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USING HEAT EXCHANGERS TO CAPTURE MOISTURE FROM FLUE GAS AND IMPROVE UNIT HEAT RATE

With increasing competition for water from farms, manufacturing facilities and cities and towns, some coal-fired power plants are finding it increasingly difficult to obtain the large flow rates of water needed for power plant cooling. At the same time, with rising fuel costs and concerns for global warming, there is renewed emphasis on improving power plant heat rate and this has led to interest in technologies which result in increased power plant efficiency. With these factors in mind, researchers from the Energy Research Center (ERC) have just completed a DOE and industry-funded project dealing with the use of heat exchangers to cool boiler flue gas, capture moisture from the flue gas, and use heat from the flue gas to improve unit heat rate. The project was led by Drs. Edward Levy, Harun Bilirgen and John DuPont.

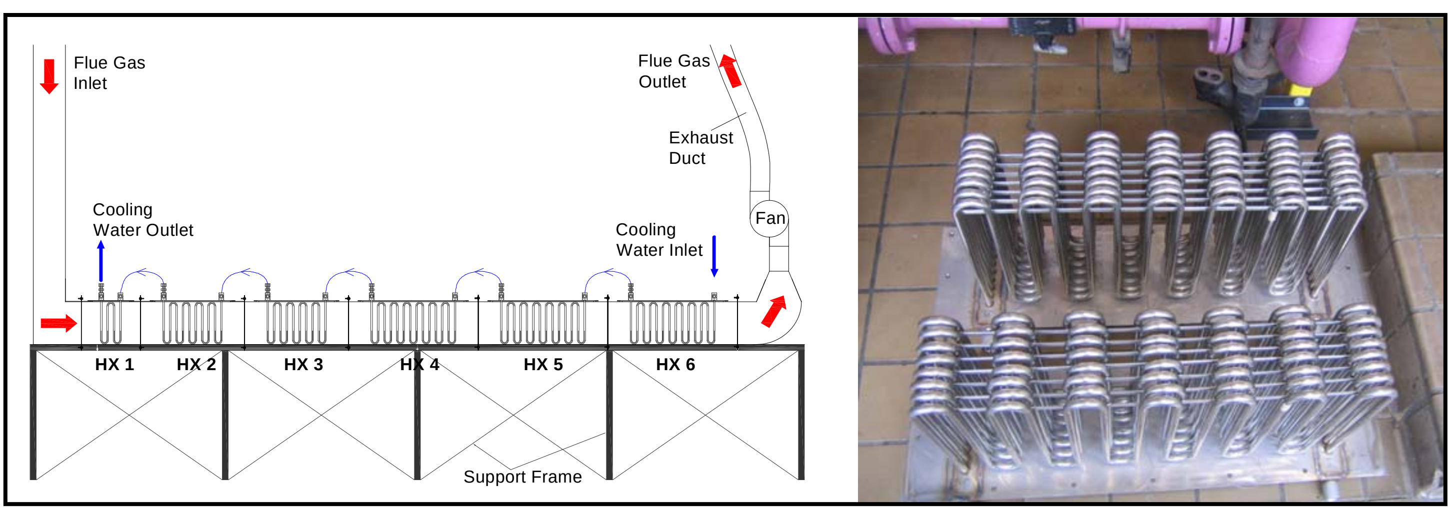
Levy explains, "The moisture content of boiler flue gas ranges from approximately 6 to 17 volume percent, depending on the type of coal and whether or not the unit has a wet SO_2 scrubber (FGD). The corresponding values for water vapor dewpoint temperature range from approximately 100 to 135°F. Most of the water consumed in a power plant with an evaporative cooling tower is used for cooling tower makeup water. Coal-fired power plants, equipped with a means of extracting all the flue gas moisture and using it for cooling tower makeup, would be able to supply from 10 percent to 33 percent of the cooling tower water needs by this approach."

Bilirgen adds, "Our condensing heat exchangers are intended for use downstream of an ESP or baghouse. For a unit without a wet FGD, the heat exchanger would operate with a flue gas inlet temperature of approximately 300°F, while if installed downstream of a wet FGD, the flue gas inlet temperature would be in the 125 to 135°F range. Cold boiler feedwater is one possible coolant for the heat exchanger, with flue gas flowing around the heat exchanger tubes and boiler feedwater flowing inside the tubes."

Use of heat exchangers in the back end of the boiler to recover water vapor from flue gas also provides opportunities to improve unit heat rate. With boiler feedwater as the coolant, sensible and latent heat transferred from flue gas will preheat the feedwater, thus reducing the steam turbine LP extraction flows to the low temperature feedwater heaters and thereby reducing unit heat rate. Results of turbine cycle analyses made by the project team show predicted reductions in heat rate ranging from 0.45 to 1.9 percent. Improvement in heat rate at a given site will depend on inlet flue gas temperature and moisture content, flue gas exit temperature and feedwater inlet temperature.

Levy continues, "The project involved slip stream tests of a small-scale heat exchanger system at three coal-fired units, laboratory corrosion studies of candidate tube materials, evaluation of condensate treatment options and costs, designs of commercial scale heat exchangers and cost/benefit studies of condensing heat exchangers."

"The slip stream field tests resulted in important insights on the effects of heat exchanger design and process conditions on heat transfer and water vapor condensation rates. The resulting field test data also made it possible to validate computer software developed by the project team for predicting the effects of heat exchanger design and operating conditions on rates of heat and mass



(a) (b)

Apparatus Used in Slip Stream Field Tests: (a) Elevation View and (b) Photograph of Two Heat Exchanger Tube Bundles transfer from flue gas. The software was then used to design full-scale heat exchangers for use in coal-fired power plants."

The field tests were performed at two units without scrubbers and one with a wet FGD, where the unscrubbed units were firing low-sulfur high-moisture coals and the scrubbed unit was firing a high-sulfur bituminous coal. In all cases, the flue gas contained gaseous species such as SO_2, H_2SO_4, and HCl, some of which wound up in the condensed water which formed on the heat exchanger tubes. The condensate was collected and analyzed for contaminants, and this resulted in data on sulfate and chloride concentrations in the condensed water.

DuPont adds, "The field test results were used to specify condensate acid concentrations for the laboratory corrosion studies, which, in turn, identified tube materials which would provide adequate service life for heat exchangers operating at the temperatures and acid concentrations expected with condensing heat exchangers. Based on results from our corrosion studies, we recommend that 304 stainless steel be used for tube material for locations where the tube wall temperature is less than the local water vapor dew point temperature. We also recommend that Alloy 22, a high nickel alloy with excellent resistance to sulfuric acid corrosion, be used in locations where tube temperatures are greater than the local water vapor dewpoint temperature and less than the local sulfuric acid dew point temperature." (Note: Sulfuric acid dew point temperatures range from approximately 320°F to 250°F for the acid concentrations found in boiler flue gas. Water vapor dewpoints range from approximately 135°F to less than 110°F.)

The cost/benefit studies considered installed heat exchanger cost, condensate water treatment costs, and the costs of fan power to overcome flue gas pressure drop and pump power to overcome cooling water pressure drop. The benefits considered in the analysis included the incremental generated power resulting from using captured heat to preheat boiler feedwater and the value of the recovered water. Using this approach, the analyses concluded that for water recovery applications, condensing heat exchangers installed at units with wet FGD's would produce the largest flow rates of condensed water and would be the most cost effective to install and operate. Because of higher flue gas inlet temperatures, condensing heat exchangers used in units without scrubbers would result in larger heat rate improvements and incremental increases in power. However, the higher inlet flue gas temperature would make it necessary to use more expensive tube material than is needed downstream of a wet FGD. The research is continuing to develop designs for maximizing percentage water capture and heat rate improvement and minimizing the costs of the heat exchangers.

There are also potential applications of condensing heat exchangers in carbon capture and sequestration systems (CCS). Amine and ammonia post-combustion CO_2 scrubbers require inlet flue gas temperatures below 100°F for efficient operation, and the types of heat exchangers described by the Lehigh team are candidates for use in pretreating boiler flue gas before it flows into a CO_2 scrubber. In addition, it is expected that, in most cases, the concentrated streams of CO_2 produced by post-combustion CO_2 scrubber systems and by oxyfuel boilers will be compressed to over 2,000 psia before being transported by pipeline to geologic sequestration sites. These concentrated streams of CO_2 can contain high concentrations of water vapor which should be separated from the CO_2 before compression and here, too, condensing heat exchangers may have an important role to play. ■

Measurements Being Made with Condensing Heat Exchanger Apparatus During Slip Steam Field Test.

RESEARCHERS' PROFILES

- ***Edward Levy*** is Professor of Mechanical Engineering and Mechanics and Director of the Energy Research Center. His research deals with emissions control, water use and performance improvement in coal-fired power plants.
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- ***John DuPont*** is Professor in the Materials Science & Engineering Department and Associate Director of the Energy Research Center. His research interests are in welding, corrosion, and alloy development.
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