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Realization of Energy Conservation in Oil Refining Process/Drastic Overhaul of Fuel Oil Desulfurization Unit Implemented by Our Company

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RH-equipment, Energy Conservation Promotion Group

◎ **Key Words: Rationalization of heating, cooling and heat transfer (heating facilities, etc.), and rationalization of electric motive power and heat conversion (electric motive power applied facilities, electric heating facilities, etc.)**

◎ Outline of Theme

In order to achieve targets of the refinery for energy conservation (20% reduction in specific energy consumption), efforts have been made to discover issues concerning major equipment, fuel oil desulfurization unit, and to improve them. Although such activity used to be mainly conducted in a single department in the past, this activity was regarded as one collecting much technical information from specialized departments inside and outside the company. As a result of deliberations by members in our department and other departments in the refinery, heat recovery was realized under a severe condition of high temperature and pressure. Moreover, in order to reduce fuels of a distillation column furnace, equipment having the same function were combined and readjusted to the process configuration capable of utilizing heat source of equipment which became unnecessary for stock preheating. In addition, all rotating equipment in the unit was investigated, and modification for improving their efficiency was considered and implemented. As a result of such drastic overhaul, large-scale reduction in energy consumption was realized.

◎ Implementation Period of the said Example

- Project Planning Period: March 2002 ~ February 2004, Total of 22 months
- Measures Implementation Period: March 2003 ~ April 2005, Total of 14 months
- Measures Effect Confirmation Period: May 2005 ~ August 2005, Total of 4 months

◎ Outline of the Business Establishment

- Production items: LPG, gasoline, kerosene, diesel oil, heavy fuel oil, acrylic acid and pulverized coal
- Number of employees: 320 (as of April 1st 2005)
- Annual energy usage (data of FY2004): Fuel 897,778KL (crude oil equivalent), Electricity 717,092 thousand KWh

◎ Process Flow of Target Facility

Aichi Refinery refines crude oil to produce petroleum products such as gasoline, kerosene, diesel oil, etc. A heavy fuel oil desulfurization unit taken up as the theme is an device which produces desulfurization heavy fuel oil, etc. with less than 0.3wt% of sulfur content by hydrodesulfurization reaction using high-sulfur heavy fuel oil as stock, as shown in the process of Fig. 1.

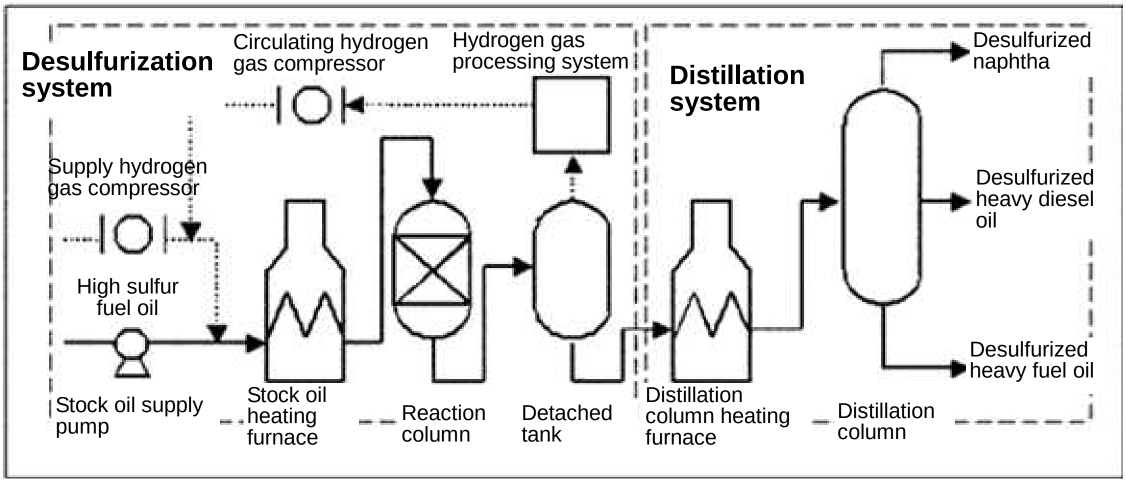


Fig. 1 Outline of the Process Chart of the Facility

1. Reasons for Theme Selection

Aichi Refinery has committed itself to energy conservation by setting targets to promote energy conservation that specific energy consumption should be reduced by 20% by 2008 in comparison with 1990 level, and this effort has brought results as shown in Fig. 2. The energy conservation promotion group in the department plays a leading role in activities. As its achievement, the group has reduced specific energy consumption by 15% by FY2004 by embodying and implementing activities to discover issues for energy conservation of each device.

However, energy consumption of the refinery has been on the increase due to reinforcement of devices by implementation of sulfur free of gasoline and diesel oil in recent years. Innovative modifications on facilities became necessary because operation improvement activities have limitations to promote further energy conservation in the future. To this end, a heavy fuel oil desulfurization unit (hereinafter RH unit) which has high energy consumption was completely overhauled. Attention was mainly paid to the following four points:

(1) Is there an efficient way to recover energy?
(2) Is it possible to reduce energy consumption by reviewing and consolidating the process flow of RH unit?
(3) Are more efficient operation and modifications of rotating equipment possible?
(4) Is it possible to lower the temperature at outlet of heating furnace?

Overall consideration on energy conservation issues started with the aim of streamlining energy use.

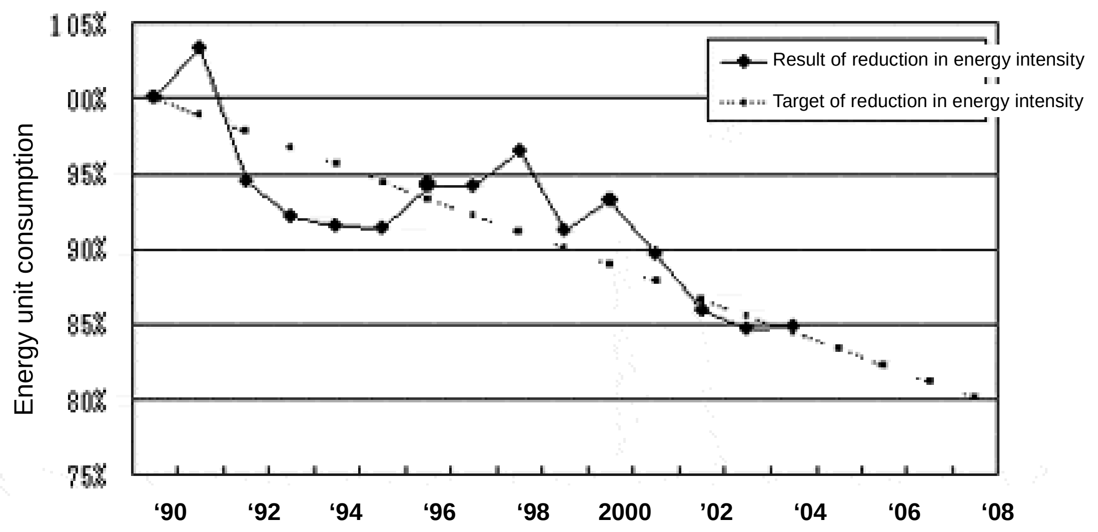


Fig. 2 Changes in Specific Energy Consumption

2. Understanding and Analysis of Current situation

(1) Understanding of Current Situation

Because RH unit which uses heavy oil as its stock performs desulfurization reaction under higher temperature and pressure compared to other desulfurization units using light oil, fuel consumption in its heating furnaces is large. Moreover, operation of its large compressors under high pressure consumes a lot of electricity. As shown in Fig. 3, energy consumption by RH unit is larger than that by other desulfurization units, accounting for about 39% in the whole system. It was decided therefore to review operation and equipment of the whole RH unit based on the above-mentioned points to discover energy conservation issues.

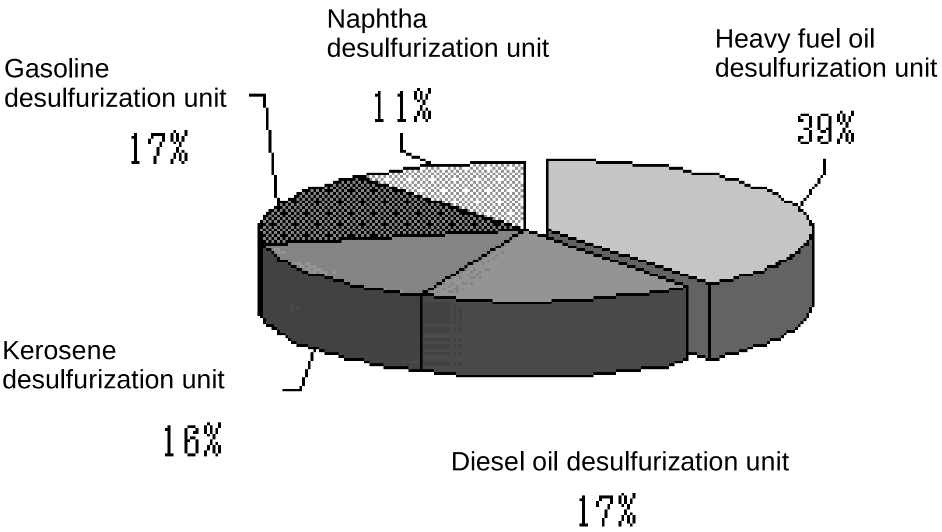


Fig. 3 Compositions of Energy Consumption

(2) Analysis of Current Situation

① "Efficient method of energy recovery"

Hydrodesulfurization reaction is exothermal reaction so that inlet temperature of reaction column is higher than outlet temperature. Generally, the unit has heat exchangers at inlet/outlet of reaction column to collect heat from oil at outlet.

Inlet temperature of reaction column C in Fig. 4 is adjusted by heat exchanger A and circulating hydrogen gas D to set it lower than outlet temperature of reaction column B. However, as heat recovery of heat exchanger A may be excessive depending on operation, appropriate temperature control was impossible, and a tube inside heat exchanger A was removed. We considered what we could do about "loss of non-exchanged heat which amounts to 1,500KL (crude oil equivalent) per year, and heat recovery from oil at outlet of high-temperature reaction column B was reviewed accordingly.

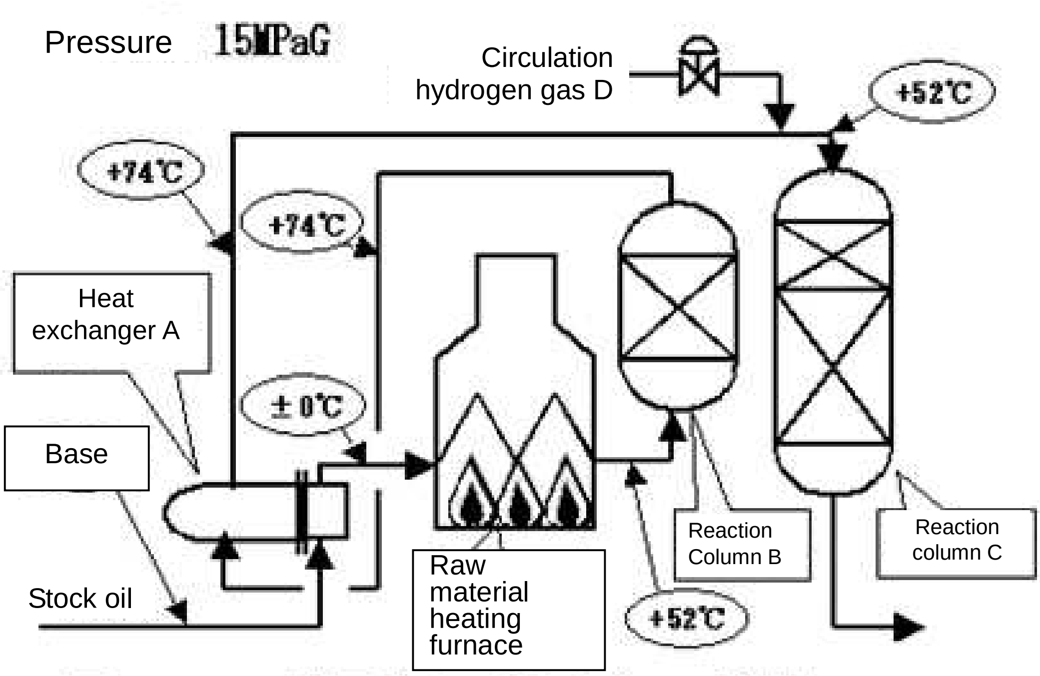


Fig. 4 Streamlining of Heat Recovery - Outline of Flow

② "Review and consolidation of the unit's process flow"

A heating furnace is placed in a position which requires heat source. Generally, a heating furnace of hydrodesulfurization unit is placed in stock feed system required to be heated up to reaction temperature or in distillation column feed system required to be heated for distillation. Table 1 shows comparison of the number of heating furnaces in RH unit of Idemitsu Kosan. RH unit in the Aichi refinery has more heating furnaces than that of other refineries. It has the above-mentioned two heating furnaces and also a reaction column intermediate heating furnace. That is because the unit is based on design to desulfurize heavy stock more efficiently. However, that is a negative factor in terms of energy conservation. The RH unit of A refinery constructed based on the newest design does not have an intermediate heating furnace nor a distillation column heating furnace. We thought therefore, "one unit has five heating furnaces. Heat loss by exhaust gas is as enormous as 4,700KL (crude oil equivalent) per year, and it might be possible to stop some of them or to reduce burden." Accordingly, we decided to implement considerations of energy conservation from a viewpoint of restructuring the process with a target of stopping the distillation column heating furnace.

Table 1 The Number of Heating Furnaces of Heavy Fuel Oil Desulfurization Unit

	Stock heating furnace	Intermediate heating furnace	Distillation column heating furnace	Total
Aichi refinery	2	2	1	5
A refinery	2	0	0	2
B refinery	2	0	1	3

③ "More efficient operation and modifications of rotating equipment"

a. Streamlining of compressors and rotating machines

We thought, "There are 60 compressors and rotating machines in the RH unit, and some are old and others have low operating rates. Energy used is enormous and there should be a measure to improve as much as possible." To this end, we investigated energy usage, efficiency, operation rates, etc. of all equipment and machines. As a result, it was found out that large circulating hydrogen gas compressors use energy of 17,000KL (crude oil equivalent) and their efficiency is low. Moreover, there are a number of pumps such as ones with low operation rates on a regular basis, ones with a wide variation range of operation, and ones whose efficiency is declining. We though that drastic energy conservation could be realized by modifying them so that we started considerations.

b. Utilization of the maximum capacity of membrane separation facilities

It is necessary to keep high purity of circulating hydrogen gas of RH unit because of catalyst activity and catalyst lifetime. RH unit has both naphtha contactor system (operated from the beginning of construction) which removes hydrocarbons such as methane by countercurrent contact with naphtha to maintain purity of circulating hydrogen gas and membrane separation system (expanded for the purpose of energy conservation) which separates them by membrane separation (see Fig. 5). Naphtha contactor system requires large high-pressure pumps, having high electric consumption. On the other hand, membrane separation system does not require power source, because it separates hydrogen from hydrocarbons by difference in molecular transmission rate between high-pressure system and low-pressure system separated by hollow fiber membrane (see Fig. 6). Although "membrane separation" requiring the minimum energy consumption is used to the maximum extent in the current operation, we though that "membrane separation could be utilized more and energy of 2,800KL (crude oil equivalent) could be saved per year, by completely stopping naphtha contactors". In fact, capacity of membrane separation facility is set lower than the maximum capacity so that further energy conservation can be fostered by utilizing remaining power of membrane body. It was decided that locations of problems should be confirmed and elimination of bottlenecks should be considered.

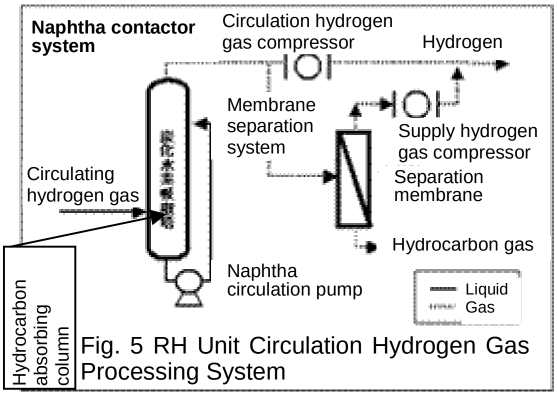


Fig. 5 RH Unit Circulation Hydrogen Gas Processing System

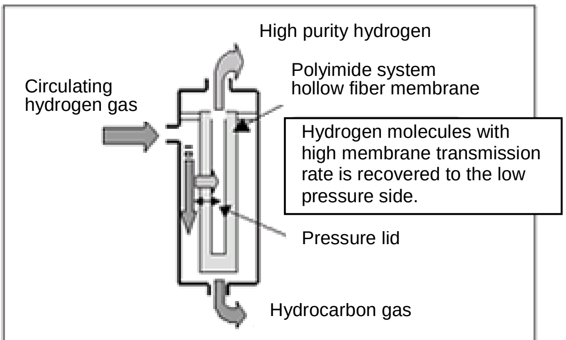


Fig. 6 RH Unit Membrane Separation System

As described above, we analyzed and deliberated improvement measures based on 4 points shown in “1. Reasons for Selecting the Theme.” Deliberations were comprehensive on each system of the RH unit, and results are summarized on Table 2. We started activities from issues to which greater effect is expected.

Table 2 List of Issues

	Points	Categories by system	Conditions	Issues for energy conservation	Effect expected
1	Is there an efficient way to recover energy?	Stock tank-heating furnace (stock preheating)	Preheater is in bypass condition	Restoration of heat exchanger’s tube bundle	L
2	Is it possible to reduce energy consumption by reviewing and consolidating the process flow of RH unit?	High-pressure separator-Distillation column heating furnace-Distillation column	Preheater is in bypass condition	Reduction in fuel burden of heating furnace or extinction	L
		Distillation column overhead receiver-Stabilizer-NH unit	Constant operation	Bypassed and reboiler heat source is utilized for other uses	L
3	Are more efficient operation and modifications of rotating equipment possible?	Circulating hydrogen gas compressor	Constant operation	Streamlining	L
		Other rotating machine	Constant operation	Operation flow (review of pump capacity of designed flow)	L
		High-pressure separator-Naphtha contactor-Circulating hydrogen gas compressor - Circulating hydrogen gas compressor	Installation of membrane separation system; Pump is activated when naphtha circulation is needed.	Naphtha circulation pump is stopped by the maximum utilization of membrane separation	L
4	Is it possible to lower the temperature at the outlet of heating furnace?	High-pressure separator-Naphtha contactor-Circulating hydrogen gas compressor - Circulating hydrogen gas compressor	Outlet temperature of heating furnace is high	Development and introduction of highly active catalyst with low temperature	S
		Intermediate flush/Intermediate heating furnace-Reaction column (desulfurization)	Intermediate heating furnace operation	Reduction in outlet temperature of intermediate heating furnace	S

L ---Large, S---Small

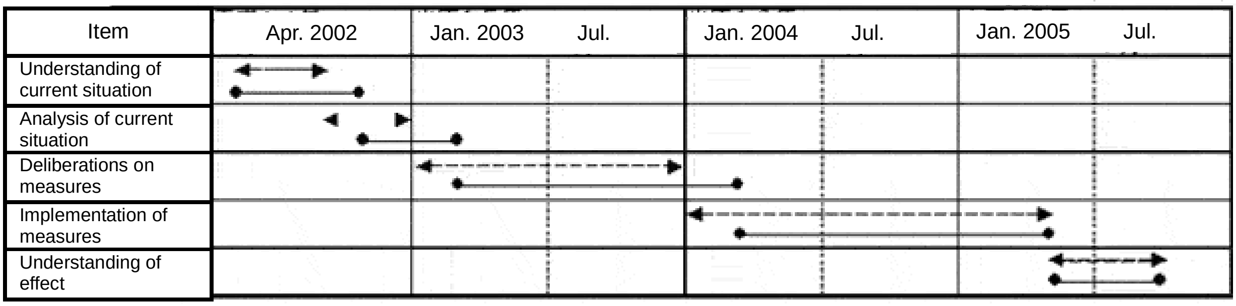
3. Progress of Activities

(1) Implementation Structure

The Energy Conservation Promotion Group in the Oil Production Department 1 has promoted discovery and improvement of issues on energy conservation under the name of an activity of each department's book of income and expenditure in TPM activity. In order to achieve more results, we requested technical staff of operation and facilities in the department, and members concerned departments (engineering department in charge of facility management and management department in charge of facility planning) in the department to participate in this activity in addition to members for promoting an activity of each department's book of income and expenditure. In implementing this activity, time was first spent on deliberations, and much information was shared from understanding of current situation of each system of the unit, deliberations on measures, their implementation to understanding of their effect. Cooperation was sought from technical staff of the petroleum refining technology center and the facility management center at the headquarters which provide specialized technical support if necessary. Plans and achievement of the activities are shown o Table 3.

Table 3 List of Schedule

Plan
Achievement



(2) Target Settings

Target: 5,000KL per year (crude oil equivalent)

This is a lofty target as this number accounts for 60% of the original target of energy conservation.

(3) Problem Points and their Investigation

① Efficient method of energy recovery

As mentioned above, heat exchanger A cannot control temperature in operation so that heat exchange tubes are removed. It is necessary to restore tubes to achieve an energy conservation effect, and at the same time, problems which do not affect operations should be addressed.

Therefore, we firstly proceeded to deliberations on control method of the amount of heat recovery at heat exchanger A. Reaction temperature of the RH unit depends on kinds of stock, properties and processing amount, and its operation adjustment range is ±5℃during continuous operating period of about 11 months (Desulfurization catalyst of the RH unit has a one-year cycle operation pattern. It is in operation for about 11 months from early active period when catalyst activity is high until a late stage when activity decreases, and then the unit is stopped for about a month to exchange catalyst). A plan to carry out this adjustment by a heat exchanger is the best option. To be specific, we reached a conclusion that part of fluid is bypassed and variable control is carried out by the amount bypassed. However, the relevant portion is high-temperature and high-pressure and connecting pipes are copper pipes with the thickness of 33mm. This means that it is necessary to take into account heat expansion so that we proceeded to deliberations with caution. As for the amount bypassed, catalyst activity, flow pattern of fluid, mass balance in the system of process fluid and heat balance were simulated beforehand, and it was analyzed in detail based on operation data of the past 10 years and older to calculate the amount bypassed (see Fig. 7). In addition, in order to maximize heat recovery, the amount of circulating hydrogen gas at inlet of downstream reaction column was approximated to the threshold limit amount (the minimum limit) in reaction. As for the threshold limit value (the minimum value) in reaction was decided upon comprehensive investigations on information of the relevant unit’s licensor, catalyst makers and other companies as well as the past record of operation, and consultations with special departments in the company.

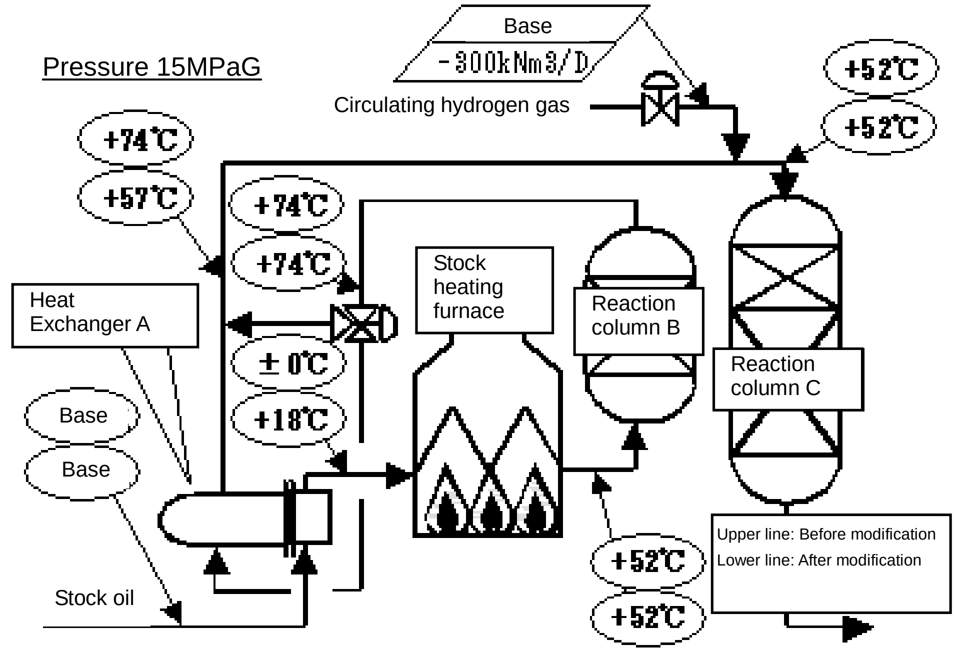


Fig. 7 Simulation Result of Heat Balance

② Review and consolidation of the unit's process flow

In order to stop a distillation column heating furnace, using the same refining method as the RH unit of A refinery is an idea that one can easily come up with, however, it is not realistic as there is much difference between refining methods. Thus, a new refining method was deliberated. It is necessary to obtain the same level of heat source as heat quantity of the distillation column heating furnace, and this applies to temperature conditions of desulfurized heavy fuel oil at the bottom of distillation column in the unit. However, there is little allowance in use of heat, because heat of desulfurized heavy fuel oil is utilized for stabilizer-system reboiler and stock-system preheating. It was necessary therefore to review functions of the process again, stop the stabilizer and use its heat source. This stabilizer is a distillation column which separates off-gas contained in naphtha. However, naphtha from the column's bottom contains traces of sulfur content so that it is sent to a naphtha desulfurization unit (hereinafter NH unit) and then desulfurized. NH unit also has the process of separating off-gas and it is possible to stop stabilizer of the RH unit if the following procedures are taken. We considered them without delay.

a. Off-gas separated in stabilizer contains hydrogen sulfide and it is sent to NH unit remaining contained in naphtha. It is necessary to avoid corrosion by hydrogen sulfide in NH unit.

b. It is necessary to deliberate on process whether off-gas can be appropriately processed in the off-gas separation process of NH unit.

As for the foregoing a, it was judged that corrosion does not proceed rapidly by performing evaluations based on operation, analysis data and inspection histories in cooperation with the facility management department. As for the foregoing b, we implemented distillation simulation, and it was conformed that off-gas can be appropriately processed in NH unit.
As explained above, we reached a conclusion that the stabilizer can be stopped, and consequently we decided to use heat of desulfurized fuel oil for the distillation column heating furnace. As for effect of the distillation column heating furnace in use of heat, our technical capabilities made it possible to review and deliberate on the process flow by implementing simulation of the distillation column (see Fig. 8).

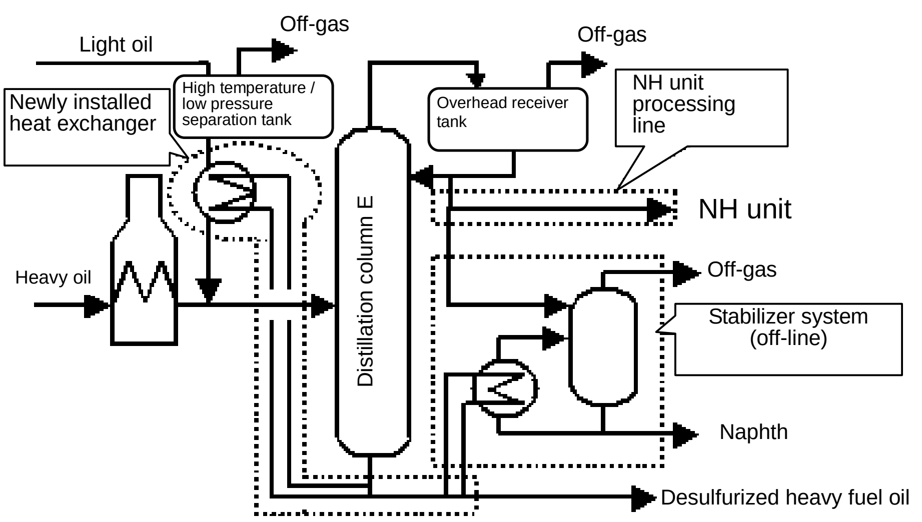


Fig. 8 Restructuring Modification of the Process of Distillation Column System

③ More efficient operation and modifications of rotating equipment

a. Streamlining of circulating hydrogen gas compressor

A circulating hydrogen gas compressor uses a rotor from the time when the RH unit was constructed (30 years ago). However, as operation of the RH unit reduces the amount of circulating hydrogen gas by the above-mentioned modifications for energy conservation, reduction in load of the relevant machine was anticipated. Although decrease in shaft power is expected because of reduction in load, operation at the maximum efficiency point of the compressor is difficult. Thus, it was a possibility of realizing energy conservation by reviewing the maximum efficiency point. Furthermore, it was found out that great energy conservation effect is expected when further decrease in shaft power is promoted by adopting state-of-the-art rotor with high efficiency. As a result, the circulating hydrogen gas compressor was redesigned.

b. Efficient operation of rotating machines

Operating conditions of all rotating machines were investigated. A high-pressure pump shows the following operation pattern as in Fig. 9, and this pumps repeats the pattern of supplying reaction column B with oil and the patter of waiting at the minimum flow. However, this is a high-temperature and high-pressure pump so that repeating of start and stop of the pump imposes a strain on operators and stop/rerun of the system has great effect on other systems. A method of reducing electricity without stopping pumps was deliberated accordingly.

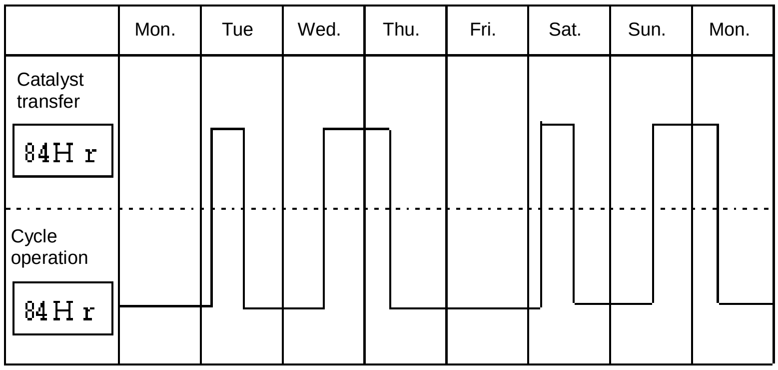


Fig. 9 Operating Conditions of High-pressure Circulation Pump

c. Utilization of the maximum capacity of membrane separation facilities

In order to have capacity that matches capacity of the membrane body, deliberations on problems of parts other than membrane on the process and measures were conducted. As a result of deliberations, we reached a conclusion that reinforcement of capacities is possible by reviewing capacities of a flow control vale at inlet and a safety valve.

4. Details of Measures

① Efficient method of energy recovery

Restoration of tubes in heat exchanger A, bypass piping of the heat exchanger, and installation of three-way valves were measures used (see Fig. 10). Temperature control of reaction column C became possible when flow of fluid passing through the heat exchanger was adjusted to adjust heat quantity recovered by opening and closing a newly installed three-way valve.

② Review and consolidation of the unit's process flow

Based on results of deliberations, stabilizer system of the RH unit was stopped and a light-oil preheater was newly installed (see Fig. 8). As a result, load on the heating furnace was significantly reduced. However, because heat recovery comparable to combustion heat quantity of the heating furnace was not possible, the heating furnace could not be stopped. Nevertheless, fuels for the heating furnace of the RH unit were reduced by 25% by "efficient method of energy recovery" and "review and consolidation of the unit's process flow (see Fig. 11)."

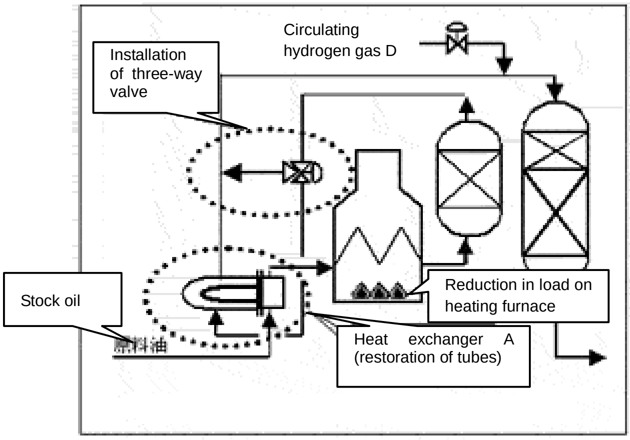


Fig. 10 Modifications for Streamlining of Heat Recovery

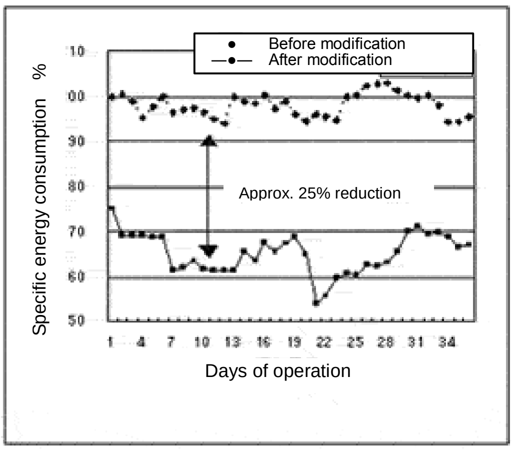


Fig. 11 Changes in Specific Consumption of RH Unit

③ More efficient operation and modifications of rotating equipment

a. Streamlining of circulating hydrogen gas compressor

Redesign of the circulating hydrogen gas was set to reach the maximum efficiency point with flow of circulating gas under normal operation of the RH unit. Shaft power has significantly improved compared to the past due to effects of modifications and change to a high-efficient rotor so that energy conservation effect more than the target (reduction in about 10% of steam for drive) was achieved.

b. Efficient operation of rotating machines

In order to reduce load without stopping the high-pressure circulation pump, a method of reducing revolutions at circulation operation was deliberated. There are two methods of controlling revolutions such as VVVF method (inverter) and fluid coupling method. Comparing costs of modifications, energy conservation effect, operability and profitability, the most advantageous fluid coupling method was adopted. Revolutions of pump after modifications were set as 100% during catalyst transfer (see Fig. 12) and as 50% (the minimum revolutions of unit) during other times (circulation operation), and electricity could be reduced.

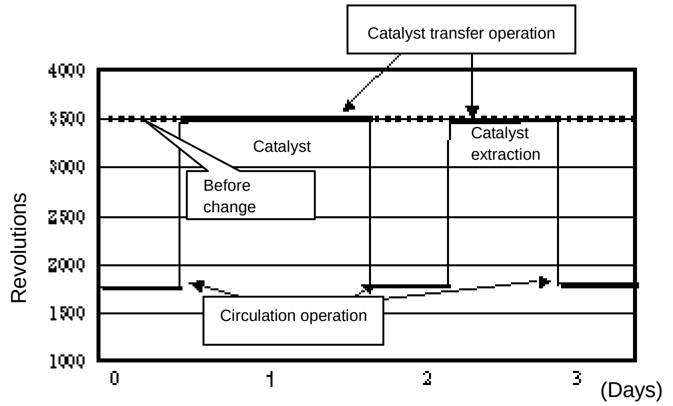


Fig. 12 Effect of Controlling Revolutions of Pumps

c. Utilization of the maximum capacity of membrane separation facilities

As a result of modifications, it became possible for the membrane separation facility to process circulating hydrogen to the maximum capacity of membrane body. In addition, downtime of naphtha circulation pumps was extended 20 days and electricity used was reduced.

5. Effects achieved after Implementing Measures

Energy conservation of 8,900KL per year (about 1.8 times of the target) was achieved by the above-mentioned evaluations. This accounts for 1.3% of the total energy consumed in the refinery.

Table 4. The Result of "Realization of Energy Conservation in Oil Refining Process/Drastic Overhaul of Heavy Fuel Oil Desulfurization Unit Implemented by Our Company"

Items	Energy Conservation Target	Energy Conservation Efficiency (results)			
	Fuel reduction	Fuel reduction	Power reduction	CO_2 reduction	Reduction amount
	(L/year) crude oil equivalent	(L/year) crude oil equivalent	1,000KW/year	TON/year	1,000(¥)/year
1. Efficient method of energy recovery	900	1,500	-	4,400	44,800
2. Review and consolidation of the unit's process flow	2,800	4,500	-	13,200	134,500
3. More efficient operation and modifications of rotating equipment					
a. Streamlining of circulating hydrogen gas compressor	800	1,300	-	5,600	56,800
b. Efficient operation of rotating machines	300	(600)	1,450	1,700	18,000
c. Utilization of maximum capacity of membrane separation facilities	200	(400)	1,000	1,100	12,000
Total	5,000	8,300	2,450	26,000	266,100

6. Summary

As the RH unit is operated under severe conditions of high-pressure and high-temperature, we had a perception that modifications for energy conservation are difficult. However, achievements of energy conservation more than the original targets were made as a result of long-term and persistent efforts for deliberations. Activities were fruitful in terms of technical improvements as well as mind-set of achieving great results. We wish to continue to implement activities aiming at achieving 20% reduction in specific energy consumption by continuously challenging energy conservation of the unit.

7. Future Plans

In order to maintain achievements of activities, further deliberations were conducted.

(1) Specific energy consumption, fuel basic unit, heating furnace efficiency, etc. should be evaluated by monthly performance management, and PDCA cycle activity for maintenance of management should be ensured.

(2) In order to achieve energy conservation targets, we should challenge drastic overhaul of units as in the case of heavy oil desulfurization unit by deliberating improvement measures for energy conservation of other units.