Annual Research Report

2008

(Research Results related to EERN)
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Contents

General Overview

Base research subjects
- Energy Engineering Research Laboratory

Research Fields

Fossil Fuel Power Generation
- Proposal of Advanced Integrated Coal Gasification Combined Cycle Power Generation System with CO₂ Capture
- Development of Dry Gas Cleaning System for Biomass/Refuse Gasification Power Generation
  - Performance Verification by Tests with Pilot Plant and Feasibility Evaluation
- Development of Technology for Reducing both Emissions of NOx and Unburned Carbon using In-Furnace Blending Method
- Development of Ice/Oil/PCB Elimination Technology using DME
- Development of Coating Technology for Preventing Sulfide Corrosion on Boiler Tubes in Coal Fired Power Plants
  - Development of a Practical Compound Film of Low-cost and High Corrosion Resistance

New Energy
- Development of Biomass/Waste Power Generation System with Carbonizing Gasifier and Gas Engine
General Overview

Energy Engineering Research Laboratory

Brief Overview

Amidst the profound changes of the business environment for energy companies due to the deregulation of the energy/power market, worsening of global warming and lifestyle diversification, the Energy Engineering Research Laboratory aims at contributing to (i) the creation of a new highly efficient, clean and low cost power/energy supply system and (ii) the shift towards a recycling-based society while ensuring energy security. The Laboratory intends to achieve this by providing innovative fundamental technologies and presenting alternative energy sources.

In FY 2007, the Laboratory analyzed the combustibility, characterized the burnt gas and identified relating issues of various liquid fuels for gas turbines. Basic combustion characteristics of fuel droplets were also identified. The use of these fuels is expected to increase from the viewpoint of energy security as the supply of LNG is expected to become tight in the near future.

Moreover, the scope of the application of the DME dewatering technology which was developed as a upgrading technology for sub-bituminous coal was expanded to the removal of ice in cold regions and the removal of oil at normal temperature for the purpose of environmental conservation and the feasibility of these applications was confirmed. The development of a low cost technology to decompose volatile organic compounds (VOC) was advanced for the purpose of environmental conservation. Furthermore, a basic study and examination of the analysis methods were conducted to expand the application scope of fuel cells and heat pumps as highly efficient energy conversion devices. In regard to fuel cells, for performance prediction was expanded to several types of fuel cells. In regard to heat pumps, research was conducted to enhance the performance. The feasibility of an advanced humid air turbine (AHAT) system was also examined.

Achievements by Research Theme

Operation and maintenance technology in thermal power generation
[Objectives]

To understand the basic combustion characteristics of alternative or new type of liquid fuels, establish a fundamental technologies for combustion and develop an assessment tool for reliabilities of equipment using under a high temperature environment at existing thermal power plants, for the purpose of advancing the operation and maintenance technologies for thermal power generation

[Principal Results]

- The requirements for liquid fuel serving gas turbines were clarified. New types of fuels, including non-conventional fossil fuels, such as oil sand, etc., and biofuels, such as jatropha oil, etc., were evaluated based on the property analysis results and their applicability to gas turbines and the problems were investigated.
- To evaluate the applicability of palm methylester, a type of biomass fuel, to gas turbines, the evaporation characteristics of a single droplet under micro-gravity were investigated using a micro-gravity experiment facility.

Fuel reforming and environmental protection technology
[Objectives]

To develop base technologies relating to reforming of low grade fuels, coal ash utilization and decomposition of volatile trace substances for the purpose of contributing to the diversification of fuel and environmental protection

[Principal Results]

- With the DME dewatering technology, the feasibility of ice removal from frozen coal and wood was affirmed at the temperature below 0 °C. Furthermore, the applicability of the DME extraction technology to oil removal was confirmed. Oil can be removed from oil absorbing sheets/oil sorbents having absorbed vacuum pump oil, and also from glass, wood, paper and metal to which insulation oil is attached.
- A VOC decomposing module using a ceria catalyst was developed and its performance for the decomposition of benzene, toluene and xylene was verified (Fig. 1). An design of a practical scale system revealed a low cost and compact system is achievable.

High efficiency energy conversion technology
[Objectives]

To develop fuel cell technologies, clean fuel technologies, heat transfer technologies of refrigerant for heat pumps, heat storage technologies and an evaluation technology for various energy systems, on the basis for highly efficient energy conversion technologies in the future
**[Principal Results]**

- In connection with a generating technology using fuel cells, performance models were developed for polymer electrolyte and solid oxide fuel cells. On a molten carbonate fuel cell, the dynamic characteristics were discussed and the dynamic model (Fig. 2) focusing on change of gas concentration in the cell was developed. The model clarified the characteristics of overload. Moreover, a new application of the molten carbonate fuel cells was proposed as a mitigating function of voltage sag.
- A basic survey was conducted with a view to expanding the scope of applicability of the heat pump technology to agriculture. The evaluation of the basic characteristics of heat transfer was continued to enhance the performance of heat exchangers for CO₂ heat pumps.
- The feasibility of a AHAT system as a small to medium size, high efficiency power generation system was evaluated and the R&D issues were identified for commercial plant.

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**Fig. 1** Reaction Test Results for VOC Decomposing Module

- Material balance equation for gas concentration

\[ V_i \frac{dC_i^*(t)}{dt} = k_i \left[ C_i^* (0) - C_i^*(t) \right] + \frac{A_i J_i}{nF} \left( 1 - e^{-\frac{V_i}{R_T}} \right) \]  \[ \text{[mol/s]} \]

- Changes of gas concentration at the overload current

\[ C_i^*(t) = C_i^* (0) + \frac{A_i J_i}{nFk_i} \left( 1 - e^{-\frac{V_i}{R_T}} \right) \left( \tau_g - \tau_f \right) \]

\[ C_i^* \]: Gas concentration [mol/cm³], \( V_i \): Electrode volume [cm³], \( A_i \): Electrode area [cm²]
\( J_i \): Overload current density [A/cm²], \( k_i \): Volume transfer rate [cm³/s]
\( \tau_g \): Space time [s], \( \tau_f \): Time constant of internal current change [s]

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**Fig. 2** Schematic diagram of dynamic model on gas concentration change
Proposal of Advanced Integrated Coal Gasification Combined Cycle Power Generation System with CO₂ Capture

Background
CO₂ emissions control from coal fired power plants is an important issue for global warming prevention. Electric power industries are advancing various measures such as the improvement of power generation efficiency and the introduction of carbon neutral fuels such as biomass fuels to this problem. On the other hand, discussion for the application of CO₂ capture and storage (CCS) to coal fired power plants has been active internationally. However, if power plants with the current CO₂ capture technology are introduced, it will be impossible to avoid great decreases of the power generation efficiency and rises in power generating cost. For this reason, the development of new highly efficient power generating systems is desired.

Objectives
To improve the power generation efficiency and reduce the generation cost, this study aims to propose a highly efficient integrated coal gasification combined cycle power generation system with CO₂ capture, and to clarify the advantage of our proposed IGCC system through numerical analysis.

Principal Results
1. Features of proposed IGCC system with CO₂ capture (Fig. 1)
   The system has a new O₂-CO₂ blown coal gasifier where captured CO₂ is effectively used. The synthesis gas is burned with the mixed gas of O₂ and CO₂-rich recycled exhaust gas in the oxy-fuel gas turbine (closed gas turbine) system. Non-recycled exhaust gas is directly compressed and CO₂ is liquefied. In this system, the gasification performance and power generation efficiency improve greatly. Furthermore, CO₂ separation process (CO₂ absorption process, etc.) is not needed.

2. Expected effects
   (1) It was estimated that O₂-CO₂ blown coal gasifier improves the carbon conversion and cold gas efficiency as compared to the current O₂ blown (O₂-N₂ blown) coal gasifire and air blown coal gasifire because CO₂ enhances the gasification reaction (Table 1). These effects allow us to realize a compact gasifier and a simple char recycle system.
   (2) The gas turbine is compacted because the inlet gas of the gas turbine is CO₂-rich and the specific gravity of CO₂ is higher than that of air. Furthermore, the CO₂-rich gas which has a low specific heat ratio, and the addition of a regenerative heat exchanger improve the power generation efficiency in the gas turbine.
   (3) CO₂ separation process (CO₂ absorption process etc.) is not needed because the exhaust gas of the gas turbine is directly compressed and CO₂ can be liquefied. Furthermore, the proposed system is expected to have the efficiency of 42% (HHV) in a system with a 1300°C-class gas turbine and 45% in a system with a 1500°C-class gas turbine because the addition of a regenerative heat exchanger improves the power generation efficiency (Table 2). If the molten carbonate fuel cell instead of the gas turbine is applied to this system, efficiency of near 60% is obtained.

3. Development items
   The following development items are enumerated to put this system into practical use.
   • Optimization of the total system
   • Realization of the compact gasifier and simple gasification system (char recycle system etc.) by making the best use of great improvement of the gasification performance
   • Measures for carbon deposition in the gas cooling process and the gas cleaning process
   • Optimization of the design and control method in the oxy-fuel gas turbine (closed gas turbine) system

Future Developments
It is scheduled to conduct the feasibility study (F.S.) of this system to clarify the power generating cost, and confirm the gasification performance using 3ton/day coal gasifier.

Main Researcher: Hiromi Shirai, Ph. D.,
Senior Research Scientist, Plant Engineering Sector, Energy Engineering Research Laboratory

Reference
H. Shirai, et.al., 2007, “Proposal of a highly efficient system with CO₂ capture and the task on integrated coal gasification combined cycle power generation”, CRIEPI Report M07003 (in Japanese)

*1: the system where collected particles (char) containing unburnt carbon from raw coal gas are recycled to the gasifire
6. Fossil Fuel Power Generation

Fig. 1 Comparison between IGCC systems with CO₂ capture

In the current system, the carbon monoxide (CO) in the synthesis gas is reacted with steam in a catalytic reactor, called a shift converter, to yield CO₂ and more hydrogen. CO₂ is then separated by a physical or chemical absorption process. On the other hand, in the advanced system, the oxy-fuel gas turbine (closed gas turbine) system is applied, and CO₂ separation process is not needed because the synthesis gas is burned with the mixed gas of O₂ and the recycled exhaust gas instead of air to obtain CO₂-rich exhaust gas whose components are CO₂ and steam.

Table 1 Comparison of the gasification performance in three gasifier types

<table>
<thead>
<tr>
<th>Gasifier type</th>
<th>O₂-CO₂</th>
<th>O₂-N₂</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon conversion</td>
<td>%</td>
<td>100</td>
<td>69.9</td>
</tr>
<tr>
<td>Char Generated Char</td>
<td>t/h</td>
<td>13.9</td>
<td>51.8</td>
</tr>
<tr>
<td>Carbon content, wt%</td>
<td></td>
<td>0</td>
<td>72.9</td>
</tr>
<tr>
<td>Ash content, wt%</td>
<td></td>
<td>100</td>
<td>27.1</td>
</tr>
<tr>
<td>Synthesis gas Flow rate</td>
<td>t/h</td>
<td>274.6</td>
<td>274.6</td>
</tr>
<tr>
<td>Calorific value, MJ/m³N</td>
<td></td>
<td>11.1</td>
<td>10.3</td>
</tr>
<tr>
<td>CH₄ vol%</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>H₂ vol%</td>
<td></td>
<td>21.3</td>
<td>24.4</td>
</tr>
<tr>
<td>CO vol%</td>
<td></td>
<td>66.5</td>
<td>56.9</td>
</tr>
<tr>
<td>CO₂ vol%</td>
<td></td>
<td>5.4</td>
<td>0</td>
</tr>
<tr>
<td>H₂O vol%</td>
<td></td>
<td>5.3</td>
<td>18.7</td>
</tr>
<tr>
<td>N₂ vol%</td>
<td></td>
<td>1.5</td>
<td>18.7</td>
</tr>
<tr>
<td>Cold gas efficiency</td>
<td>%</td>
<td>80.8</td>
<td>78.8</td>
</tr>
</tbody>
</table>

It is estimated that the carbon conversion was 100% for the O₂-CO₂ blown gasifier. It means that coal is gasified perfectly. The cold gas efficiency, which is the ratio of the energy of the synthesis gas to the energy of supplied coal, is 80% which is the highest out of the three gasifier types. Therefore, the O₂-CO₂ blown gasification system presents the possibility of greatly contributing to the improvement of the gasification performance as compared to conventional gasification systems.

Table 2 Comparison of the efficiency between the O₂-N₂ blown IGCC system and the O₂-CO₂ blown IGCC system

<table>
<thead>
<tr>
<th>Gasifier type</th>
<th>O₂-N₂</th>
<th>O₂-CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine type</td>
<td>1300 °C</td>
<td>1300 °C</td>
</tr>
<tr>
<td>CO₂ recovery ratio, %</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Gross efficiency (HHV/LHV), %</td>
<td>47.7/49.8</td>
<td>42.7/44.7</td>
</tr>
<tr>
<td>Net efficiency (HHV/LHV), %</td>
<td>42.5/44.5</td>
<td>34.9/36.5</td>
</tr>
</tbody>
</table>

*2 NEDO report No. 04002145-0, 2005.3 (in Japanese)

In the O₂-CO₂ blown IGCC system (1300 °C class gas turbine), the efficiency of 42.0% at capturing CO₂ by 99% or more can be obtained and the improvement of power generation efficiency is expected. On the other hand, the efficiency in the O₂-N₂ blown IGCC system (1300 °C class gas turbine) decreases up to 34.9% when 90% of CO₂ is captured.
**Principal Research Results**

**Development of Dry Gas Cleaning System for Biomass/Refuse Gasification Power Generation**

*Performance Verification by Tests with Pilot Plant and Feasibility Evaluation*

**Background**

Gasification power generation plants have significant potential for highly efficient power production utilizing biomass and refuse derived materials, which will establish the recycling-based society. The suitable capacity of the power plant will be between several hundred kilowatts to a few thousand kilowatts for the expected users including municipalities. The gas purification system for the plant should be superior in operability and easy maintenance by eliminating waste water treatment; high environmental compatibility is also required in the system as well. CRIEPI has suggested the dry gas purification system as displayed in Fig. 1 and has developed a series of sorbents that are required in the system. It is necessary to evaluate the gas purification performance of the system with a demonstration plant and to examine feasibility of the commercial size plant.

**Objectives**

The study aims to prove performance of the dry gas purification system by a series of tests of the developed or selected sorbents in the demonstration plant under a stream of actual biomass-derived gas. According to the test results, the advantage and the feasibility of the dry gas purification is evaluated by designing tentatively the commercial size plant and comparing with a conventional wet system of the same size.

**Principal Results**

1. **Performance of the dry gas purification system**

   Performance evaluation was tested by installing the developed and selected sorbents in the demonstration plant under simulated gas stream containing various impurities. Power generation test was conducted by introducing the actual biomass gas from biomass gasifier to the plant and by supplying the purified gas to the molten carbonate fuel cell (MCFC). Sufficient performance for impurity removal was attained with copper-based mercury sorbent, glass fiber reinforced halide sorbent and zinc oxide sulfur sorbent as shown in Fig. 2. The purified fuel gas derived from biomass accomplished stable power generation with the MCFC as indicated in Fig. 3. These results demonstrated that the dry gas purification system fulfills the requirement for biomass gasification power generation as well as regulations for environmental protection.

2. **Feasibility evaluation of the dry gas purification system**

   The commercial sized system that includes the fixed bed system utilizing the sorbents was designed by using performance data acquired for the developed and selected sorbents. The plant scale was adjusted to the gasifier with processing capacity of 25 t/d of biomass material. The wet gas purification system with same scale and removal performance was configured by conventional process. The utility, plant size, capital cost and operational cost were compared for both systems. The dry system consumes 30% less auxiliary power (internal consumption rate of 14%), which will contribute to the efficiency increase. Plant size of the dry system is 30% smaller than the wet system because of its simple system configuration, thus the plant cost is possibly reduced by 20%. Operational cost for the dry system is significantly low because the absorbing solvent for wet desulfurization, detergents, and waste water treatment can be eliminated.

   These results revealed that the dry gas purification system is superior to the wet system. The dry gas purification system is sufficiently feasible to establish the biomass gasification power generation system.

   A part of this work was carried out under joint research with New Energy and Industrial Technology Development Organization (NEDO).

**Main Researcher:** Makoto Kobayashi, Ph. D.,
Senior Research Scientist, Energy Conversion Engineering Sector, Energy Engineering Research Laboratory

**Reference**


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*1: Kobayashi et al., “Development of Dry Gas Cleaning System for Multiple Impurities for Biomass Derived Gasification-Fuel. -(each report has its specific subtitle according to the developed sorbents)-“, Series of CRIEPI Reports M06007, M06008, M06009 (in Japanese)
6. Fossil Fuel Power Generation

The thoroughly dry gas purification system that combines conventional processes with the processes based on CRIEPI developed impurity removal sorbents has potential to obtain purified gas applicable to the MCFC power generation.

**Fig. 1** System configuration of dry gas purification system for the biomass/refuse gasification power generation.

**Fig. 2** Impurity removal performance of the system evaluated by introducing simulated fuel gas.

Concentration of all impurity was reduced below the detection limit of corresponding analyzer instruments, thus the sufficient performance for impurity removal was demonstrated for copper-based mercury sorbent, glass fiber reinforced halide sorbent, and zinc oxide sulfur sorbent.

**Fig. 3** Demonstration test result of the dry gas purification system by operating MCFC with the purified gas.

Stable power generation was accomplished for MCFC fueled with the purified gas from actual raw syngas from biomass gasifier. This confirms that the dry gas purification system fulfills the requirement for biomass gasification power generation as well as regulations for environmental protection.
Development of Technology for Reducing both Emissions of NOx and Unburned Carbon using In-Furnace Blending Method

Principal Research Results

Background

In pulverized coal fired power plants, it is important to reduce emissions of both NOx and unburned carbon from the viewpoint of environmental protection. Also, considering the security of fuel supply and the cost of fuel, it will become increasingly desirable for power plants to use different types of fuel. One method of reducing these emissions is to be fired with a high volatile content coal. When two types of coal are fired in a boiler, two different blending methods can be utilized. One is the line blending method, in which the two types of coal are stored in a bunker on the mill. The other is the in-furnace blending method, in which each type of coal is fired by each burner without prior blending in the bunker (Fig.1). In general, the line blending method is utilized in Japanese coal fired power plants. On the other hand, the in-furnace blending method is expected to reduce emissions of both NOx and unburned carbon. However, the effect of the in-furnace blending method on these emissions has not yet been clarified.

Objectives

The effect of the coal properties on the emissions of both NOx and unburned carbon by the in-furnace blending method is clarified using a coal combustion test furnace (MARINE furnace) with three staged burners.

Principal Results

1. Combustion of blended bituminous coals

In the case of the in-furnace blending method, which means that high volatile content coal is fired by the upper burner and low volatile content coal is fired by the middle and lower burners, the emissions of both NOx and unburned carbon are the lowest among other types of in-furnace blending method and the line blending method (Fig.2). The reason for the reduction of these emissions is considered to be that a large amount of NOx formed in the region of the middle and lower burners is decomposed by the reduction matter in high volatile content coal in the region of the upper burner. On the other hand, the reason for the decrease in unburned carbon is considered to be that the combustion time of low volatile content coal in the furnace is able to be lengthened by firing from the middle and lower burners.

Furthermore, from the viewpoint of the blending combination between two types of coal, the effect of the in-furnace blending method on reducing emissions of both NOx and unburned carbon becomes high using lower volatile content coal, which exhausts a large amount of NOx. Also, as the volatile matter content of higher volatile content coal is high, this reduction becomes considerable.

2. Combustion of sub-bituminous coal blended with bituminous coal

When the in-furnace blending method is utilized for the combustion of blended sub-bituminous coal, sub-bituminous coal is fired from the upper burner instead of bituminous coal with high volatile content. Then, NOx emission at the exit of the furnace was decreased compared with that for the line blending method (Fig.3).

For the line blending combustion of sub-bituminous coal, unburned carbon concentration in fly ash becomes much higher as the moisture content of the sub-bituminous coal increases. The reason for this is considered to be that the combustibility of bituminous coal is inhibited because of moisture vaporized from the sub-bituminous coal. In the case of the in-furnace blending method, the increase in unburned carbon at high moisture content in sub-bituminous coal was able to be reduced compared with that for the line blending method. The reason was considered to be that the combustion flames of bituminous coal and sub-bituminous coal were separated (Fig.4).

Main Researcher: Michitaka Ikeda, Ph. D., Research Scientist, Plant Engineering Sector, Energy Engineering Research Laboratory

Reference


*1: Emissions of both NOx and unburned carbon decrease as the volatile content in coal becomes high. (Makino et al., JIE Journal, 74, 906 (1994)
6. Fossil Fuel Power Generation

Fig. 1 Concept of two types of blending method

Line Blend: Two types of coal are stored in the bunker on the mill
In-Furnace Blend: Each coal is fired by each burner without prior blending in the bunker

Fig. 2 Influence of blending method on emissions of NOx and unburned carbon during blending combustion between two types of coal

In the case of in-furnace blending method, in which high volatile content coal is fired by upper burner and low volatile content coal is fired by middle and lower burners, emissions of both NOx and unburned carbon are lower than these emissions on the line blending method.

Fig. 3 Relation between NOx emission at the exit of furnace and blending combustion of sub-bituminous coal

When the in-furnace blending method is utilized for blending combustion of sub-bituminous coal, NOx emission at the exit of furnace is decreased compared with that for the line blending method.

Fig. 4 Relation between unburned carbon concentration in fly ash and blending combustion of sub-bituminous coal

In the case of in-furnace blending combustion of sub-bituminous coal, the increase in unburned carbon is able to be reduced compared with that for the line blending method.
**Principal Research Results**

**Development of Ice/Oil/PCB Elimination Technology using DME**

**Background**

There is a pressing need for low-cost dewatering of high-water-content solids such as coal and sewage sludge. Pre-existing technologies consume a great amount of energy due to their reliance on high temperature to evaporate the water content out of solid substances. In this research, we turned our attention to coal and sewage sludge; using dimethyl ether (DME)\(^1\). In this method, the water contained in coal is extracted into liquefied DME for separation from coal. After dewatering, DME is depressurized and subsequently vaporizes, thereby leaving the water to be separated at room temperature. There is already a clear advantage in energy efficiency, according to full-scale performance test calculations for the DME dewatering process. At the present time, we are focusing on understanding the technology's suitability for cold-weather regions, as well as its ability to eliminate substances such as oil and PCB.

**Objective**

Our objective is to verify the practicable possibilities for expanding first the elimination of ice in cold-weather regions, and later the elimination of oils and PCB at room temperature, using the DME desiccation method on materials other than the traditional target material, water.

**Principal Results**

1. **Potential to remove ice from frozen coal and wood pieces in a sub-zero environment**

   We installed a test-tube level (10 ml/batch) DME desiccation test device (Fig. 1) in an environment kept at a constant temperature of \(-10^\circ C\), and were then able to use liquefied DME to extract 44.5% of the icy moisture content from sub-bituminous coal (particulate diameter: 4-8 mm, moisture content: 42.4 wt%). Similarly, we were able to use liquefied DME to extract 53.5% volume of ice from frozen cedar chips (length: ~1 cm, thickness: 1-3 mm, moisture content: 68.9 wt%) in an environment kept at a constant temperature of \(-23^\circ C\).

2. **Capability of removing a variety of oils from a variety of materials at room temperature**

   We let vacuum pump oil to adsorb into an artificial oil-absorbing sheet, and then used our laboratory's prototype to bring liquefied DME into contact with the oil-soaked sheet. We estimated that this would be the most difficult form of oil removal, but the results of our experiment showed that we succeeded in removing all the oil from the absorbent sheet at room temperature. Furthermore, we also succeeded in removing all the oil from glass, wood pieces, paper and metal that had been covered in insulating oil. In addition, we succeeded in removing both the moisture content and the oil, simultaneously, from damp soil that had been permeated with heavy oil (Fig. 2).

3. **Room-temperature PCB removal from high moisture content sediment polluted with PCB**

   We brought PCB-polluted river sediment \(^2\) with a high moisture content into contact with liquefied DME. At room temperature, we were able to remove more than 99% of the PCB from the high moisture content sediment, and were simultaneously able to remove the moisture content (Fig. 3), thereby succeeding in cleansing the sediment of PCB such that PCB density levels were at or below environmental standard levels (dioxin poison volume 150 pg-TEQ/g).

   (The PCB-removal research was carried out in conjunction with Associate Professor Takaoka and Assistant Professor Oshita of Kyoto University, Faculty of Engineering, Urban and Environmental Engineering.)

**Future Developments**

We will continue to study the practical applications of the DME desiccation technology verified on the removal targets of the current experiments.

**Main Researcher:** Hideki Kanda, Ph. D.,
Research Scientist, Fuel Reforming Engineering Sector, Energy Engineering Research Laboratory

**Reference**


\(^1\): Standard boiling point: \(-25^\circ C\); boiling point at 0.5MP: 20°C. Not only water, but also ice, oil and PCB were dissolved into the liquid-state DME. In China, it is rapidly being propagated as a cheap alternative to imported LPG, and is a next-generation green fuel.

\(^2\): Due to past illegal discarding and dumping, there are rivers in which slime has been detected with PCB in excess of allowed levels. Although there have been studies on the use of acetone in PCB removal, the water in slime interferes with this process, in addition to which, the acetone remaining behind as residue in the soil gives rise to a new set of problems, all of which make this method difficult to implement.

Awards won since last year's annual report: Environmental Technology/Project Award, Environmental Engineering Forum, Japan Society of Civil Engineers; The Chemical Society of Japan Award for Young Chemists in Technical Development for 2007; Fuji-Sankei-Business-I Award (Vice-Grand Prize), 22nd Advanced Technology Award established by Kenichi FUKUI.
6. Fossil Fuel Power Generation

Coal is produced in abundance even in overseas northern climes and inland cold-weather areas. In these cold-weather regions, the temperature in winter falls below the freezing point of water. For this reason, using DME to directly remove icy moisture from frozen coal slurry without having to melt the moisture itself is an effective desiccation method. The results of this experiment verified this practical possibility.

Fig. 1 Left: Overview of the Test Device; Right: Photograph showing ethanol temperature (~23°C for wood chips)

Oil-sorbent Sheet: 0.34 kg
Vacuum Pump Oil: +2.60 kg
Vacuum Pump Oil: −2.70 kg
Soil: 3.63 kg
Heavy Oil: +1.15 kg
DME 100 L
Moisture Content: −0.75 kg
Heavy Oil: −1.15 kg

Fig. 2 Removal of oil from oil-absorbent sheets and moist soil

After PCB has been removed with DME, sediment becomes paler in color and shrinks. This is because the slime is also desiccated simultaneously, which has a moisture content of 60%. Because DME is a gas at normal temperatures and pressures, it does not leave any residue. For this reason, it has clearly become a candidate for application as an environmental cleansing technology.

Fig. 3 River sediment from which PCB has been removed with the help of DME (left: before DME contact; middle: after DME contact; right: waste liquid including PCB) (Photographs courtesy of Associate Prof. Takaoka and Assistant Prof. Oshita of Kyoto Univ., Urban and Environmental Engineering)
Principal Research Results

Development of Coating Technology for Preventing Sulfide Corrosion on Boiler Tubes in Coal Fired Power Plants

Development of a Practical Compound Film of Low-cost and High Corrosion Resistance

Background
In coal fired power plants, the concentration of H2S becomes higher in the burner area where there is a strong reducing atmosphere. Therefore, the boiler tubes are damaged due to sulfide corrosion. The damaged tubes should be repaired by buildup welding or thermal spraying. If the damage by sulfide corrosion is large, the boiler tubes need to be replaced. Thus, these repairs become costly. To deal with this problem, we have embarked on development of an economical and straightforward technique of coating for preventing sulfide corrosion in 2004. We designed the compound film of TiO2 and the carbon film in 2006. The sulfide corrosion could be reduced by 50%. However, the corrosion resistance of the film did not achieve the required value (10%).

Objectives
This study aims to develop film structure which has high corrosion resistance on the basis of current coating technology. Moreover, the coating process is simplified.

Principal Results
1. Success in development of compound film that has superior corrosion resistant to 10% or less
In order to improve the corrosion resistance, the coating film has to improve the gas-tightness. SiO2 is selected as a prime film material, and SiO2/TiO2/C/TiO2 compound film is developed. As a result of the sulfide corrosion test performed, the developed film demonstrated corrosion of 10% or less compared to that in the uncoated sample (Fig.1, Fig.2). In addition, this coating didn't affect the structure of base metal such as carburization.

2. Simplification of coating process for low cost
In previous coating processes, the oxidation or degreasing were performed during each coating as shown in Fig 3(a). In the simple coating process, the oxidation and degreasing are performed after all coating as shown in Fig. 3(b). The performance of the film in simple process is confirmed to be the same as that in previous processes. It is possible to oxidize and degrease by the heat when the boiler starts. Therefore, the coating process can be simplified. Moreover, the coating material costs are also low as listed in Table 1. Decrease of major repair costs can be expected due to this technology compared with the protection film of 50Ni50Cr flame spray coating.

Coating of developed film on the inspection of boiler every two years ensures the boiler soundness. It is expected that the total cost of boiler life decreases because it doesn't need large-scale repairs such as buildup welding and panel exchange, etc.

Future Developments
In order to prove reliability and applicability of developed film, the durability evaluation will be performed in the coal fired power plant boiler. After that we will put it to practical use at an early stage.

Main Researcher: Makoto Kawase, Ph. D.,
Research Scientist, Energy Conversion Engineering Sector, Energy Engineering Research Laboratory

Reference
6. Fossil Fuel Power Generation

**Iron sulfide (FeS)**

- Approx. 110 μm

**Fe, Cr oxides**

- Approx. 80 μm

**Base metal**

**Test conditions**
- Speciment metal: STBA24
- Temp: 500°C
- Gas: CO₂/ H₂/ N₂/ CO/ H₂O/ H₂S = 12%/ 4%/ 67%/ 8%/ 9%/ 330ppm
- Test term: 3016 hours

**Test conditions**
- Speciment metal: STBA24
- Temp: 500°C
- Gas: CO₂/ H₂/ N₂/ CO/ H₂O/ H₂S = 12%/ 4%/ 67%/ 8%/ 9%/ 330ppm
- Test term: 3016 hours

**Corroded layer**
- FeS

**Coating layer**
- FeS

**Fig. 1** Comparison of sulfide corrosion between developed compound film and non-coating.

**Fig. 2** Performance comparisons of developed films.

**Fig. 3** Coating Process.

**Table 1** Material cost for coating

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (μm)</th>
<th>Coating efficiency</th>
<th>Cost (yen/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>1.0</td>
<td>0.6</td>
<td>1833</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.5</td>
<td>0.6</td>
<td>789</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>0.75</td>
<td>1272</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.5</td>
<td>0.6</td>
<td>789</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>4683 yen/m²</strong></td>
</tr>
</tbody>
</table>
Principal Research Results

Development of Biomass/Waste Power Generation System with Carbonizing Gasifier and Gas Engine

Background
To create a sustainable recycle-oriented society, it is important to develop the utilization technology for biomass and solid waste, which are promising energy resources. In general, biomass and solid waste are widely and thinly distributed, so it is not easy to gather up them in large amounts. Therefore it is difficult to improve the generating efficiency of the biomass and solid waste power generation system through adoption of large-scale operations.

Objectives
The aim of our project is to suggest a small-scale and high-efficiency power generation system utilizing biomass and solid waste. The integration of carbonizing gasification technology and the gas engine technology allows such a power generation system. The performances of the carbonizing gasifier and the gas engine are evaluated with the demonstration test facilities as a joint research of CRIEPI and Kansai EP (Kansai Electric Power Co., Inc.), in order to put the developed system to practical use.

Principal Results
1. Features of the system
CRIEPI has developed the carbonizing gasifier using biomass and solid waste as fuel. On the other hand, Kansai EP has developed the small and high-efficiency gas engine generator with natural gas. The small-scale and high-efficiency power generation system with biomass and solid waste (as shown in Fig.1) has been devised by integration of both technologies. The installation of carbonizer, as a pretreatment of gasifier, makes it possible to use a variety of fuels. The utilization of waste heat from the gas engine, as a heat source of the carbonizer, results in high thermal efficiency of the system.

2. Performance of carbonizing gasifier
A gasification test (as shown in Fig.2) of Japanese cedar as a typical woody biomass was carried out. Table 1 shows the industrial analysis and ultimate analysis of Japanese cedar. As the result of the test, the calorific value of produced gas was higher than 1,000kcal/m3N by maintaining air ratio of 0.42 or less. The performance of gasifier achieved cold gas efficiency over 67.5% (calorific value of produced gas 1,170 kcal/m3N, carbon conversion over 99%) at 0.39 air ratio.

3. Performance of gas engine
The original gas engine generator (rated power 440kW) runs on natural gas, and has adopted a pilot ignition system which shows high ignition performance. The gas-supplying system of the gas engine was redesigned for the low-calorie gas. In case of the produced gas, of which calorific value is about one-tenth of that of natural gas, the rated power of the gas engine was 320kW, and the generating efficiency of the gas engine reached 34% in LHV basis. Furthermore, the stable operation of the gas engine with a low-calorie produced gas, of which calorific value is 850kcal/m3N, was carried out by optimization of fuel-feeding condition. It means that high-moisture biomass is available as the fuel of this system. Fig.3 shows the operation condition of the gas engine.

4. Performance of the system
In the operation of the carbonizing gasification and gas engine power generation system with biomass and waste, the performance targets of gasifier and gas engine were attained (as shown in Table 2). The combined efficiency of the gasifier and gas engine power generation system was over 23% on LHV basis. So, the system was found to be small-scale, but to have an extremely-high performance (as shown in Fig. 4).

Future Developments
Some modifications of the system for higher performance will be made. The heat transfer test of the gas-gas heat exchanger will be planned. The test data will be useful in the design of the exhaust gas heat exchanger. The feasibility study on the practical plant of this system with food-processing waste will be carried out.

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Reference
Gasification performance of cedar on the LHV basis. Total generating efficiency of the system reached 23% on the LHV basis. The new biomass/solid waste power generation system co-developed with Kansai EP is small-scale, but shows higher efficiency than other biomass/solid waste-fired power systems.