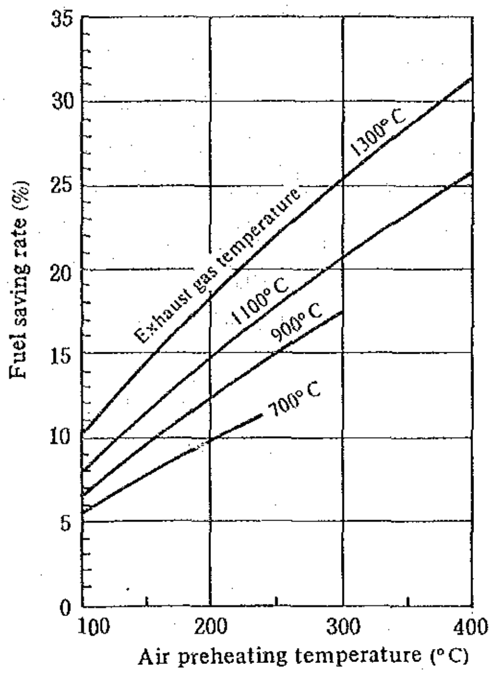


Fig. III-7-30 Fuel saving rate due to air preheating

(3) 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 a lower sulfur content and heat recovery from the exhaust gas comes to extent of lower exit temperature.

In the Japanese exhaust gas temperature standard, the standard of an exhaust gas temperature by capacity and by fuel is determined in consideration of these points as shown in Table III-7-16.

Table III-7-16 Standard exhaust gas temperature of boiler

Division		Standard exhaust gas temperature (°C)			
		Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other byproduced gas
For electric industry		145	145	110	200
Others	Evaporation; More than 30 t/h	200	200	170	200
	Evaporation: 10 to 30 t/h	—	200	170	—
	Evaporation: Less than 10 t/h	—	320	300	—

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.

But the existing boiler without a waste heat recovery unit out of the boilers of 10 to 30 t/h in the evaporation is taken as the same value as the boiler of 10 t/h or less.

The results in Japan, researched by the Energy Conservation Center, are shown in Fig. III-7-31 and the highest frequency value is less than the value of the standard. The value of the margin is the installation situation of a waste heat recovery unit and half of the boilers of 30 t/h or more are provided with both an air preheater and economizer. Moreover, most of the small size boilers are equipped with only an air preheater. The boilers without a waste heat recovery unit in either case are only about 3%.

The results of the diagnosed factories in Thailand are shown in Fig. III-7-32. Note that these values can not apply for an exact comparison because these values are not measured just after the cleaning of a heating surface and not converted to a condition of 100% load.

For the case in Thailand, because a low sulfur content fuel is not used and the highest frequency value is around 250° C, a tentative standard should be suggested to be taken as 250° C.

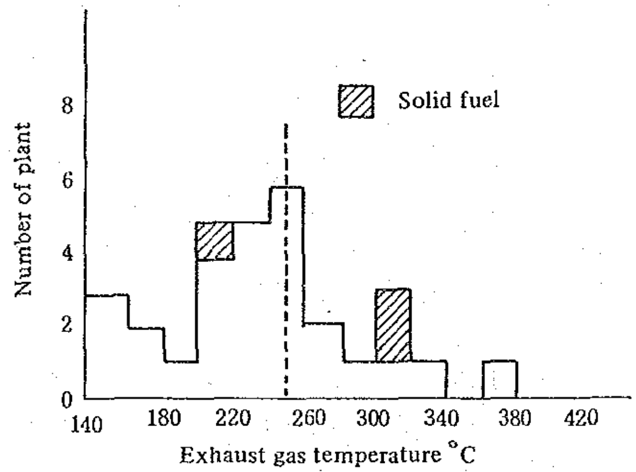


Fig. III-7-32 Boiler exhaust gas temperature

1.7.3 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 heat 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.