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ENERGY RESEARCH CENTER

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FOSSIL ENERGY –
SMART SOFTWARE FOR FLAME CONDITION MONITORING AND OPTIMIZATION

Large fossil-fired utility boilers are equipped with a firing system arrangement that includes a series of burners located at different elevations in the furnace. Flame scanners are important devices used in the operation of these burners. These scanners are traditionally used to monitor flame stability and the flame/no-flame condition of the burners, providing an important input to the burner management system for safe operation of the firing system. However, it has been recognized that flame scanners can also provide dynamic information associated with the burner combustion process. This information could be used for flame characterization and status monitoring; and furthermore, for combustion tuning of each individual burner. Tuning combustion at the burner level should result in improved overall boiler combustion, fuel efficiency, and reduced stack emissions, such as NOx and CO.

The Energy Research Center has developed smart software for flame scanner data processing, that provides flame indexing and expert advice to boiler operators on individual burner combustion. “The software was designed for oil-fired applications and it processes standard flame scanner data in the time and frequency domain employing statistical and artificial intelligence analysis for flame classification,” said Zheng Yao, who led the software development for the project. Probabilistic neural networks and a fuzzy c-means algorithm were used for flame spectral data clustering and data recognition.

The figure below shows a diagram of the overall approach used for this software application. Data from the scanner

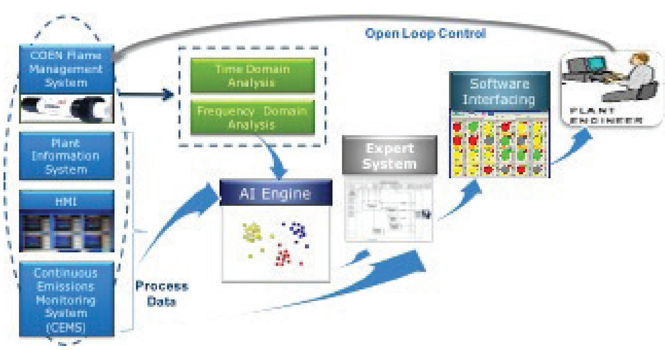

Diagram of Software Approach and Components

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WATER-ENERGY NEXUS –
AIR COOLED CONDENSERS WITH THERMAL ENERGY STORAGE

The Energy Research Center (ERC) is involved on a project for the development of an innovative dry cooling/thermal energy storage system to supplement air cooled condensers (ACCs) for power plant applications. This project, funded by the Advanced Research Projects Agency-Energy (ARPA-E), is a collaborative effort led by Advanced Cooling Technologies, Inc. (ACT, www.1-act.com), with contribution from the University of Missouri (MU) at Columbia. The three-year project is receiving $3.2 million in total funding from the ARPA-e’s Advanced Research in Dry cooling (ARID) program.

“All power plants must reject heat during power generation to conform to thermodynamic principles. For example, a 100 MWe plant usually has to reject about 200 MWth of heat in the steam condensers,” said Dr. Sudhakar Neti, professor emeritus of mechanical engineering and mechanics, now associated with the Energy Research Center, and co-principal investigator of the project. Neti continues, “once-through steam condensers withdraw significant amounts of water, in the order of 100 liters of fresh water per kWh of thermal power generation, which is nowadays considered environmentally unacceptable. Additionally, operation of these condensers has an impact on plant thermal efficiency, and their thermal discharge into the water pool used for cooling is the subject of environmental regulation to protect aquatic life near the power plant discharge. ACCs offer an interesting alternative to the use of once-through condensers; however, they suffer from large thermal inefficiencies impacted by seasonal and daily variable ambient conditions.”

The concept being developed in this project consists of a novel integrated system for better management of power plant condenser heat load. “The concept utilizes an array of heat pipes to transfer heat to a thermal storage unit with a phase change material (PCM) to absorb and reject condenser heat when it is more efficient from the point of view of the power generating unit, and it incorporates self (flow-induced) agitated fins to increase air-side heat transfer by more than 200%,” says Dr. Richard Bonner from ACT. Members of the team from ACT include Drs. Chien-hua Chen, Ying Zheng, Howard Pearlman, Fangyu Cao and Mr.

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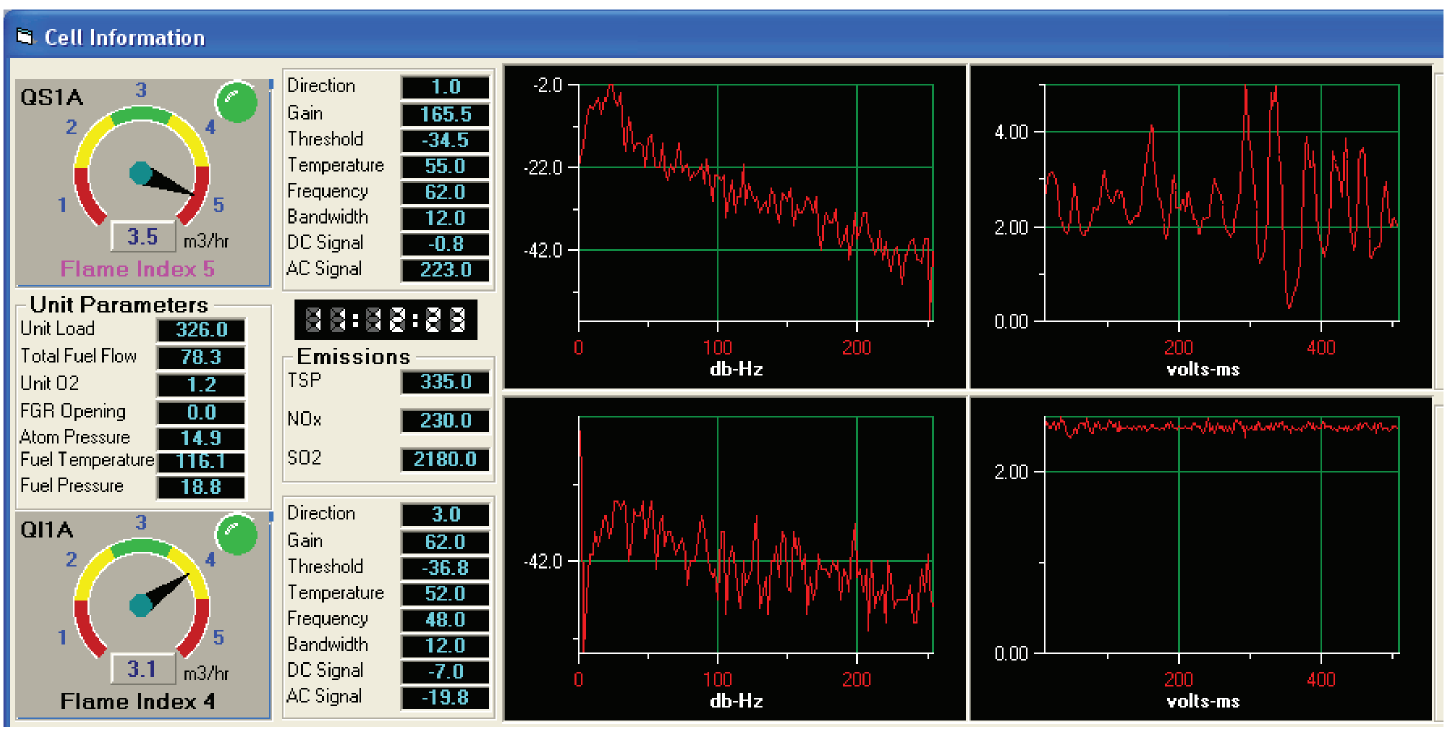
flame monitoring system, the plant data acquisition system and the stack emissions monitoring system are processed with proprietary algorithms to provide flame feature information extraction and burner flame classification. Five classification status are recognized. They include an optimal flame with proper stoichiometry, flame front separation, length, etc.; as well as flames that deviate from the optimal conditions as defined by high excess air, high fuel flow, high intermittency and waiving (as those produced by dirty burner nozzles), and skewed flames (as those produced by a combination of low excess air and off design atomization). An expert system then utilizes the flame classification information and it provides interfacing capabilities to the control room for open-loop control of the burners. Yao adds, “the software is also capable of providing recommendations to the operators on sensible individual burner maintenance scheduling.”

The software was deployed at a 350 MW opposed wall-fired unit, says ERC’s director, Dr. Carlos Romero, who was co-principal investigator of the project. “The unit firing system consists of a 24-burner arrangement with common secondary air registers per burner pair. The unit fires Bunker C oil with steam fuel atomization and an expected atomizing viscosity at the nozzle in the range between 15 to 30 cSt. Each burner is equipped with one iScan flame scanner from COEN. These scanners work with a dual UV/IR spectral response, with UV peak at 350 nm and IR peak at 700 nm.” This unit provided an adequate vehicle for testing of the smart flame software approach, since it is equipped with burners with no physical access for flame observation, and overall boiler combustion and emissions is greatly affected by the combustion conditions of an individual burner.

Unit test results verified the functionality of the software and its performance in terms of flame classification from burners with visual observation access to their flames. A software interface screen snapshot is included below. This screen corresponds to Burners 4 and 5 for the particular test boiler. Information on the screen includes scanner and pertinent operating data, flame status as indicated by a color scale (where green is assigned to the optimal flame status and red to very off-design flames), as well as recommended expert advice. Parametric testing of parameters that influence individual burner and global boiler combustion were also performed at the host unit. Yao explains, “software performance during testing demonstrated the benefit of the smart flame software in terms of real-time individual flame status monitoring and recommended corrective actions to bring flames to an optimal status. Testing with different burner tips, with different degree of fouling, also demonstrated the usefulness of the smart software in providing recommendations to the operators on when to schedule cleaning and replacement of burner nozzles.” Romero adds, “long-term running of the unit with the smart flame software has allowed control room and boiler operators to operate with individual burner optimal flames, even those flames with no visual access through observation doors. Additionally, boiler combustion control biases have been tuned based on the software recommendations, leading to reduced CO and NOx emissions.”



Smart Flame Monitoring Software Interface Screen, Showing Burner Scanner Information and Flame Status

WATER-ENERGY NEXUS

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Sean Hoenig. The figure below shows a conceptual diagram of the proposed design.

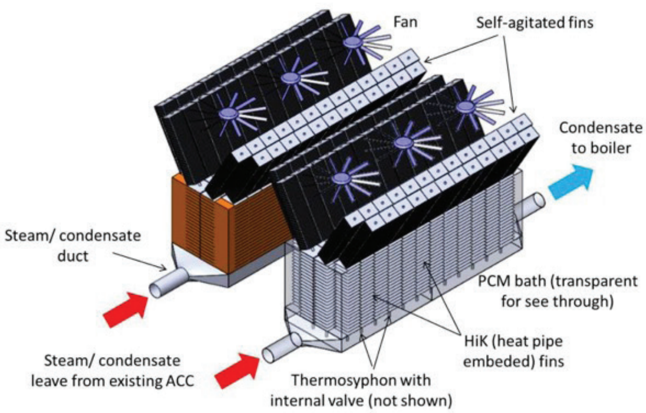
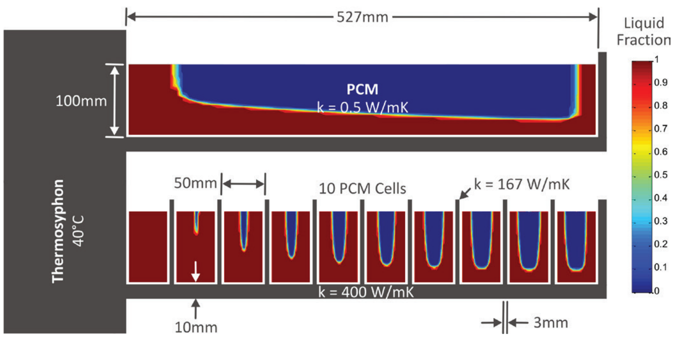


Diagram of Supplemental Condenser Concept

Other members of the project team include Dr. Carlos Romero, Director of the Energy Research Center; Joshua Charles, a research scientist and PhD student at the Center; and graduate students: Fengxiang Nie, Chunjian Pan, Arunachalam Subramanian, He Yun and Xingchao Wang. Charles explains, "the type of PCMs being researched in this project provide for latent heat thermal energy storage at higher densities, while providing isothermal energy transfer, which is thermodynamically more efficient. Three PCM materials with melting temperatures around 25°C were selected from more than 50 PCM candidates. PCMs were screened by differential scanning calorimetry (DSC) on melting temperature, latent heat of fusion, thermal conductivity, stability, and cost. The three selected PCMs include combinations of hydrated salts that contain CaCl2, MgCl2 and KNO3." Current calorimeter testing at Lehigh University - ERC with these salts target more than 2,500 thermal cycles (more than 200 days of testing) and degradation of PCM storage capacity of less than 10%, with no phase separation and composition changes. To date, hydrated salts are meeting the specified target.

Additionally, corrosion experiments and Computational Fluid Mechanics (CFD) modeling are being conducted in the project. Corrosion testing is being carried out under static and dynamic conditions for the selected PCMs and a range of encapsulation materials that include copper; carbon, stainless and Corten steel; and 5086, 6061 and ionized aluminum. Corrosion results up to date have provided guidance on material compatibility for corrosion rate criteria of less than 2 mills/year (0.05mm/year) and less than 12% increase in thermal resistance based on the extent of corrosion. CFD modeling has been used to guide the design and optimization of the thermal energy storage system. Designs have included concentric and axial fins arrangements that provide sufficient heat transfer from the thermosiphon heat source to completely melt and freeze the PCM within appropriate target timeframes for this particular application (see figure below).



Model Results for PCM Module After 10 Hours, With & Without Axial Fins

According to Drs. Chien-hua Chen and Ying Zheng, "the goal of the current project is to demonstrate the concept of an integrated novel condenser with thermal energy storage for power plant-scale applications with a modular 200 kWh laboratory unit. This prototype will be in operation in 2017 for continued performance and reliability testing." Romero adds, "current cost of electricity estimates for the integrated system are coming below the $150/kWth target specified by ARPA-E for these types of supplemental cooling systems. The ultimate goal is to engineer the concept into a commercial system, and test and optimize a scale-up prototype of the system at a host power plant."

NEW APPOINTMENT ANNOUNCEMENT

The Energy Research Center (ERC) is pleased to announce the return of John Sale as a Senior Research Engineer, effective June 1, 2017. John previously worked at Pacific Gas & Electric Company, Ebasco Engineering and served for 18 years at the ERC as Manager of Research Program Development before retiring. He is a graduate of California State Polytechnic College, San Luis Obispo, CA and the University of California, Berkeley. He can be reached at 610-758-4542 or 610-442-5930 (Cell) and jws3@lehigh.edu

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