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In This Issue

> *"Restlessness is discontent and discontent is the first necessity of progress."*
> **Thomas Edison**

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Thermal Plume Modeling:
A Tool for Regulatory Compliance

Plume modeling can aid in plant design and provide solid evidence to regulators in support of discharge limits.

By Greg Howick, Ph.D., and Terry Larson, P.E.

Electric power plants with steam-powered generators typically use water to cool and condense the steam for return to the boiler. The heated and sometimes briny cooling water is discharged into lakes, rivers, estuaries and oceans, and does not immediately disperse in the cooler receiving waters. The resulting plume is subject to water quality standards promulgated under the Clean Water Act and regulated through National Pollutant Discharge Elimination System permits.

An area extending from the end of the discharge pipe where the discharge can legally cause water quality standards to be exceeded is called the mixing zone. The size, shape, and conditions for use of mixing zones vary among states and types of receiving waters. For most discharges into rivers and streams, water quality standards outside the mixing zone must be met at all ambient flow conditions down to the seven-day average low flow that recurs once in ten years (7Q10).

Although measuring the extent of a thermal plume in the field is relatively easy, being present to take measurements when ambient water temperature is highest and river flow is at 7Q10 is extremely unlikely. A plume model can extend the analysis to the rare conditions stipulated in water quality regulations. For new power plants, plume modeling can be used to determine how the discharge will dissipate in the receiving water under varying ambient conditions and different outlet configurations.

Plume modeling can aid in plant design and provide solid evidence to regulators in support of discharge limits. Burns & McDonnell scientists currently model discharge plumes using the CORMIX (Cornell Mixing Zone Expert System) hydrodynamic mixing zone computer simulation. Developed for the U.S. Environmental Protection Agency, CORMIX emphasizes predicting the geometry and dilution characteristics of pollutant plumes to assess regulatory compliance. Information required for CORMIX includes bathymetry, flow or tidal regimens; water quality of the receiving water in the vicinity of the discharge, geometry of the discharge structure and the quantity and quality of the discharge.

The example of a new combined-cycle, combustion turbine power plant that proposed to discharge blowdown from cooling towers into a large Midwestern river illustrates the utility of CORMIX. The proposed discharge would enter the river through a small channel at an angle perpendicular to the direction of river flow. Unfortunately, the discharge site was habitat for a known population of freshwater mussel species protected by the Endangered Species Act. The U.S. Fish and Wildlife Service agreed to allow the discharge if the mixing zone was limited to a rectangle extending 15 meters from shore and 30 meters downstream from the discharge, and if the mussels in that rectangle were relocated. Plant designers needed to know the maximum effluent temperature that could be discharged into the river given these limits on the mixing zone.

CORMIX simulations indicated that both discharge temperature and river flow rate affected the size and shape of the plume. Increasing the temperature of the discharge increased the downstream length of the plume and the distance the plume extended from shore. Plume distance from shore was greatest at the lowest river flow tested. As river flow increased, the plume was more quickly turned downstream and distance from shore decreased (Figure 1).

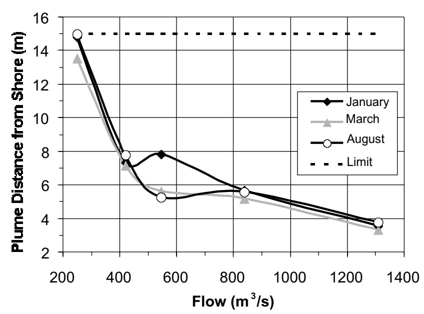

Figure 1
Effect of river flow on plume distance from shore

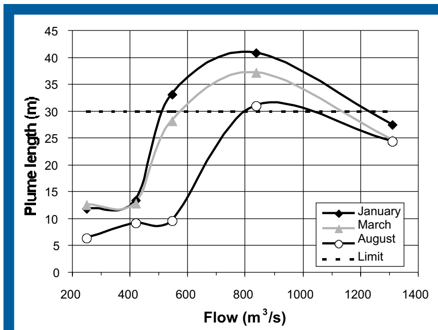

Figure 2
Effects of river flow on plume length

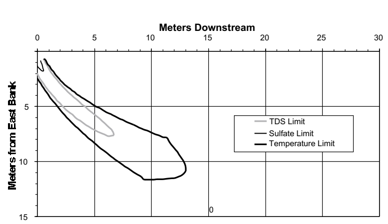

Figure 3
Modeling discharge plumes for temperature sulfate and total dissolved solids (TDS) November at 7Q10

Plume length was found to be greatest at approximately the average river flow rate. At flow rates below the average, the lower river flow rates carried the plume farther downstream before dispersing. However, the plume was narrower, with less total area than at average flow conditions. At flows above the average, increasing river flow rate generated more turbulence and dilution, which increased dispersion and decreased plume length and area (Figure 2).

For each month, plume lengths and distances from shore were determined over ranges of discharge temperatures, river temperatures, and river flows. Based on modeling results, a maximum permitted plume size of 30 meters in length and within 15 meters of the shore was established, and the maximum discharge temperatures that would generate such a plume were interpolated for each month.

In addition to temperature, total dissolved solids and sulfate concentrations in the discharge were of potential concern. CORMIX was also used to simulate the plumes for these parameters. These plumes were found to be smaller than those produced by the maximum allowable discharge temperatures (Figure 3).

Using a hydrodynamic plume model proved to be a relatively rapid and inexpensive method for evaluating numerous conditions to find the maximum discharge temperatures that would meet regulatory requirements. Discharge limitations can influence facility site selection and design.

Determination of a facility's discharge plume early in the design phase can smooth the discharge permitting process and prevent costly redesign work.

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The Rankine Cycle:
Workhorse of the Coal-fired Utility Industry

**By Steve Voss, P.E., and
Greg Gould, P.E.**

The steam cycle in a power plant is characterized by the maximum operating pressure of the cycle. The typical steam turbine power plant operates on the Rankine cycle, the workhorse of the coal-fired utility industry.

Subcritical Rankine Cycle

The main feature of the Rankine cycle is the compression or pumping that occurs when the working fluid, water, is in the liquid phase. The amount of energy available for extraction by the working fluid is dependent on the operating temperature and pressure of the fluid. Raising the steam pressure or steam temperature improves efficiency.

Why is it desirable to raise pressures and temperatures? Figure 1 represents the Rankine cycle. The upper line represents the steam temperature and pressure generated by the boiler. The lower line represents the condensing portion of the steam cycle. The difference between the upper and lower lines determines how much energy can be extracted by the steam turbine, and thus the efficiency of the cycle. The condenser operates at a temperature and pressure dictated by external conditions such as the temperature of the atmosphere or the cooling water temperature. It is not feasible to substantially lower this line. The only way to improve the cycle efficiency is by pushing the upper line higher.

In a typical coal-fired steam cycle power plant the operating pressure is 2400 psi. Steam temperature is typically 1000 or 1050 degrees F. Steam temperature is limited by available materials that can survive at elevated temperatures. Most larger units have a reheat cycle (shown as line from point 2 to 3 in figure 1), where the steam is produced in the boiler, passes through a portion of the turbine, is "reheated" in the boiler and then goes through the remainder of the turbine. This increases the efficiency of the cycle without increasing the maximum steam temperatures.

The operating pressure of conventional coal-fired power plants can be classified as subcritical or supercritical. The critical point is where the temperature and pressure are such that the fluid is no longer classified exclusively as liquid or gas. It is thought of as a fluid above the critical point. The critical point for water is slightly above 3200 psi. Figure 1 shows a typical 2400 psi subcritical Rankine cycle with single reheat. The critical point is shown slightly above the cycle shown. Figure 2 shows a similar single reheat cycle, but operating at 3500 psi, or in the supercritical range. Increased efficiency is represented by the increase in area under the curve, approximately as shown in Figure 3.

Increasing the steam pressure improves cycle efficiency. It also provides the opportunity to go to a "double reheat" cycle, which allows even more improvement in overall efficiency. The overall net efficiency for a typical subcritical coal-fired unit is about 10,000 Btu / kWh. Increasing the initial steam pressure to 3500 psi from 2400 psi improves the heat rate by about 1.5%. The efficiency of a unit with 3500 psi initial steam pressure and double reheat is about 4% better than a typical subcritical unit. For a 600 MW unit burning $1.20 per million Btu fuel with an 80% annual capacity factor, this represents an annual cost savings of about $2 million.

Existing subcritical units in the United States typically have a steam drum where the working fluid circulates through the water walls either by heat transfer and gravity in the case of nat-

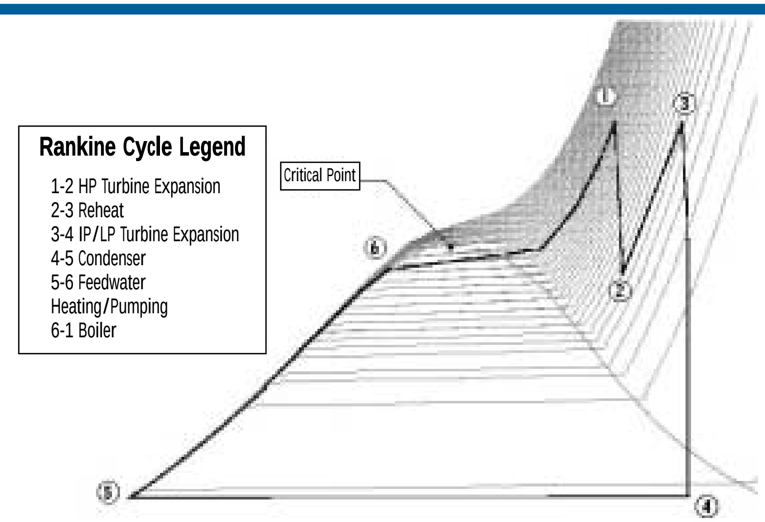

Figure 1
Temperature Entropy Diagram
Subcritical Rankine Cycle

ural circulation, or with the addition of pumps in the case of forced circulation.

Supercritical Benson Cycle

Supercritical units use a once-through design, also referred to as the Benson cycle. In a once-through boiler the fluid passes through the unit one time, and there is no recirculation as takes place in the water walls of a typical drum-type boiler. Since there is no thick-walled steam drum, the startup time and ramp rates for a once-through unit can be significantly reduced from that required for a drum-type unit.

Why Aren't There More Supercritical Units?

So if supercritical units are more efficient and have better startup and ramp rate characteristics, why isn't supercritical the right answer for any new coal-fired unit?

First, there is history. Most coal-fired plants in the United States are subcritical. The first commercial power plant using a supercritical steam cycle was placed into service in 1957. By the mid-1960s, about half of all U.S. units being ordered were supercritical. The purchase of supercritical units in the United States dropped off dramatically in the 1970s, primarily because of the onset of base-loaded nuclear power stations. Plants designed to burn fossil fuels during this time period were built to follow load, and the subcritical cycle was selected because experience with cycling supercritical units (which were all originally designed for base load operation) was minimal. Also, supercritical units that had been built in the United States up to that point suffered from a variety of problems.

Second, typical U.S. supercritical units suffered more from the rapid increase in unit size than from technology. Most of the supercritical units in the United States were designed for coal firing. More than half had pressurized furnaces and one-quarter of the supercritical units were equipped with double reheat sections. During development of the supercritical unit in the 1960s, the average fossil unit grew in size from 247 MW to 500 MW. While the U.S. generally quit building large coal-fired units in the 1980s, they continued to be constructed in Europe, Japan, and elsewhere around the world. There have been considerable advances in design and operation of supercritical units. Units now have improved bypass systems, which simplify startup. New units are also designed to operate with sliding pressure, which improves load change characteristics. Many of the "supercritical-related" problems with the early supercritical units have been resolved with new designs.

Third, since the once-through design does not have a place for blowdown from the system, the water entering the boiler must be of a much better quality than in drum-type units. A condensate polishing system and closer attention to system water quality are both necessary to successfully operate a supercritical unit. Supercritical units are also more susceptible to water induction than drum-type units.

Fourth, controllability of a once-through unit is tougher than a drum unit. Once-through design requires faster responding controls and adaptive tuning over the entire load range. This is much easier to accomplish with today's Distributed Control Systems (DCSs) than with the old discrete component electronic control systems. The need for better control systems was known back in the 1960s, but the advancement of Direct Digital Control (DDC) proved unsuccessful

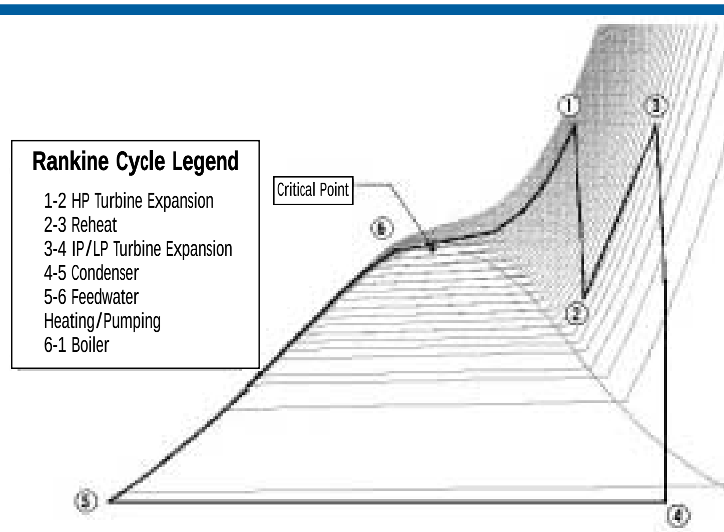

Figure 2
Temperature Entropy Diagram
Supercritical Rankine Cycle

because it required the use of redundant mainframe computers, which did not provide the reliable control required for power plants.

Lastly, there is the higher capital cost. The added capital cost of a supercritical unit over a drum-type unit ranges from no change to 3-5% depending on the source of the information.

Where Is All This Headed?

The last big hurdle is overcoming a technology that is decades old. The latest developments are aimed at even higher thermal efficiencies: 4500 psi with temperatures of 1500° F results in as much as 20% better thermal efficiency than conventional drum-type units. The limiting factors are the materials of construction that can withstand extreme conditions and what advances in metallurgy and ceramics can solve the problems.

The construction of coal-fired base-load power has been all but non-existent in the United States for the last 20 years. A few projects have been completed here and there, but the majority of the technological advances have taken place overseas, where the market for coal-fired boilers has been better. Since 1997, over 22,000 MW of coal-fired generation has been built in Europe. In that same time, less than 10% of that number has been built in the United States. An interesting trend to note is that over 80% of the overseas units are supercritical. There are approximately 360 supercritical units worldwide.

What About Unit Availability?

The availability of supercritical units built since 1990 is every bit as high as the subcritical units. The early supercritical unit population in the U.S. has a dark cloud that followed it around due to availability problems. Some of the problems can be attributed to the supercritical cycle, but just as many can be attributed to the fact that the supercritical units are on the average newer units that were built to tighter emission control standards and have had more control equipment. As any statistician or maintenance person can confirm, a system with more moving parts has a higher potential for failure than a simple system.

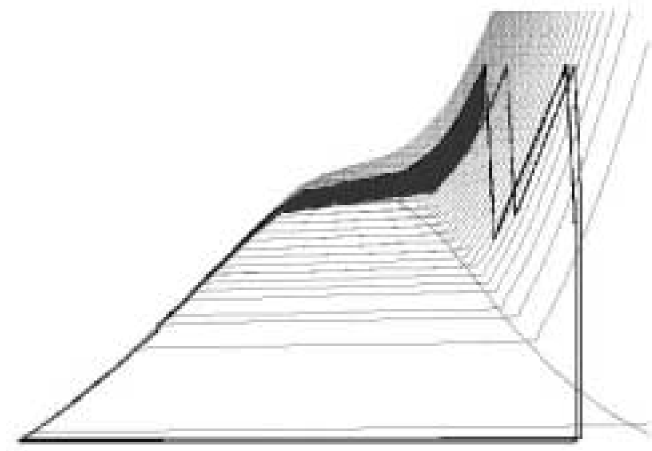

Figure 3

Temperature Entropy Diagram
Super vs. Subcritical Rankine Cycle

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Aircraft Parking:
Three Fundamental Methods

By Stacy Jansen, Brian Tompkins and Renita Mollman, P.E.

Many challenges await the aircraft parking consultant / planner in determining the most efficient aircraft parking layout for a particular airline, airport or situation. Governed by Federal Aviation Administration (FAA) guidelines, three aircraft parking methodologies are available in the airport consultant / planner's toolbox. They are:

- Co-located Cab,
- Wing-aligned
- Common Stop Bar Method

In addition to understanding these three methods, the consultant must satisfy the requirements of taxiway / taxilane clearance limits, Part 77 imaginary surfaces, and aircraft nose-to-building and wing-tip clearances when parking aircraft.

Aircraft require several ground services between flights, and the consultant must provide adequate space around the aircraft for catering trucks, luggage conveyors and carts, lavatory service vehicles, potable water, 400-Hz power, preconditioned air, and hydrant or truck fueling to the aircraft. Aircraft service and maintenance manuals provided by the aircraft's manufacturer illustrate the ideal ground service equipment layout. However, such layouts must be checked and adjusted on a gate-by-gate basis for each aircraft to ensure the minimum apron space is available around the aircraft. Also, aircraft need to be within the limits of the passenger boarding bridge (PBB) without exceeding Americans with Disabilities Act slope limits from the terminal to the aircraft. The three aircraft parking methodologies must

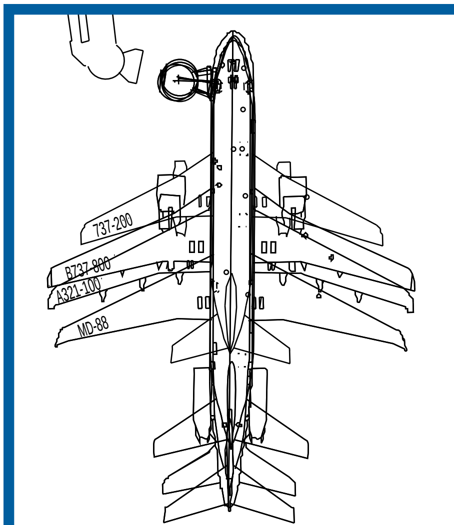

Figure 1
Co-located Cab Method

also consider aircraft turnaround times and ease of operation for the pilot when taxiing into the gate. Overlapping these methodologies may best use the resources available to create efficient gate operations.

Co-located Cab Method

With this method, the PBB is extended and rotated to the same location for each aircraft that park at that position, and then pulled away and retracted similarly. Hence, the passenger door for each aircraft will be in the same location, allowing the PBB operator to move the PBB to one location and only adjust vertically for differing aircraft door sill heights. When using a two- or three-tunnel apron-drive PBB, the co-located cab method allows the PBB to operate with minimal movements, saving time for operators and increasing apron safety by restricting the swing movement of the PBB. This method results in the aircraft parking layout illustrated in Figure 1.

The co-located cab method is a must when fixed-radius, or "radial," PBBs are used, as they do not provide much flexibility in cab rotation. Pinning down the location of the cab restricts nearly every other facet of the aircraft parking operation. With a radial PBB, apron operations must have different servicing arrangements for each aircraft. For example, with truck refueling, the truck must be positioned differently for each aircraft to overcome the inflexibility of the radial PBB. Strictly abiding by the co-located method often causes problems when hydrant fueling is present and when accommodating a variety of narrow and wide body aircraft at one position. Hydrant fueling becomes a safety issue as excessive lengths of hose traverse the apron. If this is not desired by the owner or is simply impractical, multiple hydrant pits for one aircraft position may be necessary. In addition, the number of and markings for each stop bar become confusing and difficult to read for the marshaller (tug driver). Compromise with the other two methodologies is often warranted.

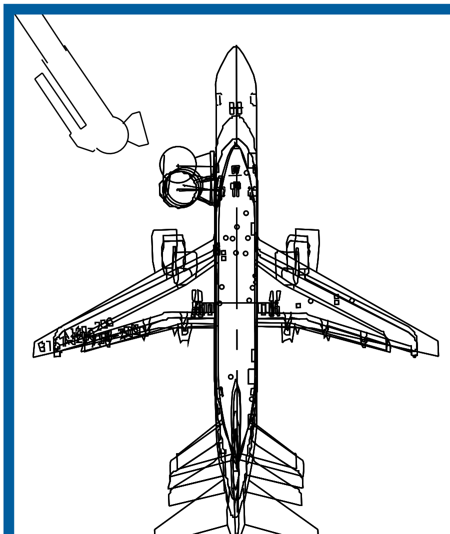

Figure 2
Wing-aligned Method

Wing-aligned Method

The wing-aligned method puts the hydrant fueling operation at the forefront. Alignment of the aircrafts' main wings is such that the fuel ports are within a 30-foot radius of the hydrant pit. This reduces hose length across the apron and minimizes actions for refueling personnel. Parking the cart at the same location and accessing the same fuel pit for each aircraft operation increases safety. The wing-aligned method is depicted in Figure 2.

As previously mentioned, the first methodology often necessitates multiple hydrant pit locations when dealing with a new layout, or the co-located cab method simply cannot be utilized because of the existing fuel pit location. The cost of installing additional fuel pits often disqualifies the co-located cab method as a viable solution, and the wing-aligned method becomes more advantageous.

Common Stop Bar Method

The common stop bar method, shown in Figure 3, organizes the aircraft so that the majority of aircraft or groups of similarly sized aircraft are parked at the same stop bar. This methodology is important because it provides the marshallers with minimal parking position options and reduces overall error.

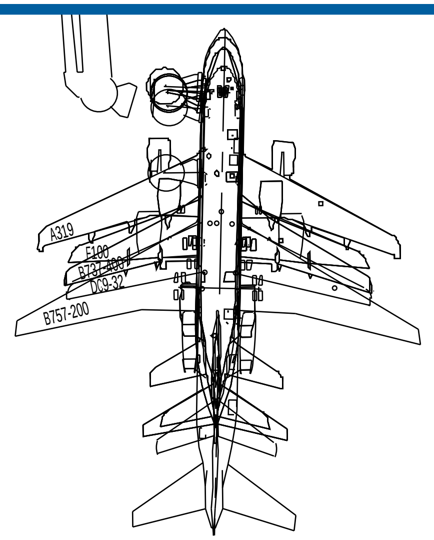

Figure 3
Common Stop Bar Method

This method is rarely used strictly on its own, since it also is impractical if hydrant fueling is present, and a variety of narrow and wide body aircraft must be accommodated at one position. Often, this will be the last methodology applied after first considering the co-located cab and wing-aligned methods. Minor adjustments in aircraft positions may reduce the number of stop bars without negatively affecting the intentions of the previous methods.

Conclusion

The aircraft parking method most preferred by the client will commonly be the method that minimizes the operations out of their control. For example, if the client is an airline that directly employs the operators of the PBB, but not the ground servicing operators, it will typically prefer the wing-aligned or common stop bar methods. These two methods allow the greatest freedom of maneuverability to the PBB operator while reducing the aircraft to a limited parking envelope. From the airline's standpoint, it does not have direct management over the ground servicing operators. Therefore, it would prefer to limit the ground operators' freedom around the aircraft. This reduces the ground operator's movements to a few common tasks, which reduces the potential for errors and increases safety.

The combination of the three aircraft parking methodologies to best suit the site and fulfill the desires of the client is governed by a few simple rules. However, it is important to know what is the most preferred method of the client so that an initial layout can be devised, and then adapted to save money, time, and best accommodate the mix of aircraft to be served at that position.

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