Modeling Air Leakages on a Tri-Sector Air Heater

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ABSTRACT

Public Service Indiana has used the PEPSE Heat Balance Code for several years to help determine increased operating costs due to operating parameter deviations. Until recently these studies have been made using turbine cycles only (i.e., throttle pressures, throttle temperatures, etc.). We have now, however, started performing these types of studies using the PEPSE boiler models.

This paper describes one such study which involved air leakages on a tri-sector regenerative air heater. Because a tri-sector air heater has significantly different flow paths than a conventional air heater, a model was configured to more accurately reflect the air leakages. The purpose of this paper is to determine the effects of the air leakages and determine the amount of error from using a simplified and a more detailed model.

INTRODUCTION

Public Service Indiana is the largest investor owned utility in the state of Indiana with a net system capacity of 5999 MW. Over half of this capacity is located in Southern Indiana at the Gibson Generating Station. This station consists of five similar units which went into commercial operation during the mid to late 1970's with the last unit going on line in 1982. Four of the five General Electric Turbine-Generators have a net rating of 635 megawatts while unit 5 is a scrubbed unit which is rated at 625 megawatts net. These base loaded units are similar in design as each is equipped with a 4588 KLBH supercritical Foster Wheeler Boiler.

In the past, the PEPSE Heat Balance Code has been used to evaluate operating and performance characteristics due to "off design" operating parameters related to the turbine cycle. The PEPSE models which have been developed have been used to help justify refurbishment or replacement projects and to improve operating practices. Recently, we have expanded our ability to perform these types of studies by developing a boiler model for the Gibson units. Considering a 1% change in boiler efficiency on these units would result in more than $500,000 in added fuel cost annually, we began to evaluate the operating characteristics of the boiler.

This paper will discuss a project that was done to evaluate the effect of air heater leakages on a Gibson unit and determine the associated costs incurred. The study was somewhat complicated by the fact that these units are equipped with tri-sector air heaters. These heaters present more complex air and gas flow paths than bi-sector air heaters and present various opportunities for air leakages. Once the model was developed, various air leakage scenarios were evaluated. This paper will describe the model development, the cases generated, and the results.

TRI-SECTOR AIR HEATERS

The air heaters being modeled for these units are ljungstrom type regenerative tri-sector air heaters. These heaters were developed in the early 1970's by the Air Pre-heater Company. The heaters were designed for large coal fired units to heat two air streams with one exit gas flow. The manufacturer of the heaters claims an improvement in unit efficiency can be realized from the heating and drying of the pulverized coal by the boiler exit gas. The heater is designed to rotate elements through the hot exit gas flow to absorb the furnace exhaust heat. The elements then continue their rotation through the primary air flow to heat this air for the drying of the pulverized coal. The elements complete their rotation as they pass through the secondary air stream to heat the combustion air.

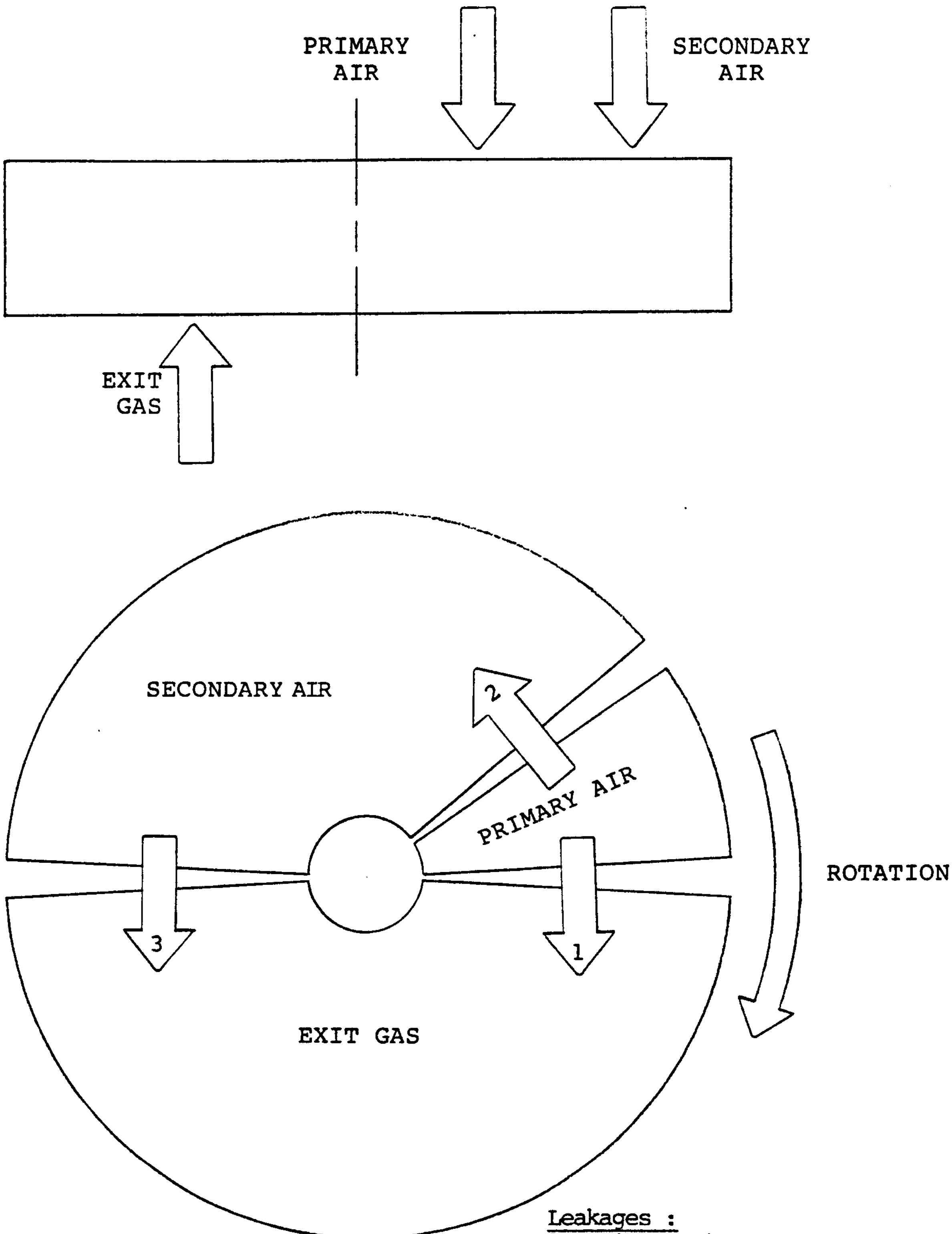
Figure I illustrates how these heaters are configured. Unlike the conventional bi-sector air heater, there are three flow paths through the heater. Half of the heater area is used to heat the rotating elements with the hot exit gas from the boiler. The other half is divided into the primary and secondary air paths. The primary air sector is generally around 30 degrees to 50 degrees of the inlet side of the heater. This area can vary with the size of the unit and the amount of the air flows required. These heaters operate at a higher pressure than most heaters presenting a greater chance for air leakages. The Gibson units operate at approximately 15 IN WG at the secondary air inlet and about 60 IN. WG at the primary air inlet.

SIMPLIFIED PEPSE MODEL

A simplified model was first developed to simulate the flow paths to the air heater and the leakage flow paths. The schematic of this model is shown in Figure II. The tri-sector air heater was modeled using two regenerative air heater components in series using a common exit gas flow path. The exit gas stream leaves the boiler and first enters the primary air-air heater component. The gas stream then continues to the secondary air-air heater component. This flow path was used to simulate the rotation of the elements. There are three separate leakages which have been modeled to simulate the leakages which actually occur in the heater. Because the primary air flow has the highest inlet pressure, leakages are shown from the primary air stream to the exit gas stream downstream from the air heater and to the secondary air stream upstream from the air heater. The remaining leakage results from the secondary air stream to the exit gas stream downstream from the air heater. These leakage locations may be better described by viewing the configuration of the heater in Figure I.

The model shows the inlet air entering from the forced draft fans and splitting into the primary and secondary flow paths. This split is maintained at about 20% to the primary side and 80% to the secondary side after leakages. The secondary air passes through a glycol heat exchanger and then on to the air heater. The primary air is sent to the primary air fans where the pressure is boosted to 60 IN WG to control coal flow. This flow then continues on to the air heater.

TRI-SECTOR AIR HEATER CONFIGURATION



Leakages :
1. Primary Air To Gas
2. Primary Air To Secondary Air
3. Secondary Air To Gas

FIGURE I.

TRI-SECTOR AIR HEATER
SIMPLIFIED MODEL

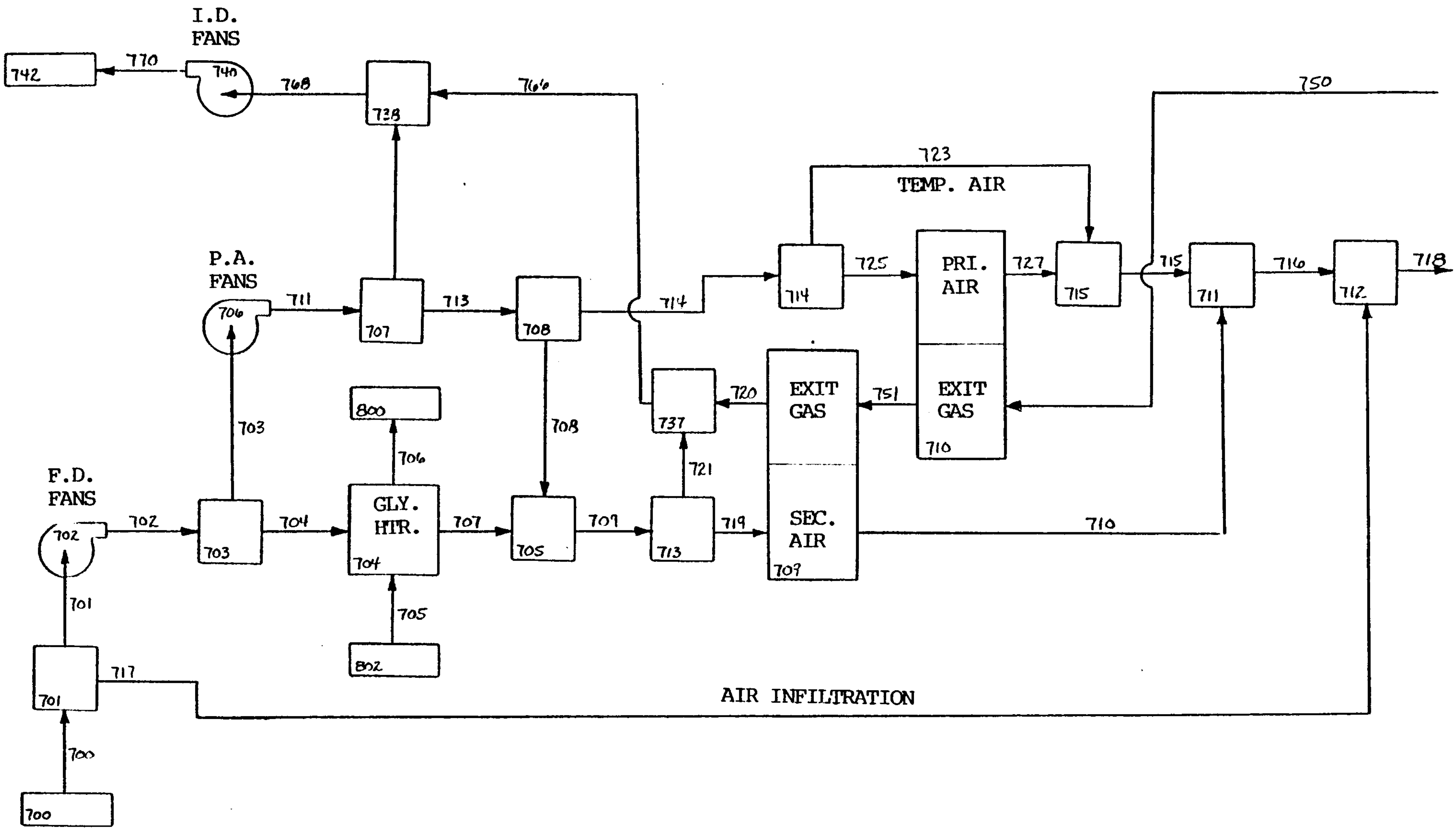


FIGURE II.

These flows are split only to reflect the proper stream properties for leakage purposes. After the streams pass through the air heater, they join with a mixer and enter the furnace as one stream. The model also shows an air infiltration leakage bypassing the entire air and gas system. This was done to simulate the ambient air which enters the furnace through openings in the casing. This flow was maintained at approximately two percent of the total air flow throughout the course of the study.

A combination of sources was used to develop this model. Design data was used to determine pressure drops and fan pressures. Test data from the manufacturer was used to proportion the leakage flows and our own test data was used to determine primary and secondary flows and various temperatures throughout the model. It was assumed that the leakage flows were proportional to the inlet pressures for the purposes of this study and were therefore maintained at the various leakage amounts. The base case was developed using a 6% air leakage rate. This reflects a total air to gas leakage of 6% even though the primary component leakages were considerably more. Due to the high pressures associated with the primary air flow, these leakages typically run 14 to 16% of the primary air flow. The largest leakage, as might be expected, is the primary air to the exit gas leakage. This is due to the high primary air pressure and the slight negative pressure in the exit gas flow. The other high flow leakage is the primary air to secondary air leakage. This leakage presents a negligible loss in boiler efficiency because the two air stream properties are similar (except for pressure). This does cause, however, the primary air fans to push more flow to compensate for the lost flow. The air heater section was the primary concern for this study; therefore the boiler model was developed based test data at several high load conditions and its properties were held constant for each load case of the study.

The objective of this study was to determine the effect of excessive air heater leakages. It was determined that several cases would be made up to an air to gas leakage of 15%. Past air heater tests indicate leakages ranging from 7 to 15% for these units. The necessary flows were hand calculated to determine what each splitter must bleed off for each case. Preliminary results from these cases indicated a substantial increase in load to the fans. With excessive amounts of air leakage, the induced draft fans were receiving their normal flow plus the leakage flow. Also, because of the leakage, the boiler would receive less flow and would therefore demand more from the input air source to maintain the same boiler load. This caused both the F.D. Fans and the P.A. Fans to run much harder while trying to compensate for the leakage flows. Due to this discovery using the simplified model, it was decided to develop a more detailed model showing each fan and the fan characteristics.

DETAILED PEPSE MODEL

Figure III shows the detailed PEPSE model of the air and gas system for the Gibson units. This model is basically the same as the simplified model except it shows both the "A" and "B" air and gas paths. This model shows both air heaters and has them modeled in series as was previously done. The model also shows the correct number of fans which are: two forced draft fans, two induced draft fans, and three primary air fans. Manufacturers catalogs were used to input the fan and motor efficiencies as designed. The design curves for these fans were used because the results would show a relative difference and not an actual efficiency.

The performance mode PEPSE models were developed using the optional boiler efficiency calculation method. Using this method, only one inlet air description and one flue gas description can be used to input the necessary data for the boiler efficiency calculation. Because the model shows a dual air and gas path, only one path could be specified. This did not present a problem with this study because it was assumed that the "A" and "B" sides were virtually identical. With the same stream properties present on each side, the boiler efficiency calculation will be correct. The inlet air description was specified as the secondary air stream or the combustion air stream immediately after the glycol heat exchanger. The primary air stream was input as a special air flow input to add this flow to the heat in entering air for the boiler efficiency calculation.

Results

Three separate load cases were generated at the various air leakage rates to determine what costs were incurred. The high load cases of 3775, 4166, and 4588 KLBH were chosen because these are based loaded units and normally operate in this range. Figure IV shows the pertinent information resulting from the PEPSE cases. It was discovered, as might be expected, that the air heater leakages have no effect on boiler efficiency. If the boiler efficiency calculation is based on PTC-4.1, air heater leakage is not reflected in the efficiency of the steam generator. While the air heater component falls inside the boundary of the efficiency calculation, the losses due to the heat in the dry flue gas is corrected for air heater leakage. This causes the calculation to include the air heater effectiveness only. Figure IV lists the apparent and the corrected boiler efficiency. This was done by running cases with the flue gas description before and after the mixing of the leakages in the exit gas flow. As the data shows, the corrected boiler efficiency is virtually the same at each leakage flow. There is a very slight variation between cases because only the losses due to the heat in the dry flue gas is corrected.

The most obvious contributor to the overall inefficiency of the unit was the increased load to the fans. Figure IV shows the additional power that is needed at the higher leakage rates. This power, which was obtained from PEPSE's first law report, can significantly increase the auxiliary power needed for the unit and can result in increased

TRI-SECTOR AIR HEATER
DETAILED MODEL

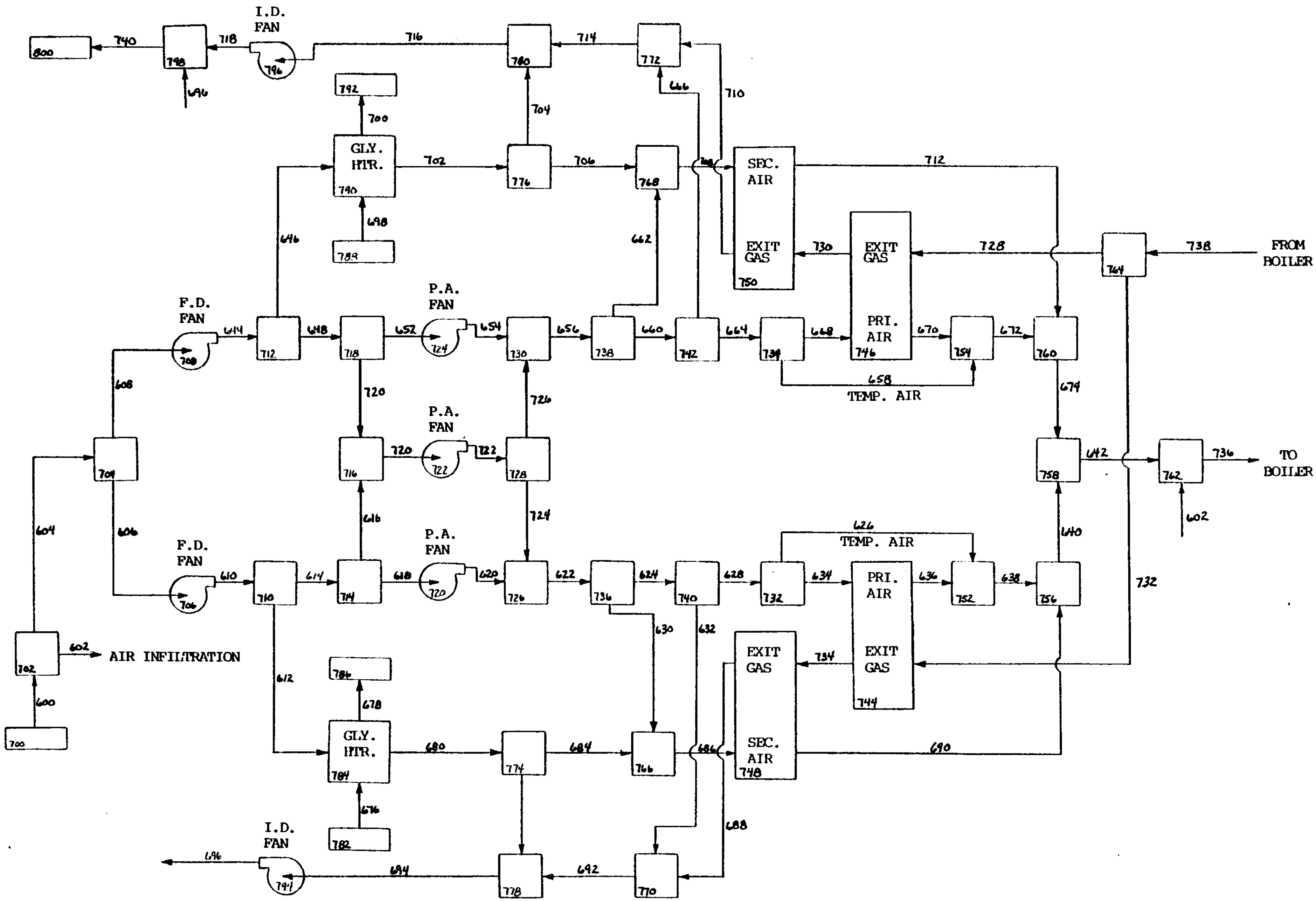


FIGURE III.

DATA RESULTS

Main Stream Flow (KLBH)		Air To Gas Leakage Rate			
		6%	9%	12%	15%
3,775	Apparent Boiler Eff. (%)	87.653	87.640	87.624	87.601
	Corrected Boiler Eff. (%)	87.677	87.677	87.676	87.670
	Fan Power (MW)	7.54732	7.91339	8.33960	8.81789
	Power Differential (MW)	Base	0.36607	0.79228	1.27057
	Annualized Increased Fuel Costs (1987 $)	—	36,900	80,000	128,400
4,166	Apparent Boiler Eff. (%)	87.621	87.605	87.583	87.552
	Corrected Boiler Eff. (%)	87.647	87.645	87.640	87.629
	Fan Power (MW)	8.82338	9.29665	9.84274	10.49860
	Power Differnetial (MW)	Base	0.47327	1.01936	1.67522
	Annualized Increased Fuel Costs (1987 $)	—	44,100	95,000	156,300
4,588	Apparent Boiler Eff. (%)	87.570	87.549	87.519	87.473
	Corrected Boiler Eff. (%)	87.598	87.593	87.582	87.561
	Fan Power (MW)	10.37120	11.02890	11.77670	12.63880
	Power Differential (MW)	Base	0.65770	1.40550	2.26760
	Annualized Increased Fuel Costs (1987 $)	—	56,700	121,300	196,000

FIGURE IV.

fuel costs. This data shows that at high loads and at high leakage flows, an increase in fuel costs of almost $200,000 per unit can result. This increase in fuel cost reflects the differential in total fan power between the indicated leakage flows and the 6% base leakage flow. These costs are based on annual generation at current fuel prices.

Another important consideration that the PEPSE model shows is the amount of flow and the efficiency of each fan. Although the design efficiency curves are used in the model, the output shows that the load on the FD and ID fans has reached a level which is past the optimal efficiency on the curve. In fact, the output shows the I. D. fans are exceeding their rated load. This adds credibility to the model by the fact that on several occassions these units have been limited by their I.D. fan capacity. The PEPSE data shows that at high loads and high leakage flows (15%), the ID fans are operating at approximately 104% of their rated load. Most fans will operate with some percentage of design margin, however the PEPSE data assumes design efficiencies and no leakages in ducts or other seals. Independent of these considerations, the data clearly shows that the ID fans are the limiting factor in the air and gas system. Also, because the fan efficiencies are decreasing, once they reach a certain load, the power needed to drive the fans increases significantly. This explains why the fuel costs increase rapidly at the higher leakage flows. Also, since the design efficiencies are used, the power needed to drive the fans is probably slightly low making the increased fuel costs conservative.

The model developed for this study seems to be an accurate representation of the air and gas flow paths for a Gibson unit. While some assumptions were made for this study (proportion of leakage flows, design fan efficiencies, and similar "A" and "B" stream properties), the model can be adjusted with more test data or better assumptions to provide useful information for other types of studies. This study could be enhanced by including the actual fan efficiencies in the model if this data were available. This model should provide a useful tool for performing other types of studies on the air and gas system or the boiler. Some studies which should be considered are: effect of air heater effectiveness, sensitivities due to inlet air conditions, and sensitivities from operator controlled parameters.

SUMMARY

Tri-Sector regenerative type air heaters were developed in the early 1970's for use on large coal fired units. These heaters are designed to increase unit efficiency by heating the combustion air and the primary air which dries the coal as it is sent to the boiler. Although the gas and air flow paths for these heaters are more complex than the conventional by-sector air heater, they can effectively be modeled using the PEPSE heat balance code. This study, which evaluates the effect of air heater leakages, illustrates one method of developing such a model.

An air heater model was developed which accurately configures the leakages that occur in the heater. With this model, several cases were generated varying the load on the boiler and the leakage rate. The results from the cases generated indicate that significant increases in auxiliary power occur due to the increased load on the fans. Each set of fans, the I.D., F.D., and P.A. fans must run harder to accomodate the increased leakage flows. The model shows, based on current capacity factors and fuel costs, that high leakage rates can result in an added annual fuel cost of approximately $200,000. The model also shows that the induced draft fans become a limiting factor in the air and gas system which is consistent with operating experience.

The model developed for this study accurately represents the air and gas system for these units. With some additional test data, this model can be enhanced to provide useful information for several other studies pertaining to the boiler or the air and gas system.