Technical Paper

Progress of the Weston Unit 4 Supercritical Project in Wisconsin

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Abstract

Construction is ongoing at Wisconsin Public Service (WPS) Corporation's Weston Unit 4, one of the few supercritical pulverized coal power plants currently under construction in the United States (U.S.). Weston 4 is a coal-fired 590 MW Babcock & Wilcox (B&W) spiral wound universal pressure (SWUP™) installation in Rothschild, Wisconsin.

Weston 4 will deliver 3.641 million lb/h steam at 3775 psig. Steam will be superheated to 1085F and reheated to 1085F. This unit features the first U.S. application of P92 alloy for main steam lines and will burn low sulfur Powder River Basin (PRB) coal. The supercritical design was selected for its efficiency and availability. Commercial operation is scheduled for June 2008.

The development of supercritical technology was pioneered in the U.S. In fact the first boiler with steam pressure above the critical value began commercial operation in the U.S. in 1957. That 125 MW B&W Universal Pressure boiler located at Ohio Power Company's Philo plant delivered 675,000 lb/h steam at 4550 psi. The steam was superheated to 1150F with two reheats to 1050F and 1000F. In addition, the largest single supercritical units in the world (the 9 units of the 1300 MW series) are also installed in the U.S., including a 1300 MW boiler that set a record for 607 continuous days of operation.

This paper discusses the Weston Unit 4 project, a brief history of supercritical units in the U.S., and will look at future trends in high temperature and pressure supercritical units.

Background and project description

To meet the increasing demand for economical energy, Wisconsin Public Service made the decision to build and operate a new 590 MW unit using advanced clean coal technologies at their Weston Power Plant site. The Weston 4 boiler (Fig. 1) is designed to supply steam to the 590 MW Toshiba turbine at a rate of 3,641,000 lb/h (1651.2 t/h) at 3775 psi, superheated to 1085F and reheated to 1085F (260.3 bar/ 585C/ 585C). A Heater Above Reheat Point (HARP) cycle is used with a feedwater temperature of 556F (291C). The 1085F main steam temperature is the highest of any new supercritical boiler currently under construction in the U.S.

The fuel is typical Powder River Basin (PRB) coal from the Wyoming area. The design coal analysis is as follows:

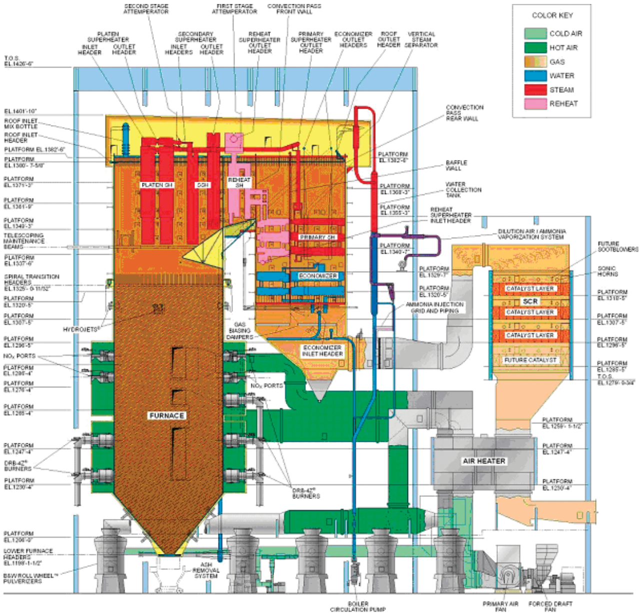

Fig. 1 WPS Weston 4 sideview.

Ultimate		Proximate	
C	51.00	VM	32.90
H	3.50	FC	34.50
O	11.97	H_2O	27.30
S	0.32	Ash	5.30
N	0.60		
H_2O	27.30	HHV	8,800 Btu/lb
Ash	5.30	HGI	51

The PRB coal requires special design requirements for the fuel handling, furnace and emissions control equipment. PRB coals often leave a reflective, whitish deposit on the furnace walls from their high calcium content. This deposit, although not usually very thick, can have a major impact on the furnace exit temperature. The increased furnace exit temperature can increase the main (and reheat, when applicable) steam temperatures, increasing attemperation spray flows and tube metal temperatures. B&W has vast experience in designing for PRB fuel firing. To account for this reduction in overall furnace absorption, the furnace sizing and arrangement is adjusted and water-assisted ash removal equipment is provided. B&W utilizes the Diamond Power Specialty Company Hydrojet® boiler cleaning system (Fig. 2) to effectively remove the reflective PRB ash deposits.

Combustion system

The firing system includes five Stock® gravimetric feeders, five B&W-89™ pulverizers, and 25 B&W DRB-4Z® burners. The burners are arranged with two elevations of five on the front wall and three elevations of five on the rear wall with each elevation being supplied by a different pulverizer. The B&W-89 pulverizer is a well-proven design with more than 950 in operation.

The combustion air supply system includes two centrifugal primary air fans, two axial forced draft fans and two trisector-style regenerative air heaters. The air quality control system includes a selective catalytic reduction (SCR) system, an SO_2 dry scrubber, and a single pulse jet baghouse. Two centrifugal ID fans handle the flue gas.

Fig. 2 Diamond Power Specialty Company Hydrojet® boiler cleaning system.

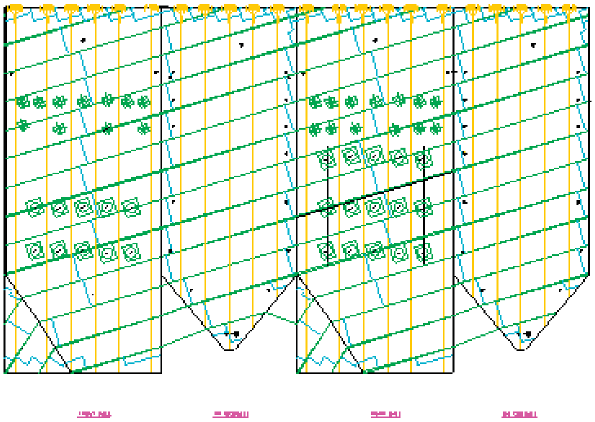

Fig. 3 Spiral wound furnace tube arrangement.

Spiral furnace

The spiral furnace tube geometry provides several advantages. Since each tube traverses around the entire circumference of the furnace (see Fig. 3), all the tubes experience a similar heat flux pattern and thus, similar heat absorption. Therefore, with the spiral arrangement, the inherent heat absorption differences caused by furnace geometry and by different pulverizer firing combinations are minimized. The heat flux patterns vary around the perimeter of the boiler as the view factors for radiation changes; this results in the heat flux being lowest in the corners and highest in the center of the various walls. The heat flux patterns also vary due to different mill combinations (different burners out of service). It is important to minimize the waterside effects of these varying heat flux patterns. The waterside heat transfer considerations require a certain minimum mass flow as a function of load to assure that departure from nucleate boiling (DNB) does not occur in the high heat flux areas of the furnace while operating in the subcritical operating region. The spiral arrangement facilitates achieving this minimum mass flux as it reduces the number of parallel flow paths around the furnace perimeter.

The system is designed for sliding pressure operation below 100% load with the throttle pressure vs. load characteristic shown in Fig. 4. The variable pressure operation enhances unit efficiency primarily by the effect on the turbine cycle. The entropy change across the turbine throttle valves is eliminated and also, to a smaller degree, the boiler feed pump power requirements at lower loads are reduced.

Critical piping

The Weston 4 unit will be the first in the U.S. to utilize P92 piping for the main steam lines. While the use of P92 material for high energy piping is new to the U.S., it has been well-proven by its use in Europe and Japan since the 1990s. Until recently P91 was the main material choice for designing new

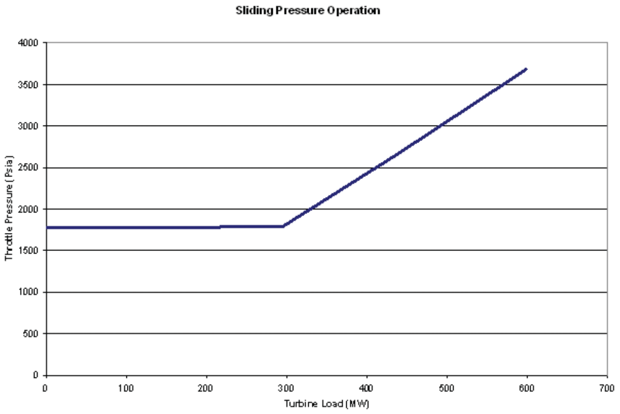

Fig. 4 Sliding pressure operation.

high energy piping systems operating over 1000F. P91 was a replacement for P22 beginning in the early 1990s as the material of choice for high energy piping in U.S. power plants.

The ASME code adopted P92 material for Sections I and VIII construction with Code Case 2179 in 1994. This material was originally developed in Japan as STBA29-STPA29 by Nippon Steel. The European X10CrWMoVNb9-1 was developed as an equivalent to STBA29-STPA29. With the exception of modulus of elasticity, the mechanical properties of P92 are superior to those of P91, especially at temperatures above 1100F. By selecting P92 material rather than P91 for the Weston 4 main steam piping, the wall thickness is reduced by 20%. This produced a significant reduction in material requirements as well as pipe hanger and support steel costs. P92 material was considered for the hot reheat lines, but P91material was chosen due to diameter-to-wall thickness ratio concerns.

Background — History of supercritical units in the U.S.

A reliable and efficient once-through boiler design has been the vision of boiler design engineers for many years. In the U.S., patents for once-through boiler concepts date from as early as 1824. The development of once-through boilers was seen as a way to eliminate the need for the steam drum and with the hope that the design would better cope with water impurities.

B&W's research in once-through boilers began at the company's Bayonne, New Jersey, laboratory in 1916. Through the 1930s and 1940s power plant operating conditions were limited to the subcritical regime because of the limitations of metallurgy and water chemistry. The era following the Second World War brought on brisk economic development in the U.S. This rapid economic development increased the desire for more efficient power plant operation. The desire for improved efficiency, coupled with improvements in both boiler tube metallurgy and water chemistry technology, brought a renewed interest in the supercritical cycle. B&W increased its research work and in 1951 established another heat transfer test facility in Alliance, Ohio, capable of operation at 5000 psi (34.5 MPa).(1)

The vision of the supercritical power plant was also shared by American Electric Power (AEP) and General Electric (GE). AEP entered into a contract with both B&W and GE to build the world's first ultra-supercritical power plant. With the commencement of commercial operation in 1957 of the B&W 125 MW Philo unit, the U.S. moved into the supercritical era.

During the 1960s there was rapid growth in power plant size with most of the large units being the supercritical cycle. During this period B&W's once-through boiler design capability grew from 125 MW to more than 1100 MW. One of the world's largest supercritical units, B&W's 1300 MW unit at TVA Cumberland, was started up in 1972. During the next 18 years, eight additional B&W 1300 MW units would be started up, including the AEP Mountaineer unit which held the world record of 607 days without an outage.

The constant pressure supercritical boiler design of this era was for base load and load cycling operation rather than for daily start/stop service. This design met the industry requirements of that time because the supercritical plant would have the lowest heat rate in the utility system and therefore, the unit should be base loaded.

With the decline in the U.S. economy in to the 1980s, the growth rate of electric power demand declined significantly. This caused a further change in the utility buying pattern as they could no longer justify building larger power plants (600 MW and larger). The trend toward smaller size installations made the economics of the supercritical cycle less favorable. However, development and advances in once-through boiler technology continued through the 1980s in Europe and Japan, satisfying a need for efficient, large-scale units that could cycle in meeting load demands in those areas.

While the historical base-loaded market demand in the U.S. was met by the constant pressure, supercritical boiler design, the recent trend is toward units capable of full variable pressure furnace operation. Units being specified now are expected to be base loaded in the near term, with on/off or load cycling operation being a distinct possibility in the future. B&W brought the first fully variable pressure operation-capable unit to the U.S. by converting the Jacksonville Electric Authority Northside Unit 1 from a constant pressure to a variable pressure operating unit with a spiral wound furnace in 1981. More recently several new projects are in various states of development or construction which utilize the variable pressure furnace design. The Weston 4 project is just one of these.

Future trends in high temperature and pressure supercritical units

A variety of political and financial pressures stemming from global concerns about power plant emissions, including greenhouse gases, are elevating interest in improving plant efficiency. Higher plant efficiency is obtained mainly by increasing both turbine throttle temperature and pressure conditions. Some additional improvement in efficiency can be obtained through further development of processes and components such as double reheat, auxiliary power reductions, waste heat utilization, and turbine efficiency improvements.

How to best apply the capital funding available on a power plant project is a critical question for the plant designer. The cost basis of technological improvements must be known to make an economic evaluation in today's competitive marketplace. A very good reference on this issue is an ABB paper written by H. Kotschenreuther, "Future High Efficiency Cycles."(2) This paper reported the specific investment cost ranking of several technology improvement steps for better plant efficiency. From least cost to highest cost per efficiency improvement, million German Marks DM / % net LHV efficiency (million $ / % net LHV efficiency), were:

1. Reducing condenser back pressure, 5.4 (4.6)
2. Increasing to 8th extraction point feedwater heater, raising feedwater temperature, 6.7 (5.7)
3. Raising live steam and reheat temperature, 14.5 (12.3)
4. Raising live steam temperature, 15.0 (12.7)
5. Using separate boiler feedpump turbine (BFPT) instead of main turbine driven pump, 16.8 (14.2)
6. Raising live steam pressure, 46.2 (39.1)
7. Changing from single to double reheat, 67.0 (56.7)
8. Using separate BFPT condenser, 71.7 (60.7)

This tabulation clearly shows that to optimize plant efficiency, raising steam temperature before raising steam pressure is better by a 3:1 cost/benefit ratio.

The current state-of-the-art for supercritical units has main steam temperatures ranging up to about 1121F (605C), and hot reheat temperatures ranging up to about 1135F (613C). The highest main steam pressures of about 4423 psi (30.5 MPa) have been designed in Europe while the highest main steam and reheat temperatures have been commissioned in Japan. The most advanced cycle conditions for the current market in the U.S. have been developed for the AEP Hempstead project. B&W is supplying the boiler design at 3785 psi (26.1 MPa), 1116F/1126F (602C/608C). These conditions are in the range of a practical upper limit for steam temperatures utilizing ferritic outlet header materials.

For significantly higher service temperatures, advanced austenitic steels or nickel based *super alloys* will be needed. The alternative to austenitic steels is to use Ni-based alloys, although the associated increased cost must be justified. The essential technology improvement is the development of stronger, high-temperature materials, capable of operating under high stresses at ever increasing temperatures.

Europe, Japan, and the U.S. all have programs to develop advanced materials for use in ultra-supercritical power plants. The goal of the European COST-522 program on advanced steam power plants is to identify materials for use in steam at 1202F/4350 psi (650C/30 MPa) while the Japanese national program has a goal of 1202F/5135 psi (650C/35.4 MPa). A demonstration program on this issue was also launched in 1998 by a group of 40 European utility, research laboratories and equipment manufacturers with economic support from the European Commission's THERMIE program. Commissioning of the advanced plant is foreseen for the year 2010 and the THERMIE program has aimed at 1292F/5440 psi (700C / 37.5 MPa) steam and net efficiencies of 52-55% LHV, depending on site and fuel conditions.(3)

B&W is a consortium member of the U.S. Department of Energy (DOE) / Ohio Coal Development Office (OCDO) *Boiler Materials for Ultra Supercritical Coal Power Plants* program. The specific objectives of the Ultra Supercritical Materials Project are to:

- Identify materials performance issues that limit operating temperatures and thermal efficiency of coal fired electricity generating plants.
- Identify improved alloys, fabrication processes, and coating methods that will permit boiler operation of steam temperatures up to 1400F or 760C and steam pressures up to 5500 psi.
- Work with alloy developers, fabricators, equipment vendors and power generation plants to develop cost targets for the commercial deployment of alloys and processes developed.
- Define issues impacting designs that can permit power generation at temperatures greater than or equal to 1600F or 870C.
- Lay the groundwork for ASME Code approval.

The economic and environmental benefits of the plant are encouraging. The plant efficiency resulting from the ultra-supercritical conditions is expected to reach 48% HHV for a double reheat cycle, which is a substantial improvement compared to the typical subcritical plant value of 37%. This efficiency expressed in terms of the customary European terms of lower heating value would be nearly 52% LHV. This efficiency improvement is expected to save nearly $12 million annually or $240 million during a 20-year plant life for a 750 MW plant operating at 60% capacity factor at a coal cost of $1.50/MBtu. The CO_2 and other fuel related emissions will be reduced from 0.85 to 0.67 tons/MWh, a reduction of nearly 22%.(4)

The project that began in 2001 is nearly complete. Valuable design information was gained through the series of project tasks including mechanical properties, steamside oxidation resistance, fireside corrosion resistance, weldability, fabrication ability, and the use of coatings/claddings. A similar effort is now ongoing for material development on the turbine side.

References

1. J.W. Smith, “Babcock & Wilcox Company Supercritical (Once-Through) Boiler Technology,” published 1998.

2. Kotschenreuther, H., “Future High Efficiency Cycles,” Coutsouradis, D., et al. (Eds.), Materials for Advanced Power Engineering, Part I, 31-46, 1994 Kluwer Academic Publishers, printed in the Netherlands.

3. J.M. Sarver, and J. M. Tanzosh, “Steam Oxidation Testing of Candidate Ultrasupercritical Boiler Materials,” 28th International Technical Conference on Coal Utilization and Fuel Systems, March 2003, Clearwater, Florida, U.S.A.

4. R. Viswanathan, J.F. Henry, J. Tanzosh, G. Stanko, J. Shingledecker, and B. Vitalis, “U.S. Program on Materials Technology for USC Power Plants,” Fourth International Conference on Advances in Materials Technology for Fossil Power Plants, October 2004, Hilton Head, South Carolina, U.S.A.

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