**2006 Prize of the Chairman of ECCJ**

# Energy Conservation by inhibiting the coke generation in tube of furnace

Idemitsu Kosan Co., Ltd., Chiba Refinery
1st Oil Manufacturing Department
D-Dream Group

◎ **Key phrase: Rationalization of fuel combustion; heating; cooling; rationalization of heat transmission (heating facility)**

## ◎ Outline of Theme

We are pursuing the high efficient operation of equipments through proper management/evaluation and making improvement of facility in terms of operation and maintenance procedures. Despite the fact that various measures were implemented to lower the loads in the past, the fuel consumption intensity of the furnace feedstock of heavy oil direct desulfurization unit has been increasing in recent years. Under such circumstances, we have tried to inhibit the coke generation that adheres to the inner surface of the tube in the heating furnace and is one of the intensity factor increases by identifying the current problems to be solved, as well as utilizing heating furnace analyzing simulator and management tools. As a result, we have succeeded in reducing the fuel consumption intensity and achieving significant energy saving effects.

## ◎ Implementation Period for the Said Example

January 2004 — August 2006 (Total 32 months)

- Planning period: January 2004 — April 2005 (Total 16 months)
- Measures implementation period: May 2005 — May 2006 (Total 13 months)
- Measures effect verification period: June 2006 — August 2006 (Total 3 months)

## ◎ Outline of the Business Establishment

- Production items: LPG, Naphtha, Gasoline, Kerosene, Light oil, Heavy oil, Lubricant
- Employees: 462 (as of April 1, 2006)

- Annual energy consumption (actual result for FY 2005)

| | |
|---|---|
| Fuel, etc. (crude oil equivalent): | 803,000 KL |
| Electric power: | 514,000 MWh |

## ◎ Overview of Target Facilities

A heavy oil direct desulfurization unit (hereinafter referred to as "LX unit") produces desulfurized heavy oil through the reaction of heavy residual oil and hydrogen under high temperature and high pressure using a catalyst. The stock oil heating furnace (hereinafter referred to as "LX-H1A･B") is a major facility that consumes about 34% of the total energy consumption in the entire plant (Figure 1).

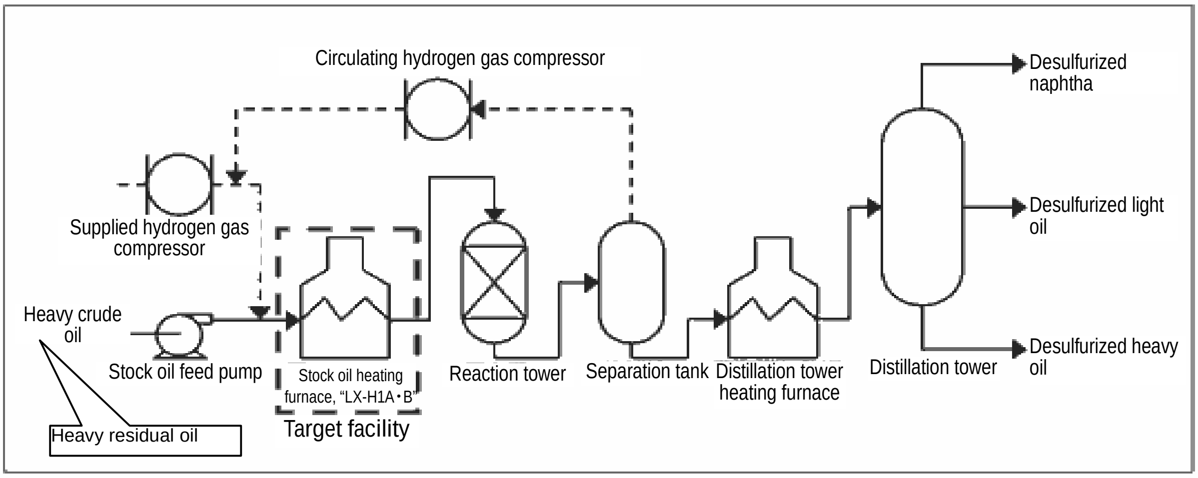


Figure 1 General flow diagram of the target facility

## 1. Reasons for Theme Selection

Our business office is conducting performance management (evaluation of the operating data to the reference value) in order to grasp and control the daily operating conditions of the equipment. We have found that despite periodically removing the coke (hereinafter referred to as "decoking") that adhered to the inner surface of tubes, fuel intensity of "LX-H1A･B" which consumes a significant amount of energy in the "LX" unit has increased by 1.2 COE-L/KL after the decoking operation conducted in 2003 compared to that in 1998. We considered that such a phenomenon occurred because "the decoking effect had worn off" and decided to work on this theme.

# 2. Understanding and Analysis of Current situation

## (1) Understanding of current situation

### 1) General description of "LX-H1"

The LX unit is used to desulfurize heavy residual oil using hydrogen and catalyst under high temperature and high pressure. The stock oil heating furnaces are set two type of furnace, LX-H1A and LX-H1B, in the unit. Each heating furnace is of the center wall type, and the tubes are installed four tubes in total by two stages at the top and bottom and on both sides (Figure 2). The temperature of the stock oil to be transferred to the heating furnace is approx. 290 °C; the stock oil passes through these four tubes of both LX-H1A and LX-H1B, and its temperature is raised to approx. 390 °C.

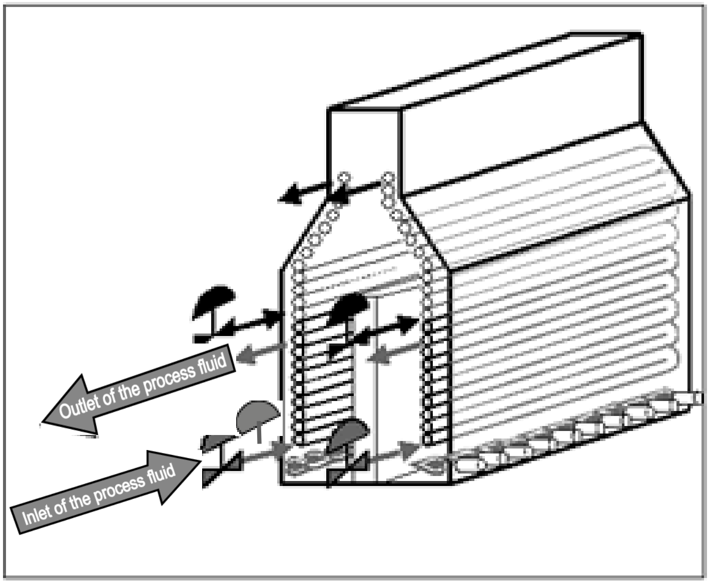


Figure 2: Arrangement of tubes in LX-H1A・B

### 2) Current management of the tubes in the heating furnace

**a. Fouling of tubes**

LX-H1 is the fuel gas burning heating furnace, so unlike those that use the fuel oil, the outer surface of the tube is rarely fouled. On the other hand, the inner surface of the tube is fouled by coking (the generation of coke through the polycondensation substances contained in the stock oil), so the operator has to manually adjust the main valve of the burner in order to keep the surface temperature of the tube uniform.

**b. Decoking operation**

It was found that the accumulating speed increases at an accelerated pace when the thickness of the coke adhering to the inner surface of the tube reaches 5.4 mm, so that, using this thickness as an indication, we conducted periodically operations to remove the coke adhering to the inner surface of the tubes in the heating furnace. We have so far conducted these decoking operations in order to improve the heat transfer efficiency and to reduce the gas consumption.

We planned and executed the decoking operations after estimating the accumulation trend based on the thickness of the coke obtained from the radiographic examination to be conducted during periodic maintenance. We had conducted periodically the decoking operations until 1998, but thereafter, we only conducted one decoking to remove the coke accumulated in the lower tubes in 2003 (Table 1).

Table 1 Record of decoking operation conducted on LX-H1A and LX-H1B

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper column | | | ● | | | | ● | | | | | | | | |
| Lower column | ● | | | | ● | | | | ● | | | | | ● | |

When we asked the maintenance staff the reason for this, they answered that because the evaluation to estimate the thickness of coke in the upper tube showed that it had not reached the level requiring decoking, they conducted no decoking operation after 1996. However, when the unit consumption indexes of the heating furnace after the decoking operation in 1998 and in 2003 are compared, the index of 2003 is definitely higher than that of 1998. (Figure 3).

Incidentally, the unit consumption index is used to indicate the change or difference in the fuel consumptions intensity; as the fuel consumption intensity in 2003, when the operation to remove the coke in the lower tubes of LX-H1A and LX-H1B was performed, is 100.

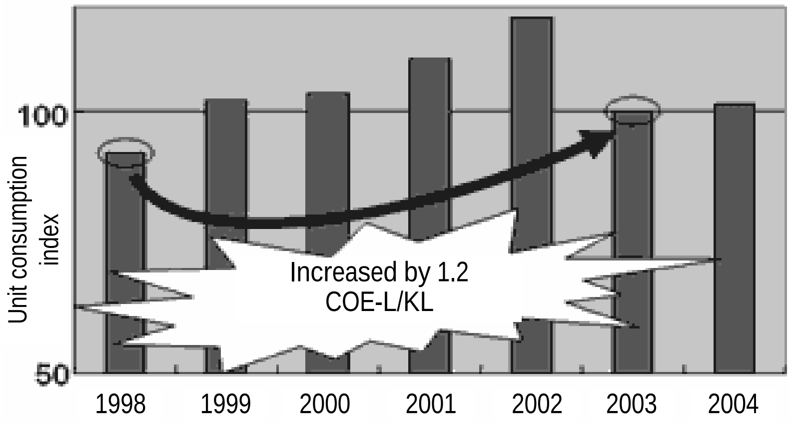


Figure 3 Change in the unit consumption index

## (2) Analysis of Current Situation

Despite the thickness of the coke had not reached the level requiring decoking, the unit consumption index increased. All members of our group gathered together for brainstorming to clarify why the unit consumption index had increased, and prepared a fishbone diagram (Figure 4).

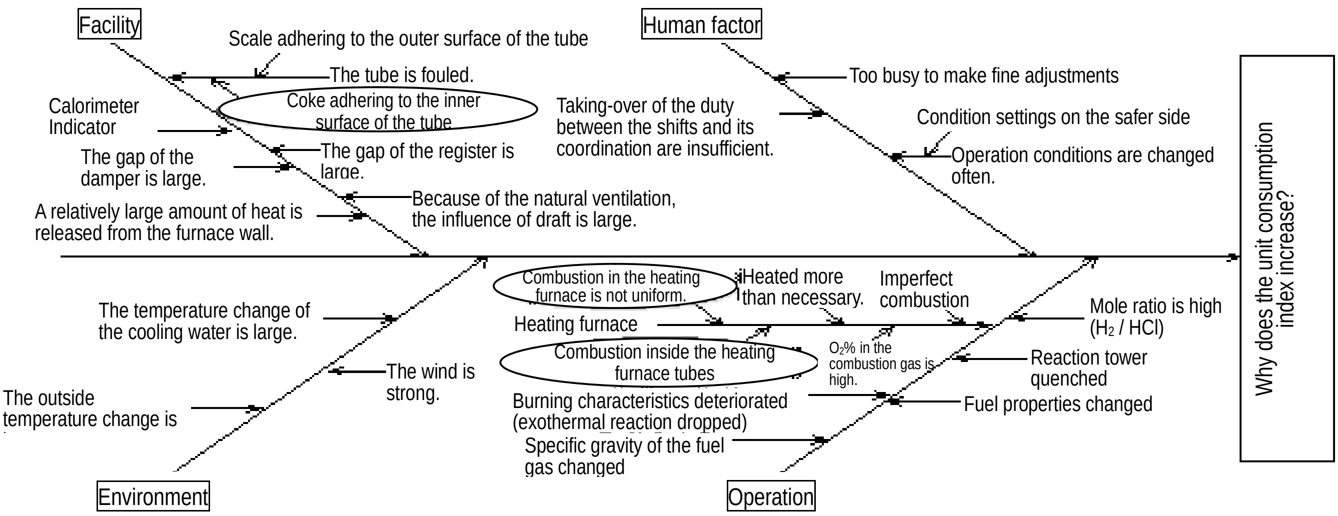


Figure 4: Fishbone Diagram to clarify the reason why the unit consumption index increased

Using the fishbone diagram we prepared, we tried to narrow down the possible causes and concluded that there are no problems in the human and environmental factors. However, three following points are listed as problem issues, in the facility factors, “Coke adhering to the inner surface of the tube” and in the operation factors, “Fluid status inside the heating furnace tube changed” and “Combustion in the heating furnace is not uniform”. The two problem points in the operation side are closely related to the problem point in the facility, “Coke adhering to the inner surface of the tube”, so we conducted further examination considering these to be complex problems.

# 3. Progress of Activities

## (1) Implementation Structure

We decided to assign the responsibility of each task to the members of the group in the section to proceed with the activities. Not to delay the progress, we made a rule that each member should report the problems in each case and that a meeting should be held periodically (Table 2).

Table 2: Organization to take measures and schedule for activities

| Item | Person in charge | Plan ⇠⇢ Implementation → Meeting ☆ | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2004 | | | | | | 2005 | | | | | | 2006 | | | | | |
| | Month | 2 | 4 | 6 | 8 | 10 | 12 | 2 | 4 | 6 | 8 | 10 | 12 | 2 | 4 | 6 | 8 | 10 | 12 |
| Identification of the current situation | Nakayama and Sato | | | | | | | | | | | | | | | | | | |
| Analysis of the current situation | Aikawa and Hiromi | | | | | | | | | | | | | | | | | | |
| Examination of measures to be implemented | All members | | | | | | | | | | | | | | | | | | |
| Implementation of measures | Suzuki and Mihara | | | | | | | | | | | | | | | | | | |
| Identification of effects | Saito and Yoshimura | | | | | | | | | | | | | | | | | | |

## (2) Target Settings

The targets are to improve the heat transmission efficiency of the heating furnace and to reduce the fuel consumption (crude oil equivalent) to 1,600 COE-KL/year (10% of the fuel intensity of the entire LX unit).

## (3) Problem Points and Their Investigation

### 1) Coking to the inner surface of the tube in the heating furnace

First of all, we examined the coking to the inner surface of the tube in the heating furnace, which is a problem in the facility.

#### a. Coking mechanism of the tube in the heating furnace

When the conditions of the heat input from the heating furnace burner deteriorate (deflection of the flame, overheating, etc.) or when the gas flow inside the tube locally changes, the temperatures in boundary layer between fluid and the inner wall rise. When the temperature of the boundary layer rises above 425 ˚C, coke is generated and adheres to the inner surface of the tube. This phenomenon is referred to as "coking" (Figure 5). When the coking occurs to the inner surface of the tube, the heat from the burner is blocked by the generated coke and is not transmitted sufficiently to the fluid inside the tube and, as a result, the fuel intensity increases. During the actual operation, it is possible to control the temperature inside the tube not to reach the designed temperature, but in reality, it is difficult and actually impossible to control the temperature of the boundary layer.

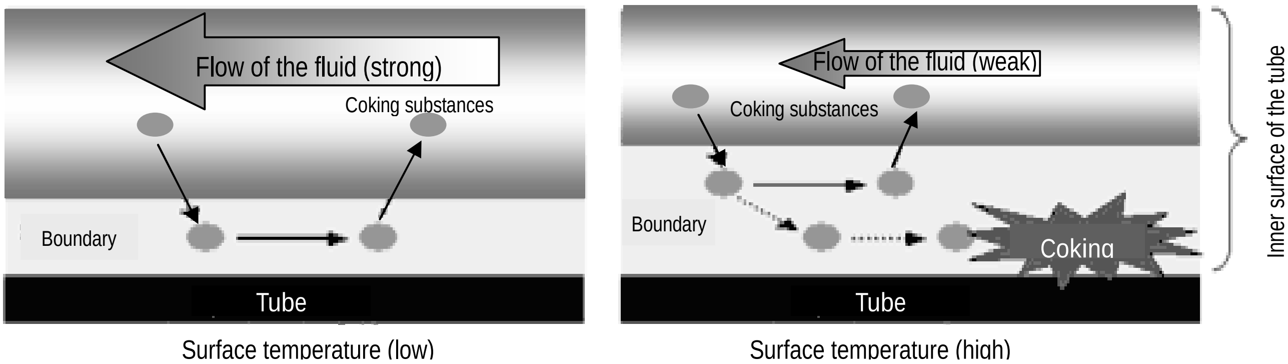


Figure 5 Mechanism of coking

#### b. Estimation of the thickness of the coking to the inner surface of the tube in the heating furnace

The thickness of the coke layer is estimated using the general equation to determine the surface temperature "Tm = To + ΔTf + ΔTc + ΔTm" (the temperature of the fluid inside the tube + temperature difference due to the boundary layer inside the tube + temperature difference due to the coke inside the tube + temperature difference inside the tube wall) (Figure 6).

Here, for the thermal conductivity of the tube, the constant estimated from the tube material is used, and for the thermal conductivity of the coke the constant identified from the past test results is used. The temperature difference, ΔTc, due to the coke inside the tube is calculated using the thermal conductivity of the coke and the thickness of the coke layer. For other operating data, the actually measured values are used. We control the thickness of the coke layer by developing an estimate equation to calculate the thickness of the coke layer from the difference in the temperature of the outside surface of the tube and the temperature of the fluid inside the tube.

However, it was found that the downward tendency of the percentage of the absorbed thermal quantity is largely increase compared to the estimated thickness of the coke layer after 2002, when we confirmed the percentage of the thermal quantity absorbed by the fluid inside LX-H1 (Figure 7).

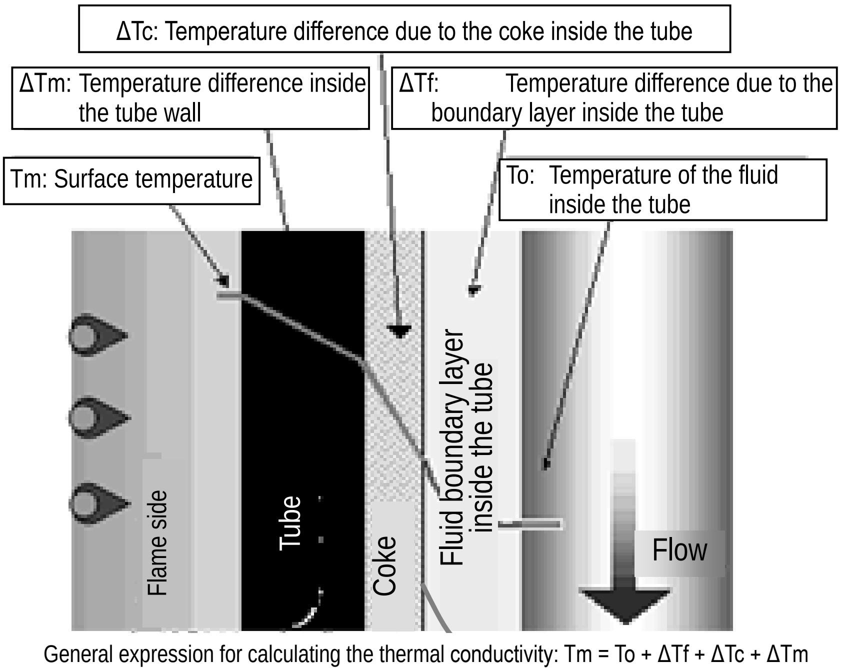


Figure 6 Method for estimating the thickness of the coke layer

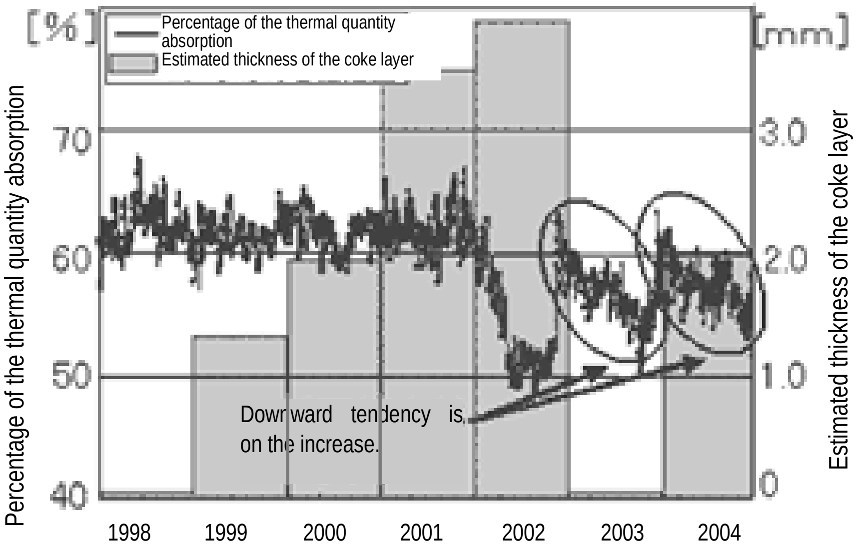


Figure 7 Percentage of the thermal quantity absorption in LX-H1 and the estimated thickness of the coke layer

**c. Influence of the operating changes on the properties of the coke**

From the performance management being conducted on a daily basis and the changes in the combustion heat quantity with respect to the heat absorption quantity, we conducted a thorough investigation through focusing on the change in the properties of the stock oil and the increase in the unit consumption index. As a result, we found that the stock oil had become heavy. Therefore, we examined how the properties of the coke changed when the stock oil became heavy (Figure 8).

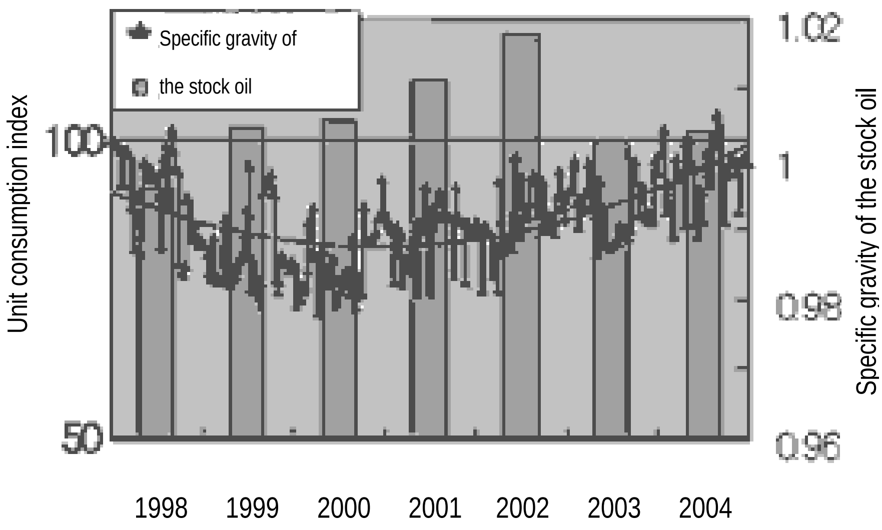


Figure 8 Specific gravity of the stock oil and the unit consumption index

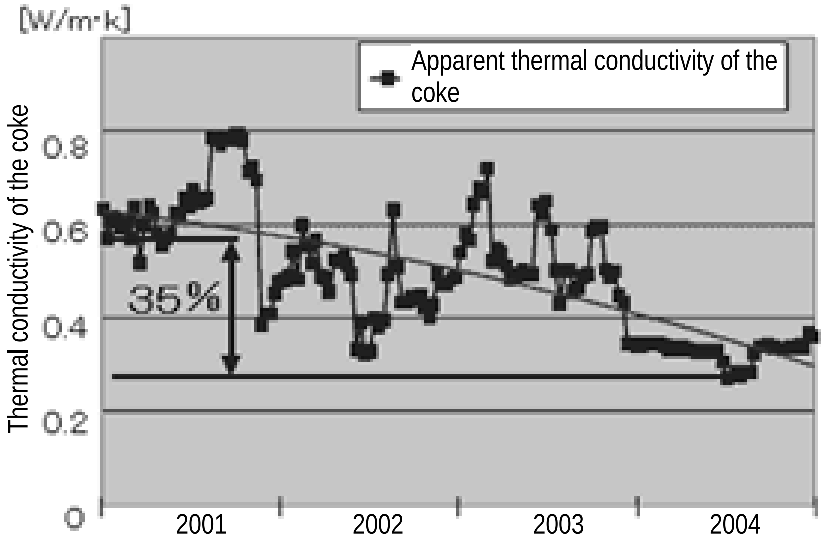


Figure 9 Change in the thermal conductivity of the coke

Based on the experience of developing an estimate equation to calculate the thickness of the coke layer, we decided to use a general equation for calculating the thermal conductivity for this verification. From the thicknesses of the coke layers measured by the radiographic tests conducted during four periodical maintenance works in the past, we found the thermal conductivity of the coke and confirmed the change tendency of it. As a result, the apparent thermal conductivity of the coke dropped by 35% when compared to that of 2001 (Figure 9) and that, with the change in the properties of the stock oil, the properties of the coke as well as the thermal conductivity changed.

In order to improve the unit consumption index based on these results, we believed that we had no choice but to thoroughly eliminate the coke to be adhered to the tube in the heating furnace and asked all the members of the group to propose their improvement plans. Of these, we selected four plans (Table 3) and evaluated them based on the matrix including the feasibility and possible effects, and reached the conclusion that the only way to remove the coke adhering to the heating furnace tube is to increase the frequency of the decoking operations.

Table 3: Matrix for the action plans for removing the coke adhering to the heating furnace tube

| Action plan | Feasibility | Economical efficiency | Effect | Score | Total score |
|---|---|---|---|---|---|
| Replace the tubes in the heating furnace | ○ | × | ◎ | 11 | ② |
| Increase the frequency of the pig decoking operations | ◎ | △ | ◎ | 13 | ① |
| Removal of the coke by operations using light oil | × | × | △ | 7 | ④ |
| Change stock oil to light oil | △ | × | ◎ | 10 | ③ |

◎ : 5 points
○ : 4 points
△ : 3 points
× : 2 points

However, when the frequency of the decoking operations is increased, the cleaning costs also increase and it is necessary to stop the equipment for cleaning for a significantly longer period of time, which results in production loss. Even if we did conduct the decoking operations, spending such costs and time, the unit consumption index would increase again when the coke adheres once again. Therefore, the increased frequency of the decoking operations is not a fundamental solution.

Consequently, we explained our study progress to the maintenance experts for seeking advice from the experts in the company and we received valuable advice that it would be better to study the replacing of the tubes in the heating furnace as an option.

**d. Examination about the option of replacing the tubes in the heating furnace**

Since enormous costs are required for replacing the tubes, we examined the investment cost and effects, and found that this option would not be approved by the internal rules. We, therefore, consulted with the manager on this issue and had an advice that we could make use of “a subsidy for such a project for reducing the emission of carbon dioxide” from the Ministry of the Environment and we could be able to replace some tubes (in LX-H1A) during the periodical maintenance and repair work in 2005 in order to reduce the unit consumption index. Thanks to this subsidy, we managed to justify the investment cost and effects, and make a plan to replace some tubes during the periodical maintenance and repair work in 2005, and confirmed the changes.

As a result, it was confirmed that the unit consumption index improved by about 3%, and if all the tubes were replaced, it would improve by about 12%. Consequently, we consulted with the related departments and expert sections and, as a result, it was determined that all the tubes would be replaced during the periodical maintenance and repair work in 2006 (Figure 10).

However, in order to achieve the fundamental improvement, the coke will not to be accumulated during the operations thereafter. It is necessary to significantly reduce the accumulation of the coke more than before. The major challenge to prevent the coke accumulation in the heating furnace cannot be solved by simply replacing the tubes. Consequently, we examined the problems in the operation identified in the fish bone diagram.

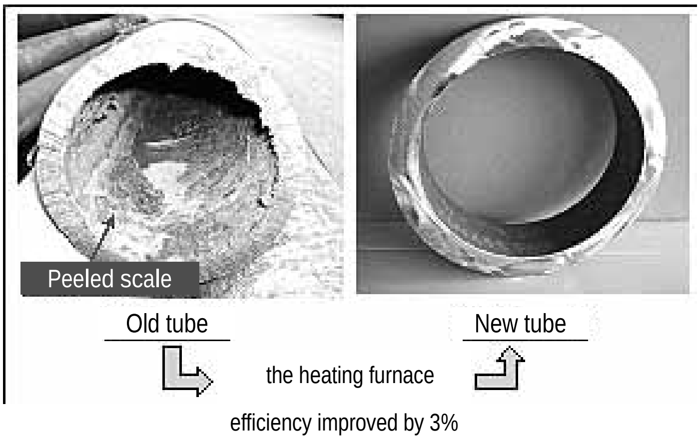


Figure 10: Tube cross sections before and after replacement

## 2) Flow condition in the heating furnace tube

The flow condition in the heating furnace tube is one of the causing factors of tube coking. . When the flow velocity of the stock oil in the tube decreases, the liquid layer will be broken and local heating may occur (Figure 11). In order to prevent this phenomenon and to improve the flow condition, the flow velocity in tube is certain level kept, and it was confirmed that the current control management is satisfactory.

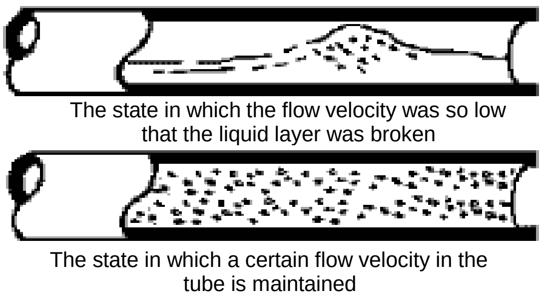


Figure 11 Flow condition in the tube

## 3) Combustion inside the heating furnace

To date, it has been confirmed by the surface thermometers attached to five sides of the heating furnace tubes that there is no local temperature rise and no scattering has occurred in the temperature readings. However, when we performed measurements using the infrared thermometer at points where no surface thermometer is installed, we found that there are some hot points locally (Figure 12). This means that at such hot points, the coke may have potential to be generated locally. As mentioned earlier, the replacement of old tubes with new ones without measures to inhibit the generation of coke is not a fundamental solution. Therefore, to inhibit the generation of coke inside the heating furnace tubes, we developed a systematic diagram to secure the continuous uniform combustion (Figure 13).

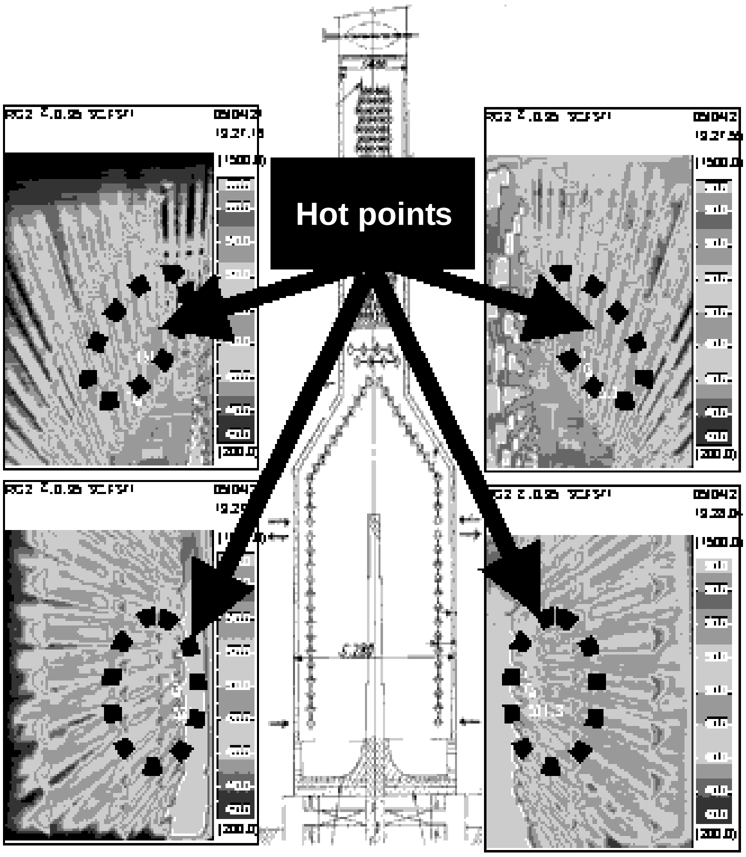


Figure 12 Measurement results inside the tube using an infrared thermometer

| Objective | Approach | Measure | Effect | Feasibility |
|---|---|---|---|---|
| In order to secure continuous uniform combustion | Change the | **Install skin thermometer.** | ◎ | ◎ |
| | | Change the burner output | ○ | × |
| | | **Installation of the fuel gas flow meter** | ◎ | ◎ |
| | | Change the type of heating furnace. | ○ | × |
| | | Change the heat exchanger. | ◎ | × |
| | Change the operation. | Lower the heating furnace load by increasing the heat recovery. | ○ | △ |
| | | Increase the flow velocity in the tube. | ◎ | × |
| | | Lower the operating temperature by changing the catalyst. | ○ | × |
| | Operations in the field | Detail adjustment of the burner | ○ | △ |
| | | Detail adjustment of $O_2$ | ○ | △ |
| | | Fully open the main valve of the burner. | ○ | × |

Figure 13 Systematic diagram to identify the possible ways to secure continuous uniform combustion

Of the above, we selected, as effective and feasible items that deserved to be examined, the installation of the tube surface thermometers and the installation of the flow meters in the fuel gas supply lines on both sides of the heating furnace.

**a. Examination on the installation of the surface thermometers**

First, we thought that it was necessary to grasp the temperature variations in the heating furnace before the examination of the installation of the surface thermometers (Figure 14). However, the measurable range of the infrared thermometer during the operation was limited and it was very difficult to grasp the temperature variations precisely inside the heating furnace. From the related departments and expert sections we obtained the information of a simulator for analyzing the combustion state of inside the heating furnace, and concluded that we might be able to determine the optimum installation position of the surface thermometers using such a simulator. Immediately we conducted analysis of the surface temperature distribution of the heating furnace tubes using the simulator. As a result, the temperatures of the lower tube increased at both sides of the heating furnace inside, and the temperatures of the upper tube increased at the center of wall sides due to the radiant heat (Figure 15). From the simulation results, we decided to add the surface thermometers at the points likely to be hot.

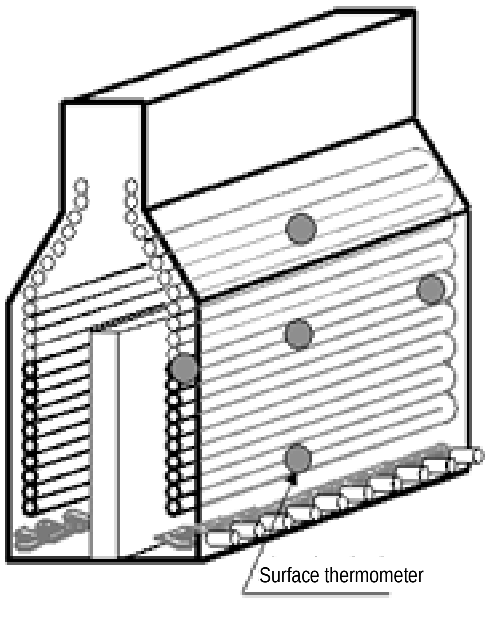


Figure 14 Locations where the surface thermometers are currently installed

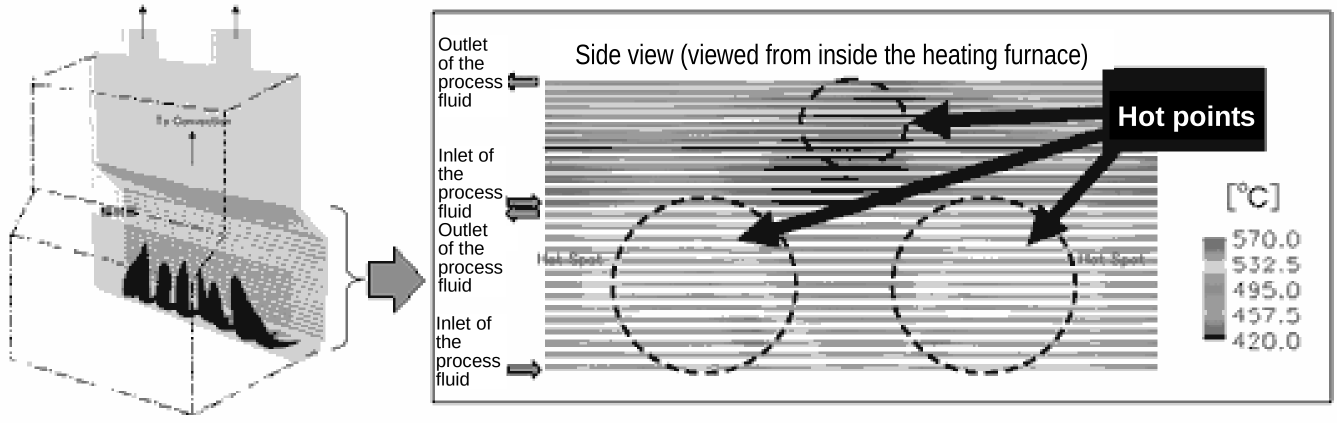


Figure 15 Results of the combustion analysis

**b. Examination on the installation of flow meters in the fuel gas supply lines**

Next, we examined the effectiveness of installing the flow meters in the fuel gas supply lines. Until then, we could not grasp the fuel gas quantity supplied to each heating furnace (Figure 16). However, if it is possible to adjust the fuel gas flow rates accurately at LX-H1A and LX-H1B sides (at four points), it is possible to inhibit the abnormal generation of coke by the local heating at each side. In addition, through appropriate heat balance control, a more uniform heating condition can be maintained.

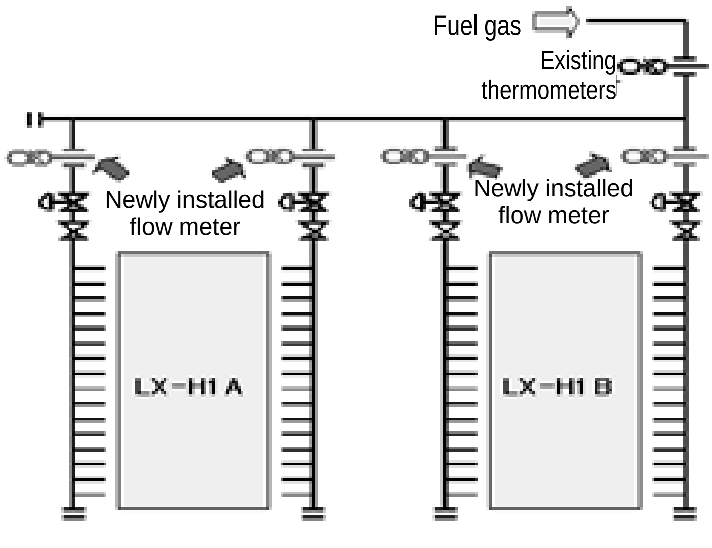


Figure 16 Schematic drawing of the existing fuel gas supply line

# 4. Details of Measures

## (1) Removal of Coke by Replacing the Tubes in the Heating Furnace

During the periodical maintenance and repair work in 2006, all the remaining tubes in the heating furnace were replaced with new ones. As a result, the load on the heating furnace was minimized, and we could confirm the further drop of the unit fuel consumption index.

## (2) Measures for Minimizing the Generation of Coke in the Tube

### 1) Heating furnace surface temperature thermometers

During the periodical maintenance and repair works in 2005 and 2006, the number of surface thermometers installed was increased from 5 points on the one side to 15 points, used the hot points estimated by the heating furnace combustion analysis as indicators. As for the sensors of the surface thermometers to be installed, in accordance with the advice from the related departments and expert sections that instead of the conventionally used pad type sensors, a “fan-shaped pad” (Figure 17) should be used because it has a wider contact surface and offers stable temperature indications, we decided to adopt such type of pad. The fan-type pad thermometer can measure directly the temperature of the tube surface without being influenced by the radiant heat in the furnace, so that it is more reliable than the conventional pad type thermometer and, as a result, the measured surface temperature dropped by about 100 ˚C (Figure 18).

Furthermore, we checked the indications of the newly installed surface thermometers and they showed almost same tendency with the temperature distribution obtained by heating furnace combustion analysis; therefore, it was confirmed that the results of the simulation were in line with those of the actual operation (Figure 19).

From the knowledge gained to date, it is known that when the boundary temperature exceeds 425 ˚C, the coking substances are generated and when it exceeds 450 ˚C, the coking proceeds with increasing speed. Therefore, as the operating guideline, we set the surface temperature to be 425 ˚C or under, and set the control upper limit value as 450 ˚C. Moreover, we also set the control upper limit value of the fluid temperature inside the tube at 400 ˚C.

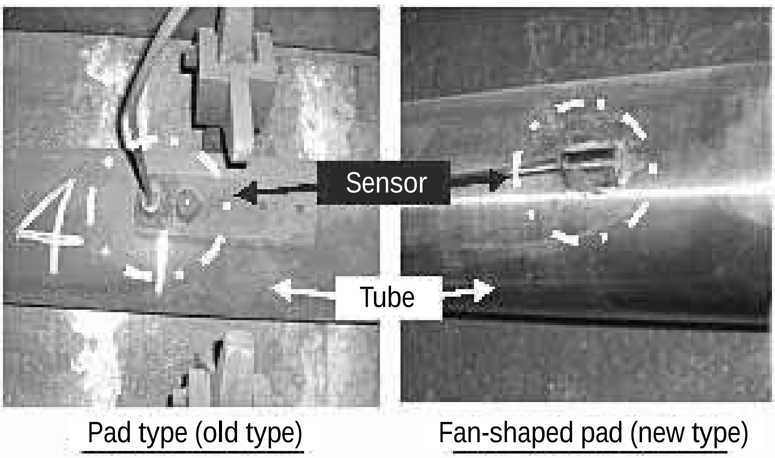


Figure 17 Fan-shaped pad type thermocouple

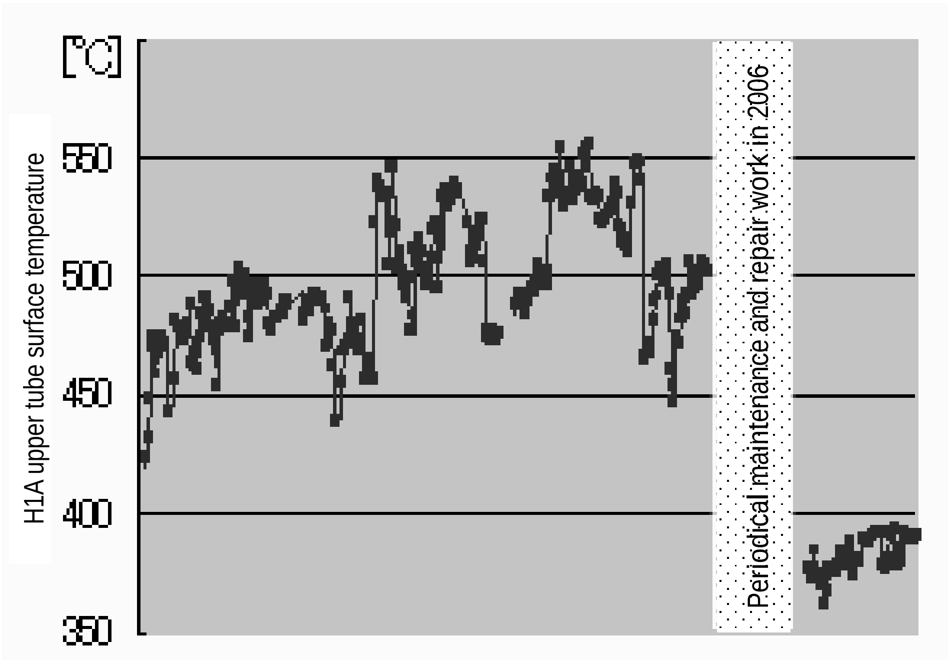


Figure 18 Temperature change after replacing the thermometer sensors surface

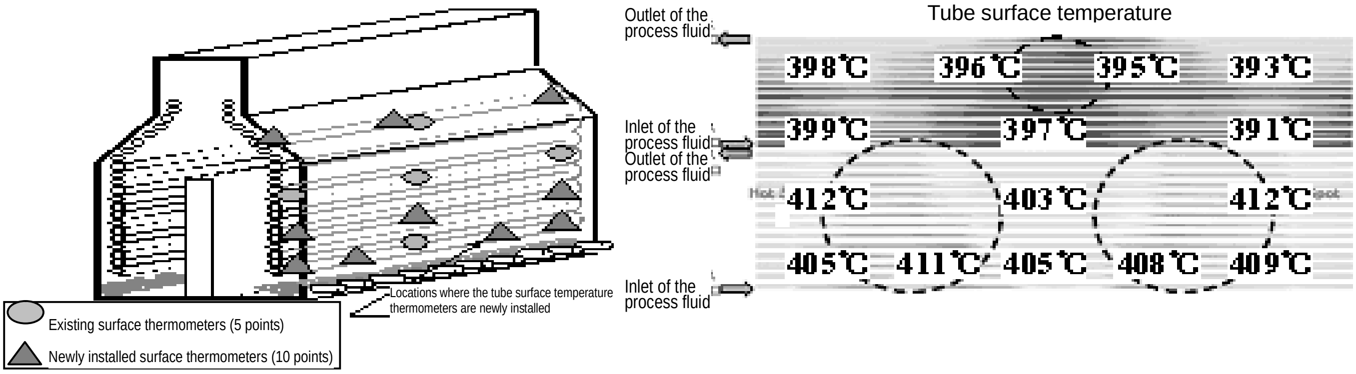


Figure 19 Locations where the tube surface temperature thermometers are newly installed and their indications

## 2) Installation of the fuel gas flow meters

We installed the fuel gas flow meters on each side of LX-H1 (Figure 20). Using a personal computer, we also created a continuous integrating tool that indicates the difference between the heat quantity given from the fuel gas side (fired duty) and the heat quantity received at the process side (heat duty). By monitoring the trend of the estimated values and adjusting the combustion rate, it became possible to maintain uniform heating in each row, to minimize the generation of coke in the newly replaced tubes and to check the increase of the unit fuel consumption index.

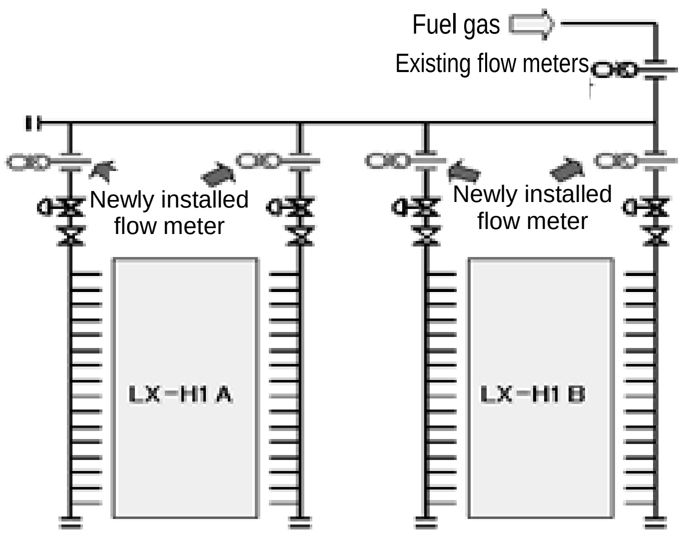


Figure 20 Installation points of the fuel gas flow meters

## 5. Effects Achieved after Implementing Measures

By implementing the measures mentioned above, we reduced the energy consumption by 2,140 COE-KL/year whereas the initial target was 1,600 COE-KL/year; that is, more than expected effects exceeding the target were achieved (Table 4).

Table 4 Effects of measures implemented

| | |
|---|---|
| Energy conservation volume in money | 61,300,000 yen per year |
| Energy conservation volume(crude oil equivalent) | 2,140 COE-KL per year |
| Reduction volume of $CO_2$ | 5,300 tons per year |

## 6. Summary

We had a strong preconception that it was difficult to avoid the generation of coke in the tubes of LX-H1A and LX-H1B. However, by utilizing the heating furnace combustion analyzing simulator and new management tools, we solved the challenging problems and achieved significant energy saving effects; we also matured from a technological and awareness perspective. Formerly, we tended to give priority to “making improvements to the events that occurred”. However, in this particular case, we tackled the problems with the new stance of “implementing necessary measures so as to prevent the problems”. We developed self-confidence through the activities this time that the reform of consciousness produced significant energy saving effects; we will continue the energy conservation activities always bearing in mind with the aim of significantly reducing the burden of the global environment.

## 7. Future Plans

Based on the results of the activities mentioned above, we will control the coke generating conditions in the heating furnace tubes so as to minimize the influence on the tubes. We will consider the introduction of the adjustable burner in order to seek a more stable and uniform combustion of the heating furnace and more efficient operation of the heating furnace. We would also like to actively promote the lateral spread of these technologies and appropriate measures to other works facing similar problems so as to contribute to energy conservation.