Performance and Risks of Advanced Pulverized-Coal Plants

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Pulverized-coal combustion is the most widely-used technology in coal-fired power generation and is based on decades of experience. The gas side typically operates at atmospheric pressure, simplifying the passage of materials through the plant. The main developments in pulverized-coal combustion have involved increasing plant thermal efficiencies by raising the steam pressure and temperature used at the boiler outlet/steam turbine inlet while ensuring that the units can operate reliably and load follow satisfactorily. The majority of existing coal-fired power plants are based on subcritical technology. Supercritical pulverized-coal power plants first came into operation in the early 1960s. More recently, in the 1990s, ultrasupercritical facilities have been constructed and operated successfully.

Raising the steam pressure and temperature results in higher efficiencies (see Table), and thus lower total plant emissions, including CO₂. A potential 50% efficiency (LHV basis) is foreseen for ultrasupercritical technology (depending on plant location).

<table>
<thead>
<tr>
<th>Pulverized coal power plant</th>
<th>Main steam pressure, MPa</th>
<th>Main steam temperature, EC</th>
<th>Reheat steam temperature, EC</th>
<th>Efficiency, %, net, HHV basis (bituminous coal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcritical</td>
<td>&lt;22.1</td>
<td>Up to 565</td>
<td>Up to 565</td>
<td>33-39</td>
</tr>
<tr>
<td>Supercritical</td>
<td>22.1-25</td>
<td>540-580</td>
<td>540-580</td>
<td>38-42</td>
</tr>
<tr>
<td>Ultrasupercritical</td>
<td>&gt;25</td>
<td>&gt;580</td>
<td>&gt;580</td>
<td>&gt;42</td>
</tr>
</tbody>
</table>

Approximate pressure, temperature and efficiency ranges for subcritical, supercritical and ultrasupercritical pulverized coal power plant

- Definition of supercritical and ultrasupercritical boiler pressure and temperature profiles differs from one country to another.
- Usage of the term ultrasupercritical varies but the ranges above are used frequently and are adopted in this article.

In Europe, efficiencies are expressed on the basis of lower heating value (LHV). That is, the lower heating value of the fuel excluding the latent heat of vaporization of the water/moisture in the combustion process (net heat of combustion). In the US, efficiencies are expressed in terms of higher heating value (HHV). In other words, the higher heating value of the fuel including the latent heat of vaporization of the water/moisture formed in the combustion process (gross heat of combustion). Since LHV does not take into account the energy used to vaporize the water, ef-
ficiencies expressed in LHV are usually somewhat higher than HHV. The result is that, for virtually identical plant performance (coal fuel in vs. power out), the US efficiency (HHV basis) would be reported as being 2 - 4 % lower than European efficiency (LHV basis).

At an operating pressure above 22.1 MPa in the evaporator part of the boiler, as the cycle medium is a single phase fluid with homogeneous properties, there is no need to separate steam from water in a drum. Hence, once-through boilers are favored in supercritical cycles. These do not require a boiler blowdown, which has a positive effect on the water balance of the plant with less condensate needing to be fed into the water steam cycle and less waste water to be treated and disposed of. However, they usually require a condensate polisher and use oxygenated water chemistry to maintain steam purity. Once-through boilers can be used with pressures of more than 30 MPa without any changes in process engineering. Wall thicknesses of the tubes and headers, however, need to be designed to match the planned pressure level. In the convective sections are the superheater and reheater sections and an economizer. The final stage of heat recovery is the air heater, which generally takes the flue gas temperature down from economizer exit temperature of 350–400°C to 120–150°C. Pressure differentials are sufficiently low to permit rotary air heaters to be used on most large units.

Supercritical designs in the early 1960s experienced material failures. Increasingly, better materials that were developed over the last few decades, improved supercritical plant reliability and resulted in the installation of numerous supercritical boilers in Europe and Japan and more recently in Canada, China, India, Republic of Korea, Russia, Taiwan, the US and other countries throughout the world.

Today’s supercritical pulverized-coal power plants provide reliable, cost-effective power on a continued basis, load cycling capability, fast daily start-ups and fast, sustained load response as well as load rejection capability. Because total plant costs vary considerably depending on project scope and specifications, it is difficult to make a direct comparison between subcritical and supercritical capital costs. However, for a comparably-sized plant the engineering, procurement and construction (EPC) cost for a supercritical unit is 2-5% higher than a subcritical unit. Operation and maintenance costs are about the same for the two designs. Supercritical units have additional costs for the condensate polisher and more sophisticated maintenance requirements, but lower costs for consumables such as limestone, ammonia and coal due to higher efficiencies.

For a new ‘best practice’ supercritical boiler/turbine power plant (including FGD for SO2 control and SCR for NOX reduction), engineering, procurement and construction (EPC) specific price would be around 900 US$/kWe gross (Europe 2000 prices). This is no more expensive than a subcritical plant and less expensive than a new integrated gasification combined cycle (IGCC) plant for which EPC prices are quoted as 1250-1440 US$/kWe. Investment costs of existing IGCC plants have been between 1650-2200 US$/kWe (Europe 2000 prices).

As stated in the previous paragraph, the adaptability of pulverized-coal supercritical and ultrasupercritical systems in the near-to medium-term for low CO2 emissions is an important issue, since the technology as it stands would require incorporation of scrubbers to remove the CO2 from the large volumetric flow of flue gas. As a consequence, heat rate and specific cost would increase. The method most advanced in status that can efficiently absorb CO2 at the low concentration (~14%) present in conventional flue gases is chemical scrubbing using amines, but sorbents of improved selectivity and lower heat requirements for regeneration need to be developed. Other issues are high degradation rates, corrosion and lack of large-scale experience with scrubbing gas mixtures containing oxygen.

High efficiency supercritical and ultrasupercritical pulverized-coal power plants can satisfy the growing demand for electricity worldwide.

Current materials based on ferritic/martensitic alloys permit steam temperatures up to around 600°C in state-of-the-art supercritical plants. Although iron-based alloys could be further developed to achieve even higher conditions, it was recognized during the early 1990s that there would be greater scope for advancement by exploiting alloys based on nickel. The increased steam conditions affect primarily the water-walls, final superheater and reheater tubing and the thick-walled components (mainly the high pressure outlet headers and the piping to the turbine).

There are currently few commercial ultrasupercritical pulverized-coal power plants operating at up to 29 MPa and up to 620°C. However, the utilization of these systems should increase, especially following demonstrations of achieving 50% efficiencies in future ultrasupercritical units (30 MPa/700°C).

The risks that supercritical and ultrasupercritical pulverized-coal systems face are generally not technical, but uncertain regulatory and permitting obstacles can make capital investment and financing of new facilities more expensive. Engineering and construction lead-times for such large power plants are typically 3-5 years after permits are obtained which can in itself take many years. Furthermore, there is the major issue remaining to resolve in supercritical as well as ultrasupercritical technology, which is the reduction of CO2 emissions. There are risks and technological barriers to supercritical and ultrasupercritical systems and the question of carbon capture and storage (CCS) from pulverized-coal power plants.

High efficiency supercritical and ultrasupercritical pulverized-coal power plants can satisfy the growing demand for electricity worldwide and ease increasing reliance on natural gas to fuel power plants. These technologies, combined with the installation of best available air pollution control equipment, will reduce existing pollution levels by burning less coal per megawatt-hour (MWh) produced, thus reducing total emissions including CO2 and capture most of the pollutants prior to release. There are numerous research and development projects currently underway throughout the world investigating the short-, medium- and long-term future of supercritical and ultrasupercritical pulverized-coal power generation.

Supercritical pulverized-coal combustion is a proven, reliable and efficient technology. Benefits of supercritical/ultrasupercritical technologies are reduced fuel costs, increased efficiency, reduced total plant emissions including CO2, greater plant availability and reduced effect of part load operation. Costs are comparable with subcriti-
Recent Biomass Test Burn Proves Successful

Despite sustainability, lower emissions, carbon neutrality, and a major push toward ethanol and biodiesel on a national level, biomass accounts for less than four percent of U.S. energy consumption. This low rate stems from obstacles like seasonal availability, low energy density, and the high capital investment often required to use biomass. Co-firing biomass and fine-coal waste in a briquetted form may eliminate these obstacles. For instance, coal/biomass briquettes are more amenable to drying without dust problems; they can be stored, moved, and processed in existing infrastructure; they expand the distance to economically transport the biomass; and the production of a briquetted fuel can be quickly implemented at a reasonable cost.

To demonstrate the feasibility of this approach, a trial to burn engineered fuels made from coal and biomass was conducted in December at the East Kentucky Correctional Complex (EKCC) in West Liberty, Kentucky. The test burn was led by Darrell Taulbee and Jim Neathery, CAER researchers. Co-briquetting biomass with fine coal has been under development by Dr. Taulbee for several years as a way to use biomass in conventional coal-fired furnaces as well as a means to utilize the fine coal that is often discarded in waste impoundments. This approach works well for stoker boilers, like the one at the prison. There was also a start-up company, KeLa Energy, which participated in the test burn by providing fuel pellets also made from coal and biomass.

Four fuel formulations weighing about one ton each were evaluated during the tests; two were briquetted fuels and the other two were extruded fuels in the form of cylindrical pellets. Biomass content ranged from 10 to 17% and included sawdust, processed sorghum, and weeds. The weeds, which performed well during the tests, were taken from reclaimed surface mines and fallow fields in Eastern Kentucky, lands that are not used for growing food crops, and which are located near sources of waste coal.

After balancing the feed rate and combustion air to the furnace, the samples burned and the ash discharged from the grate without incident. More importantly, the emission of two major pollutants, sulfur dioxide and nitrogen oxides (SO$_2$ and NOx), were substantially reduced. Two of the engineered fuels that were prepared from samples of the coal used at the prison exhibited average reductions of ~26% and 15% for NO$_x$ and SO$_2$, respectively. A third fuel that was prepared with a high-ash, low-value fine coal exhibited analogous reductions of 14% and 11%. However, the fourth fuel that was prepared with a high quality sample of fine coal served to show just what is possible in terms of potential emissions reductions as this sample provided a 42% reduction in NOx emissions and a 39% reduction in SO$_2$.

We hope the success of this test burn will help spur a domestic industry that supports the use of Kentucky’s energy resources, particularly our abundant biomass resources, while simultaneously providing a more environmentally-friendly, cleaner-burning fuel. We also hope that these tests will assist KeLa Energy in its effort to break ground in the coming months for the construction of their first commercial plant.
WOCA is an international conference organized by the American Coal Ash Association (ACAA) and the University of Kentucky Center for Applied Energy Research (CAER). The 2009 conference marks the two organizations’ third joint biennial meeting. It will again focus on the science, applications and sustainability of coal ash worldwide. As such, it will encompass all aspects of coal combustion products (CCP’s) as well as gasification products.

For more information, go to: www.worldofcoalash.org

West Liberty Open House

The CAER’s eastern Kentucky office held its first Open House on December 9th to introduce the West Liberty Program Coordinator, Greg Copley, to his constituents. The lab’s program managers were also there to discuss their research, and industrial support to those who might need these services.
**Who Should I Believe?**

Marybeth McAlister
Editor, Energeia

“Strip mining is the worst environmental tragedy our state has ever seen. It is a disastrous practice that benefits only corporations at the expense of citizens.” Or is it . . . “Once the areas are reclaimed as mandated by law, the technique provides flat land for many uses in a region where flat land is at a premium. New growth on reclaimed mountaintop mined areas can support game animals in a way mountains could not.”

“Let’s stop using fossil fuels and start concentrating on renewables. Global warming, high oil prices, and increasing government support are driving renewable energy.” No, wait. It’s . . . “Renewables are a good idea, but there will never be enough to replace fossil fuels. Plus, they bring with them their own problems. Some are unreliable and intermittent or unsightly.”

“Electric cars will be used to replace gas guzzlers.” But . . . “You still have to plug electric cars in at night and that uses electricity, which uses coal or natural gas.”

“The Kyoto accord would have reduced global warming. We are selfish money grubbers for not signing on.” That’s naïve. “The Kyoto accord would have weakened the U.S., while allowing emerging economies to prosper because they didn’t sign the accord.”

“Nuclear = all things bad. It’s radioactive and dangerous. Look at Three Mile Island. Look at Chernobyl. What do you do with the waste? “ Rather . . . “Nuclear = most things good. With 16% of the world’s electricity already coming from nuclear energy, 440 nuclear power plants already in operation and 32 nuclear reactors under construction, obviously industrialized countries feel it is safe. There are no emissions with it. We will run out of fossil fuels eventually.”

**Enough!**

Who is right? I really want to know.

What is the truth? I want to do the right thing. I am a well-intentioned person. I recycle. I keep my heat turned down in the winter. I stalk my teenagers through the house, turning off lights behind them. I try to conserve. I try to do what is best for my family and my nation. I believe that most of us believe in doing what is right, doing what is best for everyone, even at greater personal expense. But what is right? What are the guidelines to use in making an informed, unemotional decision?

I watched Al Gore’s movie. I was aghast. I came to work and spoke with many of my scientist co-workers about it. They proceeded to pull apart his premise and explain through numbers and charts, why Gore either exaggerated, or was plain wrong. But the Inconvenient Truth dramatically displayed believable charts and graphs (especially when Gore climbed on the lift that heaved him to the top of the CO₂ emissions chart).

. . . and another example . . .

Matthew Simmons was the CAER’s Distinguished Lecturer in 2007. He studied energy for over 30 years in the Mideast and spent decades analyzing energy problems. He concluded that ‘proven reserves’ weren’t ‘proven.’ His crusade now is to educate the public that the world’s oil peak is much closer than the Saudis tell us. Simmons argues that Saudi reserves could soon face a serious and irreversible decline, and considers what the world will look like when Saudi petroleum reserves peak. In preparation for his visit, I read his book Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy. OK, I skipped the charts and tables, but in the end I was convinced of the validity of his argument. It has been a little over a year and I have heard the other argument that says his estimates are unnecessarily alarmist.

Many of my more liberal friends have come to regard me as an apologist for the fossil fuel industry. I don’t believe I am. But I do think that I have become more of a realist. What I have learned from spending many years here with researchers is that energy is a complex issue. You can dissect it and examine it from multiple perspectives. People can feel passionately about environmental issues, but they still want the lights to come on when they flip the switch. Renewables alone will not satisfy that need. We have to support renewable energy, while simultaneously providing the quality of life, to which we have become accustomed. It isn’t as simple as “Let’s just use renewables.”

My answer to these diametrically opposed solutions is to study multiple sources. Talk to many experts. Listen to AM and FM radio. Gather views from both MSNBC and Fox news. Be open to it all. For the answers I seek, I find that listening to both extremes inevitably pushes me toward the middle. I am also trying to be open to the ever-moving target of change. Because the answer is “A” today, that doesn’t mean it won’t be “B” tomorrow.

Each Energeia reader could probably go a long way toward convincing me of his or her point of view, but in the end, I will establish my own, culled from all perspectives. It is far easier to institute a belief system and maintain it, no matter what. It is much harder to examine and re-examine the variables.

Just hope I’m never on your jury. We could be out a long, long time.
Long-time readers of *Energeia* will notice a change to our newsletter. We have given it a facelift after 20 volumes (aka 20 years and 120 issues). The title’s font, which looked pretty cool in the early 1990s, had gotten a little dated. We have given it a more classic look. Also, we have changed the secondary color from green to blue. While we do not want to give the impression that we are moving away from our environmental endeavors, we are trying to illustrate that we are part of the University of Kentucky, and proud to be part of UK’s ‘big blue’ umbrella. Although we have incorporated these small changes, *Energeia* remains the beacon of energy-research reporting it has always been. Thanks for sticking with us through the years.