dti

REFURBISHMENT OF YAOMENG BOILER NO. 1

Once-through Boiler with Vertical Tube Technology

PROJECT SUMMARY 306

CLEANER FOSSIL FUELS PROGRAMME – CLEANER COAL R&D PROGRAMME

OBJECTIVES

- To evaluate the performance of the original boiler unit and conduct heat flux measurements for input to boiler modelling for a new design.
- To develop a non-intrusive device for flow measurement in individual furnace tubes for the assessment of the waterside performance and to prove the new design.
- To conduct steam oxidation trials on candidate furnace wall tube materials.

SUMMARY

The benefits to the operator, Yaomeng Power Generation Limited, (YPGL) from the project have included:

- Increased power output capability.
- Improved load following capability.
- Improved turndown without fuel oil support.
- Improved plant availability and part load efficiency.
- Significant savings on fuel consumption.
- Reduced emissions.
- Reduced auxiliary power draw.

All leading to savings on power generation costs.

This brochure describes the principles used for the Yaomeng upgrade to a Mitsui Babcock Posiflow boiler and illustrates the clear benefits to boilers designed or converted to utilise this low water mass flux, optimised internally ribbed vertical tube boiler technology.

Figure 1. Yaomeng Boiler No. 1 as it is today

It also illustrates how the support from the Department of Trade and Industry (DTI) has enabled Mitsui Babcock to undertake a more comprehensive design investigation than would normally be possible with a commercial project to permit the consolidation of the design techniques used for Yaomeng, or updating to enable more competitive designs to be offered for future plant.

The natural progression from sub-critical conditions to the benefits delivered not only for refurbishment of existing plant but also to new-build of super-critical boilers at today's state-of-the-art steam conditions is also demonstrated in this brochure.

BACKGROUND

Situated in Henan Province, PRC, Yaomeng Power Plant consists of 4 × 300 MWe coal-fired boilers. Unit 1 (shown in Figure 2) and unit 2 entered service in the mid-1970s. They were high mass flux, once through, sub-critical universal pressure (UP) boilers, designed for base load operation to generate main steam at 570°C. A full height division wall connected in series with the outer walls was used to create a symmetrical twin furnace layout, with tangentially firing burners. The furnace width was 17m, the depth 8m and the water mass flux 1800kg/m^{2}s. The design required that flow measuring devices and individual valves were needed to preset the flow distribution to each furnace wall circuit during the commissioning stages.

Figure 2. Yaomeng Unit No.1 before Refurbishment

From 1992 onwards, after overheating in the pressure parts led to a restriction of 545°C on the main steam temperature, the maximum output was reduced to 270 MWe. The boiler's intrinsic intolerance to load change and operation below 230 MWe were also problematic and the prospect of more onerous emissions legislation was thought likely to impose further restrictions or even closure. Instead YPGL chose plant upgrade. Mitsui Babcock's main objectives from the refurbishment were to permit the achievement of full design load, to give the boiler full operational flexibility in following load demand, and to maintain stable operation over the full load range. The scope of work for Mitsui Babcock centred on the upgrade of the furnace pressure parts, and improvement of the burners, start-up system and control philosophies.

The DTI-supported collaborative project between Mitsui Babcock, Cranfield University and the Thermal Power Research Institute, (TPRI) took advantage of the boiler refurbishment contract to allow a more thorough investigation of the furnace performance, focusing on the design and functioning of the innovative features associated with the vertical tube furnace walls, the development of a non-intrusive flow meter and an investigation of steam oxidation behaviour. Use was made of the flow metering technology developed at Cranfield and work carried out to assess furnace wall performance pre-and post-upgrade with a view to using the Posiflow technology concept in future advanced super-critical boiler plant.

PROJECT ACTIVITIES

Appraisal of Existing Boiler Pre-Refurbishment

For the assessment of the original plant, thermocouples were attached to selected furnace outlet tubes and monitored over a range of operating loads. The metal temperature was approximately 360°C at high load, well below the design temperature of 400°C, but increased to 463°C at 70% turndown. The temperature differential between adjacent tubes was up to 70°C, imposing unacceptably high stresses in the outlet headers and hence reducing plant life. Highest metal temperatures occurred at the lowest loads, and led to failures in the water walls and outlet mixing headers.

On the basis of their analysis Mitsui Babcock deduced that the original high water mass flux design was the principal reason for poor operation of the furnace at low loads. Furnace tubes absorb unequal quantities of heat, depending on their location, and changes in the combustion firing pattern due to mill, fuel or combustion air changes, even though the total heat absorption might be constant. Therefore under conditions of a change in the heat flux to a tube or group of tubes, the flow through them requires regulation to compensate accordingly, but this is not possible for all operating conditions with the original high mass flux system at Yaomeng.

New Posiflow Design

The features that Mitsui Babcock have incorporated into the advanced technology once through design to achieve intended load and full operating flexibility are:

- New vertical tube furnace walls featuring state of the art optimised small bore ribbed tube to maintain the required heat transfer throughout the height of the boiler, thus permitting the use of a low water mass flux of 700kg/m^{2}s which produces a self-regulating flow response characteristic to prevent local over-heating.
- An improved start up system that will give a shortened start-up time and reduced heat and water consumption.
- Upgraded burners to improve NO_x emission levels and extend the safe range of operating loads without fuel oil support.
- Control philosophy upgrades for combustion, feed water and start-up systems to obtain the optimum loading rates and load flexibility.

The proposed new furnace arrangement is shown in Figure 3, the Three-dimensional, Computer Aided Drawing (3-D, CAD) model generated as part of the new boiler design process. Careful selection of the new furnace wall components has enabled the existing boiler footprint and main support structure to be retained, together with the simplification in the feed water connections to give a parallel flow regime for the furnace and division walls to reduce pressure losses even further.

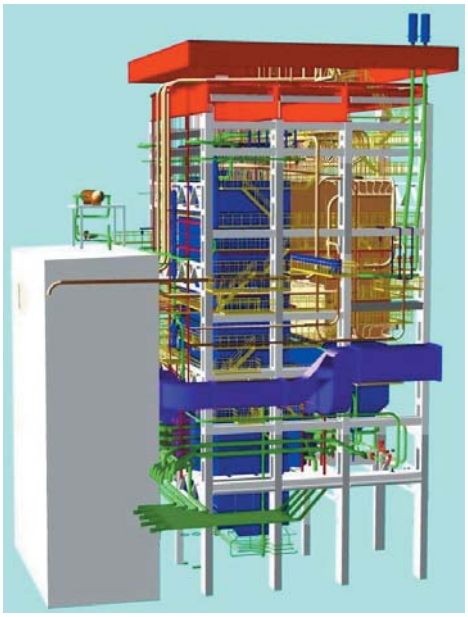

Figure 3. 3-D, CAD model of the new boiler

Thermal performance calculations for the furnace and an assessment of the fluid flow distribution through the walls for BMCR and a range of part loads, was made using Mitsui Babcock in-house software. The results showed that predicted tube mean wall temperatures were within design limits over the entire operating load range, unlike the predictions for similar parameters for the high water mass flux arrangement. Static and dynamic stability calculations have confirmed the stable characteristic of the new boiler design, again over the entire operating range.

A comparison of the optimised small bore ribbed tube used on Yaomeng is made with more conventional ribbed tube in Figure 4.

Figure 4. Comparison of regular, (left) and specially optimised ribbed tube

This was also the first time that such optimised tubing had been manufactured on a full production scale. Nevertheless, the close collaboration by Mitsui Babcock with both the UK tube supplier and his toolmaker ensured that the exacting requirements for the tube internal profile would be achieved consistently.

Appraisal of Performance Post-Refurbishment

To permit verification of the refurbished boiler design, exit temperature thermocouples were fitted to tubes in all furnace walls. A section of the furnace in the front sidewall was also instrumented with both gas- and air-side thermocouples, heat flux meters and flow meters to measure operational parametric variations. The flow meters positioned within the water phase section of the furnace were novel in that this was the first time that ultrasonic flow measurement techniques had been used on such small bore, thick-walled ribbed tubing combined with such high temperatures and relatively low flow rates. At site the output was collected over the load range 230 MWe to 300 MWe. The results, which indicated that the water mass flux increased proportionately with load, and that at constant load the mass flux in the tubes towards the corner of the furnace was lower than that at the mid wall position, were in line with design expectations.

There was good agreement between results from the flux meters and design predictions, and although readings on the corner tube were lower than those for the other instrumented tubes as expected, the measured heat fluxes were up to 30% lower than design predictions for the upper levels in the furnace, probably due to furnace wall slagging.

It was evident from the significant reduction in the exit temperature differentials between adjacent tubes, typically as shown in Figure 5 for the furnace front wall, that the vertical ribbed tubing was performing well. Thus the self-regulating flow characteristics achieved with Mitsui Babcock Posiflow boiler technology had been demonstrated, a world first in commercial power generation using utility boilers.

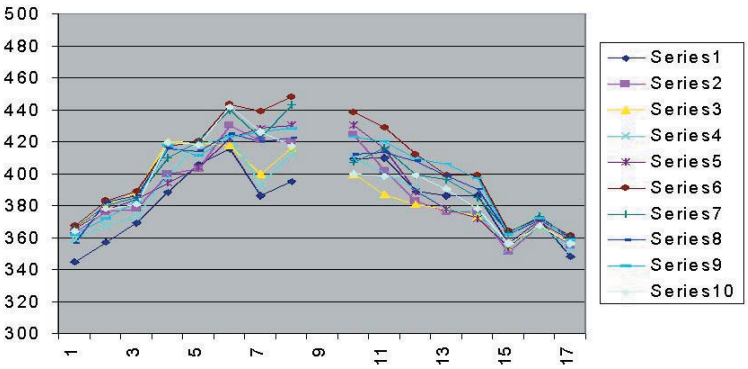

Figure 5. Furnace front wall tube exit temperatures

Steam Oxidation Studies

For the exploitation of the low mass flux technology for the next generation of advanced super-critical units in particular, for which the exit temperatures from the furnace walls will be significantly higher than at Yaomeng, an understanding of the oxide growth is an important consideration for the long term performance of the boiler, amongst other things for the influence on the continued effectiveness of the optimised ribbed tubing.

An initial investigation was, therefore, undertaken also by Cranfield University using ribbed tube similar to that used in the Yaomeng furnace wall, together with plain tube for other candidate furnace wall tube materials. Short tubular specimens were exposed to a steam oxidation environment in the temperature range 500-575°C over test periods of up to 4000hours. A duplicity in the metal loss/oxide growth techniques was used for the quantitative assessment of the specimens.

As expected steam oxidation rates were found to increase with temperature. At each temperature differences in performance between the materials were found to be within the scatter and error bands of the results expected, noting the limitations of this method of testing. Overall, for the three steels studied, the results indicated that there was a limited effect of chromium content on steam oxidation rates in the range 500-575°C. The samples of ribbed tubing exhibited similar degrees of oxidation both inside and out, indicating that the ribbing process had apparently not affected the oxidation behaviour.

CONCLUSIONS

- The results of the Performance Guarantee Tests, (PGT's) undertaken by TPRI, and subsequent operation have confirmed the major improvements in the performance of the unit.
- Peak steam output is 1010 t/hr and maximum continuous output 954 t/hr, both exceeding the guarantee requirements.
- Peak power output has been increased from 270M We to 327 MWe, and the boiler now formally up-rated to 310 MWe.
- Whereas operation without fuel oil support was difficult at any part load condition before the upgrade, it is now possible down to 40% BMCR.
- The load following capability has also been much improved and boiler thermal efficiency has increased from 90.3% to 91.4%.
- Unburned carbon decreased from 4.7% to 1.7% and the particulates emissions reduced from 1242mg/m^3 to 163mg/m^3. NOx emissions have also been cut significantly.

- The new start-up system has decreased boiler start-up and shut-down times appreciably, with up to 60 minutes having been trimmed from the time for a cold start.
- Apart from a short outage for maintenance prior to the PGT's and an enforced shutdown due to a failure in another item of plant, the boiler operated almost continuously within that 12-month period, mainly at full load or above.

POTENTIAL FOR FUTURE DEVELOPMENT

The successful completion of this refurbishment is a major milestone in both the development of the Posiflow boiler technology, and Mitsui Babcock's presence in the refurbishment market in the PRC. Wherever sub-critical once through boilers are suffering load restrictions, intolerances to load changes or high metal temperatures, this technology now offers a proven solution, which also extends to super-critical applications.

Within the UK, operators are already considering the use of this technology, which along with changes to the HP piping and turbine will allow the move from a sub-critical to a super-critical steam cycle at state-of-the-art steam conditions. Mitsui Babcock believes that this technology will become a standard for fossil fired boilers of the future, and are pleased to have enjoyed the support of DTI to enable them to be in the forefront of the development of the technology and application of it.

COST

The total budget cost for the collaborative part of the project was £420,000, with the DTI contributing £181,570, (43%). The balance of the project funding was provided by the participants.

DURATION

Original programme
30 months – July, 2000
to December, 2002

CONTRACTOR

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