An Oil to Gas Conversion Study Using PEPSE®

William C. Kettenacker

Performance Engineering, Inc.

Ijaz A. Sheikh
Robert P. Marko
Dale H. Tomlinson

Niagara Mohawk Power Corporation

An Oil to Gas Conversion Study Using PEPSE

by

William C. Kettenacker
Performance Engineering, Inc.

Ijaz A. Sheikh
Robert P. Marko
Dale H. Tomlinson
Niagara Mohawk Power Corporation

In 1984, Niagara Mohawk Power Corporation, an electric utility serving upstate New York, sought ways to reduce fuel costs at several of its oil-fired generating units. One method that was considered was to switch from oil to less expensive natural gas. Studies performed at that time showed that the costs of design changes required to convert to gas would be more than offset by the reduced fuel costs. However, at that time the conversion was not made.

Early in 1991, Niagara Mohawk again looked at the possibility of converting from oil to natural gas, specifically at its Oswego Station Units 5 and 6. Also at that time Niagara Mohawk contracted with Performance Engineering to build a PEPSE model of the Oswego Units 5 and 6 boilers. This model was subsequently used to study the fuel conversion. In addition to studying the effect of the fuel change on boiler performance, the model was used to analyze the impact of the new fuel on emissions levels.

Three studies using 100% oil, 70% oil and 30% natural gas, and 100% natural gas were performed. Results of the studies showed a boiler performance equal to or better using natural gas fuel, either alone or in combination with the oil. Based on the results of the PEPSE studies and the costs of converting to gas, Niagara Mohawk plans to convert the two Oswego Units to a combination of oil and gas firing by 1995.

An Oil to Gas Conversion Study Using PEPSE

1.0 Introduction

Early in 1992, Niagara Mohawk Power Corporation, an electric utility serving upstate New York, sought ways to reduce fuel costs and improve emissions at several of its oil-fired generating units. One method that was considered was to switch from oil to natural gas, either alone or co-firing with oil, specifically at its Oswego Station Units 5 and 6. To assist in the analysis of this conversion process, Niagara Mohawk with guidance from their architect engineering (A/E) firm and Performance Engineering, Inc., used a PEPSE boiler model previously developed by Performance Engineering for analyzing the units' design.

Two studies were performed: (1) 75% MCR with all natural gas firing, and (2) 100% MCR with 70% oil and 30% natural gas. Results show that gas provides a cost-effective alternative to oil. As an added benefit, emissions of sulfur compounds are reduced using all gas or a mixture of gas and oil.

2.0 Unit Description

Oswego Steam Station Units 5 and 6 are nearly identical oil-fired generating units located on the southeast shore of Lake Ontario in northern New York. Each unit is capable of producing 850 MW at a steam flow of 6,300,000 lb/hr, a main steam temperature of 1005 ^{o}F, and a main steam pressure of 2600 psi. Each unit has a single reheat sub-critical boiler. Unit 5 came on line in 1975, and Unit 6 came on line in 1980. Figure 1 shows an elevation schematic of the boilers.

3.0 Model Development

This section presents a detailed discussion of the development of the Oswego design PEPSE model.

3.1 Model Construction

A PEPSE model of the Oswego Steam Station Units 5 and 6 boilers was developed in 1991 using Version 55 of the PEPSE computer program[1]. Model development was accomplished using the graphical PEPSE man-machine interface (MMI). The two boilers are similar enough in design to allow the use of the same model geometry for both, however, the presence of recirculated air to the Unit 6 boiler requires slightly different input data for the two models.

A detailed model of the units consisting of components representing each boiler section and heat transfer section was constructed. The model includes all major boiler components developed using PEPSE's more rigorous and detailed design mode input option. Four furnace components were used to simulate the four sets of burners in each furnace. The split flue back pass was modeled as two separate flow paths. All air heaters were included in the model. This high level of modeling detail was provided to offer a high degree of flexibility and accuracy when using the PEPSE model for design or analytical studies.

Figure 2 shows the design PEPSE model constructed for the boilers. The remainder of this section discusses the model in detail.

3.1.1 Flue Gas Path

Furnace air is introduced through a source component (Component 979). The air first passes over an air pre-heating coil (Component 975) then splits (Component 981) before entering the forced draft fans (Components 963 and 965). The air then re-mixes (Component 961) and passes over another set of air pre-heating coils (Component 955). The air then splits (Component 959) before entering the secondary air heaters (Components 976 and 978). Hot air exiting the secondary air heaters is recombined using a mixer component (Component 988), and then splits to the four furnace components (Components 701, 751, 801, and 851) using a series of splitters (Components 990, 972, and 735). The air pre-heating coils upstream of the air heaters are supplied with flow from sources (Components 973 and 953) and have their exit flows drain to sinks (Components 977 and 957).

Fuel enters the system through a source (Component 974). It is fed to the four furnaces through a set of splitters (Components 799, 797, and 733).

Hot flue gas exits each furnace component through a stream (Stream 713 from Furnace 701, Stream 731 from Furnace 751, Stream 766 from Furnace 801, and Stream 750 from Furnace 851) and enters the convective stage flow path. Flue gas from the two left furnaces and the two right furnaces mix (Components 727 and 779, respectively) and then pass over the pendant or finishing superheaters (Component 773 on the left and Component 873 on the right). Exiting the pendant superheaters, the flue gas mixes (Component 791) and then passes through a component representing the roof tubes (Component 823). The flue gas then passes through the convective rear furnace wall (Component 825) before splitting (Component 835) to the two sides of the backpass.

In the backpass, the flue gas splits into two sections, the reheat side and the superheat side. On the superheat side, the flue gas passes over two primary superheater sections (Components 837 and 839) and then two components representing the HRA (heat recovery area) wall tubes - the side walls (Component 841) and the superheat portion of the center wall (Component 843). Exiting the center wall, the flue gas passes through a component representing the primary superheater wall tubes (Component 845) and then the upper economizer section (Component 847) before mixing with the reheat side backpass flue gas (Component 946). On the reheat side, the flue gas passes through two reheat sections (Components 863 and 885) and then three components of the HRA wall tubes - the reheat portion of the center wall tubes (Component 889), the reheat portion of the side walls (Component 897), and the rear wall (Component 942). The flue gas then enters the lower reheat section (Component 944) and finally mixes with the superheat side flue gas.

Upon leaving the split backpass, the flue gas enters the lower economizer section (Component 948). Exiting the economizer, a portion of the flow is split (Component 960) for re-injection into the furnaces. The re-injected flue gas passes first through the gas recirculation (air dilution) fan (Component 964) and is then split to the four furnaces through a series of splitters (Components 966, 968, and 970). Note that the gas recirculation system is present in both models (Unit 5 and Unit 6) but is active only for the Unit 6 model.

The main flow of flue gas splits (Component 962) to go to the two air heaters. Exiting the two air heaters, the flue gas enters the precipitator (Components 980 and 982 on the left, Components 984 and 986 on the right). The gas then enters the induced draft (ID) fans (Components 994 and 998), mixes (Component 941), and exits the system through the stack (Component 943).

3.1.2 Water/Steam Path

Feedwater from the turbine cycle enters the model from a source (Component 958), mixes with economizer recirculation (Component 950), and enters the lower economizer (Component 948). Leaving the lower economizer, the feedwater enters the upper economizer (Component 847) and then proceeds to the drums (Components 743 and 745) after being split (Component 741).

From the drums, blowdown is sent to sinks (Components 947 and 951). The downcomer flow (Stream 776 from the left drum, Stream 777 from the right) leaves the drums and then mixes (Component 749). After the mix, a portion of the flow is diverted (Component 813) to the lower economizer. The main downcomer flow proceeds to the furnace water walls. It is split to the four furnace sections through a series of splitters (Components 729, 731, and 737). Within each furnace the downcomer flow is split among the water wall sections. In Furnace A, a portion of the flow is split

(Component 703) to the rear water wall section (Component 707). The remaining flow is split (Component 705) to the two components representing the front wall section (Components 709 and 715) and the two components representing the side walls (Components 711 and 717). Flow exiting the side walls and the front wall is mixed (Component 719). This arrangement is the same in the other three furnace components.

The front water wall and side water wall flows from all furnaces are mixed in a series of mixers (Components 725, 713, and 775). The rear water wall flows from each furnace are also mixed through a series of mixers (Components 831, 829, and 827) before entering the convective rear furnace wall section (component 825). The flow exiting this component mixes (Component 781) with the front and side wall flows (previously mixed) and enters the two drums. This flow was split (Component 747) prior to entering the drums.

Saturated steam leaves the drums, mixes (Component 739) and enters the component representing the roof tubes (Component 823). Exiting the roof tubes, the flow enters the HRA, first splitting (Component 833) to enter the two sides, superheat and reheat. On the superheat side, the steam splits (Component 883) to the side walls (Component 841) and the center wall (Component 843). On the reheat side, the flow splits (Components 893 and 899) to the center wall (Component 889), the side walls (Component 897), and the rear wall (Component 942). The steam from both sides then mixes (Components 895 and 891) and enters the primary superheater (Components 839, 837, and 845). The steam leaves the primary superheater, is split (Component 849), and is injected with superheat attemperation spray (Components 874 and 877). This attemperation flow enters the system through a source component (Component 879) and is split to the two sides through a splitter (Component 875). The steam on both sides is then split again (Component 777 on the left and Component 881 on the right) and enters the division superheater sections (Component 721 in Furnace A, Component 771 in Furnace B, Component 821 in Furnace C, and Component 871 in Furnace D). Steam leaving the two left furnaces and two right furnaces mix (Components 723 and 763, respectively), and are then injected again with attemperation spray (Components 783 and 789). The attemperation flow enters the system through a source component (Component 787) and is split to the two sides through a splitter (Component 785). Steam from each of the two sides then enters the pendant or finishing superheater section (Components 773 and 873), mix (Component 793), and exit the system as main steam (Component 795).

Cold reheat steam from the turbine cycle enters the boiler model from a source component (Component 954). Before the cold reheat steam enters the reheater convective stages, it passes through a reheat attemperation flow inlet mixer (Component 952). The reheat attemperation flow is introduced into the system through a source component (Component 956). The cold reheat steam then enters the reheater section (Components 944, 885, and 863) and exits the system as hot reheat (Component 887).

3.2 Modeling Assumptions

Several assumptions and modeling judgements were made during the construction of the design PEPSE boiler model schematic. These include the following:

- In Version 55, PEPSE had a limitation of 45 heat exchange components in any model, and several heat exchange components had to be left out to meet this limitation. In the original PEPSE model developed by Performance Engineering, two of the four preheating coils were left out because their effect on the cycle could be simulated by using only two. When the model was modified for the fuel conversion study, the four furnace components were combined into two to free up additional heat exchange components.

- All air to each furnace was introduced at a single inlet port to that furnace. No air was introduced to the furnaces with the fuel or as leakage. This is a PEPSE limitation - air may enter each furnace at only one port. However, this causes no noticeable effect on the results because the total amount of required (and excess) air reaches each furnace through this one air port. Leakage air may be introduced at any location in the model, if present.

- The flue gas convective stages were modeled to correspond to the major convective stages in the boiler. In the real plant, tube geometry changes, such as tube thickness or tube pitch, and other tube changes, such as material changes, occur within a single convective stage. In PEPSE, no intra-stage tube geometry changes or material changes are allowed. To model these intra-stage tube changes, separate stages would be required to reflect the changing geometries and materials. To avoid unnecessary modeling detail, all these separate "sub-stages" were not included. Instead a single stage geometry and material were used to represent major portions of each boiler section. This allows the use of one or two components to simulate the entire convective stage without requiring many components. For example, the reheater was modeled using only three components rather than the actual eight. The PEPSE results are not noticeably affected by the absence of the additional stages.

3.3 Input

All input for the design model came from design documents and drawings of the boiler sections.

One major assumption made in the development (and later tuning) of the model was that the four furnace components are identical, both in geometry and performance. This assumption is reflected in the model by identical water wall geometries and identical heat transfer characteristics. Equal water wall geometries implies that the furnaces have exactly the same number of tubes of identical dimensions. Equal heat transfer implies the furnace exit temperatures of the furnaces are equal.

3.4 Model Tuning

Development of the model schematic and preparation of the model input are only a portion of the process of developing a useable PEPSE boiler model. Once built, the model must be 'tuned' to match some set of performance criteria, the most common being the original design, the acceptance test results, or the results from a recent performance test. The original model developed by Performance Engineering was tuned to the original design conditions. For the fuel conversion study, the model was tuned to a performance test conducted in early 1992.

Tuning is the process of modifying the PEPSE-calculated pressure drop characteristics and heat transfer characteristics to match a set of design conditions or measured plant conditions. In the design input mode, PEPSE's heat transfer components' pressure drops and heat transfer are calculated based on industry-accepted first principles calculations. Details of these calculations are given in the PEPSE theory manual[2]. These first principles calculations must be modified to account for the actual design or performance of the plant. These modifications, or tuning parameters, account for the boiler vendor's adjustments to boiler performance based on years of design and testing experience, or account for the deterioration, fouling, or other performance changes of the boiler sections over a period of time.

Several factors are available to use as tuning parameters in PEPSE. For pressure drop tuning, the form loss coefficient (k), the friction factor (f), or a combined form loss and friction factor (f*L/D + k) may be modified to achieve the desired pressures throughout the boiler.

For heat transfer tuning, the tube inside film coefficient, the tube outside film coefficient, the fouling resistance, the tube thermal conductivity, or a combined factor which represents the entire thermal resistance from the inside to the outside of the tube may be modified. For radiant stages representing water walls, or for pendants which reside in the furnace itself, a radiant stage view factor may also be used for tuning. In addition, the effective heat transfer area may be changed to modify the total amount of heat transferred.

4.0 Gas Conversion Study

An economic analysis completed prior to the PEPSE study described herein indicated that the Oswego Units 5 and 6 should be fired with some amount of natural gas. The PEPSE study was performed to confirm a 1984 study performed by the A/E indicating that the boiler was capable of firing 100% natural gas with a maximum attainable load of 70%-75% MCR without changing pressure parts. In addition, the PEPSE study predicted the performance at 100% MCR using a 70% heat input from oil and a 30% heat input from gas.

Several operating limitations are present in the Oswego units. One limitation is the primary superheater (Component 845 in the model) metal temperature may not exceed 860 ^{O}F. To meet this limitation, the FEGT must be below 2600 ^{O}F. The other constraint is that the upper superheater spray flow currently has a maximum limit of 400,000 lb/hr.

Starting with the original model developed by Performance Engineering, Niagara Mohawk revised the model with assistance from their A/E on boiler operations and design parameters, and from Performance Engineering on PEPSE boiler modeling applications. The revisions included following:

(1) The pendant (finishing) superheater was split into two components to account for radiant heat transfer to the upstream tubes of the superheater, placing one of the split components in the furnace (radiant zone) and one in the convective path above the furnace. The distribution of radiant and convective area was made to match the PEPSE-calculated furnace exit gas temperature (FEGT) with the temperature calculated from an external source[3]. Adding the extra heat exchanger components required elimination of other heat exchangers. To accomplish this, the four furnace components and their associated heat exchangers were merged into two furnace components. This did not reduce the usefulness of the model because of the symmetry of the furnaces.

(2) Retuning was performed on the revised model from (1) above to match the complete boiler performance test data conducted in February 1992. These tuning factors were then inserted into the revised model to allow for sensitivity studies.

(3) Spray flow controls were added to control steam temperatures.

Using the revised model discussed above, several sensitivity studies were performed to investigate the effects of firing natural gas as a fuel. These studies were in the following areas:

(1) At 75% MCR with 100% natural gas firing, sensitivity studies at various fuel flows, different spray flows, and varying backpass flow splits were made.

(2) At 100% MCR with 70% oil firing and 30% natural gas firing, studies were made with different excess air levels and different fuel heat input levels.

PEPSE studies showed that 100% gas firing at 75% MCR was possible. Above that, gas levels must be reduced to assure that the FEGT remains below the 2600 °F limit. At 100% MCR, only 30% gas (with 70% oil) can be used.

5.0 Results

Highlights of the results for the 75% MCR study (100% natural gas) are shown in Figures 3 and 4. Figure 3 shows the results of fuel flow on FEGT. Figure 4 reveals that to operate at the maximum allowable FEGT, the upper superheat spray limitation must be raised. Increasing the spray flow limitation will require a minimum of time and cost, therefore, it will be implemented. All results are at 10% excess air.

Major results for the 100% MCR study (70% oil firing, 30% natural gas firing) are shown in Figures 5 and 6. Figure 5 shows the relationship between fuel flow and FEGT. Figure 6 shows the effect of excess air on FEGT at constant fuel flow.

Because of the lower sulfur level in the gas, the SO_2 levels were reduced at all loads using gas.

6.0 Conclusions

Natural gas is a cost-effective clean alternative to oil at Niagara Mohawk's Oswego Units 5 and 6 and can be fired alone at 75% MCR. A tool such as PEPSE can be used to assess the impact of changing fuels on boiler performance and total plant performance.

PEPSE is a registered trademark of NUS Corporation.

References

1. G. L. Minner, E. J. Hansen, W. C. Kettenacker, and P. H. Klink, "PEPSE Manual: User Input Description", Vol. I, Revision 15, January 21, 1990, EI International, Inc., Idaho Falls, Idaho.
2. G. L. Minner, E. J. Hansen, P. H. Klink, and W. C. Kettenacker, "PEPSE Manual: Engineering Model Description", Vol. II, Revision 7, January 21, 1990, EI International, Inc., Idaho Falls, Idaho.
3. "Steam/Its Generation and Use", Babcock & Wilcox, 39th Edition, 1978.

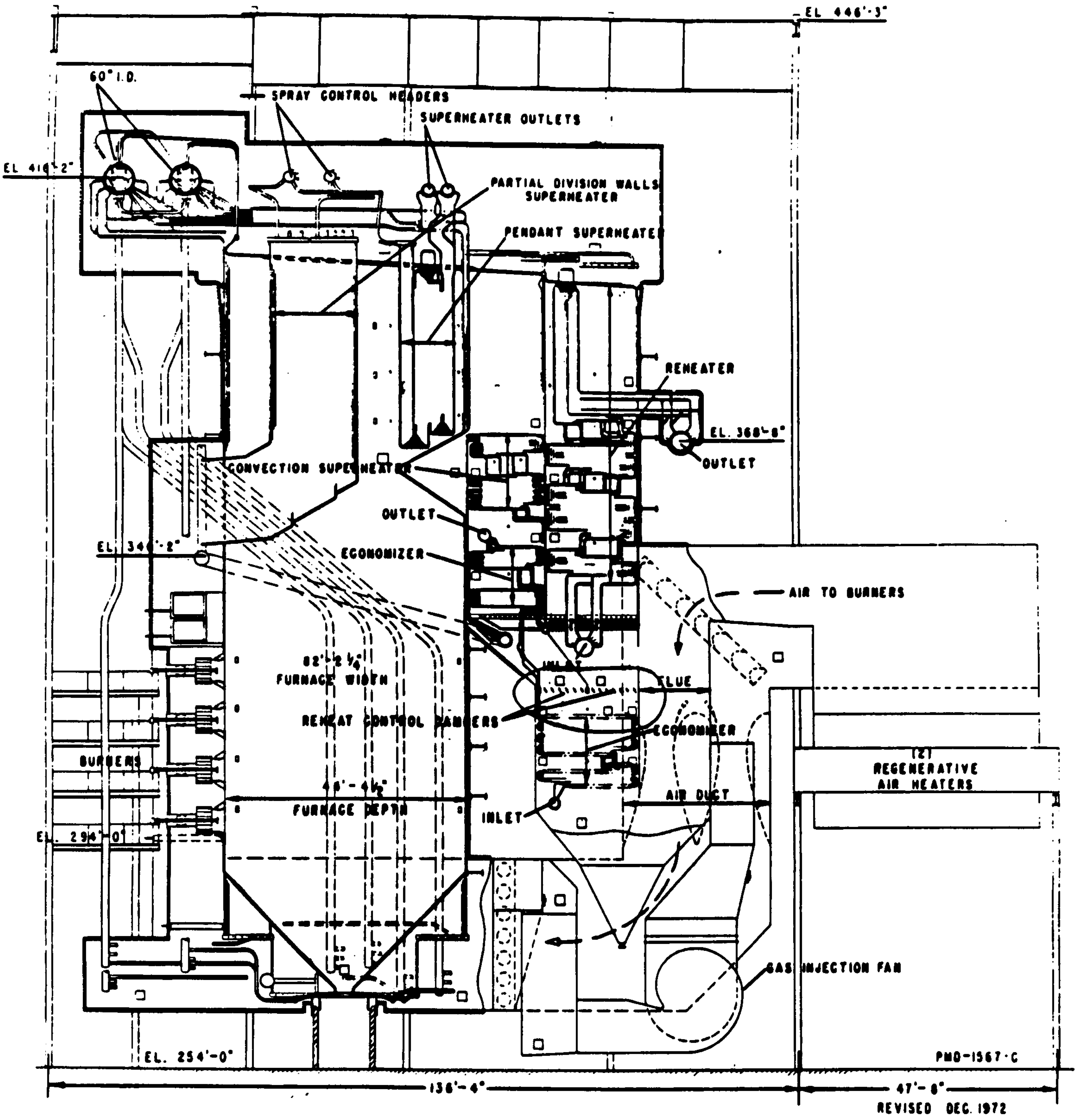


FIGURE 1

Oswego Units 5 & 6 Elevation Schematic

FIGURE 2

Oswego Units 5–6
PEPSE Boiler Model

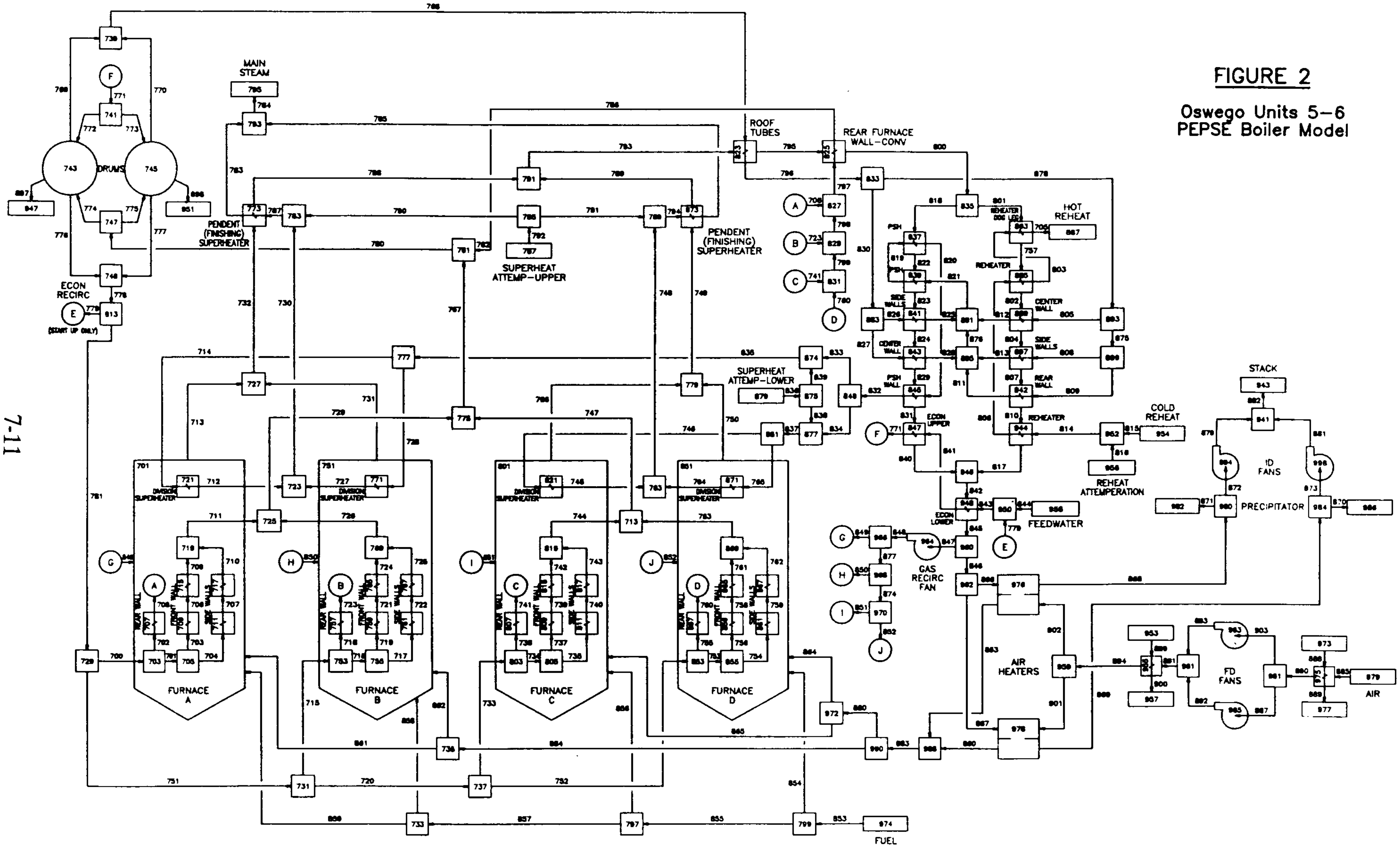
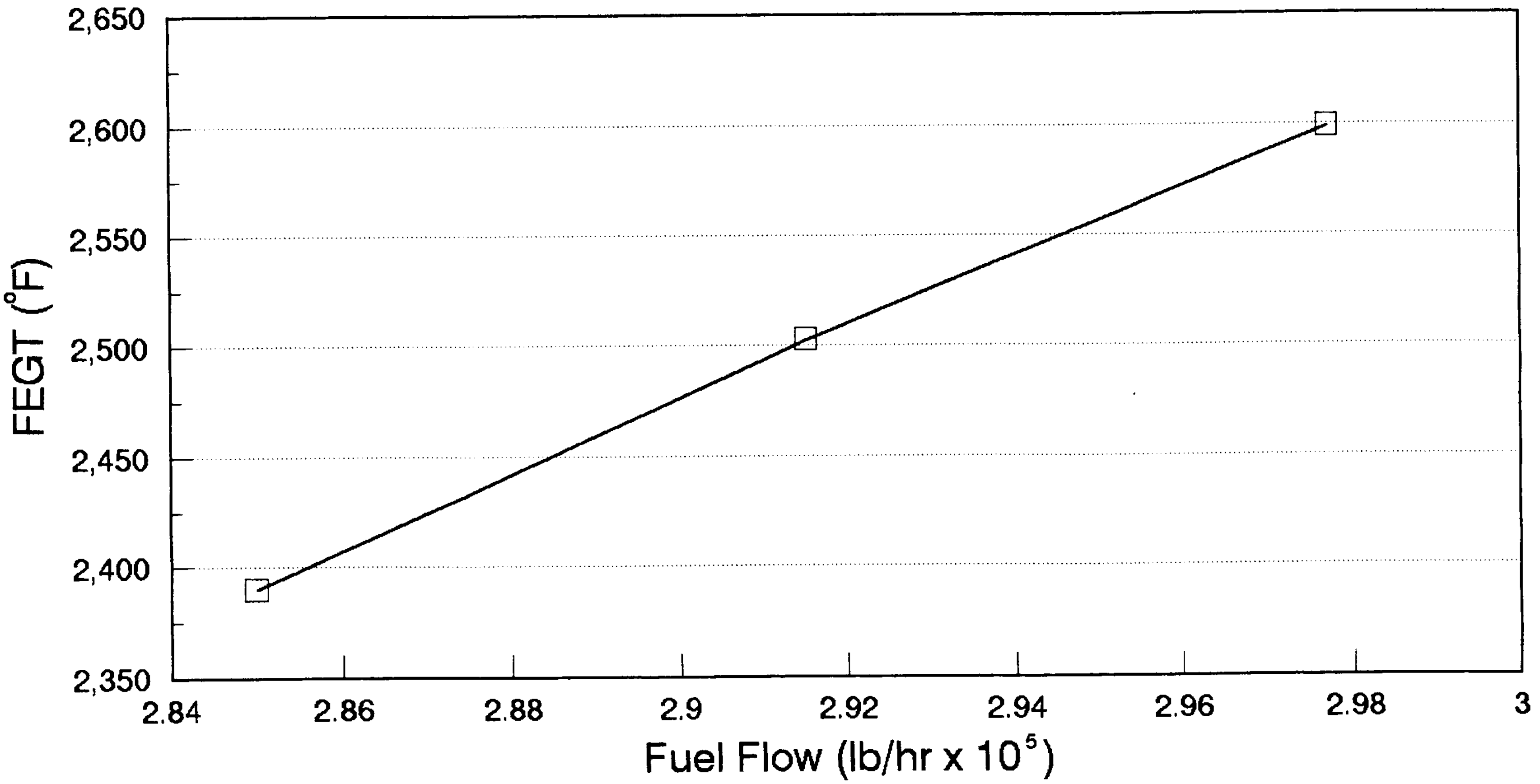


FIGURE 3

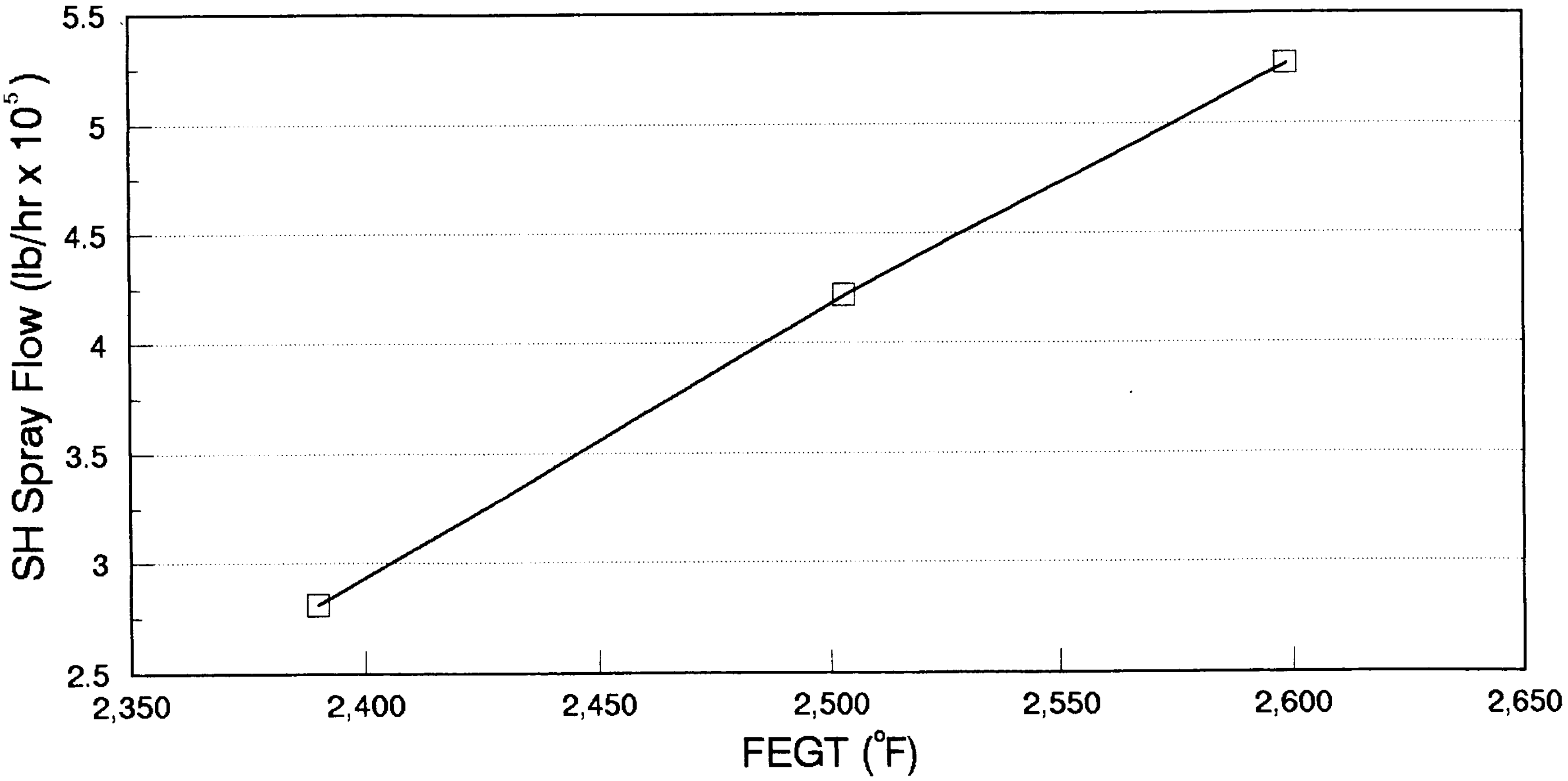
Furnuce Exit Gas Temperature vs. Fuel Flow
75% MCR - 100% Gas Firing



(Excess Air = 10%)

FIGURE 4

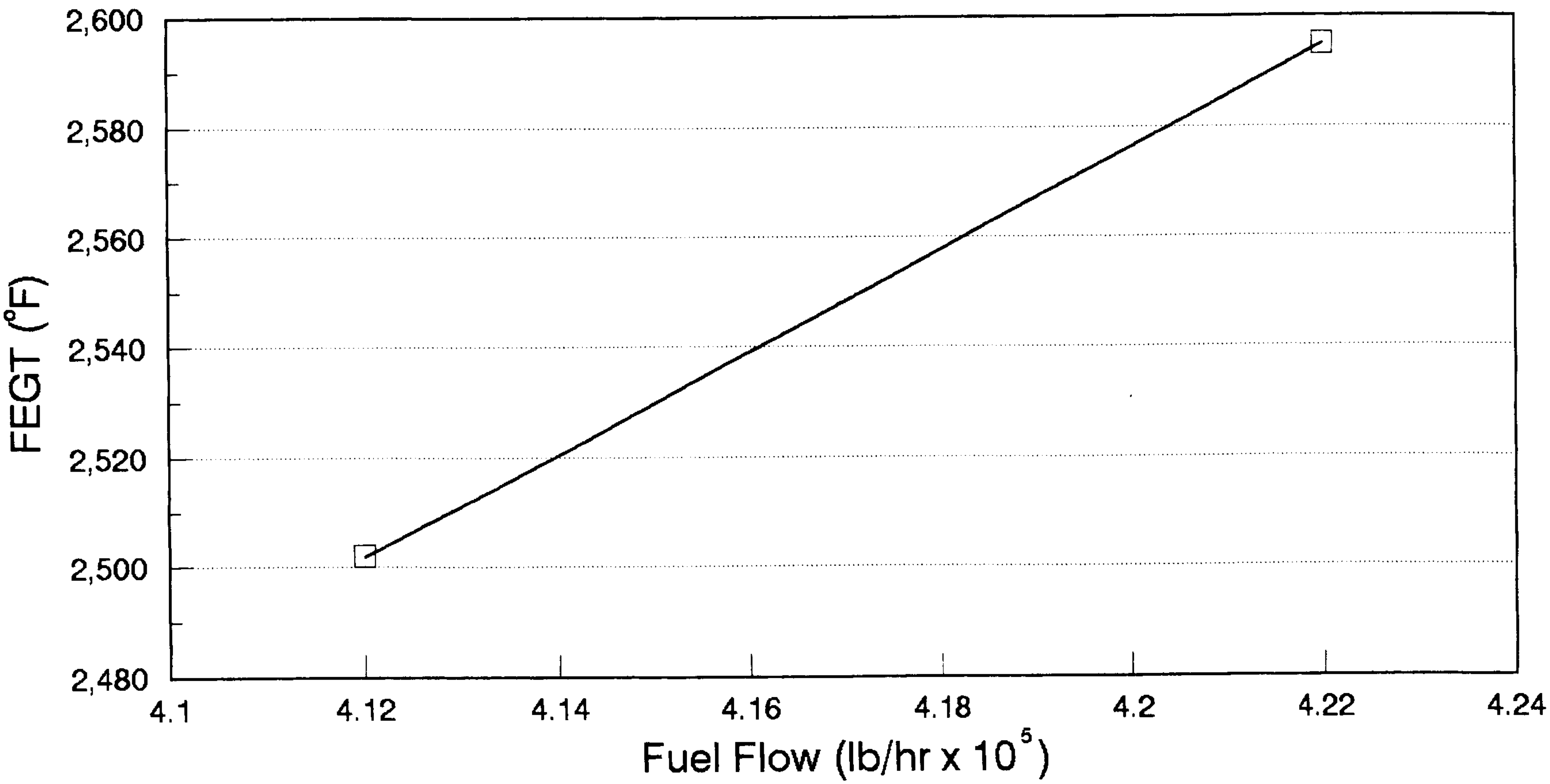
Superheat Spray Flow vs. Furnace Exit Gas Temp
75% MCR - 100% Gas Firing



(Excess Air = 10%)

FIGURE 5

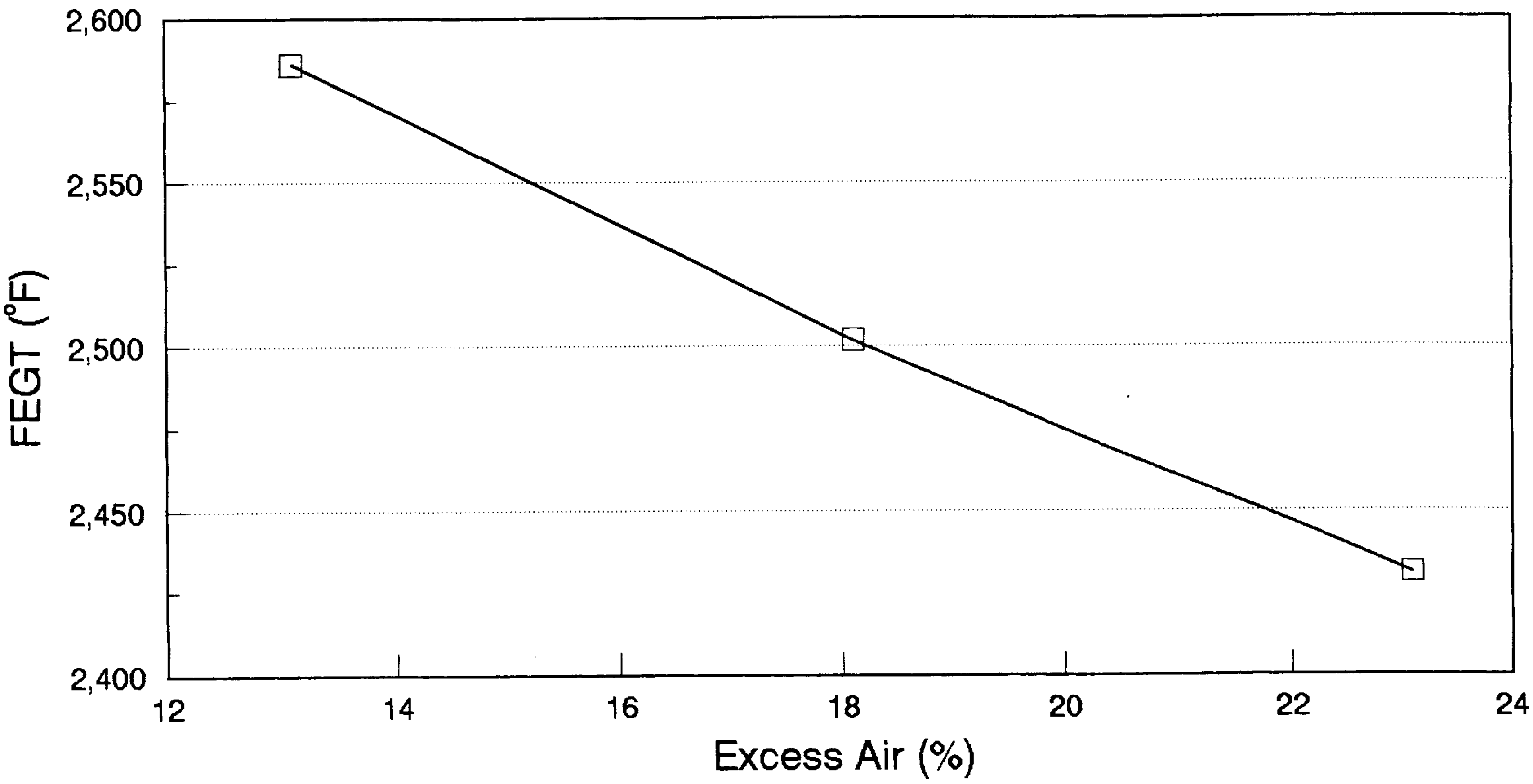
Furnuce Exit Gas Temperature vs. Fuel Flow
100% MCR - 70% Oil - 30% Gas Firing



(Excess Air = 18.1%)

FIGURE 6

Furnace Exit Gas Temperature vs. Excess Air
100% MCR - 70% Oil - 30% Gas Firing



(Fuel Flow = 412,100 lb/hr)