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CONCEPT SELECTION FOR ADVANCED LOW-EMISSION COAL FIRED BOILER

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ABSTRACT

The Babcock & Wilcox Company (B&W), under contract to the U.S. Department of Energy (DOE) with subcontract to Physical Sciences, Inc. (PSIT), the Massachusetts Institute of Technology (MIT) and United Engineers and Constructors (UE&C) has begun development of an advanced low-emission boiler system (LEBS).

The initial phase of this multi-phase program required a thorough review and assessment of potential advanced technologies and techniques for control of combustion and flue gas emissions. Results of this assessment are presented in this paper.

BACKGROUND

To address the design issues facing new and replacement coal-fired power plants, the Pittsburgh Energy Technology Center (PETC), U.S. Department of Energy, has initiated a new program called Combustion 2000. The work presented in this paper was conducted under the low-emission boiler (LEBS) portion of the program.

LEBS major goals are:

- NO_x - No more than 0.20 lbs per million btu of fuel input firing on bituminous coal.
- SO_x - No more than 0.2 lbs of SO_2 per million btu firing coal with at least 3 lbs of sulfur per million btu.
- Particulate - No more than 0.015 lbs per million btu of fuel input.
- Waste and Air Toxics - Reduced.
- Plant Efficiency - No less than 38%.

The LEBS program carried to completion will consist of four phases over a total duration of 114 months. The initial work completed to date has consisted of a thorough review and assessment of potential advanced technologies and techniques for control of combustion and flue gas emissions and boiler design. From this work final concepts have been selected for further development in the continuing LEBS program.

For each LEBS plant subsystem, including candidate concepts and/or processes, the selection for application began with identifying and developing a "long list" of possible candidate concepts or processes. The applicability and desirability of the candidates or processes to the LEBS plant was subsequently evaluated using a method developed by Charles Kepner and Benjamin Tregoe (described in their book, The Rational Manager, McGraw Hill Book Company, 1965). The K-T approach uses a systematic methodology to make qualitative decisions by establishing the objectives to be achieved, measuring each of a number of alternatives against these objectives, and then summarizing the results.

The K-T analysis thus resulted in "short lists" of candidate concepts or processes. A detailed technical and/or economic evaluation was subsequently performed in each subsystem down selection for each of the final control technologies selected using the Kepner-Tregoe method. In addition, the cost-effective integration of all power plant subsystems was an important consideration in the final selection of each subsystem concept. The potential impacts of the candidate concept or processes on all other plant subsystems were addressed during the final K-T analysis. The evaluations of the short list of candidates led to final recommendations for each B&W LEBS plant subsystem.

NO_x CONTROL SUBSYSTEM

The NO_x control subsystem includes components consisting of fuel preparation and delivery, air preheating and delivery, burners and their location, air/fuel injectors and their location, furnace, and controls hardware and software. Of these, only the assessment and evaluation of burners, furnace and the combustion system strategies for the NO_x control subsystem will be discussed in this paper. Considerations of research results were incorporated into the assessments to extend current designs.

The pulverized coal burners that were down selected can be divided into three groups on the basis of the burner design and operation: aerodynamically air-staged burners (AASB), internally fuel-staged burners (IFSB), diffusion flame burners (DFB).

None of these burners will meet the NO_x goal and it is not clear that development of a burner alone will lead to NO_x emissions that meet the goals of this program.

Of the numerous furnace geometries and burner locations considered for implementing low-NO_x combustion, the selected configurations for NO_x control subsystem evaluation includes; box, multi-sided, venturi and roof-fired types. The box, multi-sided and venturi all incorporate opposed wall fired burner arrangements.

Of the candidate combustion concepts considered, three staged combustion strategies were selected: conventional OFA, advanced OFA, and reburning. Risk for not achieving the NO_x emission goal ranges from high to moderate.

NO_x Subsystem Evaluation

Since none of the staged combustion strategies discussed above has low risk in both categories, none were eliminated from further study. Stoichiometric and thermal design criteria for each staging strategy were specified based on the background material presented earlier. In addition, AAS burners were selected for staged combustion. Fuel-staged burners were still considered as a way of implementing reburning and diffusion flames were evaluated for down-fired furnaces where long flames may be tolerated.

Preliminary design concepts were developed for each combination of combustion strategy and selected furnace configuration. The preliminary design concepts included burner sizing and arrangement, characteristic furnace dimensions, and thermal histories. The information developed in the preliminary designs was used to quantify an expected NO_x emission and implementation risk for each design concept. The design concepts were then evaluated using a K-T analysis with relative NO_x emissions, and cost and operational constraints as desirable criteria.

Results of the analysis showed the configuration which best suits all three staged combustion approaches was the venturi furnace. For the subsequent preliminary subsystem and commercial design task that follows in the program for the NO_x control subsystem, a venturi furnace configuration with advanced staged combustion and advanced low-NO_x AAS Burners has been selected.

SO_2/PARTICULATES SUBSYSTEM

The scope of supply for the SO_2/Particulates Subsystem comprises the development of SO_2 and particulate matter emissions control systems for the B&W LEBS plant. The specific subsystem emissions goals were previously stated. However, important secondary objectives are to ensure that processes selected for application:

- Have the potential to comply with possible emissions control regulations for hazardous air pollutants (commonly called "air toxics"),

- At a minimum, produce a solid byproduct that is environmentally benign for disposal, or, preferably, can be reused in the process (regeneration) or elsewhere (byproduct utilization), and

- Integrate with other plant subsystems to yield optimal overall performance and cost-effectiveness for the B&W LEBS plant.

SO_2 Removal Process Selection

The first step in selecting the SO_2 removal process was to develop a "long list" of 47 candidate processes. For initial screening, mandatory criteria were used to reduce the list to six promising technologies. The six processes were subsequently subjected to a more involved desirable criteria screening technique at the subsystem level. The desirable subsystem criteria categories chosen for this K-T analysis were *economics*, *environmental*, *performance*, and *auxiliary*. The results of this evaluation were used to further reduce the list of candidates to three processes.

A final detailed evaluation of each of the three selected processes was performed using the EPRI methodology for process economic evaluations. Capital and operating costs for each process were estimated based on process design, economic, and site-specific criteria *on a generating unit basis*. A qualitative analysis was also performed to compare the advantages of each process. The potential impacts of the processes on the boiler, balance-of-plant, and NO_x subsystems were also addressed during this final analysis. On the basis of these results and other qualitative considerations, the B&W Advanced Limestone Injection with Dry Scrubbing (LIDS) Process was selected for further development and evaluation in B&W's LEBS project.

Particulate Removal Process Selection

The particulate removal candidates passing the initial mandatory criteria screening included: reverse-gas, shake-and-deflate, and pulse-jet fabric filtration, and cold-side electrostatic precipitation. A set of desirable screening criteria were then applied to provide a quantitative ranking of the particulate control technologies. The desirable criteria categories used for screening the particulate control candidates included *performance*, *risk*, and *economics*. As a result of this screening study the pulse-jet fabric filter was selected for further development for particulate matter removal in B&W's LEBS plant.

B&W's Advanced LIDS Process

The B&W Advanced LIDS process is a limestone-based, combined furnace injection/dry scrubbing SO_2 removal process. Pulverized limestone is injected into the upper furnace cavity of the boiler where calcination and a portion of the overall SO_2 removal occurs. Flue gases exiting the boiler then pass through a dry scrubber reactor (spray dryer) where they are contacted by a calcium hydroxide slurry where a majority of the overall SO_2 removal occurs. Finally, the flue gases enter a particulate removal device where fly ash and spent sorbent are captured. The use of a fabric filter is preferred for use with LIDS because additional SO_2 removal occurs as the flue gases pass through the sorbent-containing filter cake on the filter bags. The majority of the solids collected in the fabric filter are used to produce the calcium hydroxide slurry for the dry scrubber, with the remainder being conveyed to disposal and/or utilization.

BOILER DESIGN SUBSYSTEM

Several objectives were addressed in the assessment and selection of the Boiler Design Subsystem. First, the selected boiler operating and plant steam conditions must achieve plant generating efficiencies at least as high as current conventional coal-fired plants. Second, the boiler furnace, convection pass arrangement, pulverizer and air heaters selected must not only be conducive to boiler operating considerations and provide the most effective heat transfer setting practical, but also allow for effective integration of the selected NOx and SO_2 control subsystem.

Operating Conditions

As discussed later under Balance of Plant Subsystems, a supercritical steam cycle is required to achieve the desired plant generating efficiency.

In addition to selecting steam pressure and temperature conditions, for a boiler with a supercritical cycle the mode of boiler furnace and/or superheater pressure operation must also be evaluated considering the expected cycling mode of operation of the generating unit. Given the fact that this unit would be the utility system's newest, most efficient and lowest emission plant, cycling operation is likely to be the operating mode of choice with on/off cycling minimized. Of the furnace pressure operating modes considered, including constant, variable and dual (constant furnace/variable superheater) the dual pressure mode offers the optimum in overall plant heat rate and in boiler and steam turbine conditions, and therefore has been selected.

Furnace and Convection Design

In addition to the furnace arrangement assessments described under the NOx subsystem work, the various candidate furnace arrangements as well as potential candidate convection pass configurations were evaluated from a boiler design aspect. Candidate convection pass configurations considered included various conventional surface arrangements and gas path flow arrangements in different possible combinations. A K-T type analysis was used to evaluate the candidate arrangements considering appropriate boiler design desirable criteria. An additional significant consideration in the evaluation was the adaptability of the candidate arrangements to the various potential burner concepts and SO_2 removal systems being assessed. The final selected furnace and convection pass concept as shown in Figure 1 thus provides at the lowest cost and highest rating of desirable criteria, the optimum conditions for integration of the selected burner/combustion concept and SO_2 removal concept.

Pulverizers

It is anticipated that increased coal fineness and improved control and/or monitoring of coal flow on an individual burner basis will be a significant factor in minimizing emissions and loss of combustibles. B&W's current commercial MPS pulverizer has been selected as a base from which to begin evaluations of potential performance improvement. Not only is the current standard MPS pulverizer design widely proven and respected commercially, but in addition, many available and/or potential design options have been identified which could further improve performance. These design options include various modified and advanced types of classifiers and upper housing configurations. As the benefits of increased coal fineness and flow control become defined in a later task of the program, trade-off studies will be conducted to evaluate the various design improvement options available. The most cost-effective option will be selected for the commercial design studies planned later in the program.

Air Heater

The objective of the air heater technology assessment was to evaluate various heater design types relative to each other as well as when applied to a boiler with potential application of furnace sorbent injection for SO_2 reduction. As discussed in the SO_2 Control Subsystem, the B&W LIDS process with furnace limestone injection is the SO_2 removal concept of choice. While furnace limestone injection may increase potential fouling of the air heater surface, removal of SO_3 concentrations will certainly allow a potential reduction in air heater gas exit temperature which would improve boiler efficiency. Both of these factors were considerations included in the assessment and evaluation.

From the assessments and K-T evaluations conducted, the favored and lowest overall cost air heater concept of choice is a single regenerative type unit which heats both primary and secondary air with a cold primary system.

BALANCE OF PLANT SUBSYSTEMS

The balance of plant (BOP) subsystems incorporate other equipment, components, and systems necessary for a complete and operational plant. Since the major focus of this program is application of advanced emission controls in a high efficiency power plant, the main objective in the assessment of BOP systems was effective integration and support of the advanced emission controls and high efficiency in a reliable power plant. The systems addressed were only those with potential for significant cost and efficiency impacts on the overall plant, and were not all-inclusive of the necessary systems in a power plant. For presentation in this paper, only the selection of steam conditions for the plant will be discussed.

The primary considerations in selecting the steam cycle for LEBS were: (1) obtaining a plant generating efficiency at least as high as convectional coal-fired plants, preferably above 38 percent, (2) the selected system have a history of commercial operation,and (3) the system be the most cost effective when evaluated on the basis of combined present worth of capital and life-cycle coal cost. The range of conditions considered included main steam pressures from 2400 psi to 4500 psi, steam temperatures as high as 1100°F, and both single and double reheat systems. The effect of steam condition on overall plant cost and net plant heat rate were developed and evaluated.

The cycle found to be the most economical and meeting the desired minimum plant efficiency was a supercritical with double reheat with steam turbine conditions of 4500 psi/1000 F/1025 F/1050 F. While these conditions have been selected for a basis of concept selection, further optimization will be performed in a later task as other subsystem preliminary designs and a total integrated generating unit develop.

FUTURE WORK

Following the concept selection work, preliminary commercial designs will be developed for each selected system. Before commercialization of the selected integrated systems, however, further analysis will be needed to define any additional design information and data necessary to reduce or eliminate any technical or engineering uncertainties in the preliminary commercial design. Results of this analysis will be used to formulate a detailed research and development plan. The Phase I task schedule is shown in Figure 2.

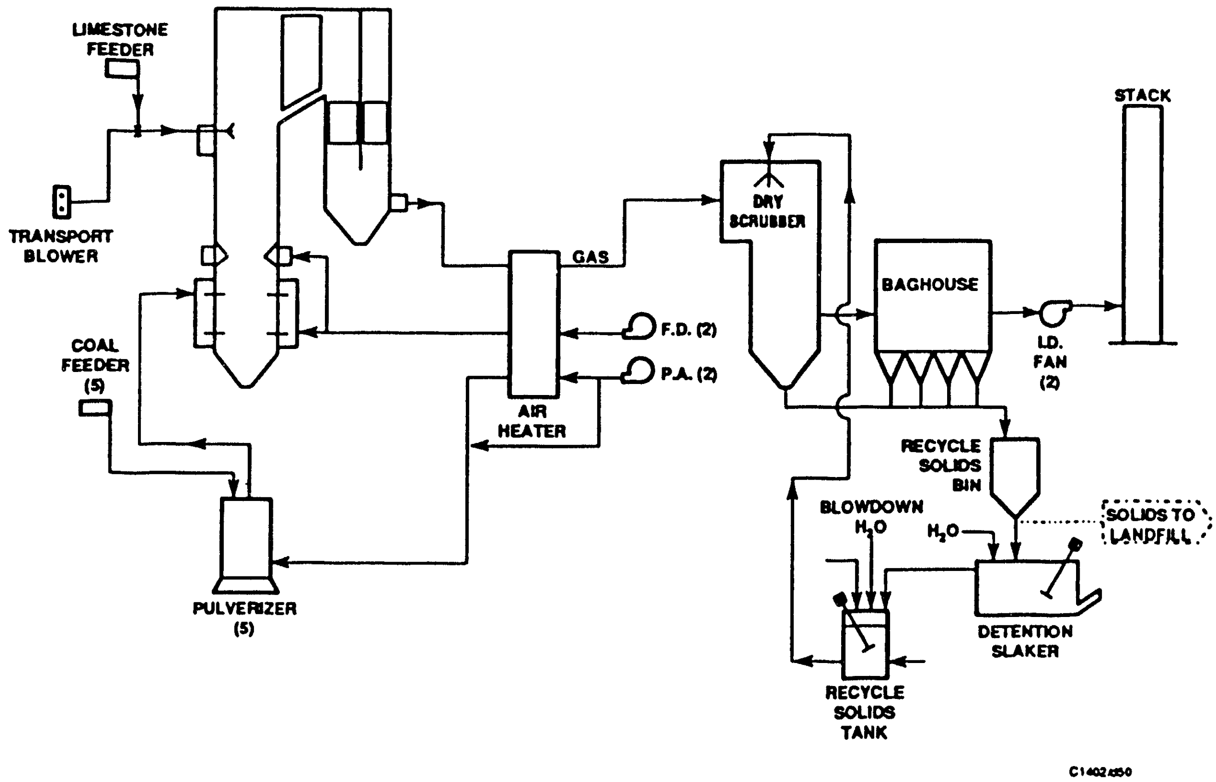

FIGURE 1 LEBS ARRANGEMENT

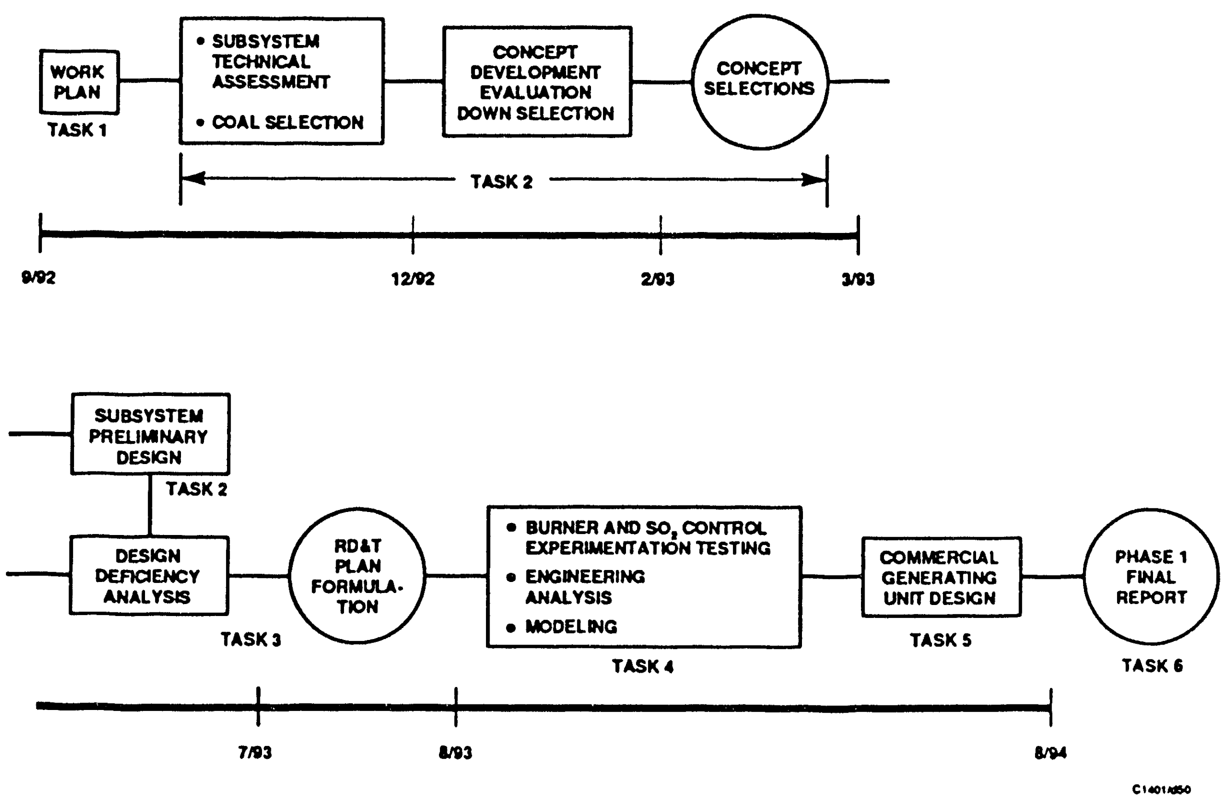

FIGURE 2 TASK SCHEDULE

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