Chapter 4

Ancillary equipment and applicable CCTs
4.1 Rehabilitation for Steam Turbine
The rehabilitations of turbine have been implemented using up-date technology for the improvement in efficiency and reliability and some of them planned concurrently to increase the production of electricity.

(1) Efficiency improvement
The efficiency improvement can be achieved by reducing turbine internal loss.
In 90th the Computational Fluid Dynamics (CFD) methods and test facilities were developed quickly for the study of optimum turbine internal construction to minimize the internal losses. The thermodynamic and aerodynamic performance of the steam turbine is primarily determined by steam path such as high-efficiency nozzle & blade with steam seal device.

1) Updated advanced flow pattern in the steam path is shown in Figure 4.1-1.

**Advanced Flow Pattern**
- Fully 3-Dimensional Viscous Analysis by CFD (Computational Fluid Dynamics)
- Curves in the radial direction enables to reduce secondary flow loss from nozzle walls or blade roots/tips.
- Validation Test was performed to confirm the improvement of performance

![CFD Models]

Figure 4.1.1 Outline of high efficiency technology
Source: Toshiba Corporation Power Systems Corporation

2) Improvement technology (typical)
(a) High and intermediate pressure (HIP) turbine
Typical efficiency improvement scopes for HIP turbine are referred to Figure 4.1.2.
Figure 4.1.2 Efficiency improvement for HIP turbine
Source: Mitsubishi Hitachi Power Systems, Ltd.,

(b) Low pressure (LP) turbine

Typical efficiency improvement scopes for LP turbine are referred to Figure 4.1.3

Figure 4.1.3 Efficiency improvement for LP turbine
Source: Mitsubishi Hitachi Power Systems, Ltd.,
(2) Reliability

Typical measures for the achievement of high reliability are as follows

1) Treatment or coating of the material such as Cr-C on the nozzle & blade with attachments

2) Adoption of high grade stem & bush made of high qualitative materials such as Incoloy, Stellite etc.,

The Oxide scale on Stem and Bush produced under high temperature steam reduce the clearance between Stem and Bush, which causes the stem-stick.

![Material of Valve stem : Incoloy](image1)
![Material of Bush : Stellite](image2)

**These material can reduce oxide scale.**

Figure 4.1.4a Example of measure for high reliability

Source: Mitsubishi Hitachi Power Systems, Ltd.,

3) Adoption of Snubber blades

In the low pressure (LP) turbine blades such as the last minus one (L-1), the last minus two (L-2) and so on which are operated in moisture condition, corrosion damage like stress corrosion cracking and corrosion fatigue are sometimes appeared. Snubber blades effectively contribute to solve these issues and to improve reliability.

![L-1 and L-2 blades are operating in the moisture condition.](image3)

**As the snubber blades eliminate corrodent traps such as lacing wire holes and reduce vibration stresses, they protect against stress corrosion cracking and corrosion fatigue.**

Figure 4.1.4b Example of measure for high reliability

Source: Toshiba Corporation Power Systems Corporation
(3) Typical example of turbine rehabilitation with Japanese technologies

Figure 4.1.5a Turbine rehabilitation (Example 1)
Source: Mitsubishi Hitachi Power Systems, Ltd.,

210MW

Capacity upgrade to 225 MW with 15-20 yrs life extension

Figure 4.1.5b Turbine rehabilitation (Example 2)
Source: Toshiba Corporation Power Systems Corporation
4.2 Risk Based Maintenance (RBM)

(1) General

Risk Based Maintenance (RBM) for boilers has been developed to provide the optimized maintenance plans contributing to the consistent long-term operation based on the American Petroleum Institute’s API1581. Since middle of 90th, RBM has been put into practical utilization and for the applied boiler plants the frequency of un-anticipated accidents decreased drastically and for some plants they could be reduced to less than half of earlier years and financial loss could save more than $10 million a year by implementation of RBM program in Japan. The evaluation of the “Risks” can be envisioned from the “likelihood of damage” and “Possible consequence of failure” specified in Figure 4.2.1. Long term maintenance plan is provided for the timings of replacement and inspection according to the evaluated risks with cost benefit analysis.

![Risk Based Maintenance (RBM) Technique can optimize inspection and maintenance plans for Coal-fired power plants.](image)

**Risk = Likelihood x Consequence**

**Merit of RBM**

Evaluate the risk and decide the priority and targets of inspection and maintenance

- Reduce maintenance cost
- Improve plant availability

![Figure 4.2.1 Risk Based Maintenance (RBM)](image)

Source: Mitsubishi Hitachi Power Systems, Ltd.,

(2) Procedure

RBM procedure is shown in Figure 4.2.2. Inspection data are referred to the previous data and verified by accumulated data base and Inspection/Maintenance planning is established.
(3) RBM Menu for Boiler Components.

Main damage and its assessment procedure are as follows.

1) Corrosion Fatigue: Crack propagation analysis
2) Creep: Analysis based on Creep database
3) Thermal Fatigue: Analysis based on low cycle Fatigue database
4) Pitting Corrosion: Pitting depth analysis
5) Corrosion/ Erosion: Corrosion/Erosion loss analysis
6) Stress Corrosion Crack: Weibull Distribution analysis.

Locations/Parts to be inspected is referred to Figure 4.2.3.
Figure 4.2.3 Typical component to be inspected

Source: Mitsubishi Hitachi Power Systems, Ltd.,

(4) Summary

1) RBM is composed of precise inspection technique and metallurgical assessment based on 30 years data base.

2) The damages can be evaluated by RBM are creep, corrosion fatigue, thermal fatigue and so on.

3) RBM program can advise an economical maintenance procedure with minimized un-anticipated accidents and financial loss.
4.3 Boiler Combustion Simulation Technology

Computer Simulation analysis has been utilized to reduce unburnt carbon or NOx emission and resolve the troubles of ash deposition for pulverized coal fired boiler.

(1) Outline of simulation technology

Simulation technology is established by incorporating pulverized coal combustion models into commercialized Computer Fluid Dynamics (CFD) software, “FLUENT”

(2) Analysis method

1) Input and output

<table>
<thead>
<tr>
<th>Data on boiler structure</th>
<th>Setup of boiler operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Boiler dimension</td>
<td>1) Feed rate of coal</td>
</tr>
<tr>
<td>2) Alignments/structures data</td>
<td>2) Coal data (particle size, heat value, composition etc.)</td>
</tr>
<tr>
<td></td>
<td>3) Combustion Air data (Flow, Temp.)</td>
</tr>
<tr>
<td></td>
<td>4) Heat transfer data</td>
</tr>
<tr>
<td></td>
<td>5) Some other data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas Flow Rate</th>
<th>Particle Trajectory</th>
<th>Gas Temp.</th>
<th>Oxygen Concentration</th>
</tr>
</thead>
</table>

Figure 4.3.1 Outline of simulation technology
Source: Idemitsu Kosan Co., Ltd

Figure 4.3.2 Input and Output (Example)
Source: Idemitsu Kosan Co., Ltd
2) How to use the output
   (a) Search of optimum operating conditions (Combustion air distributions)
   (b) Reduction of unburnt carbon to improve the efficiency
   (c) Reduction of NOx
   (d) Improvement of slagging troubles
   (e) Effect prediction in case of coal changing.

(3) Example

Reduction of unburnt carbon and NOx was produced by altering the setup of damper openings.

Figure 4.3.3 Example of application

Source: Idemitsu Kosan Co., Ltd
4.4 Advanced Process Control of Boiler, Turbine & BOP

(1) General

The coal fired power generation plant has been strongly urged for improved efficiency through Advanced Process Control (APC) for contributing to energy conservation. The power plant using a conventional DCS (Distributed Control System), the control parameters are changed by operator manually in accordance with the situation based on the experience and available allowances. However, in general, the set point data variability in manual setting is quite wide and required to consider some unexpected contingencies. Consequently, some allowances to the operating limitation are taken, which results in performance deterioration.

APC can improve the controllability of the process and it enables to optimize the allowance of variation in set-points within operating limitation. APC also improves the plant efficiency through stricter control band. The APC can provide not only high controllability but also operating optimization in total power generation plant system. APC can predict possible future behavior of the power plant and change the control variable based on manipulated and disturbance conditions and achieve both of high controllability and optimization facility in control algorithm. Outline of APC is referred to Figure 4.4.1

Figure 4.4.1 Outline of APC for coal fired power generation plant
Source: Yokogawa Electric Corporation
Benefits of APC adoption are as follows.

1) Improvement of power plant efficiency
2) Improvement in plant availability
3) Minimizing of environmental emissions
4.5 Environmental protection system

(1) General
Environmental flue gas treatment systems are very important for power plant. Rich experience in Japan on DeNOx and FGD (Flue Gas De-sulfurization) system can comply extremely low emission requirement in Japan.

(2) Environmental system

1) DeNOx system
To meet the severe and various requirements, the following Selective Catalytic Reduction (SCR) Process for DeNOx can be applied as proven technology. DeNOx System can achieve high DeNOx efficiency. Reliable and high performance Catalyst will be selected and DeNOx system can be established in coordinated with boiler and auxiliary facilities.

![DeNOx System Diagram](image)

Figure 4.5.1 DeNOx System
Source: IHI Corporation

2) FGD system
Wet type FGD System (Limestone – Gypsum Process and other Alkaline Processes) is most efficient De-SOx system for power plant. Japanese FGD Systems have high De-SOx efficiency, and compact layout can be accomplished. Fig 4.5.2 shows typical FGD arrangement, one is cylindrical type and the other is rectangular type.
Main features are:
- Simultaneous treatment of desulfurizing, dust-removing and oxidizing in one a absorber
- Large capacity treatment by single absorber up to the unit for 1000 MW power plant
- Selection of absorber type (Cylinder or Rectangular) suitable for compact layout
- Easy maintenance due to simple configuration
- Low running cost due to lower pressure loss
- Speedy load change due to slurry spray flow control

3) Non-Leakage type Gas-Gas Heater (GGH)

To prevent the particle leakage and utilize the Hot Flue Gas at the most, Non-Leakage GGH system can be applied, and it allows ESP to reduce the particle emission most effectively in Low-Low temperature range.
Fig 4.5.3 Non-Leakage type GGH

Source: IHI Corporation
4.6 Coal Preparation for Coal Fired Power Plant

(1) General

A lot of coal in the world contains high levels of ash, like Indian Gondwana coal, high levels of water, like Indian Cenozoic (Tertiary) coal (Neyveli coal mine), or high levels of sulfur (Makum coal mine). Coal preparation technology has been developed with the aim of improving these characteristics that negatively affect the use of coal, so that coal can be used as fuel more efficiently and conveniently in a more eco-friendly way. Here we introduce examples of coal preparation technology, which produce coal suitable for coal fired power plant, 1) outline of Coal Washing technology including Model Project at Angul, Odisha, which is currently being conducted in collaboration with Monnet Ispat & Energy Ltd. with support of both Indian and Japanese governments and 2) Upgrading Brown Coal (UBC).

(2) Coal washing

Freshly mined coal (raw coal) comes mixed with organic coal and containing mineral matter such as rock and clay that contribute to ash content and inorganic sulfur content. If coal is burned as fuel in its raw-mined condition, the transportation energy and auxiliary power will be lost to the mineral matter that does not contribute at all to heat production. Furthermore, the heat will be consumed in the process of converting the mineral matter into ash, and ash disposal energy will also be wasted. Moreover, ash content of raw coal changes from moment to moment depending on the degree of mixed mineral matter, so it is difficult to operate the power station at rated output.

Coal washing is a process involving physical and economical separation of mineral matter, including ash and sulfur contents, from organic coal. Coal particles are light (1.5 g/cm³), whereas mineral matter particles are heavy (2.5 g/cm³). These characteristics are utilized for separation (Gravity Concentration). Various separation machines have been invented and put into practical use based on the size of target particles or methods of gravity concentration (e.g., use of a fluid that has a density, or differences in sedimentation rate in water). In Japan, the fluidized bed type dry gravity separator is currently under development.

In future, power generation systems with higher efficiency will be introduced. However, no matter how impressive the new power generation system might be, it will be difficult to take full advantage of the capability as long as we use the coal containing a large amount of mineral matter, in which the quality of ash and other contents changes from moment to moment. Coal washing, in a sense, is a starting point of "Clean Coal Technology".

1) Typical coal washing devices: Figure 4.6.1 shows the suitable Coal Washing Devices by
coal feed size.

Figure 4.6.1 Suitable Coal washing Devices by coal feed size
Source: Japan Coal Energy Center

2) Coal Washery Model Project

Currently, JCOAL is carrying out the Coal Washery Model Project near Angul, Odisha, in collaboration with Monnet Ispat & Energy Ltd., with support of both Indian and Japanese governments. The capacity of this washery is 2.2 million t/year (400 t/hr), generating clean coal with less than 34% ash content from raw coal with a 40-50% ash content for power generation.

The biggest feature of this washery is that a coal washing device developed in Japan called Variable Wave Type JIG (Vari-Wave JIG) has been introduced for the first time in India. While the traditional type of JIG operated in India generates the sine wave, Vari-Wave JIG can generate a variety of wave patterns including the trapezoidal wave. Vari-Wave JIG can generate clean coal at a much higher yield (approximately 3% more) than the traditional JIG by selecting the most suitable wave pattern for raw coal arriving at the washery.

It is not easy to separate and recover clean coal from raw coal such as Indian Gondwana coal, which has fine mineral matter distributed densely inside the coal. One way to deal with this is to use a coal washing device with high sorting precision, such as Heavy Medium Cyclone; however, it is not suitable to sort inexpensive fuel coal, because the cost of
operation will be increased. Although sorting precision of Vari-Wave JIG is not as high as that of Heavy Medium Cyclone, it is better than traditional JIG with the same operating cost. Therefore, we believe that Vari-Wave JIG is the most efficient coal washing device for fuel coal production in India.

Figure 4.6.2 Coal Washery Model Project at Angul, Odisha
(Completion of plant Construction: June 2014)
Source: Japan Coal Energy Center

(3) Upgrading Brown Coal (UBC)

About half of coal resources in the world are low rank coal (LRC), such as sub-bituminous coal and lignite, or brown coal. LRC has limited use due to difficulty with long-distance transportation, because LRC has drawbacks such as high water content, low calorific value, and susceptibility to self-ignition. Carbonaceous characteristics of LRC include porousness, large specific surface area, tendency to absorb and retain moisture due to its hydrophilic nature, and high ratios of humic acid and humin, which are easily oxidized due to low rank of coalification. These characteristics give rise to the weakness such as high water content, lower calorific value, and susceptibility to self-ignition. UBC is a technology that paves the way for the effective use of LRC resources through amelioration of the weakness, which will make long-distance transport possible.

Pulverized LRC is mixed with cycle stock (light oil) and a small amount of heavy oil or asphalt, and then pressurized and heated in a relatively mild condition (0.35 MPa, 140°C). This releases the water content from pores in the form of vapor, while the added heavy oil or asphalt coats pores, which reduces the specific surface area and suppresses spontaneous
combustion. Furthermore, the water-repellent heavy oil prevents re-adsorption of water. In addition, the water content removed in the form of vapor is reused as heat source for heating apparatus, thereby greatly reducing energy consumption. Obtained upgraded coal powder is shaped with a briquetting machine for long-distance transport.

1) UBC process flow

Figure 4.6.3 shows typical UBC process flow

![UBC process flow diagram](image)

Figure 4.6.3 Typical UBC process flow
Source: Japan Coal Energy Center

2) Product

Fundamentals of LRC upgrading are dewatering and adsorption of heavy oil/asphalt into the surface of the pores and referred to Figure 4.6.4.

![Fundamentals of low-rank coal upgrading](image)

Figure 4.6.4 Fundamentals of low-rank coal upgrading
The upgrade coal in the UBC process is in a powdery state and for transportation to non-local customers it is formed into briquettes. Figure 4.6.5 shows briquette.

Figure 4.6.5 Briquetted UBC
Source: Japan Coal Energy Center