Predicting Boiler Performance Using an Energy Balance Computer Program

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1.0 Introduction

In 1985, Minnesota Power and the City of Duluth undertook a project to refurbish the M. L. Hibbard Units 3 & 4 boilers to supply process steam to a newly constructed paper mill. These Erie City boilers, originally designed for pulverized coal, were built in the late 1940's. The refurbishment project, completed in 1987, converted these boilers to stoker-fired units capable of burning coal, wood chips, bark, sludge, and natural gas.

Soon after start-up, questions arose concerning the performance of the refurbished boilers compared to the design performance. In an effort to investigate these concerns and determine their root cause, Minnesota Power contracted Performance Engineering, Inc. to develop a PEPSE[1] computer model of the Units 3 & 4 boilers for analytical studies. In addition, the computer model was to be used to analyze the boiler performance associated with further modifications to the unit proposed by the refurbishment contractor, ABB-Combustion Engineering Services, Inc. (ABB-CE)[2].

This model was the first of its kind in that it allowed the simultaneous firing of multiple fuels, including coal, wood chips, sludge, bark, and natural gas to simulate all possible fuel usage mixes at the plant. An algorithm was developed in the model to allow the user to merely input the percentage of each fuel desired.

The results reported here show the PEPSE model results for several proposed plant modifications and the comparison of these results with predictions by ABB-CE.

2.0 Unit Description

This section describes the general characteristics of the Hibbard boilers and provides a detailed description of the PEPSE model developed to simulate these boilers.

2.1 General Description

The M. L. Hibbard Units 3 & 4 boilers were built in the late 1940's to burn pulverized coal. Located on the shores of Lake Superior in the city of Duluth, Minnesota, these boilers originally supplied steam to two turbines, one rated at 35 MW and the other at 39 MW. In the early 1980's the units were retired.

In the mid-1980's, Minnesota Power sought a use for the old boilers and persuaded a paper company to build a pulp and paper plant near the old units. The Hibbard boilers would supply the process steam needed for this paper plant. Minnesota Power and the City of Duluth entered a joint agreement to refurbish the units to supply this needed steam. The contractor chosen to refurbish the units was then known as Combustion Engineering.

The refurbished units were modified in several ways from the original, most notably by cutting the bottom off the boilers and installing Detroit RotoGrate Stokers. The stoker allows fuel to be continuously fed into the boiler on a moving grate, with combustion air supplied from both underneath the grate upward and from overfire air above the grate. Other changes included the addition of an economizer and a secondary tubular air heater.

Each unit can burn a variety of fuels, either singly or in combination. The fuels include coal, wood chips, bark, natural gas, and sludge, a by-product of the paper process with a moisture content over 50% and an ash content of about 25%.

The units are each designed to supply 350,000 lb/hr of steam at 750^{o} F and 925 psig. All steam is supplied to the paper plant - the turbines are no longer in service.

Figure 1 shows an elevation view of the boilers.

2.2 PEPSE Model

The PEPSE model developed by Performance Engineering appears in Figure 2. The remainder of this section describes this model in detail.

2.2.1 Air/Flue Side

Combustion air enters the boiler system through a source (Component 440) and proceeds through the forced draft fan (Component 450) and on to the primary air heaters (Components 130 and 120). Primary air heater leakage is simulated using a splitter (Component 460) upstream of the air heater inlet, and the leakage is reintroduced into the flue gas in a mixer (Component 140).

Exiting the primary air heater, a portion of the combustion air (gas burner air) splits (Component 420 via Stream 205) to bypass both the secondary air heater (Component 90) and the overfire air fan (Component 380). The main air flow proceeds to the secondary air heater, first splitting to the overfire air fan (via Component 410), then splitting for by-pass air (Component 400), and finally splitting for air heater leakage (Component 390). The secondary air heater air leakage is reintroduced into the flue gas in a mixer (Component 100), upstream of the air heater.

The air bypassing the secondary air heater mixes with the heated air in a mixer (Component 370). This mixture then mixes with the overfire air/burner air mixture in another mixer (Component 360). The overfire air and burner air were previously mixed upstream in a mixer (Component 350).

Leakage or "tramp" air, introduced at a source (Component 330) mixes with the total air mixture in another mixer (Component 340) before entering the furnace (Component 10).

Fuel is introduced into the furnace through five sources (Components 220, 230, 240, 250, and 255), each representing a different fuel burned at the Hibbard station. The fuels are combined in a series of mixers (Components 260, 270, 280, and 285), mixed with backpass cinder re-injection (Component 290), and injected into the furnace. Bottom ash exits the furnace in a sink (Component 300).

Hot flue gas exits the furnace and enters a component which simulates the front backpass riser tubes (Component 35). The flue gas then enters the secondary superheater (Component 40), the rear backpass riser tubes (Component 45), and the primary superheater (Component 50). Exiting the primary superheater, the flue gas enters a component representing the downcomer tubes (Component 60). It then enters a splitter (Component 80) which serves to remove some of the flue gas ash (cinders) to be re-injected into the furnace.

The hot flue gas then mixes with the secondary air heater leakage (Component 100), enters the secondary air heater (Component 90), and proceeds to the economizer (Component 110). Exiting the economizer, the flue gas enters the primary air heater (Components 120 and 130), mixes with primary air heater leakage (Component 140), and mixes with mechanical dust collector air leakage (Component 150) introduced into the system through a source (Component 470). A portion of the ash in the flue gas is removed from a splitter representing the mechanical dust collectors (Component 160) and is dumped to a sink (Component 480). The main flue gas passes through the induced draft fan (Component 170) and mixes with electrostatic precipitator air leakage (Component

180) introduced in a source (Component 490). It then goes through the precipitator (Component 190), with the removed ash being dumped to a sink (Component 500). The flue gas exits the system through the stack (Component 200).

2.2.2 Steam/Water Side

Feedwater enters the boiler envelope from a source (Component 430) and is heated in the economizer (Component 110). From there the water enters the drum (Component 30). Water leaves the drum and enters the downcomer (Component 60). A portion of the water is split (Component 61) to the rear backpass riser tubes (Component 45), a portion is split (Component 62) to the front backpass riser tubes (Component 35), and the main water flow splits (Component 63) to the furnace water wall tubes (Component 20 and 21).

The furnace water wall flows merge (Component 64) and mix with the backpass riser tube flow (Component 75). The front and back backpass riser tube flows had mixed (Component 76) prior to mixing with the furnace water wall tube flows. The wall tube water then enters the drum.

Saturated steam exits the drum and a portion is removed as steam blowdown (Component 510) exiting to a sink (Component 520). The main steam flow enters the primary superheat section (Component 50) and is cooled with superheat attemperation flow from a source (Component 210) mixing with the steam (Component 310). The steam then enters the secondary superheat section (Component 40) before exiting the system as main steam (Component 70).

3.0 Analysis

In 1990, ABB-CE was asked by Minnesota Power to recommend ways to enable the Hibbard units to operate more efficiently and to optimize the performance of the units. Tests were performed on the units to determine their current level of performance and to find ways to improve the performance. Several major problems were noted with the boilers:

1. Elevated superheater outlet steam temperatures.
2. High exit gas temperatures.
3. Limited forced draft fan capacity.
4. Lower than design boiler efficiency.
5. Higher than design excess air levels.
6. Heavy ash build-up on tubing surfaces.

Based on the results of these tests, ABB-CE offered recommendations for all items listed above.

Several PEPSE analyses were performed, using some of ABB-CE's recommendations, to determine their impact on boiler performance.

3.1 Economizer Soot Blowing

ABB-CE noted that one possible explanation for the high exit gas temperatures was a build-up of ash on the economizer tubes, thus retarding heat transfer to the incoming feedwater and keeping the flue gas temperature high. It was noted that the gas side efficiency was about half the design value. They recommended adding four rotary sootblowers between the two banks of economizer tubes to blow this ash periodically.

A PEPSE analysis was performed using the Hibbard PEPSE model at different heat transfer rates in the economizer section. This was accomplished by varying the heat transfer coefficient multiplier over a range of values, beginning with a value obtained from tuning the model to the test results (multiplier of 0.485 or -0.485 in PEPSE input format) and increasing the value to simulate better heat transfer. Figures 3, 4, and 5 show the results of this analysis.

These results compare quite well with the predictions supplied by ABB-CE. By installing sootblowers, they predicted an approximate 50% increase in heat transfer in this section. ABB-CE projected that this performance increase would result in a decrease in the flue gas temperature leaving the economizer of 60° F, a decrease in the flue gas temperature leaving the primary air heater of 33° F, and an increase in boiler efficiency of 1%. Using an increased value of the PEPSE heat transfer multiplier of 0.78 (-0.78 in PEPSE input format), PEPSE predicts almost the identical results projected by ABB-CE. This corresponds to about a 50% increase in heat transfer in the PEPSE model.

3.2 Stoker Water Seal

ABB-CE also noted that air leakage into the boiler around the stoker was having an adverse effect on unit performance. This leakage air tends to sweep across the surface of the grate, increasing the amount of carryover, resulting in increased carbon loss and decreased boiler efficiencies. It also tends to decrease the amount of overfire air, but still acts as excess air, causing higher than design excess air levels. This results in high air and gas weights, reduced forced draft (FD) fan efficiencies, and decreased boiler efficiencies. ABB-CE recommended installing a stoker water seal to cut down on air in-leakage around the stoker.

A PEPSE analysis was performed, decreasing the amount of air in-leakage around the stoker ("tramp air"). In the analysis, this leakage flow was cut in half, to 10% of the FD fan air from the original 20%. Table 1 shows the results of this analysis.

ABB-CE did not offer any quantitative improvements for adding the water seal other than predicting a 50% decrease in leakage air to the boiler. They did offer some qualitative improvements due to decreased leakage air, however, such as greater overfire air, lower excess air, decreased particulate carryover, and better air heater performance.

3.3 Future Analyses

Only the first two items on the list of recommendations were analyzed. Later this year, the other recommendations will be analyzed using PEPSE, and their results compared against the ABB-CE predictions. An economic analysis will be performed for each, and a course of action will be plotted. Tests will be performed following the implementation of the chosen changes, and the results of the tests will be compared to the predicted results.

4.0 Discussion

A program such as PEPSE can be a powerful tool in predicting the performance of a large heat transfer system such as a steam boiler. Making accurate predictions before implementing changes can save time and money. The PEPSE boiler model developed for the Hibbard boilers has proven to be an accurate tool when compared to a boiler vendor's predictions. Because of this, the model will be used with confidence for future analytical studies.

References

1. G. L. Minner, E. J. Hansen, W. C. Kettenacker, and P. H. Klink, "PEPSE Manual: User Input Description", Vol. I, Revision 14, January 20, 1989, EI International, Inc., Idaho Falls, Idaho.

2. "Minnesota Power Company Hibbard DSD #2 Plant Units #3 & #4 (Erie City Boilers), Final Report: Boiler Evaluation and Optimization Study", PSA No. 74556, ABB-Combustion Engineering Services, Inc., May 14, 1991.

Table 1

Water Seal Leakage Air Reduction Results

Parameter	Units	Stream	Base Case	Test Case	Change
Air from FD Fan	lb/hr	355	246,148	268,278	+22,130
Tramp Air	lb/hr	365	49,230	26,828	-22,402
Total Air to Furnace	lb/hr	375	295,377	295,105	-272
Coal Flow*	lb/hr	465	10,451	10,402	-49
Air Temp to Furnace	°F	375	371	392	+21
Gas Temp from PAH	°F	55	341	329	-12
Econ Out Water Temp	°F	555	349.7	347.4	-2.3
Boiler Efficiency	%	-	71.92	72.05	+0.13

* Fuel is 40% coal, 60% wood.

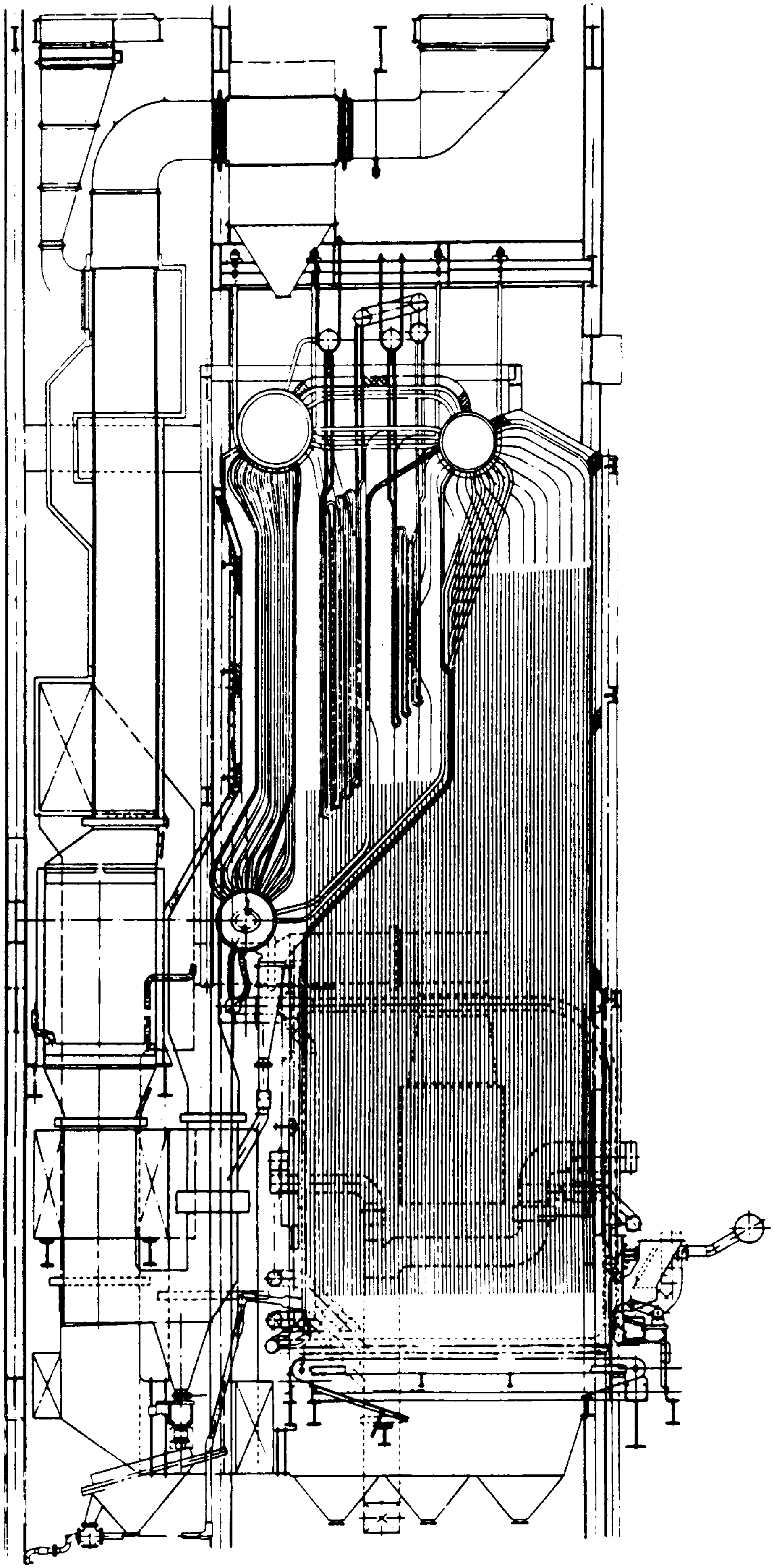


FIGURE 1 - Hibbard Units 3 & 4 Boiler Elevation

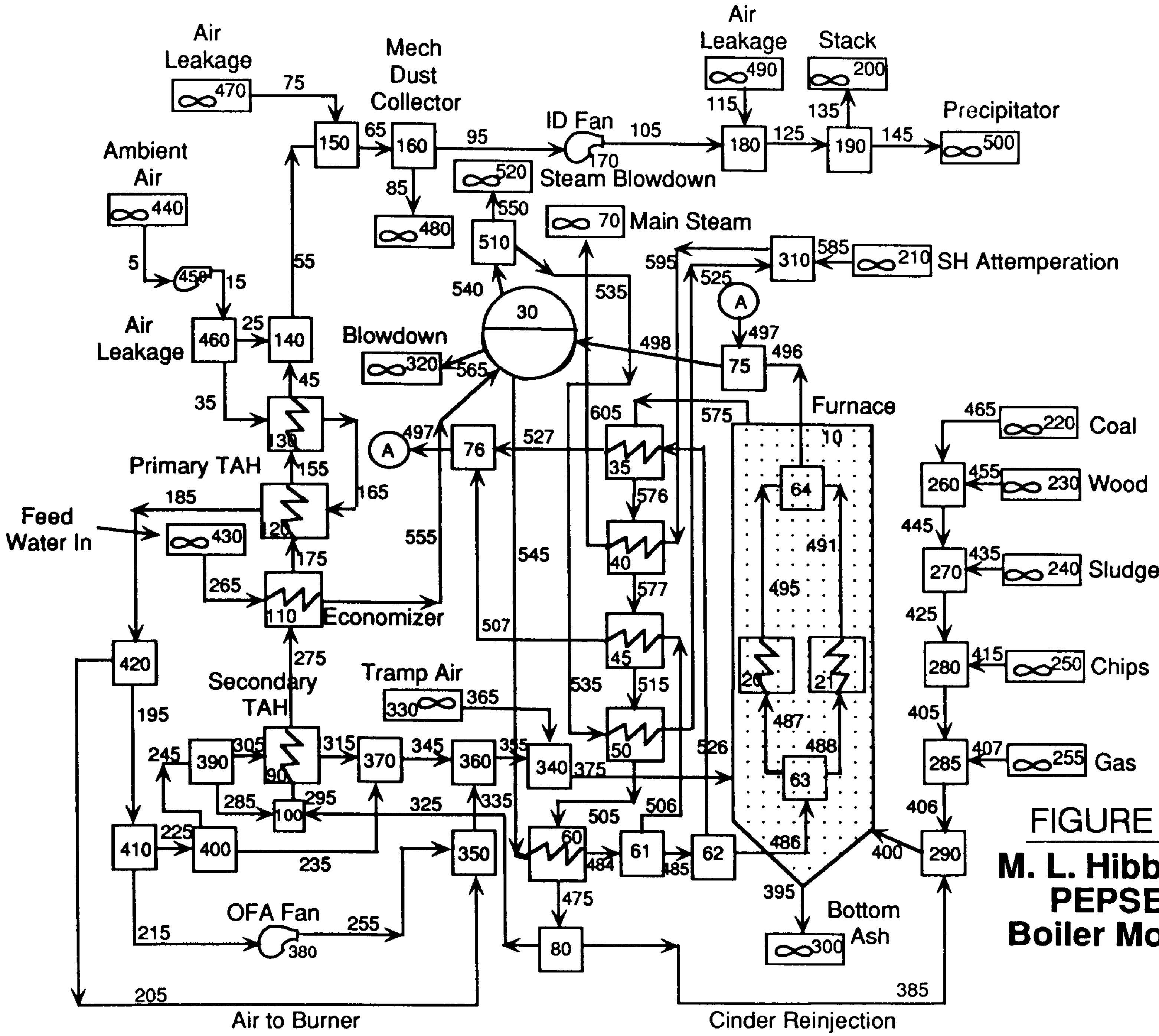
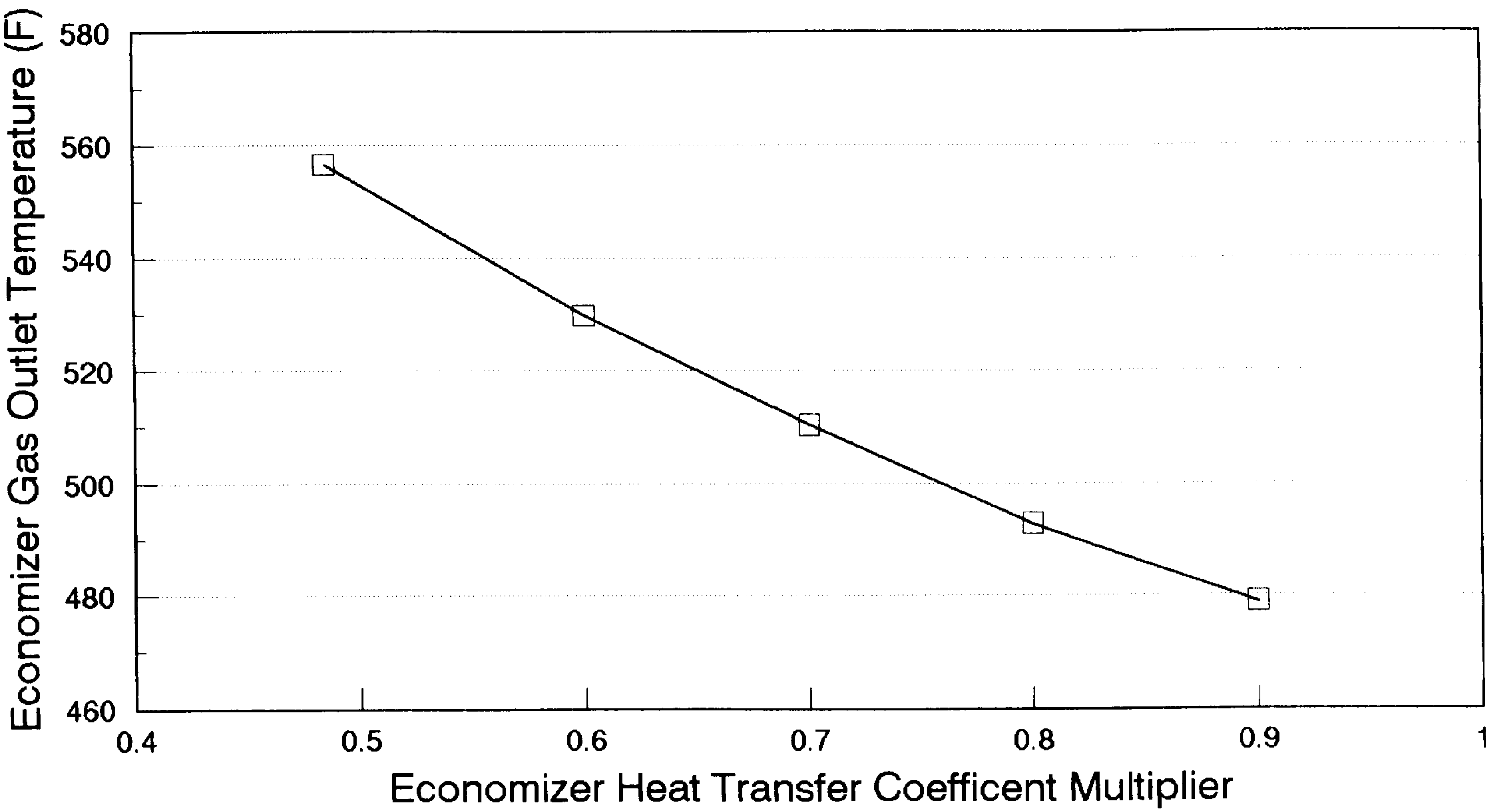


FIGURE 2
M. L. Hibbard PEPSE Boiler Model

<u>FIGURE 3</u>

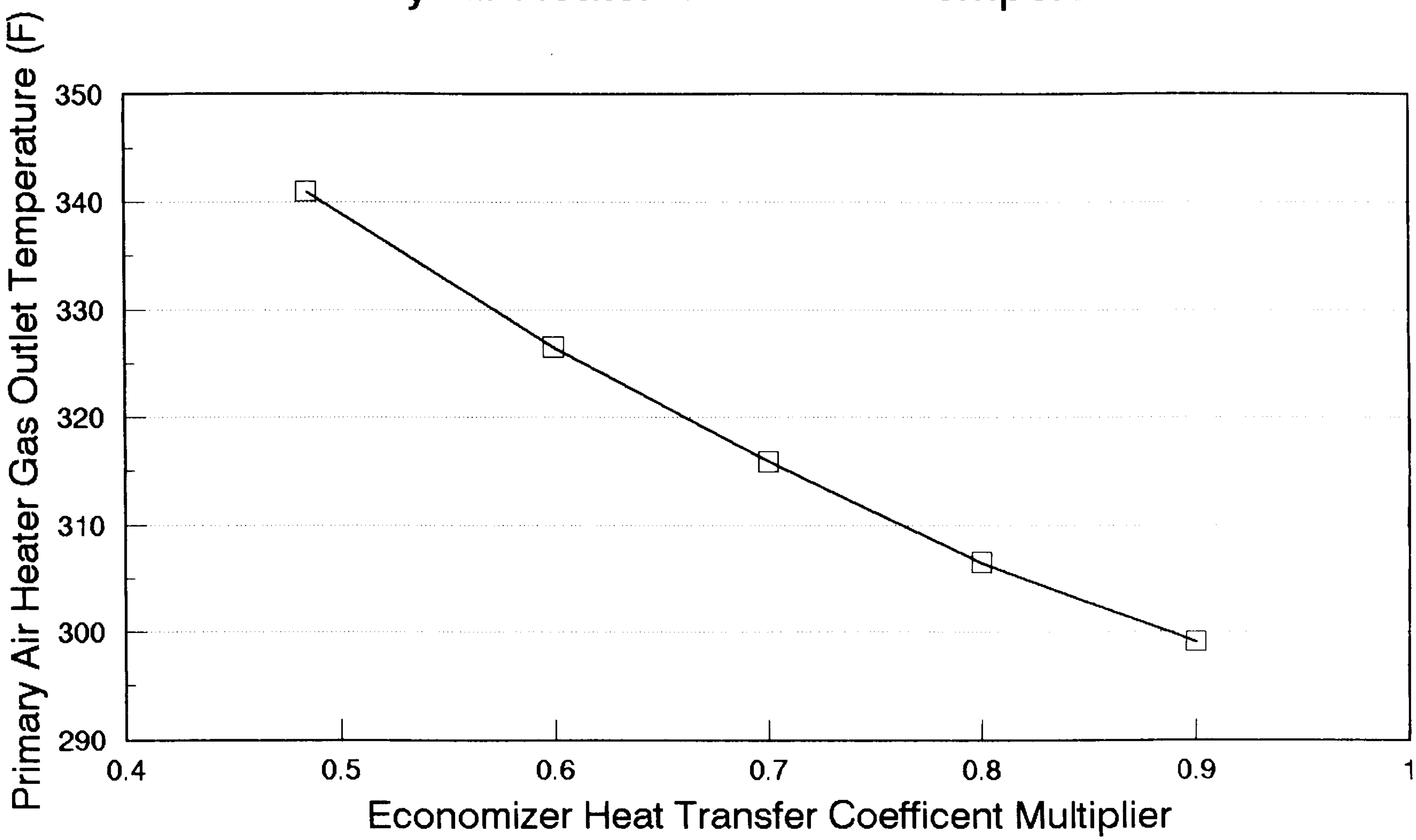
Economizer Gas Outlet Temperature



(Fuel is 60% wood, 40% coal)

FIGURE 4

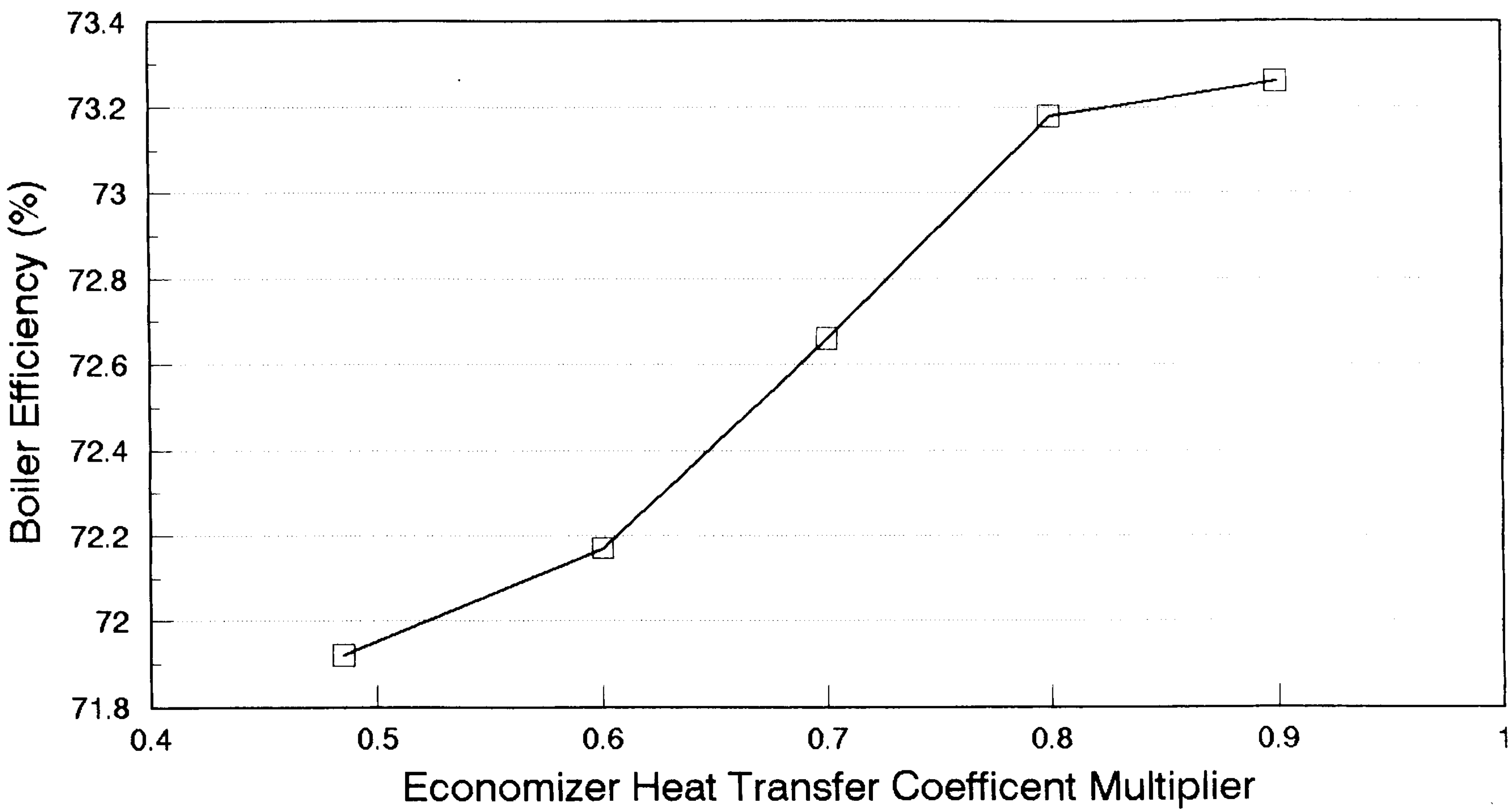
Primary Air Heater Gas Outlet Temperature



(Fuel is 60% wood, 40% coal)

FIGURE 5

Boiler Efficiency



(Fuel is 60% wood, 40% coal)