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Energy conservation realized by optimal management of heat exchangers

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◎ **Keywords: Prevention of energy loss due to radiation, conduction, and resistance, etc. (Prevention of heat loss due to radiation and conduction, etc.)**

◎ Outline of Theme

We manage, evaluate, and improve equipment from the viewpoint of operation and facilities to pursuit high efficiency operation every day. The heat exchangers for the crude oil preheating system of the second normal pressure distillation equipment, which is the object of this research, use heat energy of half-finished products for preheating crude oil. The heat recovery rate of the heat exchanger decreases due to contamination as operation hour increases. Therefore, we improved management of contamination condition to realize visualization of management beyond the wall of operation division and maintenance division. By managing degradation of heat recovery rate by monitoring, the optimum period of open cleaning has become possible. Furthermore, we have investigated the cause of contamination that retards the heat exchange. As a result, we have established a way to prevent contamination by chemical injection and have prospect of suppression of heat transfer. The double-sided approach of optimization of maintenance and improvement of daily operation realized significant energy conservation.

◎ Implementation Period for the said Example

May, 2004 - July, 2007 (total 39 months)

- Planning period May, 2004 - April, 2005 (total 12 months)
- Implementation period May, 2005 - May, 2007 (total 25 months)
- Effect verification period June, 2007 - July, 2007 (total 2 months)

◎ Outline of the Business Establishment

- Produced items: LPG, naphtha, gasoline, kerosene, diesel oil, heavy oil, lubricant oil
- Number of employees: 565 (as of April 1st, 2007)
- Type1 designated energy management factory

◎ Overview of Target Facilities

The second normal pressure distillation equipment (hereinafter 2C equipment) produces LPG, naphtha, kerosene, diesel oil, and heavy oil by heating, distilling, and cooling crude oil, which can process 220,000 barrel (35,000KL) per day. (Fig.1)
As the object of this energy conservation effort, we selected equipment that preheats crude oil by heat exchange with half-finished products of naphtha, kerosene, light diesel oil, heavy diesel oil, and heavy oil before heating crude oil in the heating furnace.

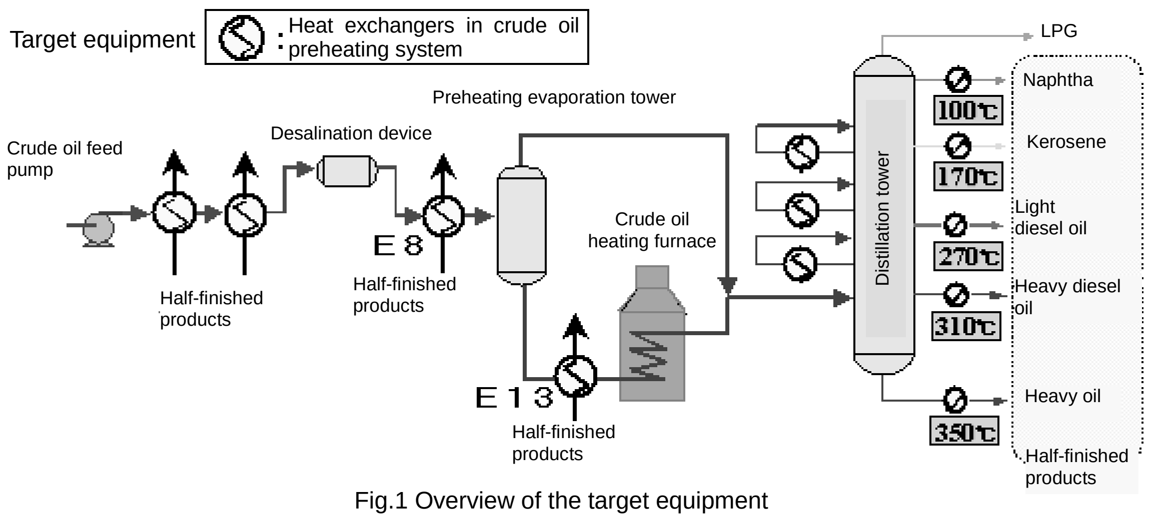


Fig.1 Overview of the target equipment

1. Reasons for Theme Selection

2C equipment has large number of heat exchangers to preheat crude oil from the viewpoint of effective utilization of heat energy. Crude oil preheating heat exchangers are the essential part of energy-conserving operation of 2C equipment. However, the heat recovery rate of the heat exchanger decreases due to contamination as operation hour increases. Although the performance is recovered by regular open cleaning of heat exchangers, it is difficult to perform open cleaning of all the heat exchangers from the viewpoint of maintenance cost and restriction on the number of days for regular repair work. The energy consumption of the 2C equipment accounts for 54.5% of all energy consumption of our department (Fig.2), so we expected that avoidance of energy loss by these heat exchangers will lead to significant energy conservation. This is the reason why we chose this as our theme.

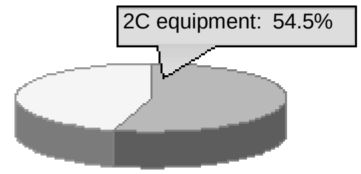


Fig.2 Total energy consumption ratio of this department

2. Understanding and Analysis of Current Situation

(1) Understanding of current situation

To distill crude oil to separate each product in the 2C equipment, the crude oil is heated from normal temperature to the target temperature. The crude oil exchanges heat with half-finished products in the heat exchangers of the preheating system until its temperature reaches 260℃ and then heated to the target temperature 365℃ in the crude oil heating furnace. (Fig.3)

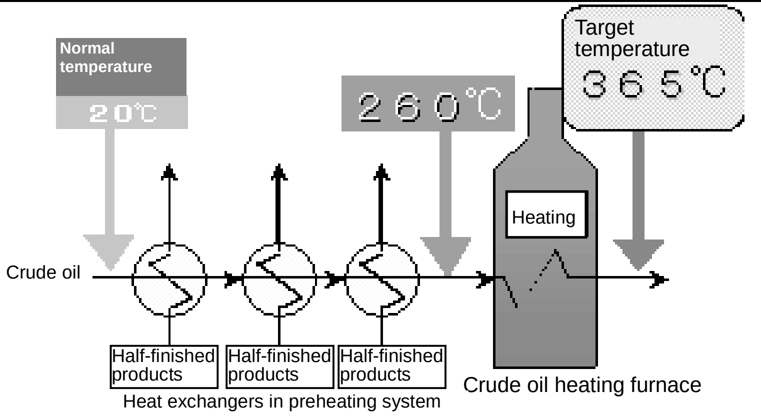


Fig.3 Flow of crude oil heating

1) Relation between contamination of heat exchangers and specific fuel consumption

Heat exchange is performed between the high-temperature half-finished products extracted from the distillation tower and crude oil, but the heat exchangers goes to worse by contamination as operation time elapses, and the inlet temperature of the heating furnace decreases. This increases the load of crude oil heating furnace and the index of specific fuel consumption (hereinafter index) rises. The index is represented the reference to the specific unit at the start of operation after planned halt. (Fig.4)

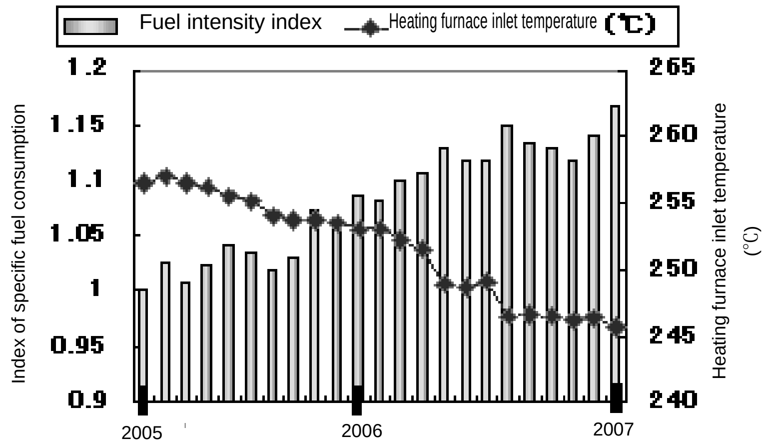


Fig.4 Heating furnace inlet temperature and index of specific fuel consumption

2) Open cleaning of heat exchangers

U-shaped pipe heat exchangers are used in the crude oil preheating system. To recover the performance, thorough open cleaning is performed. In thorough open cleaning, channel covers are removed, tube bundles are pulled out, and the contamination deposited inside of the shell tubes are cleaned. (Fig.5)

In the traditional process of regular repair work, the equipment for thorough open cleaning is selected under the basis on the past result of open cleaning check.

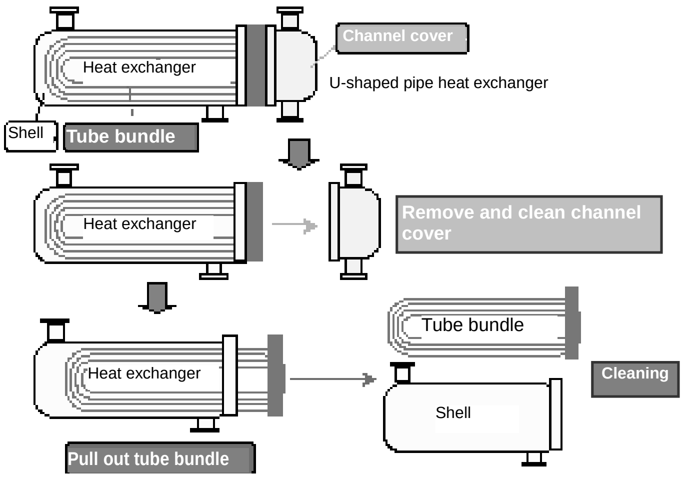


Fig.5 Thorough open cleaning of heat exchanger

(2) Analysis of current situation

Heat recovery rate can be recovered by thorough open cleaning, but there is a limit on the number of equipment to be opened. We had brainstorming meeting on maximizing exchanged heat quantity while preventing production loss due to stop of equipment. We summarize the factors on "why does the specific fuel consumption index get worse?" in Fig.7. ;

[1] Due to lighter crude oil, heavy oil fraction that accounts for a large amount as the heat source of preheating decreases and the amount of heat to be exchanged also decreased. (Fig.6)

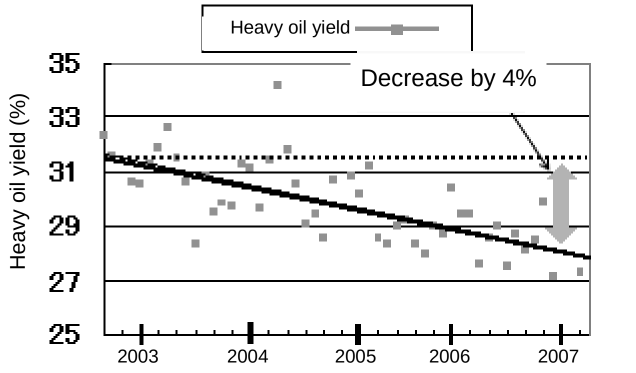


Fig.6 Trend of heavy oil yield

[2] From the viewpoint of operation management, the method to grasp the contamination in time sequence was incomplete.

[3] From the viewpoint of equipment, intervals to open the heat exchangers (intervals for cleaning) were not appropriate.

We have found that the above three factors are significant. [1] For lighter crude oil, heavy oil yield changed as large as 4% compared to four years ago and the mismatch with the initial design conditions and incompatibility of heat exchanger network in the crude oil preheating system had been induced. However, using lighter crude oil is a management strategy, so it is difficult to change the type of crude oil from the viewpoint of energy conservation. In addition, there are a lot of restricts in Plot-Design pressure in reviewing the heat exchanger network and a large amount of capital investment is required, so it is very difficult.

Therefore, we decided to discuss focusing on [2] grasping contamination of heat exchangers in time sequence to determine open cleaning intervals and [3] optimization of open cleaning intervals of heat exchangers.

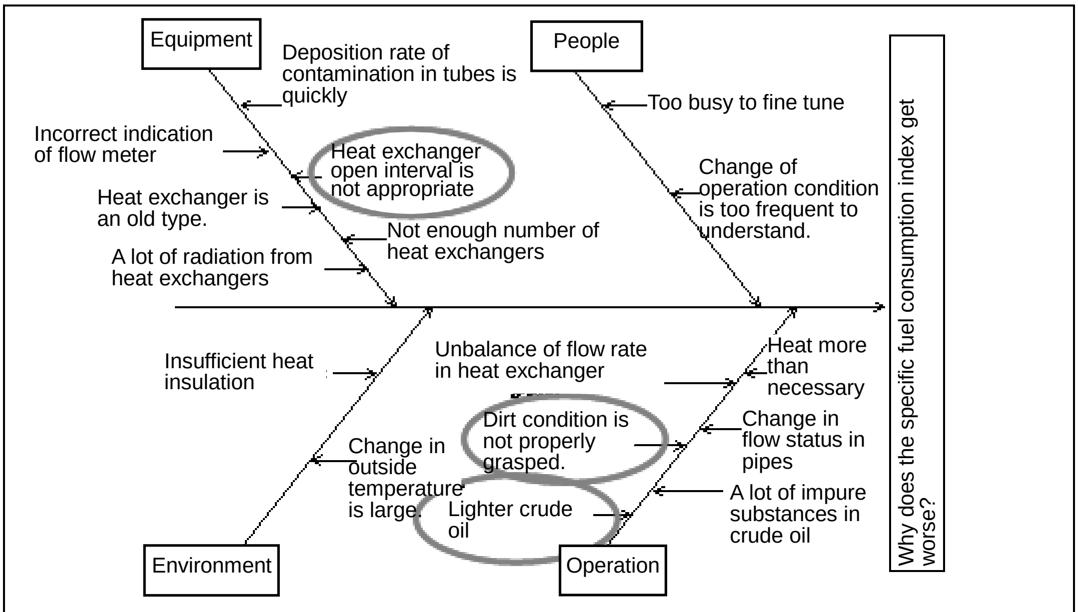


Fig.7 Fishbone diagram

1) Management of contamination of the heat exchanger

Traditionally, to manage the contamination of heat exchangers, the temperature difference (Δt) between high inlet liquid temperature (Th1) and low outlet liquid temperature (Tc2) was monitored. This depends on the fact that the low outlet liquid temperature drops as contamination accumulates and heat recovery rate decreases and that the temperature difference becomes large. Until recently, this management method was sufficient because the performance change in the material was small and variation of flow rate was also small. However, as we use wide varieties of crude oil types and change in flow rate and performance, this is not enough as the monitoring index of contaminateion. (Fig.8)

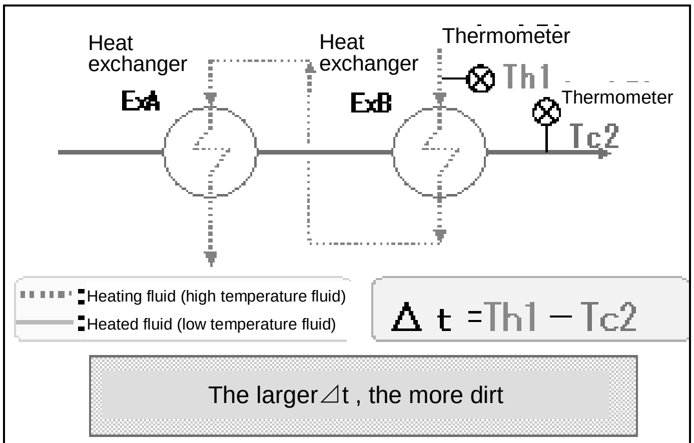


Fig.8 Management of heat exchanger contamination

2) Open intervals of heat exchangers

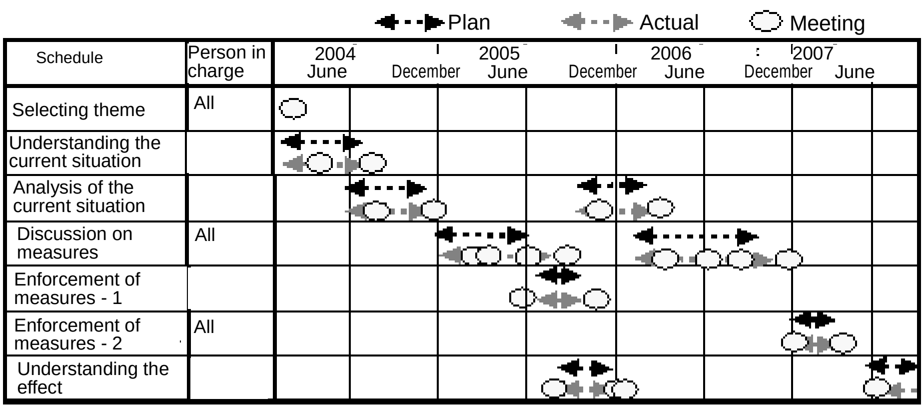
The open cleaning of heat exchangers is conducted by law, some based on the result of open check from the viewpoint of maintenance, and some performed on equipment that affects production. Loss of energy conservation due to contamination was not taken into account when determining open cleaning.

3. Progress of Activities

(1) Implementation Structure

We expected that management of contamination condition of the heat exchangers and optimization of frequencies of open cleaning focusing on energy conservation led to highly efficient energy conservation operation, so we made efforts on optimum contamination management and review of cleaning intervals. For this review, people in charge were assigned within the group to promote this activity. We made some rules such as to report problems case by case on the basis to prevent delay and to have regular meetings, etc. (Table-1)

Table-1 Record of activities



(2) Target Setting

We set our target to review the open cleaning interval of the heat exchangers, to improve heat recovery rate, and to reduce 4,000COE-KL/year of fuel consumption (crude oil equivalent) (50% of annual energy conservation of target value of the Chiba Refinery).

(3) Problem Points and their Investigation

- **Problem points and their investigation 1**

Management of contamination of the heat exchangers

Instead of traditional management using Δt, more precise grasp of contamination condition was required. We decided to try contamination management using overall heat transfer coefficient (U value), which also serves as an opportunity for learning young employees.

a. Grasping contamination using overall heat transfer coefficient

The U value is a number that expresses how well heat transfers. Using this U value, the amount of heat transfer of heat exchangers can be represented as $Q=UA\Delta T$. (Fig.9) The U value is determined by the boundary layer heat transfer resistance and contamination resistance on both sides of the heat exchanger. The boundary layer resistance depends on the flow rate and physical properties of the fluid. Contamination resistance increases with amount of contamination and temperature difference equivalent to resistance is generated. If contamination accumulates even more, the U value will be predominated by the contamination resistance and significantly decrease, so this is effective as the heat transfer index. (Fig.10)

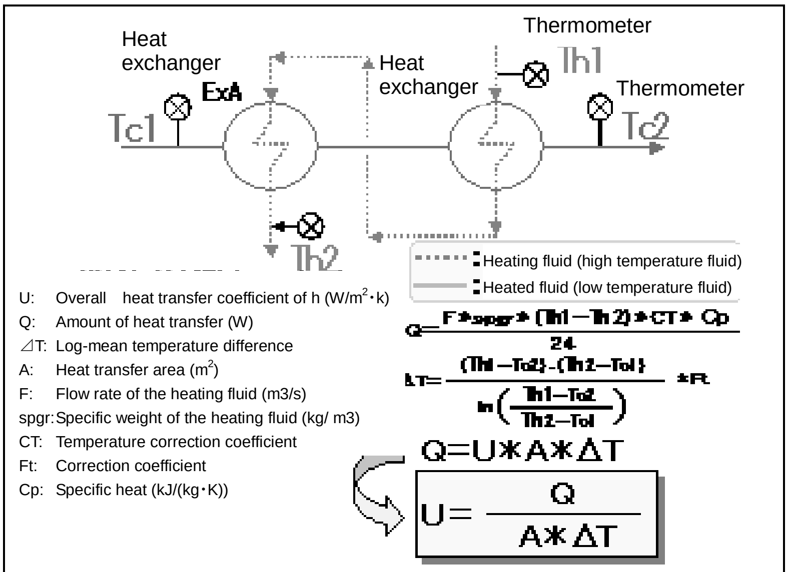


Fig.9 Overall heat transfer coefficient

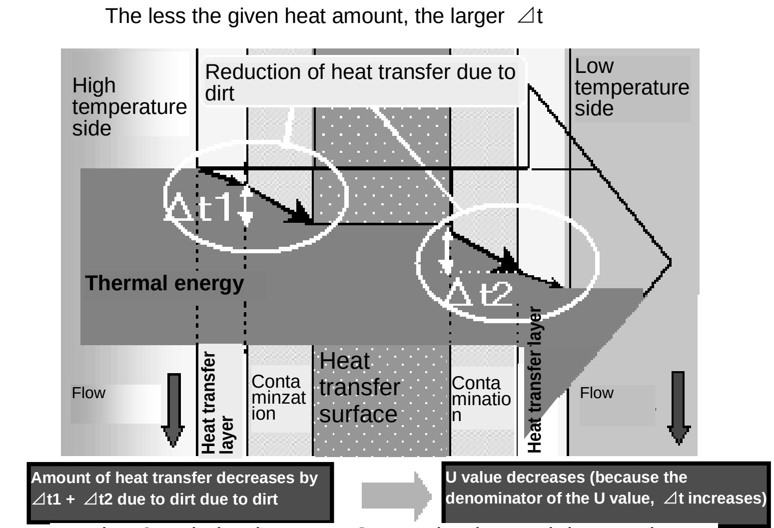


Fig.10 Relation between Contamination and the U value

b. Comparison of Δt and the U value

We compared Δt and the U value of a typical heat exchanger after thorough open cleaning. In some cases, the U value decreased significantly while Δt did not show significant reduction. (Fig.11) This is because Δt does not contain the factors such as flow rate and enthalpy as defined above. The actual data shows that Δt monitoring is incompletely. For heat exchangers in the crude oil preheating system of 2C equipment, heat transfer surface gets contamination by crude oil and heat exchange becomes worse. So we can manage heat exchange by U value for contamination monitoring.

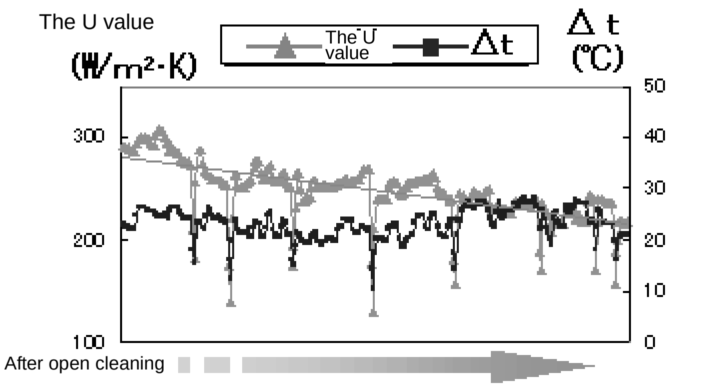


Fig.11 Comparison of ⊿t and the U value

c. Determining intervals to open heat exchangers and setting management values

We started checking change in contamination using the U value, and found a heat exchanger that shows significant degradation of performance in recent years (Fig. 12). This heat exchanger (E8) is located at the inlet of the pre-evaporation tower. Because the open cleaning interval in the past was 8 years, we have no plan of open cleaning on this heat exchanger during the planned stop in 2005. We calculated the energy loss when it operated continuously until 2007 without open cleaning in 2005, and compared the maintenance cost and energy loss when the open cleaning had been performed, and reached the result that open cleaning would bring benefits. We hastily coordinated concerned divisions to perform open cleaning during the planned stop in 2005 and decided to perform the open cleaning. We recognized that “energy conservation effect” is an important factor to decide the interval of open cleaning.

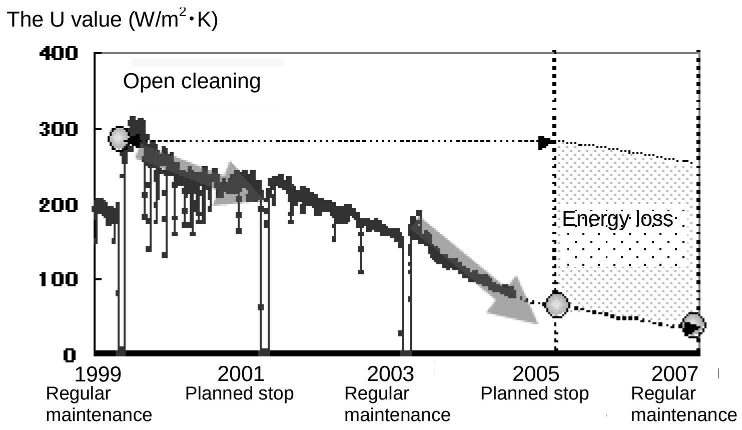


Fig.12 Energy loss of E8 based on calculation of the U value

As a result of open cleaning during the planned stop in 2005, the U value was recovered. . We found that by monitoring the U value, contamination condition can be precisely grasped and the timing of open cleaning that minimizes energy loss can be determined. We applied this method to other heat exchangers and newly added open cleaning management values to the U value as the choosing material to determine the timing of open cleaning of heat exchangers.

d. Adjustment of open cleaning intervals of heat exchangers by switching from monitoring of the U value to management

Since 2005, we had been monitoring contamination conditions of heat exchangers by the U value every day. As of June, 2006, there was little reduction of U value, so we judged that open cleaning would not be required during the regular maintenance in 2007. However, we noticed that the U value was getting worse faster than that expected in December, 2006.
For this heat exchanger E8, open cleaning was planned in 2009, but we found that U value gets worse than the expected value. Therefore, we hastily decided to perform open cleaning in 2007. We checked the data again and found that the U value precipitously dropped in six month after the open cleaning. (Fig.13)
By keeping monitoring, we can monitor the trend of contamination after open cleaning, but cannot quickly respond to change of contamination condition, which is not the original management. Therefore, we decided to create a tool to monitor and to manage the U value.
On the other hand, while the group was talking why the U value rapidly drops after open cleaning, a member asked “what is the cause of contamination?” Therefore, we also decided to thoroughly investigate the fundamental cause of contamination to make the interval to open heat exchangers appropriate.

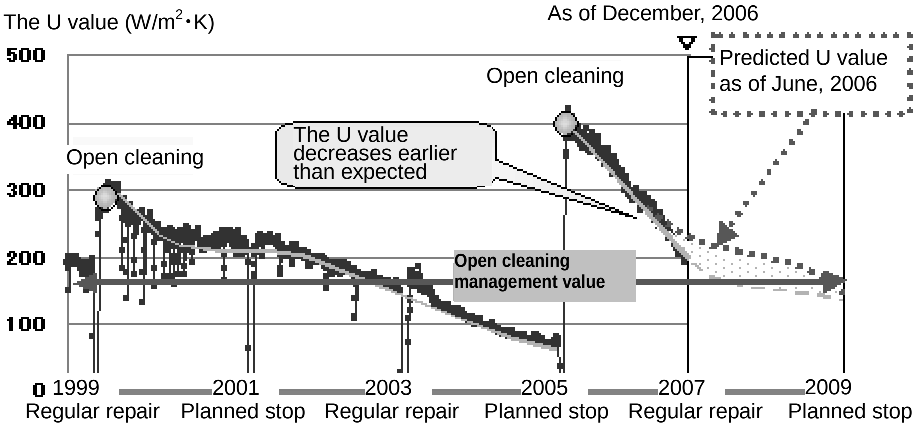


Fig.13 Trend of U value descending of E8

Derived from the case that open cleaning of a heat exchanger was hastily determined in 2007, it became clear that traditional monitoring of the U value cannot grasp the timing of open cleaning sufficiently.

In addition, to reflect open cleaning to planning of regular repair work, it must be determined earlier whether open cleaning is required or not.

We discussed if we can predict the U value in two years after open cleaning by carefully monitoring the trend of the U value with shorter intervals than before. We tried to predict the U value in two years after open cleaning based on the past data on daily operation.

Using the data when we almost forged the open cleaning as of June 2006, the result indicated that open cleaning in 2007 is recommended as of June 2006. (Fig.14) We found that prediction of U value in two years is possible by grasping trend based on the past data.

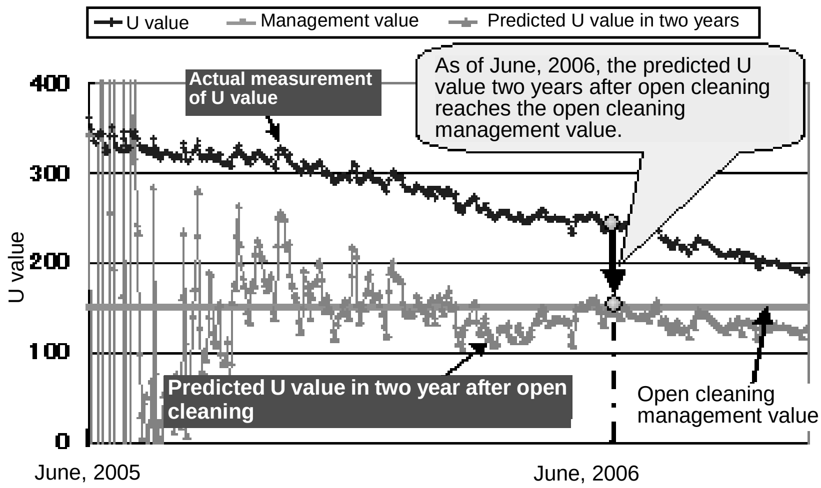


Fig.14 Verification of predicted U value of E8 in two years

- **Problem Points and their Investigation 2**

Causes of contamination of heat exchangers

Our group considered and investigated the fundamental causes of contamination again. As a result, four items were identified as the causes of contamination. We verified and reviewed each of the four items. (Fig. 15)

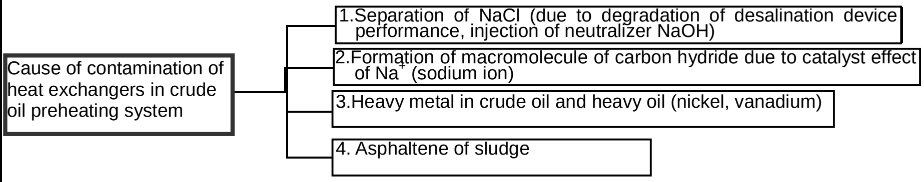


Fig.15 Cause of contamination of heat exchangers

For items [1] Separation out of NaCl and [2] Formation of macromolecule of carbon hydride due to catalyst effect of Na+, desalination device is placed before crude oil preheating heat exchangers to separate salt (NaCl), and the salt level in crude oil is controlled by the desalination rate.

In addition, water is injected into heat exchangers to resolve and prevent precipitation. For [3], trend control of heavy metal in crude oil and heavy oil is managed in regular tests. For [4] asphaltene of sludge, however, it is not currently managed, and we have no knowledge of the mechanism of sludge, etc. Therefore, we researched on literature etc. and found that preventing formation of sludge whose main component is asphaltene will diminish contamination of heat exchangers.

Asphaltene is the collective name of materials that have aromatic ring, aliphatic chain, aliphatic ring (naphtene), functional group of oxygen, sulfur, and nitrogen, and a little amount of metal, which is heavy hydrocarbon soluble to alkyl aromatics solvent. This forms aggregate and grows enormous to form sludge. (Fig.16)

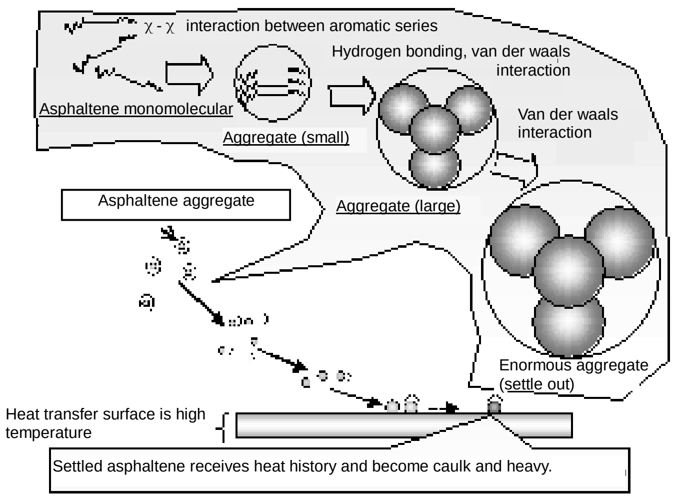


Fig.16 Asphaltene of sludge

Because asphaltene particles are not soluble to oil, they exist in oil via oil-soluble components such as resin.

However, when the stability is lost for some reason, asphaltene is precipitated, aggregates, grow enormous and settles out. Settled asphaltene receives heat history and becomes caulk and heavy. We found this is the cause of contamination.

After open cleaning in 2005, it is suspected that the surface temperature of the heat transfer surface became higher to promote sludge formation and contamination grew rapidly. We found that countermeasures against sludge formation are important keys to maintain performance right after cleaning.

We lost no time in discussing improvement proposals to reduce sludge formation of asphaltene and evaluated in matrix including their feasibilities and effects. (Table-2) As a result of evaluation, we found that methods changing the operation conditions to reduce contamination are not feasible because production loss is too large. We reached a conclusion that decomposition cleansing of asphaltene during operation is useful. We immediately started research in cooperation with staff and operation management.

Table 2 Proposals of improvement to reduce contamination in heat exchangers

◎5 points ○ 3 points △1 point	Feasibility	Economic efficiency	Safety	Evaluation
Selection of crude oil (with less asphaltene)	△	△	○	5
Lower the operation temperature	△	○	○	7
Decrease charge amount	△	○	◎	9
Shorten intervals of open cleaning of heat	○	△	△	5
Decomposition cleansing of asphaltene during operation	◎	○	○	11

As a result of the research, we found chemical that is effective to reduce sludge formation of asphaltene so progressed to enforcing it.

The mechanism for removing contamination is that the material (chemical) that works in place of resin attaches to asphaltene and stabilizes it in crude oil and that prevents sludge formation of asphaltene. (Fig.17)

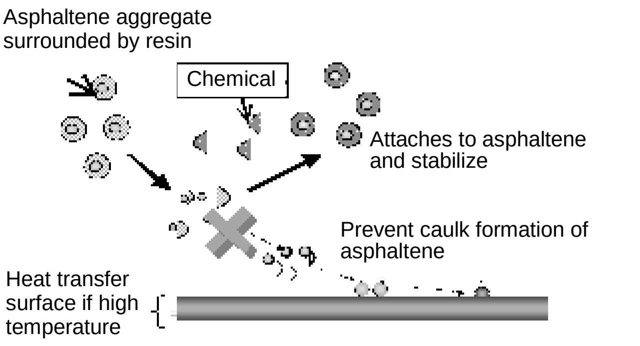


Fig.17 Mechanism to prevent contamination accumulation

4. Details of Measures

(1) Visualization of intervals of open cleaning of heat exchangers

By utilizing the U value, it is possible to grasp contamination condition of heat exchangers. We constructed a management tool to verify daily trend of the U value. At the same time, we can estimate the U value in two years from the gradient of the trend, and determine the timing when it reaches the management value so that we can determine whether open cleaning is necessary or not when the equipment is stopped. (Fig.18) By this way, we can quickly determine whether open cleaning is required or not.

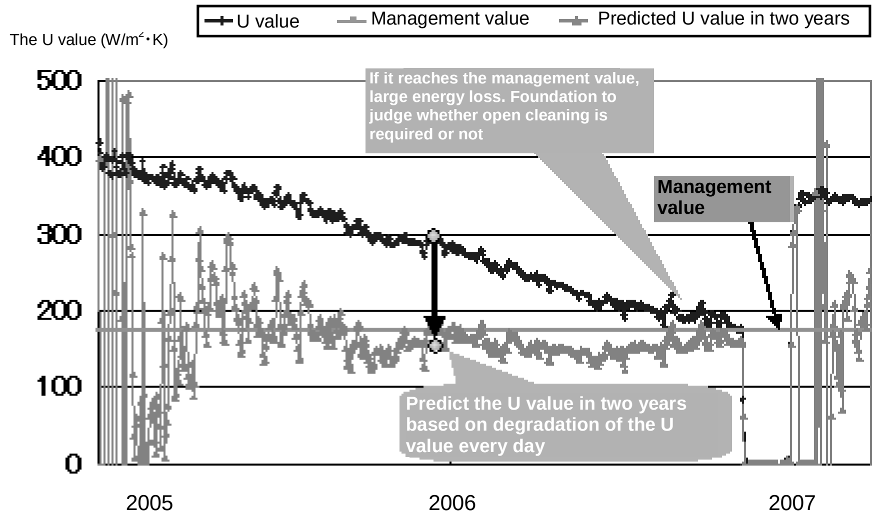


Fig.18 Prediction chart of open cleaning of E8

(2) Enhanced collaboration with maintenance department

Through the performance report for each month in the morning meeting that is held every morning with maintenance Department, the management tool is used to report contamination trend of the heat exchangers so that the timing of open cleaning can be determined at a glance.

In addition, as shown in the equipment management work flow (Fig.19), equipment that is opened is considered also from the viewpoint of energy conservation in the evaluation meeting for each system that is held with Maintenance Department (where operation and maintenance statuses for each system are discussed and actions are clarified). Equipment management activity where Maintenance Department and Operation Department work together in consideration of reduction of maintenance cost more than ever has been conducted.

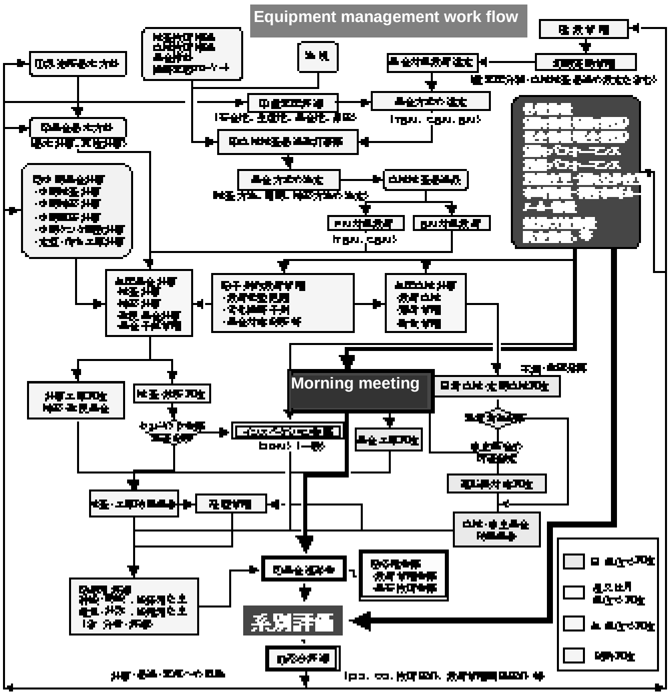


Fig.19 Equipment management work flow

(3) Effect of chemical injection

The chemical was injected to heat exchangers at the crude oil heating furnace inlet that is especially susceptible to contamination before the regular repair in 2007. We carefully verified whether it affects operation of 2C equipment or whether it affects products. Then we comprehensively managed the changes in the refinery and enforced verification operation.
As a result, there are no problems in operation and equipment. After regular repair in 2007, chemical injection has been continued up to the present.
We investigated the contamination condition of E13, which is located at the crude oil heating furnace inlet, using the U value. We compared the U values during two months after open cleaning in 2003 and 2007 and verified that the reduction of the U value is moving slowly. (Fig.20)

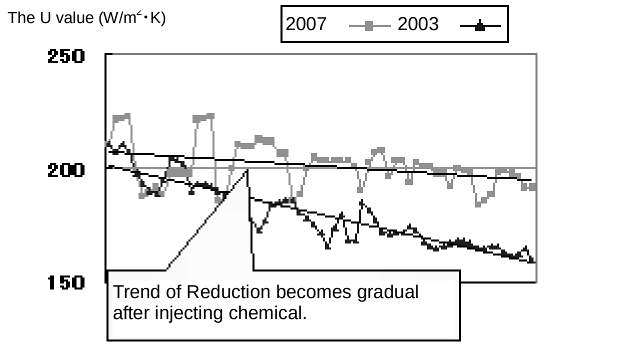


Fig.20 Change in the U value of E13 before and after injecting chemical

5. Effects Achieved After Implementing Measures

(1) Traditionally, contamination of heat exchangers is only monitored, but using the U value, we created a management tool to manage it. As a result, we can perform optimal open cleaning of heat exchanger taking in account of energy loss. For E8, the intervals to open were changed from 8 years to four years and to two years. By open cleaning of heat exchangers to increase the amount of heat recovery, we reduced 8,966COE-KL/year of energy consumption compared to the target 4,000COE-KL/year, and we obtained the result significantly exceeding the target. (Table-3)

(2) By linking with equipment management work and by enhancing collaboration with Maintenance Department, we advanced to equipment management in consideration of energy conservation.

(3) For chemical injection, increase rate of specific fuel consumption during two months after regular repair in 2003 and 2007 was 0.7% in 2007 compared to 2.3% in 2003. We verified that increase in specific fuel consumption is suppressed. However, because the injection period is short, we plan to continue monitoring its effect in the future.

Table-3 Effect of measures

Monetary amount of conserved energy	370 million yen/year
Amount of conserved energy (crude oil equivalent)	8,966 COE-KL/year
Reduction of CO_2	23,747 t/year
Cost of open cleaning of heat exchangers	13.10 million yean/year

6. Summary

Establishing prediction management of contamination condition of heat exchangers by operators and visualizing it enabled open cleaning at the appropriate timing. In addition, we realized innovation that is conscious of energy conservation and maintenance cost and realized maximum affectivity with enhanced collaboration of Operation Department and Maintenance Department. Furthermore, we found the possibility of highly effective operation with control of contamination by chemical injection. As a result of such efforts with new viewpoints, we realized significant energy conservation effect, which lead to our self confidence. We plan to continue energy conservation activities always considering promotion of reduction of global environmental load.

7. Future Plans

We plan to further improve the precision of contamination management by the tool to maintain the efficiency of heat exchangers. We also plan to actively promote horizontal development to our other facilities that face similar problems to contribute to energy conservation.