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Energy Conservation relating to the CO Boiler of Residual Fluidized Catalytic Cracking Equipment

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◎ **Keywords：Rationalization of fuel combustion, Recovery and use of waste heat**

◎ Outline of Theme

Residual fluidized catalytic cracking equipment (hereinafter called RFCC equipment) is an apparatus to turn out products of high value-added fractions including gasoline, kerosene, and diesel oil, etc. by decomposing reduced crude at high temperature over a catalyst. We were able to develop improvement issues resulting in a large energy conservation relating to the CO boiler of the RFCC equipment. By involving advanced specialist engineers from inside the company, we could achieve energy conservation that exceeded the targets through increasing the steam generation amount due to easing equipment restrictions and by reducing the auxiliary combustion gas introduction amount using a flow simulation investigation. These activities are introduced here.

◎ Implementation Period for the Said Example

June 2006 – March 2008 (Total of 22 months)

- Project Planning Period — June 2006 – June 2007 (Total of 13 months)
- Measures Implementation Period — July 2007 – September 2007 (Total of 3 months)
- Measures Effect Confirmation Period — October 2007 – March 2008 (Total of 6 months)

◎ Outline of the Business Establishment

- Items Produced — LPG, naphtha, gasoline, kerosene, diesel, heavy oil
- No. of Employees — 303 persons (As at April 1, 2008)
- Type 1 designated energy management factory

◎ Process Flow of Target Facility

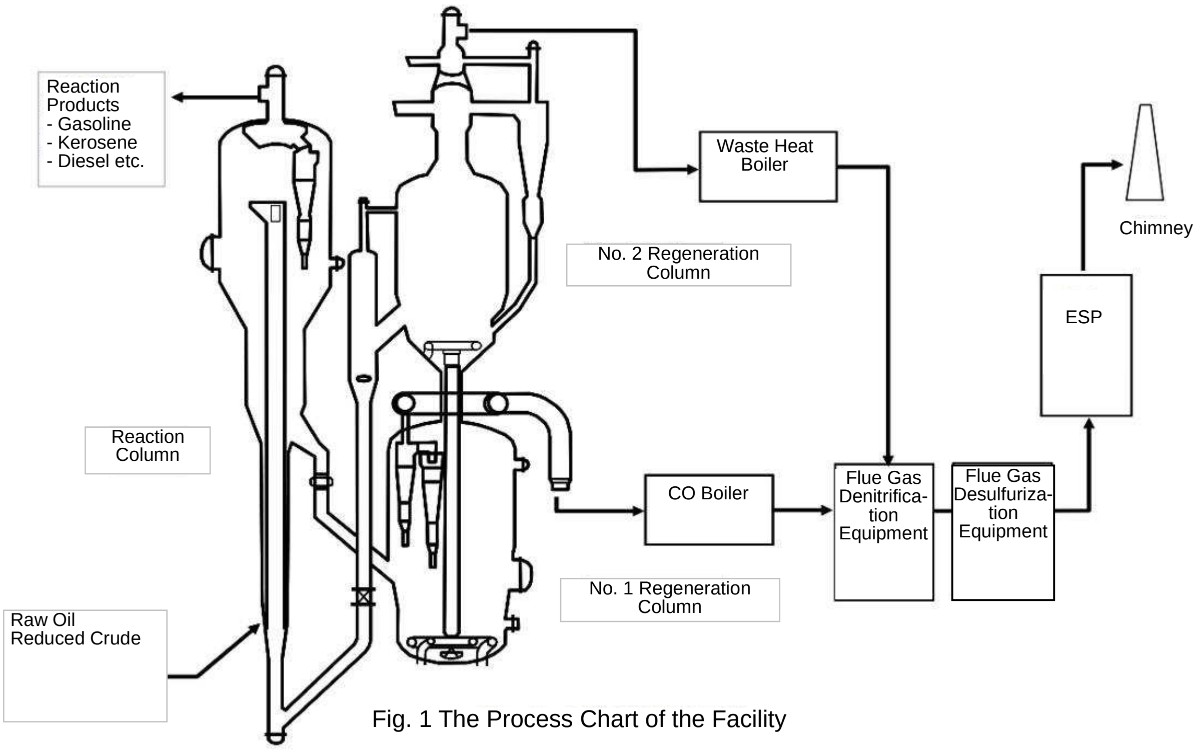

Fig. 1 The Process Chart of the Facility

1. Reasons for Theme Selection

RFCC equipment is an apparatus to decompose low-cost reduced crude into high value-added white oils including gasoline, etc. Its marginal profit is large, and it is operated continuously at close to its rated capacity . Because a huge amount of heat is generated in the catalyst regeneration process after the reaction, a CO boiler is installed for the purpose of recovering this heat. Due to the large size of the amount of heat handled, we believed that energy conservation improvement effects relating to the CO boiler would be high, and focused our attention on identifying the issues.

2. Progress of Activities

(1) Implementation Structure

In the Idemitsu Kosan Hokkaido Refinery, the medium-term management plan is being implemented divided into four cross-company sections consisting of 1. Facilities, 2. Safety and the Environment, 3. Production Efficiency Improvement, and 4. Business Activity Improvement. Energy conservation activities are positioned in the Production Efficiency

Improvement Section, and in the Energy Subcommittee we are carrying out activities independently under the catchword of “Team-centric Managed Operations” while operating the equipment under a four-team, three-shift system. In recent years, there was a feeling of having run out of ideas for making profitable improvements to equipment for the purpose of realizing energy conservation. However, because 2008 marked the first stipulated period of the Kyoto Protocol, together with the holding of the G8 Hokkaido Toyako Summit in the prefecture in July, a higher degree of interest was being shown in energy conservation in the Hokkaido region. Accordingly, based on the in-house Energy Conservation Committee, we also involved advanced specialist engineers from the company in our group in an attempt to carry out unified activities.

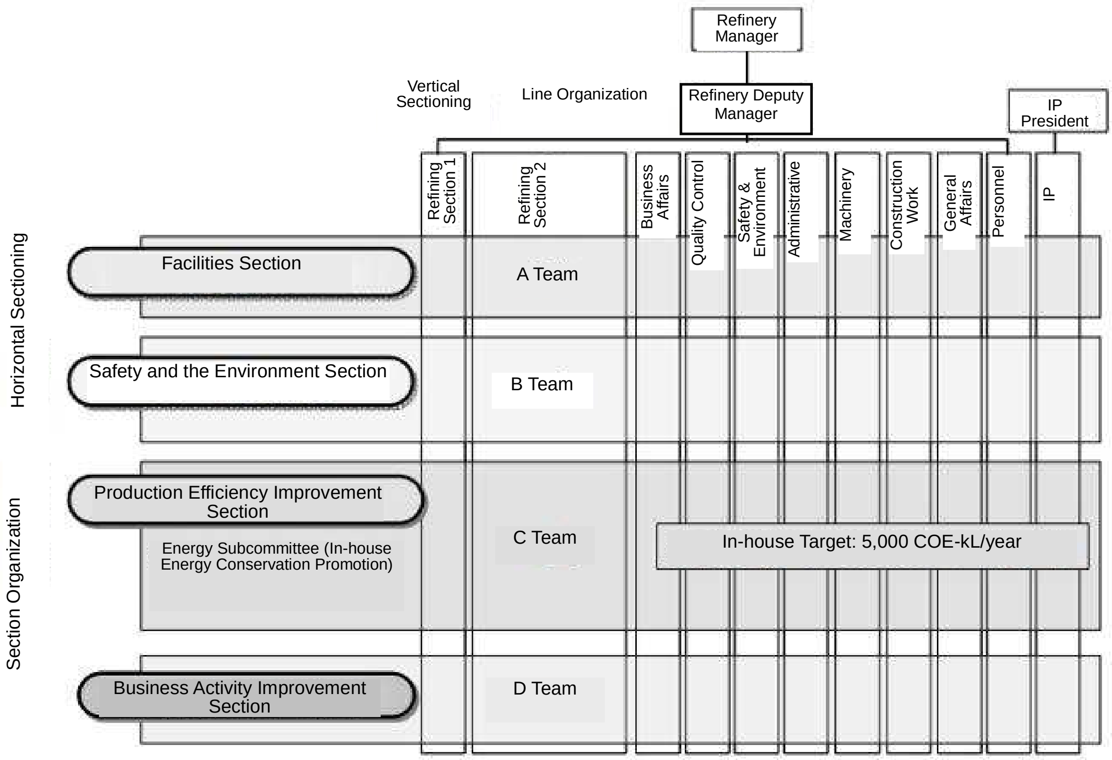

Fig. 2 Hokkaido Refinery Medium-term Management Plan Promotion System

(2) Understanding of Current Situation

The regeneration of the catalyst in the RFCC equipment is carried out through the oxidized combustion of coke above the catalyst that is regenerated by the decomposition reaction. The regeneration takes place in two stages using a system in which an incomplete combustion condition is maintained in the No. 1 regeneration column, followed by complete combustion in the No. 2 regeneration column. Boilers are installed at the gas outlets of each regeneration column for the purpose of heat recovery, and the No. 1 regeneration column has a boiler (CO boiler) installed which burns the CO gas generated in the incomplete combustion.

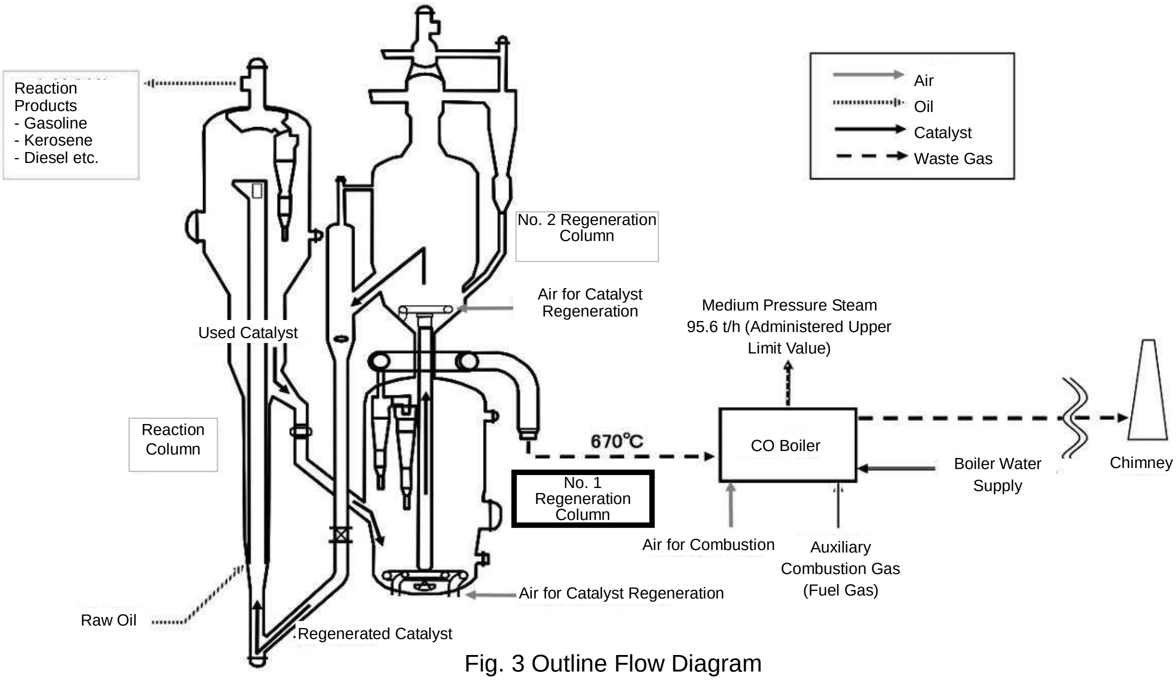

Fig. 3 Outline Flow Diagram

The CO boiler takes in waste gas from the No. 1 Regeneration Column at a temperature of 670℃, handling a huge amount of heat that allows it to generate 95.6t/h of medium pressure steam (5.0MPa).

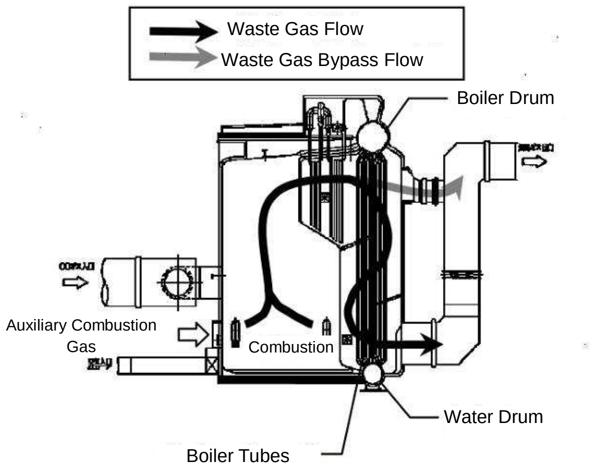

Fig. 4 CO Boiler Combustion Gas Flow

The RFCC equipment has a large marginal profit, and it is operated constantly at high operation rate. Because this means that the CO boiler loading also increases, in the situation where the steam amount exceeds the administrative upper limit, part of the waste gas that should be taken into the boiler tubes has to be bypassed, causing energy loss.

In addition, the CO inclusion rate of the waste gas supplied to the CO boiler is low, and auxiliary combustion gas (fuel gas) is introduced to maintain a continuous stable combustion. However, following the installation of the RFCC equipment, it was realized that the issue of “Whether or not the auxiliary combustion gas introduction amount (known below as the auxiliary combustion rate) is appropriate" had not yet been investigated.

Accordingly, the energy conservation improvement this time was determined to be the two points where large improvements could be anticipated: (1) the easing of the waste gas amount intake restrictions, and (2) the review of the auxiliary combustion rate.

(3) Analysis of Current Situation

1) Easing of waste gas amount intake restrictions

In order to ease the CO boiler waste gas amount intake restrictions and eliminate the bypassed portion, it was necessary to review the steam generation amount administrative values. As a result of the heat amount calculation, it was found that the loss would be eliminated if the administrative value was raised from 95.6 → 100 t/h.

Accordingly, the equipment restrictions were confirmed by contacting the boiler manufacturers regarding the performance of each piece of equipment making up the system relating to this steam generation amount. As a result of the confirmation, a problem point was identified relating to the possibility that tube (pipe) vibration may be induced if the amount of waste gas passing through the CO boiler is increased.

Table 1 Confirmation of Performance Restrictions of the Equipment making up the System

Boiler Feed Water System Performance	OK
Safety Valve Capacity	OK
Air Separator Performance	OK
Super Heated SteamTemperature and Pressure Loss	OK
DSH (Desuperheater) Spray Capacity	OK
Design Pressure (Gas side: Wind box, boiler main unit)	OK
Tube Vibration due to Gas Flow Amount Increase	NG

2) Review of auxiliary combustion rate

The CO concentration of the waste gas introduced to the CO boiler was only approximately 7%, and support for the combustion using auxiliary combustion gas was required to maintain stable combustion. The purposes of introducing auxiliary combustion gas were the following two points.

a. Prevention of CO incomplete combustion

The amount of heat required to prevent incomplete combustion of the CO is administered as the net heat constant (known as N.H.C. below), which is the total amount of heat introduced to the CO boiler divided by the combustion waste gas net weight. As a result of the investigation, it was found that the N.H.C. during normal operation was approximately 1,750 kJ/kg due to the large amount of waste gas heat introduced, and there was a large margin compared to the administrative value (1,050 kJ/kg or more).

b. Flame stability

Regarding the flame stability, the proportion of the auxiliary combustion gas heat amount introduced to the CO boiler is administered using an index known as the auxiliary combustion rate. This rate is set at an administrative rate of 10% or more of the total heat introduced to the furnace based on the manufacturer's rule of experience, and the 10% value had been maintained through adjustment since the start of the RFCC equipment operation.

The manufacturer's opinion in reply to our question regarding the 10% value was that "Although this value has not been technically verified, and the conditions for stable combustion differ according to each piece of equipment, at this stage it is hard for us to guarantee that lowering the auxiliary combustion rate will not cause problems." There were examples from other places in the past of flame-out caused by defective combustion administration of CO boilers, but we decided to attempt to reduce the auxiliary combustion rate even though the improvement carried a technical risk of which we had no previous experience.

Table 2 Purpose of Auxiliary Combustion Gas Introduction

CO Incomplete Combustion Prevention	Net Heat Content (N.H.C): Heat amount introduced to the CO boiler = Total amount of heat introduced to the fire box(kJ)/ exhaust combustion gas weight (kg) ≧ 1,050 kJ/kg (Manufacturer's recommended administrative value)
Flame Stability	Auxiliary Combustion Rate: Auxiliary gas heat amount proportion introduced to the CO boiler = Auxiliary fuel introduced heat amount/total heat amount introduced to the fire box x 100 ≧ 10% (Manufacturer's recommended administrative value)

(4) Target Settings

The target for the activities this time, which consisted of the actual issues of reviewing the steam generation amount through easing the CO boiler waste gas amount intake restrictions and reducing the auxiliary combustion rate used in the CO boiler, was set as 1,250 COE-kL/year, which is 25% of the energy conservation target of 5,000 COE-kL/year for the whole plant.

(5) Problem Points and their Investigation

1) Tube vibration due to easing of waste gas amount intake restrictions

The vibration form was a vibration known as self-excited vibration that was attributed to the increase with the waste gas flow speed through the tube. On receiving this result, repeated discussions were carried out within the group. However, as it proved a difficult situation for selecting a solution, an investigation was begun jointly with the technical specialist sections in the company, which obtained the evaluation formula shown below. This allowed the self-excited vibration to be evaluated using the flow speeds to find the occurrence limits, and the measure of increasing the Vc component in the formula avoided the vibration. The methods for increasing the limiting flow speed Vc were deduced from the evaluation formula as the items listed below.

- Raise the tube characteristic oscillation frequency f = Change the tube length
- Make the tube outside diameter larger = Replace the tube
- Make the tube weight per unit length heavier = Replace the tube
- Make thecoefficientsa and b larger = Change the tube arrangement
- Make the logarithmic decrement σ larger = Replace the tube

$$\frac{V_c}{fD} = a\left(\frac{m\sigma}{\rho D^2}\right)^b$$

Vc : Fluid-elastic vibration (self-excited vibration) limiting flow speed (known below as the "limiting flow speed")
f : Tube characteristic oscillation frequency
D : Tube outside diameter
m : Tube weight per unit length (Including the weight of the liquid inside and any attachments)
ρ : Liquid density
σ : Structural logarithmic attenuation rate (Factor relating to the attenuation)
a : Coefficient defined from the tube arrangement, interval, and diameter
b : As above

Fig. 5 Self-excited Vibration Calculation Formula

Among the measures deduced from the formula items, attention was placed on changing the length of the tubes to increase the character frequency f, due to the opinion of one of the members that “Wouldn’t it be possible by changing the tube support interval?”

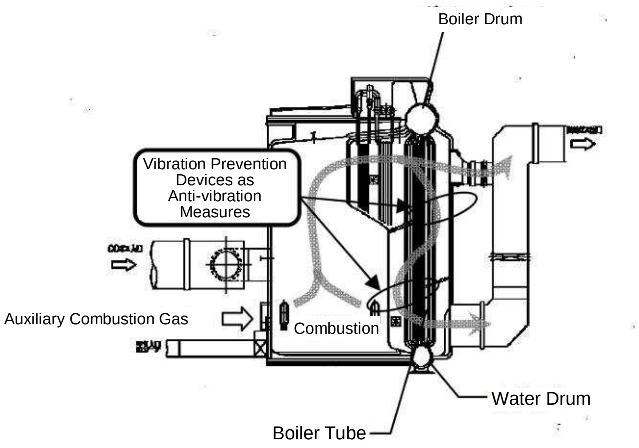

Fig. 6 Anti-vibration Measures for Preventing Vibration

When this was proposed to the in-house Facilities Management Group, we found that it would be possible to install anti-vibration devices along the tubes as a measure to prevent vibration instead of carrying out large-scale equipment modifications such as replacing the boiler tubes. It was therefore planned to implement the equipment modification.

2) Flame stabilization due to review of the combustion aid rate

When the situation in other refineries was investigated, it was found that this refinery was the only one that was still carrying out operations using the same combustion aid rate of 10%. As the securing of safe and stable operation of the refinery is obviously our mission, for reviewing the combustion aid rate we concentrated our technical resources and carried out the following investigation.

a. Confirmation of the combustion performance range of the auxiliary gas burners

Attention was focused on the performance of the auxiliary gas burner individual units, and confirmation was carried out. The figure below is a combustion characteristics diagram with the combustion amount on the vertical axis and the burner pressure difference on the horizontal axis.

As the result of confirming the lowest combustion amount, it was found that with average combustion gas properties it would be possible to reduce the combustion amount to an combustion aid rate corresponding to 7%, and even in the situation of light combustion gas properties it would be possible to reduce the combustion amount to an auxiliary combustion rate corresponding to 9%.

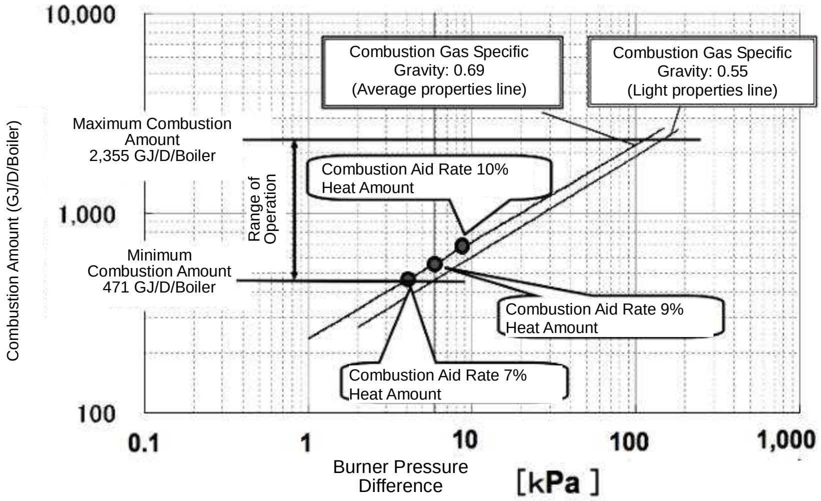

Fig. 7 Burner Combustion Characteristics Diagram

b. Confirmation of the flame-maintaining performance of the auxiliary gas burners

Although it was understood that there was scope for reducing the combustion aid rate of the auxiliary gas burner separate units, because the CO boiler is configured from auxiliary gas burners and CO gas burners, the possibility was considered that the CO burners might blow out the auxiliary gas burners. Since the verification of the auxiliary gas burner combustion continuity requires knowledge of the gas condition as it flows through the complex structure, together with knowing the combustion conditions, investigations were carried out by obtaining the cooperation of specialist departments who have this knowledge.

Regarding the investigation methods, it was found that the combustion conditions could be simulated using a combustion simulation and attention was concentrated on creating the model. In order to evaluate the influence of the CO boiler structure on the results, particular attention was paid to faithfully recreate the structure in the vicinity of the burners, and analyses were carried out.

As a result, a slight reduction was found both in the flame temperature distribution and speed vectors in the case where the combustion aid rate was reduced to 7%. However, because the condition was independent from the CO gas burner discharge and there was no influence, it was understood that there would be no problem for the auxiliary gas burner flame-maintaining performance.

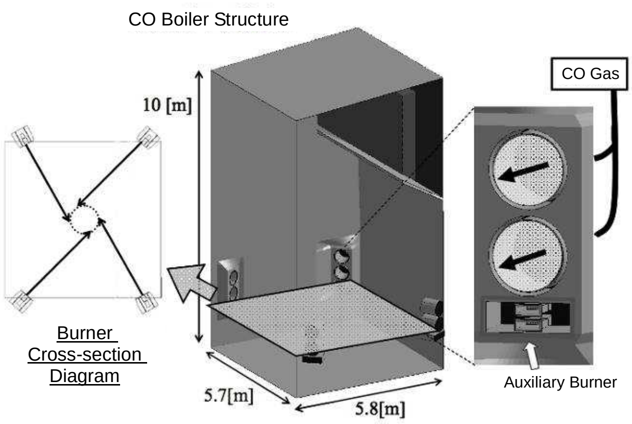

Fig. 8 Combustion Simulation Model

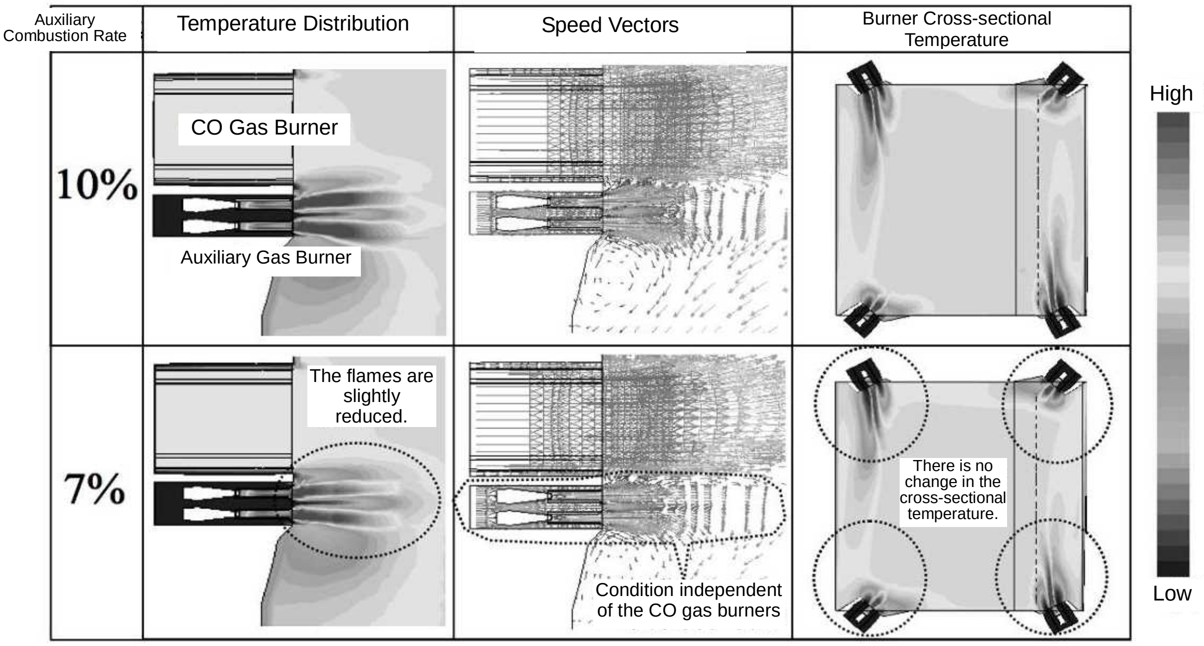

Fig. 9 Combustion Simulation Result (1)

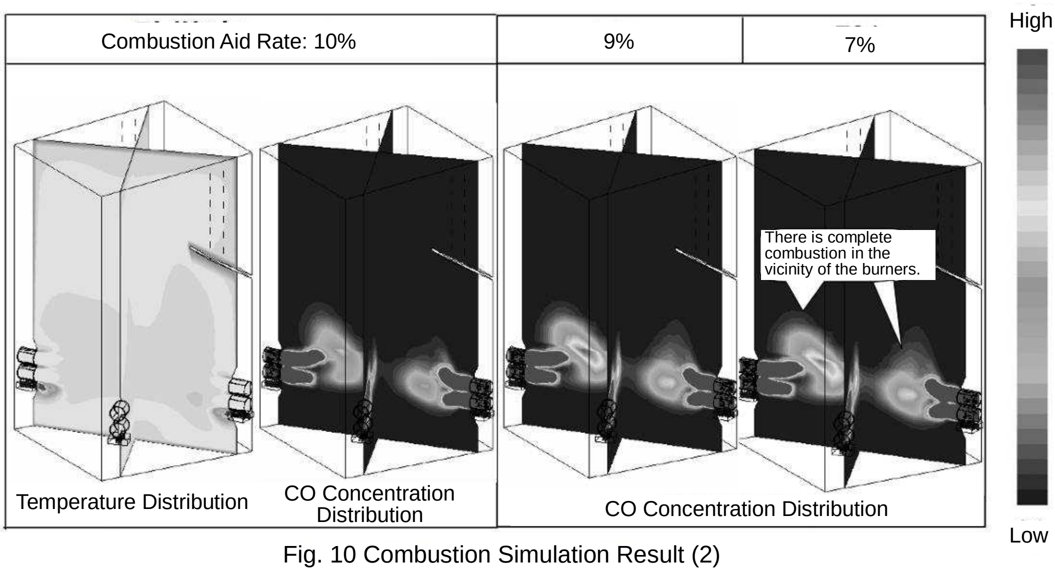

Fig. 10 Combustion Simulation Result (2)

c. Confirmation of CO gas combustibility

As a result of using the same simulation model to confirm the unburned CO gas concentration distribution when the combustion aid rate has been reduced, it was found that the structure of the boiler concerned meant that there will be no CO left unburned even when the combustion aid rate is reduced to 7%, and complete combustion can be obtained in the vicinity of the burners.

Regarding the result of investigating the reduction of the combustion aid amount used with the CO boiler, the following adjustments can be made.

- From the performance range of the burner individual units, even in the situation of light gas properties, the reduction to a combustion aid rate of 9% will be possible.
- As a result of the combustion simulation, providing that the combustion stability of the auxiliary burner is within the burner's performance range, there will be no influence from the CO gas causing flame-out. In addition, even under the conditions of a 7% combustion aid rate, there will be no occurrence of unburned CO.

From the above results, in consideration of the safe and stable operation of the equipment, the lowered target value for the combustion aid rate was set to 9%.

(6) Details of Measures

1) Verification testing of waste gas amount intake restriction easing due to implementation of anti-vibration measures

The tube supports for the vibration measures were manufactured and the mounting work was carried out in July 2007. A confirmation test with the boiler at maximum loading was implemented in October of the same year.
As a result of the test, no problems were found from an operations or equipment point of view, and it was possible to review the maximum amount of steam generated as 100 t/h.

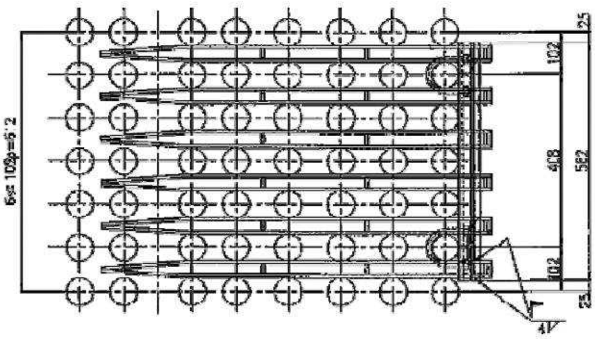

Fig. 11 Tube Supports seen from the Top

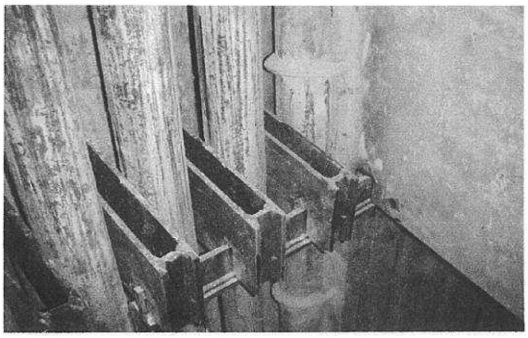

Fig. 12 Tube Support Photograph

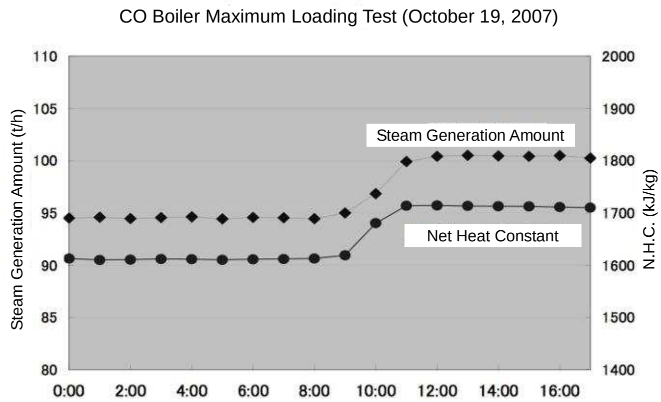

Fig 13 Trend Data obtained during the Test Run

2) Verification testing of combustion aid rate lowering

In January 2008, testing was carried out in which the combustion aid rate was lowered to 9%. As a result of this testing, no problems were found with the burner combustion situation, which had been the point of greatest concern, and no unburned CO was detected at the boiler outlet. The combustion aid gas burner performance that had been previously investigated and the combustion simulation investigation results were proved correct, and it was judged that there were no problems with the operation.

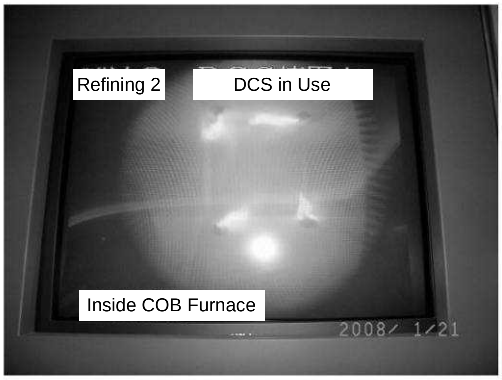

Fig. 14 Combustion Condition during Auxiliary Combustion Lowering (TV Camera)

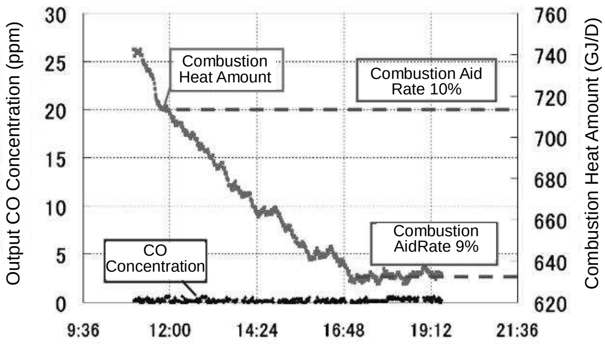

Fig. 15 Changes in Auxiliary Combustion Heat Amount and Outlet Concentration

(7) Effects Achieved after Implementing Measures

- Energy conservation amount due to waste gas amount intake restriction easing
  - 1,230 COE-kL/year (Steam generation amount increase 3.3 t/h)
- Energy conservation amount due to combustion aid rate reduction
  - 550 COE-kL/year (Combustion gas amount reduction 2,000 Nm^3/D)

The total was 1,780 COE-kL/year, and it was possible to realize an effect that exceeded the target.

3. Summary

- Large energy conservation was achieved through carrying out numerous investigations inside the group and considering solutions consisting of low cost measures without requiring large equipment modifications such as changing the boiler tubes.
- Simulation technology was applied to break through with conventions and improve the administrative values whose basis had been unclear, such as the manufacturer's rule of experience and the actual results of previous operations.

4. Future Plans

The waste gas amount introduced to the CO boiler is not constantly fixed, and differs according to the RFCC equipment operation conditions. We therefore aim to build an automatic control system in the future in order to realize operator labor-saving and maintain the energy conservation effects.

In addition, we believe that the combustion simulation which we used for reducing the combustion aid rate this time can also be used by other departments for other applications, and we would like to use it to expand the energy conservation activities.