ADMINISTRATIVE INFORMATION

1. **Project Name:** Materials For Industrial Heat Recovery Systems

2. **Lead Organization:** Weyerhaeuser Company
2901 Weyerhaeuser Way South
P. O. Box 9777
Federal Way, WA 98063-9777

3. **Principal Investigator:** J. Peter Gorog
253-924-6514/253-924-5920/peter.gorog@weyerhaeuser.com

4. **Project Partners:** Oak Ridge National Laboratory, James Keiser, 865-574-4453, keiserjr@ornl.gov
Paprican, Douglas Singbeil, 604-222-3254, dsingbeil@paprican.ca
University of Kentucky, Subodh Das, 859-514-4989, sdas@secat.net
Georgia Institute of Technology, Preet Singh, 404-894-6641, Preet.singh@mse.gatech.edu
Process Simulations Limited, Martha Salcudean, 604-822-1490, msal@interchange.ubc.ca
E3M, Inc, Arvind Thekdi, 240-715-4333, athekdi@e3minc.com
Domtar, François Jetté, 514-848-5461, francois.jette@domtar.com
Babcock & Wilcox, John Kulig, 330-860-6438, jakulig@babcock.com

5. **Date Project Initiated:** April 1, 2004

6. **Expected Completion Date:** February 28, 2007

PROJECT RATIONALE AND STRATEGY

7. **Project Objective:** The goal of this project is to identify alternate materials or operating changes through component characterization and laboratory and field studies that result in components of heat recovery systems being exposed to environments in which they are more compatible in order that industrial heat recovery systems are able to operate in a more energy efficient, productive and reliable manner.

8. **Technical Barrier(s) Being Addressed:** The project addresses materials issues in two industries: Aluminum and Forest Products. The recuperators associated with aluminum melting furnaces utilize hot flue gas to preheat the combustion air for the burners that provide heat to melt the aluminum. The centrifugally cast tubes used in the recuperators have a relatively short lifetime that averages only about 7 months for the tubes on the leading side of the recuperator where bending, warping, cracking and thinning occur. Black liquor chemical recovery boilers are an essential part of Kraft pulp and paper mills, but they are not particularly efficient at recovering energy from the black liquor fuel. The most serious recovery boiler materials issues addressed are corrosion and cracking of the co-extruded tubes that form primary air port openings, localized thinning of the carbon steel tubes in the mid-furnace area and bending, warping, cracking and accelerated thinning of superheater tubes.

9. **Project Pathway:** The pathway being used in this R&D project is based on one successfully employed by the Forest Products industry and ORNL in an earlier IMF-AIM effort. ("Alternate Materials for Recovery Boiler Floor Tubes"). The key elements of this approach include: industrial involvement in defining the problem and developing the proposal for the cost shared research

program; use of an industrial advisory team to oversee the project; global participation of materials suppliers, engineering companies, recovery boiler system designers and end-user companies; industry providing access to their equipment and data needed by researchers; development of laboratory simulation test systems; industry supporting materials testing in the actual industrial environments under investigation; utilizing special facilities and expertise at ORNL and other industrial sponsored research institutes; holding periodic review meetings with all of the participants. This approach assures that industry is a full partner in the project and quickly becomes aware of the results and recommendations made by the researchers working on the project.

10. **Critical Metrics:** The improvements in materials and changes in operations from this study when fully implemented could yield a savings in excess of 10 trillion Btu per year. The specific metrics for this project are:
    - Identify alternate materials to achieve a six-fold extension in the working life of recuperator tubes in aluminum melting furnaces. By eliminating the energy losses and unplanned outages associated with this issue the Aluminum industry would save ~ 0.6 trillion Btu's per year.
    - Help to improve the overall design of recuperators such that they are sufficiently economical and reliable so that they will be installed on new aluminum melting furnaces built over the next decade. This would save the Aluminum industry ~ 3 trillion Btu's per year.
    - Improve the overall recovery boiler efficiency of new boilers by 1.5% and increase by 20% the total amount of black liquor being burned in retrofitted boilers in the next decade. This would save the Forest Products industry ~ 7 trillion Btu's per year.

PROJECT PLANS AND PROGRESS

11. **Past Accomplishments:** The major progress on this project is as follows:
    - For the aluminum recuperator task, infrared camera studies have been conducted and modeling studies have been initiated. The paper industry has a long-standing history of utilizing infrared cameras to monitor the conditions in recovery boilers, and it was suggested such a camera be tried in the aluminum melting furnace. Subsequently, a demonstration at the Logan Aluminum facility in Russellville, Kentucky, was arranged with SynFab, one of the companies that supplies cameras to the paper industry. The camera was installed on the flue duct of melting furnace #3 in a position where all the recuperator tubes could be viewed. The camera clearly showed each tube and even the thermocouples that had been mounted on the tubes. Based on the information collected with the IR camera, the furnace operators could identify hot spots and damaged tubes.
    - Also for the recuperator task, computational fluid dynamics (CFD) modeling studies have been initiated to understand the air flow in the recuperator tubes. Initial studies indicated significant non-uniformities in the air distribution to the recuperator tubes, but more extensive studies are needed before any firm conclusions can be drawn.
    - For the mid-furnace corrosion studies, the field work is complete. Analysis of data taken from an operating boiler looking at gas compositions in the mid furnace before and after a modification to the air system is underway. This work will be used to validate the predictions of gas compositions using a CFD model. The laboratory studies are nearing completion. The main focus is currently centered on characterizing the corrosion of carbon steel samples coated with a layer of chromium and aluminum. The effects of thermal cycling have also been examined. All of the samples removed from operating boilers have been analyzed. The results of work have identified the role of gas composition and thermal cycling on the stability of the oxide layer and its ability to protect the tubes from corrosion.
    - Significant progress has been made on the superheater task. Several conference calls were held between ORNL and Paprican staff members and the members of the advisory team assembled by the Principal Investigator. As a result of these discussions, the laboratory studies and the field corrosion

probe studies were defined. Six alloys were selected for testing, and the laboratory testing program, to be conducted at Paprican, was defined. It was agreed that the corrosion probes would expose the same materials, and arrangements were made with mills in Columbus, Mississippi and Ashdown, Arkansas to expose the corrosion probes.

- The primary air port corrosion and cracking task is essentially completed. Utilizing contributions from the researchers who participated in this project, a summary report has been compiled and edited. The document underwent further editing and formatting by the Principal Investigator's support staff, then it was submitted to the ORNL Program Manager for publication and distribution.
- Two meetings involving the research staff, the Principal Investigator and members of the advisory committee were held to discuss the work to be conducted to bring the project to completion. Progress on this project has been documented in the quarterly reports which have been written and submitted, in papers that have been presented and published, and in presentations at committee meetings and to a number of user groups.

12. **Future Plans:** In the previous report, planning was based on the assumption that full funding would be available and the work would be extended over an additional year to permit "catching up" on the remaining tasks. However, funding limitations necessitated changing plans so that the project received about half the budgeted funds for FY06 ($500K) and enough for FY07 to write final reports and have a concluding meeting. The efforts planned on each of the tasks for the remainder of FY06 and the first six months of FY07 are as follows

- On the aluminum melting furnace recuperator tube task, a cracked, embrittled tube will be examined by Secat to try to determine the cause of tube degradation, ORNL staff will continue to work with Logan Aluminum staff to interpret the data collected with the IR camera, and modeling studies will continue. As time permits, the modeling will include CFD study of air flow in the recuperator bundles and the flue gas flow across the tubes. Finite element modeling may be conducted to characterize the stress generated in poorly cooled tubes that are subjected to appreciable heating on one "side". This modeling is intended to address the warping that is sometimes seen in tubes on the front row of the recuperator bundles.
- The mid-furnace studies will be brought to a conclusion and a final report prepared.
- Construction of the superheater corrosion probes will be completed and the probes taken to the two mills for insertion in the superheater sections of their recovery boilers. Depending on when the probes are actually inserted, the exposure will be for 1000 or 1500 hours. Following exposure the probes will be removed and the samples examined to determine the extent of reaction in the superheater environment. The superheater corrosion studies being conducted at Paprican will be completed, and the samples subjected to a thorough examination. Following completion of the examinations of the laboratory coupons and the corrosion probe samples, a final report will be prepared.
- A final meeting to review progress on the project will be scheduled for early in calendar year 2007.

Date	Milestone/Deliverable	Partner Activities
August 2006	Initiate superheater corrosion probe exposures	Partners – Provide access to furnaces, assistance in installing probe and telephone line for monitoring probes
July 2006	Initiate laboratory superheater corrosion studies	Partners – Provide guidance on testing procedure and conditions
August 2006	Meet with Logan Aluminum staff to discuss infrared camera studies and modeling results	Partners – Contribute camera results and participate in discussions
September	Complete mid-furnace corrosion studies	Subcontract – Collect final data for

2006		preparation of final report
March 2007	Conduct project review meetings	Subcontractors – Contribute information, Partners – Participate in meetings
March 2007	Submit final report	Subcontractors – Contribution material for final reports

13. **Project Changes:** Funding for this project has been significantly reduced, and the anticipated extension reported in the previous Project Summary Form has been reduced so that the work will only carry into the second quarter of FY07. As a result of the funding reduction and the changes in the project duration, some subtasks have been modified or eliminated.

14. **Commercialization Potential, Plans, and Activities:** This technology will be implemented by tube suppliers, by equipment designers and manufacturers and by end-users. Throughout this project the researchers have developed and will continue to develop material recommendations and suggestions on changes in operating procedures. The combination of this information and the close working relationship between the researchers and various industrial partners should encourage rapid and extensive utilization of the knowledge developed in this project.

15. **Patents, Publications, Presentations:**

- Publication and Presentation "Assessment of Molten $Na_2S\ xH_2O$)/NaOH Solutions as a Cause of Composite Tube Corrosion in Kraft Recovery Boilers", Joseph R. Kish, Douglas L.Singbeil, James R. Keiser and Francois Jette, Paper No. 06236, CORROSION/2006, San Diego, CA, March 12-16, 2006
- Publication and Presentation "Mid-Furnace Corrosion in Kraft Recovery Boilers and Its Control", Vikas R. Behrani, Jamshad Mahmood and Preet M.Singh, Paper No. 06238, CORROSION/2006, San Diego, CA, March 12-16, 2006
- Presentation "Materials Issues in Black Liquor Recovery Boilers and Gasifiers", James R. Keiser, American Forest & Paper Association Recovery Boiler Meeting and Conference, Atlanta, GA February 7-8, 2006
- Publication and Presentation "Investigation of a Superheater Tube Cracking Problem", James R. Keiser, Gorti B. Sarma, Kimberly A. Choudhury, François R. Jetté, Richard L. Emerson, Elizabeth F. Walker, Joseph R. Kish and Douglas L. Singbeil, Paper No 05EPE139, 2005 TAPPI Engineering, Pulping and Environmental Conference, Philadelphia, PA August 28-31, 2005
- Publication and Presentation "Diagnosis of High Temperature Cycling Associated with Primary Air Port Cracking in Kraft Recovery Boilers", L. A. Frederick, J. R. Kish and D. L. Singbeil, Paper No 05EPE217, 2005 TAPPI Engineering, Pulping and Environmental Conference, Philadelphia, PA August 28-31, 2005
- Publication and Presentation "Reducing Primary Air Port Composite Tube Cracking in a Kraft Recovery Boiler Through Changes in Operation", J. R. Kish, I. Karidio, D. L. Singbeil, L. A. Frederick, J. R. Keiser, K. A. Choudhury, F. R. Jetté, Paper No 05EPE218, 2005 TAPPI Engineering, Pulping and Environmental Conference, Philadelphia, PA August 28-31, 2005