PEPSE APPLICATIONS

FOR

THE POWER PLANT PERFORMANCE

INSTRUMENTATION SYSTEMS PROJECT

EPRI RP 1681/2153

Energy Incorporated
PEPSE User's Group Meeting
November 1-2, 1984
New Orleans, Louisiana

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Abstract

Potomac Electric Power Company was selected host utility for an EPRI sponsored project to develop a "state of the art" performance monitoring demonstration system where advanced measurement devices and sensor instrumentation can be implemented with innovative performance algorithms which are computed on various computer systems.

The PEPSE model was implemented in the early phases of this project and has been used as a tool in realizing the project goals. The initial goals of the PEPSE model were to bench mark the host utility operating heat rate, realize areas for cycle performance improvement and develop requirements for additional instrumentation and algorithms necessary for the projects on-line computer monitoring systems.

The PEPSE model has also been used extensively in cause and effect evaluations of the cycle performance due to changing parameters within the boiler. This task is accomplished by supporting the projects parametric boiler model with field test data and PEPSE generated cycle relationships.

This paper presents the aforementioned technical areas of the EPRI project with emphasis on the PEPSE applications, its benefits and shortcomings.

INTRODUCTION

The PEPSE program has been used to model the turbine cycle at Potomac Electric Power Company's Morgantown Unit 2. This model is used as a tool in the EPRI power plant performance instrumentation system project being hosted at Morgantown.

This project was initiated in response to escalating fuel costs and the resultant increasing attention to thermal performance by the industry and the Regulatory authorities in particular.

The project's overall goal is to develop a "state of the art" performance monitoring demonstration system on a host utility unit where advanced measurement devices and sensor instrumentation can be implemented with innovative performance algorithms which are computed and displayed on distributed, modular, computer systems.

The focus of the program is to provide the means to measure, calculate and display on-line fossil power plant heat rate/performance as necessary to maximize impact on the following:

- Operator controllable parameters
- Thermal performance optimization of the boiler and its auxiliaries.
- Turbine cycle performance optimization
- Incremental heat rate determination for accurate electrical system dispatch and costing of generation.
- Communication optimization between plants and dispatch Control Center.
- Documentation of official utility heat rate and fuel accounting record.
- Indication of maintenance needs and spare part requirements.
- Input to maintenance cost-benefit and scheduling.

This paper will summarize the focal points of this project and show the various uses of the PEPSE program in accomplishing the project task todate.

PROJECT SCOPE

The program detailed by the specific tasks in the Statement of Work is designed to accomplish the following:

- Implement the cycle and boiler related instrumentation that is both necessary and available to measure the parameters required to thoroughly quantify total unit heat rate and component contribution to it.
- Establish a computer based performance system to read-out and utilize the instrumentation installed. The system is building on that currently existing on the host unit. The system emphasizes accuracy, repeatability, and practicality.
- The system design incorporates the peripherals, programs and a structure to accommodate software development (performance algorithm calculations) and testing of both the software and the instrumentation upon which it is based.
- The system is also designed to accommodate anticipated future contract tasks including dynamic analysis for control optimization and heat rate penalty, operator guidance techniques and/or any other performance related power plant study which would require a fully instrumented test bed for its evaluation.
- The boiler portion of the plant is receiving the same rigorous monitoring and analysis as the turbine cycle. In addition, the boiler system is being subjected to an in depth analysis of all the parameters which currently limit unit heat rate including physical, thermodynamic, economic, environmental and industry tradition. The most tangible of these limits will be extended by closer monitoring and thus a clearer understanding of their cause and effect such that lower heat rates can be economically reached and the methods of maintaining them can be established. A major goal is the optimization of fireside parameters such as excess air and exit gas temperature.
- Unit dispatch based on on-line determination of incremental heat rate will be achieved by application of the heat rate characteristics determined by the system. The mechanics of accumulating the proper heat rate data at the plant, communicating it to the control center and the control center implementation method will be the products of this effort.
- On-line determination and use of incremental heat rate for dispatch will be the focal point around which all other plant/control center communication improvement efforts will revolve.
- Tests under controlled conditions designed to provide specific project needs are being conducted as necessary. The primary test and utilization of the system will however result from the continuous operation of the data collection, storage and cal-

culation system and the ongoing review, analysis and improvement of its results by the Potomac Electric Power Company project team and their respective contractor/consultants.

- All software developed during the course of this project will be done in conformance with ANSI FORTRAN 77 standards.

  The developed codes will be on-line process computer subroutines or modules that can be integrated with each other and with standard calling routines and will be complete with full instructions on how to handle input and output. Every reasonable attempt will be made to make the software as transportable as possible.

PROJECT TEAM

In early 1982 several utilities responded to EPRI's request for proposal. In July of 1982, Potomac Electric Power Company was selected as the host utility and project manager. Initial contract work began in October of 1982 and the current contract runs through March of 1986.

The project team consists of the Potomac Electric Power Company personnel drawn from their Central Diagnostic Team, their Process Computer Section, the Morgantown Station Performance Engineers and the Dispatch Control Center engineering staff.

The primary subcontractors to Potomac Electric Power Company on the project are: Power Technologies, Incorporated in Schenectady, New York, relating to turbine cycle analysis, software development, instrumentation selection, data acquisition system development and dispatch system studies; and Lehigh University in Bethlehem, Pennsylvania relative to boiler optimization.

Combustion Engineering in Windsor, Connecticut will be a critical source of boiler design and modeling information and consultant to the project relative to fireside and heat transfer analysis.

General Electric Company's Turbine Performance Engineering Department is providing a critical review of turbine cycle test instrumentation, methods and procedures as well as turbine design information.

Many other organizations are supplying equipment and services over the life of the project.

HOST UNIT DESCRIPTION

The host unit, Morgantown No. 2, is a coal fired, supercritical pressure (3500 PSIG, 1000°/1000°F) Combustion Engineering boiler, with a tandem compound General Electric turbine rated at 575MW. The design includes a Ljungstrom air heater and an electrostatic precipitator. The unit uses eastern bituminous coals with approximately 6 percent moisture, 14 percent ash and 2 percent sulfur and a heating value of about 12,000 BTU/pound as fired. The plant receives shipments of a large number of coals, some of which are burned separately and others as mixtures. The plant site is on U.S. Route 301 at the Potomac River in Charles County, Maryland approximately 50 miles south of Washington, D.C.

The plant consists of two very similar units which were placed in service in 1970 and 1971 respectively. Original design included a process monitoring computer with a full set of performance calculations and associated instrumentation. The system accuracy level is above that of normal plant instruments but less than ASME acceptance level. This existing system is being expanded and upgraded to the current "state of the art" practice.

The project goals dealing with incremental dispatch and plant/control center communication will be implemented at the Potomac Electric Power Company Dispatch Control Center located northwest of Washington, D. C. near Rockville, Maryland.

The Control Center consists of two Xerox Data Systems Sigma IX computers with expanded active memory and data acquisition and control equipment housed in a specially designed building with full environmental and electrical power conditioning. The Control Center was placed in service in 1976. The automatic generation control system was separately designed and implemented on the Control Center computers by Rockwell International, the original system vendor. It was placed in service in 1983. The generation control system accepts economic and regulation signals from the Pennsylvania-New Jersey-Maryland Interconnection (PJM) and develops individual generating unit desired generation target values which are digitally transmitted to the generating stations. Individual unit target values are constrained by limit values telemetered from the generating stations.

INITIAL PROJECT RESULTS

Boiler Program - Exercise of a parametric model developed to characterize the boiler system has indicated the relationships between the various system parameters and includes a furnace model by the boiler manufacturer. Field tests are being conducted to verify the model. Initial analysis and field test indicate a close coupling between excess air, unburned carbon and grind size of the pulverized coal. These results are influencing project emphasis.

Incremental Heat Rate - Modeling of the PEPCO dispatch system has characterized the sensitivity of production cost to performance measurement accuracy and provides the project with guidance as to how accurately performance must be measured. Random errors in the measurement of performance have a significant impact on system operating cost at levels above two percent of rated input. Performance measurement bias has a significant impact on system operating cost at levels above one percent of rated input. The model also indicates the penalty imposed by the convexity requirement for positive sloping incremental curve shape which introduces a significant modeling error into the input/output curve. This in turn results in errors in dispatch, increases in production costs, and justifies research on alternative dispatch algorithms.

Turbine cycle and Instrumentation - Initial effort in this area has concentrated on specification and procurement of the instrumentation, data acquisition and computational equipment to complete the demsonstration facility including data storage, retrieval and display capability. Systems received todate include: watthour metering, turbine exhaust pressure tap sequencing, turbine pressure ratio transmitter, turbine N2 packing flow metering, stack oxygen, duct velocity, air and flue gas humidity and flue gas sulfur trioxide.

Computational system development has included implementation of packaged systems for: Fortran 77, statistics, graphics, cycle analysis and data base management. Project software development has included data storage and retrieval and standardization of existing performance calculations.

Baseline tests of the unit have been conducted and analyzed to provide initial baseline condition for monitoring throughout the project life and to indicate areas of instrumentation need.

DEVELOPMENT OF THE MORGANTOWN MODEL

The Morgantown Unit has been modeled using the PEPSe program. The model was developed using the performance mode of the program on the project's Prime 750 computer. This model is intended to provide turbine operating heat rates from a data base developed from the plant Honeywell computer monitoring system.

The model was built and tested prior to inserting operating data. The test were made by shutting off all non heat balance extractions and inserting design data from heat balances and comparing unit heat rates and outputs. The plant heat balance and models are shown in Figure No. 1 and Figure No. 2 through 5.

The model has a few special features that were incorporated during the testing program. The first of these can be seen in Figure No. 4 which shows the open heater No. 4 (Component No. 406). To account for changes in levels of this heater an infinite sink (No. 553) and an infinite source (No. 552) were used. These two components are used to adjust the flow balance resulting from heater level changes. Similar components are used in the condenser hotwell and other open heaters.

Testing revealed that several stage extractions had unusally high temperatures. This is represented in Figure No. 6 and is due to the location of the extraction ports within the shell. Testing by General Electric has shown the stage extraction conditions may not reveal the true average shell enthalpy. The blade vs. temperature profile shown in Figure No. 7 explains this phenomenon. To compensate for this problem a stage bypass was modeled and enthalpies were adjusted to compensate for stage leakages by calculating a bypass flow as shown in Figure No. 8.

TURBINE CYCLE HEAT RATE TEST

The unit was tested over its normal operating range with specific attention to valve crack points. The cycle was isolated except where extraction flows were being measured. The data was being scanned by the Honeywell data acquisition system and dumped to the Prime 750 for analysis on the PEPSE program as shown in Figure No. 9.

CYCLE PERFORMANCE EVALUATION

The test data now on the Prime 750 was averaged and built into a standard data base. This data base was then read into the PEPSE program input code format for evaluation by the model. (See Figure No. 9) The model was run for the test cases and then compared with design condition cases to determine the restorable heat rate losses in the cycle.

The restoration of components to design condition while running in the performance mode provides a means for providing true restored heat rate for each component. These results were used in economic cost studies for developing cost/benefits of performing unit maintenance.

A comparison of restorable heat rates combined with pressure and flow plots shown in Figure No. 10 and 11 can identify long lead time parts necessary for the next major overhaul. This will require either a good set of design data, or ideally a bench mark test such as a start-up ASME acceptance test.

The project bench mark test has identified the unit heat rate and established several areas of maintenance requirements for the next unit overhaul. Future testing will identify pre-overhaul condition and post overhaul conditions. After the overhaul it is intended that the EPRI project will be trending critical unit condition on-line to develop an understnading of rates of deterioration and component losses. Much of the critical instrumentation additions needed for this phase of the project has been identified as a result of the base line testing.

INCREMENTAL HEAT RATE

The development of incremental heat rate curves for dispatching and pricing has been accomplished on the project by on-line testing using the PEPSE model for cycle balancing. Heat rate by input-output methods yields a great deal of scatter and inaccuracies due to fuel measurement errors. To compensate for this problem the turbine cycle heat rate was developed by PEPSE modeling and modified by boiler heat loss calculations. (Figure No. 12)

The heat rates are then corrected to expected normal operating conditions over the load range and modified for seasonal changes. These heat rates are then developed into I/O curves and then to incremental dispatch functions for use by the PEPCO dispatch control center as shown in Figure No. 13.

The EPRI project is addressing several areas for review relative to dispatching. These areas are as follows:

1. The benefits, sensitivity and instrumentation required to develop on-line modifiers to the unit dispatch curve.
2. The penalty involved in positive sloping incremental curve shape imposed by the existing dispatch system. Many units do not have this curve shape as a result of valve loops.
3. Economic benefits in dispatching units with respect to turbine valve points and instrumentaion requirements to monitor on-line valve positions.

BOILER PARAMETRIC MODELS

The boiler phase of the project is intended to identify the instrumentation necessary to monitor on-line performance as well as the variables and algorithms necessary to optimize boiler efficiency.

This is being accomplished by integration of the Combustion Engineering furnace model with the parametric model developed by Lehigh University. (Figure No. 13A) The parametric model identifies the various correlation of the boiler with auxiliary equipment and the turbine cycle.

The relationships to the turbine cycle were accomplished using operating test data and functional relationships developed by the PEPSE program. The relationship of unit heat rate reheat temperature and final feedwater temperature was developed using the model (Figure No. 15). The final feedwater temperature is related to the turbine reheat bowl pressure and flow and thus varies as the spray flow is varied. This correlation was fed to the CE model in developing realistic operating conditions. Algorithms were developed to relate reheat temperatures to final feedwater temperatures and main steam to reheat steam flow rates based on the model test results described early.

Figure No. 15 shows the basic results of boiler excess air and coal fineness on unit heat rate. This indicates a possible improvement of 100 BTU/KWH on heat rate. This information will be correlated to tube wastage rates and coal mill maintenance.

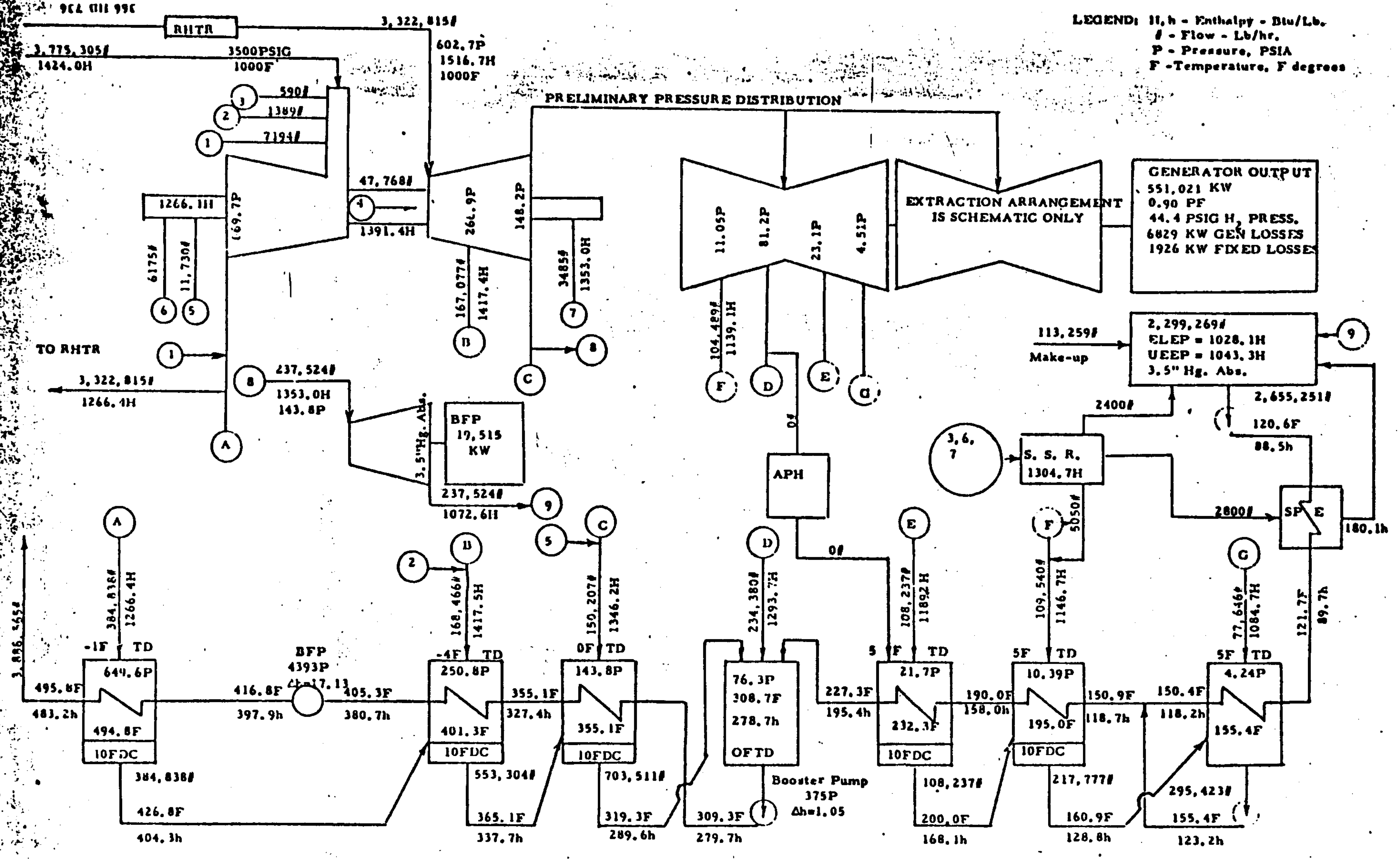
Major emphasis of the project at present is testing of the boiler to prove the parametric model and locate on-line instrumentation for continuous monitoring.

This information will be integrated with the tube wastage program, the extensive air heater studies and various other programs to understand the boiler physics and ultimately to optimize boiler performance.

CONCLUSION

The various phases of the EPRI project are being investigated at PEPCO. Tools such as the PEPSE program will help to answer many of the questions involved in the realization of the project goals.

It is the goals of the EPRI program to provide the plant performance staff with the necessary tools to develop an economically feasible performance monitoring and heat rate improvement program.



VALVE BEST POINT
NET HEAT RATE

$$= \frac{3,775,305\ (1424.0 - 483.2) + 3,322,815\ (1516.7 - 1266.4)}{551,021 - 1259} = 7973\ \text{BTU/KW-HR}$$

551,021 KW @ 3.5" Hg. Abs. 3%MU
WITHOUT AIR PREHEATING
TC4F - 33.5" LSB   3600 RPM
3500 PSIG   1000/1000F
GEN: 695,000KVA @ 60 PSIG H_2 PRESS. & 0.90 PF (LIQ)

GENERAL ELECTRIC COMPANY, SCHENECTADY, NEW YORK

V M Dolin

562
366 HB 736   1/16/67

FIG NO 1 - HEAT BALANCE

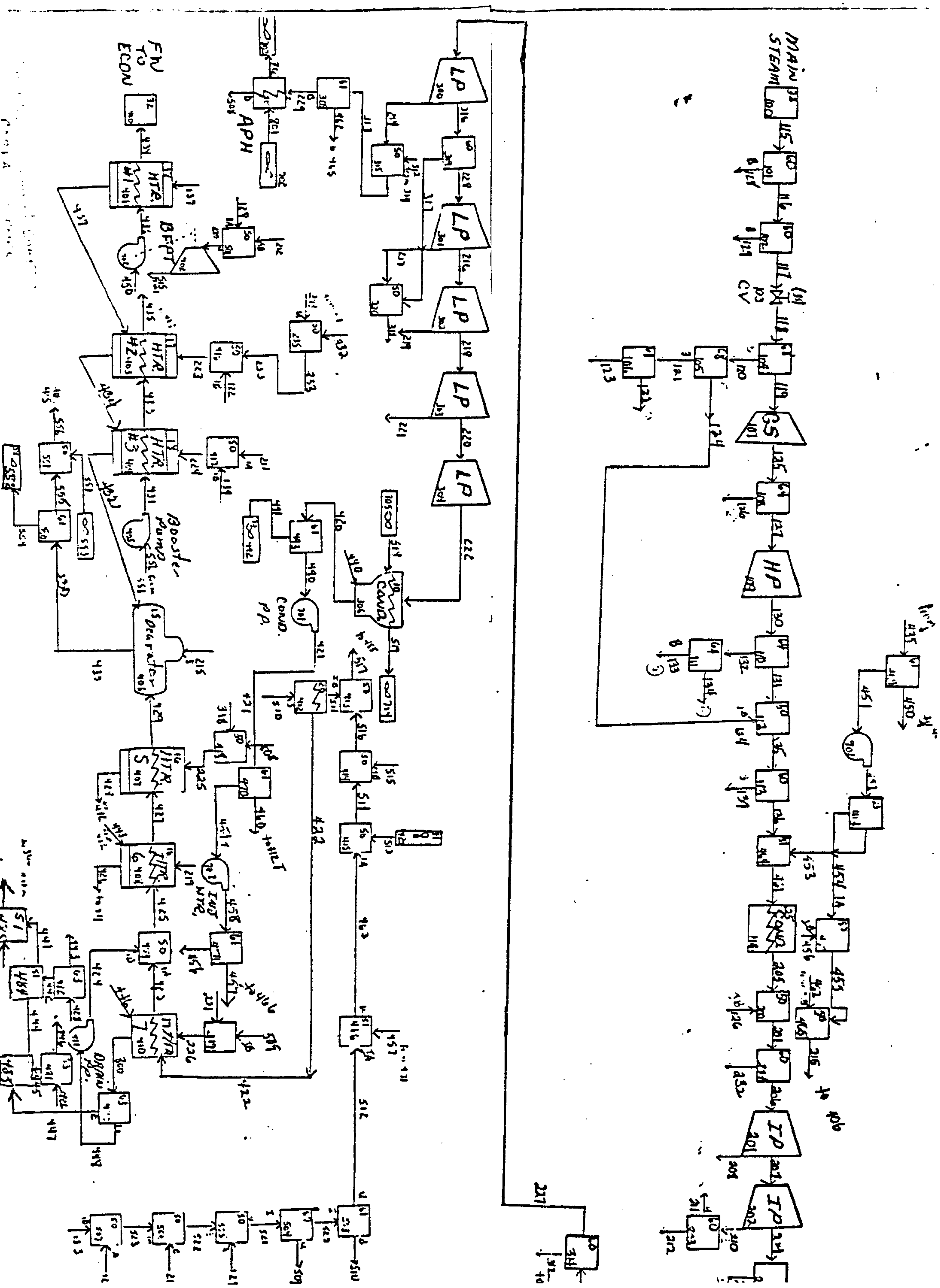
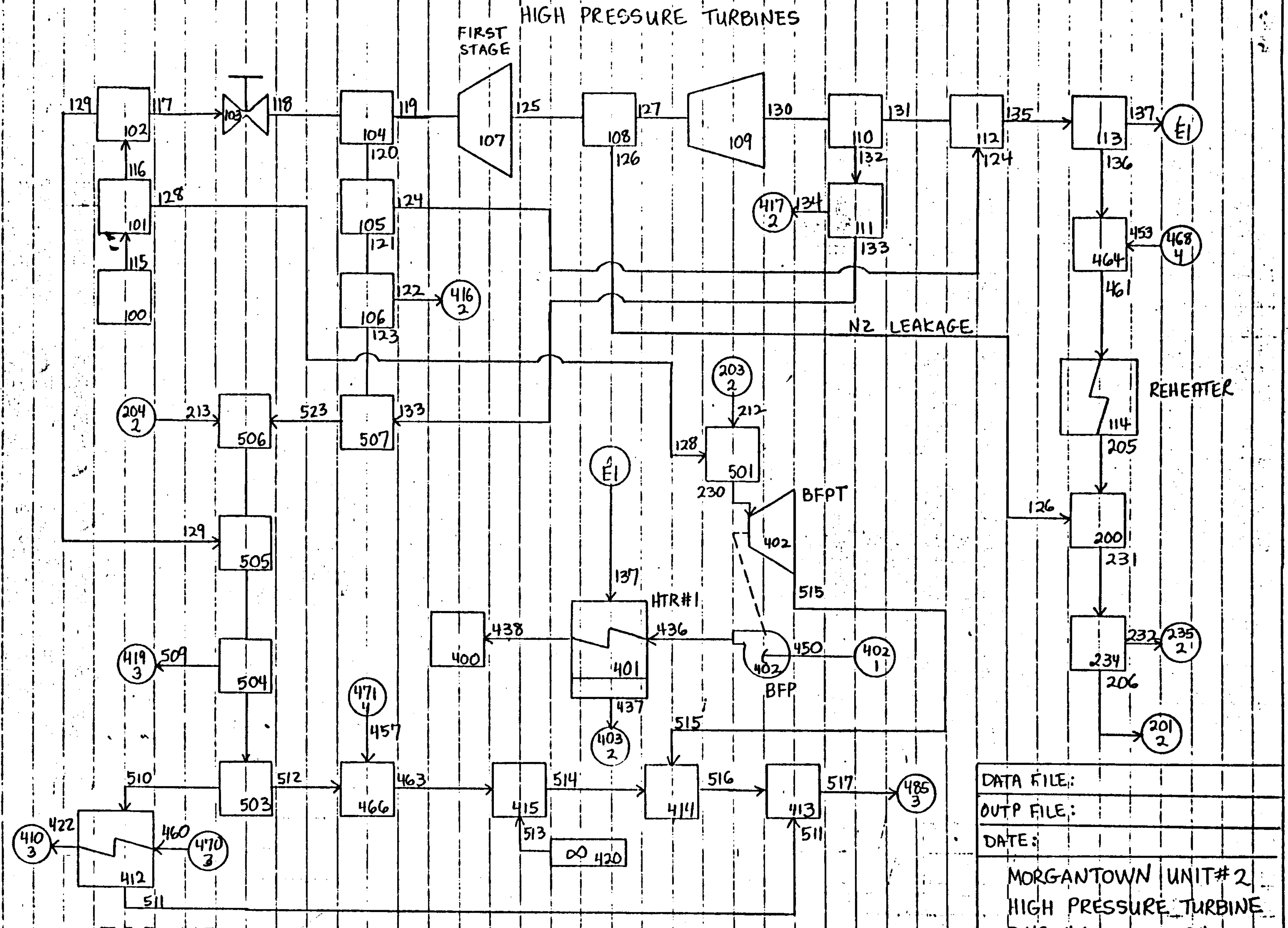


FIG NO 2 - PEPSE MODEL



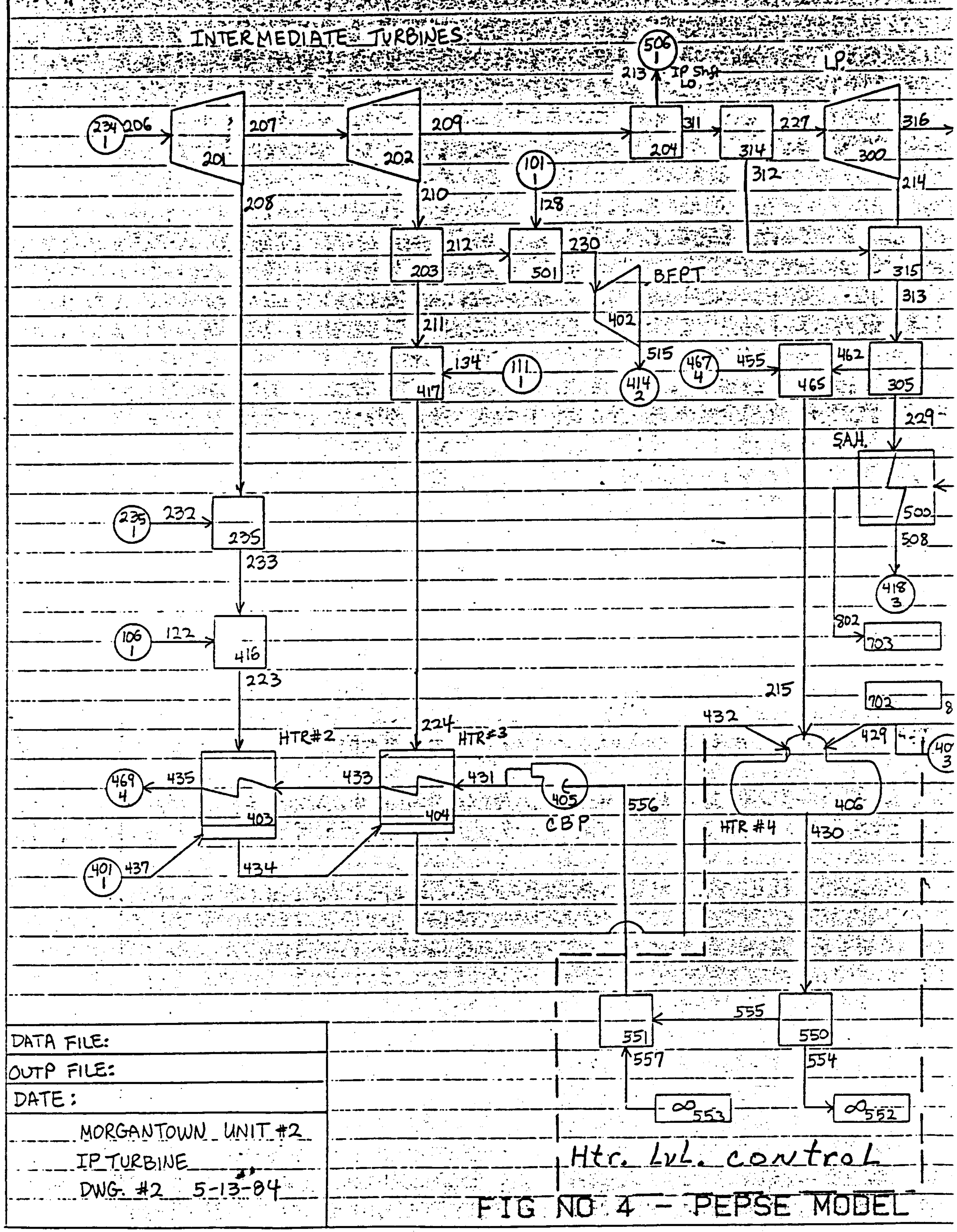
DATA FILE:

OUTP FILE:

DATE:

MORGANTOWN UNIT#2
HIGH PRESSURE TURBINE
DWG. #1 5-14-84

FIG NO 3 - PEPSE MODEL



DATA FILE:

OUTP FILE:

DATE:

MORGANTOWN UNIT #2

IP TURBINE

DWG. #2 5-13-84

FIG NO 4 - PEPSE MODEL

MORGANTOWN UNIT #2
LP TURBINE
DWG # 3 5-13-84
DATA FILE:
OUTP FILE:
DATE:

L P TURBINES

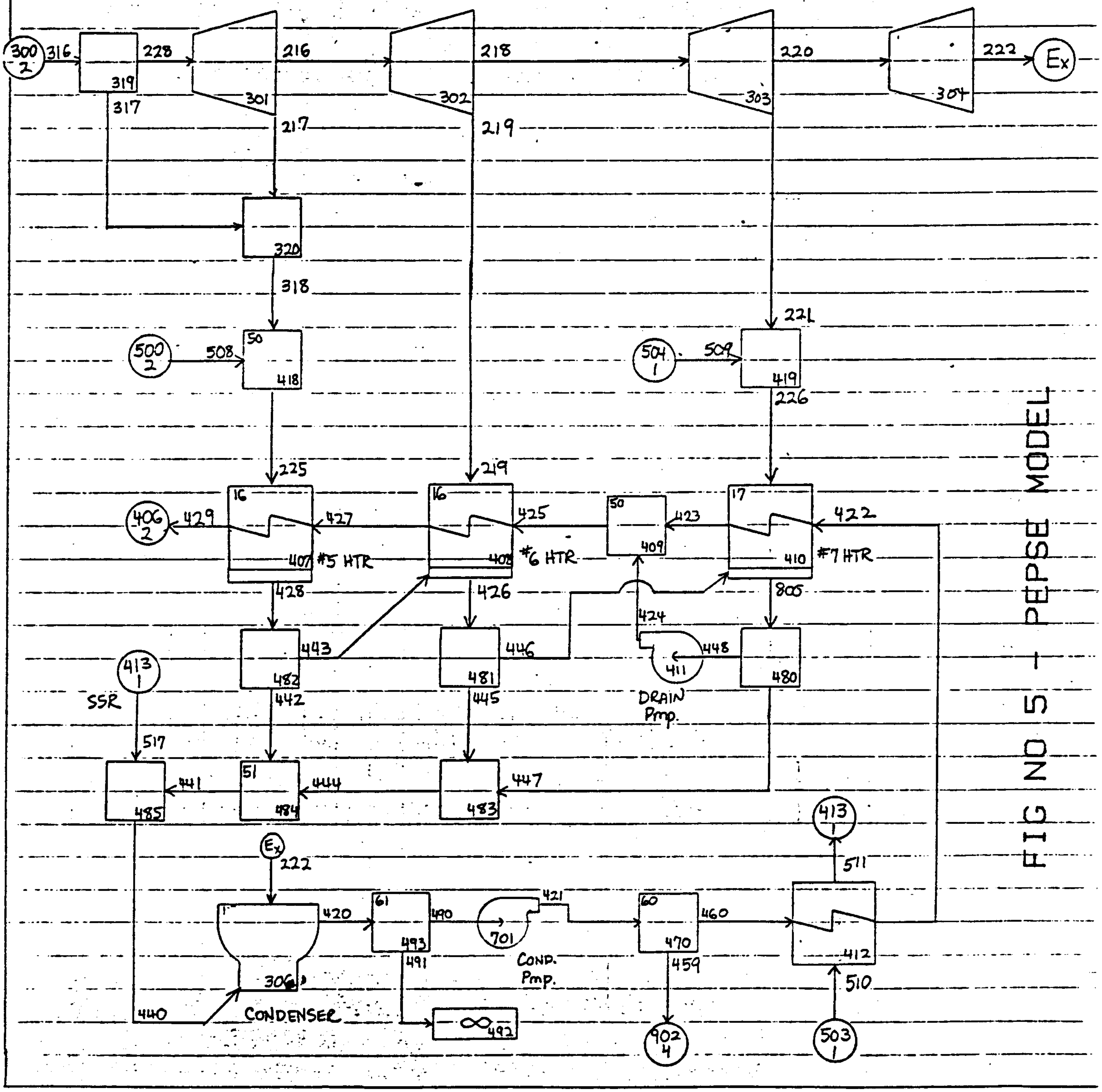


FIG NO 5 — PEPSE MODEL

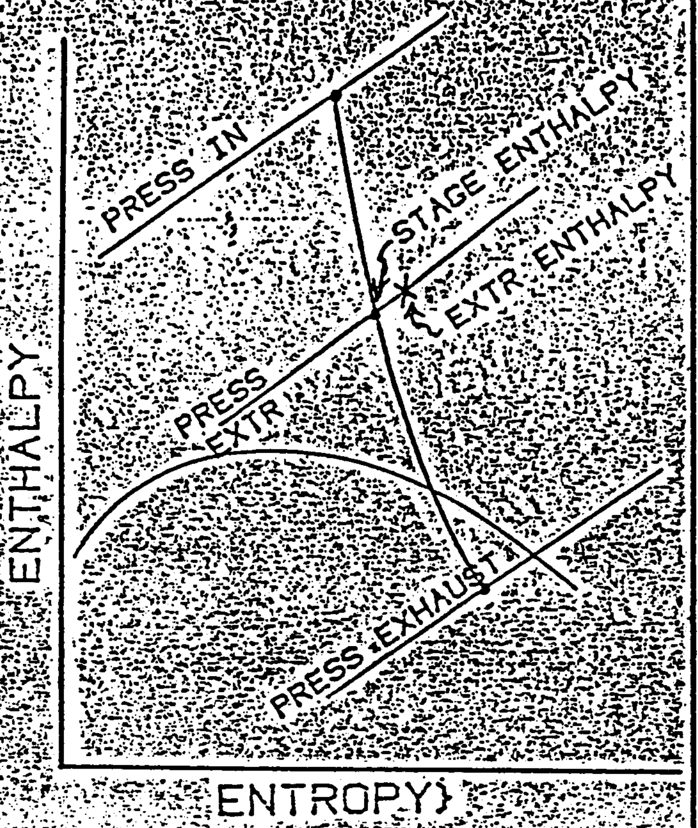


FIG. 6 MOLLIER PLOT

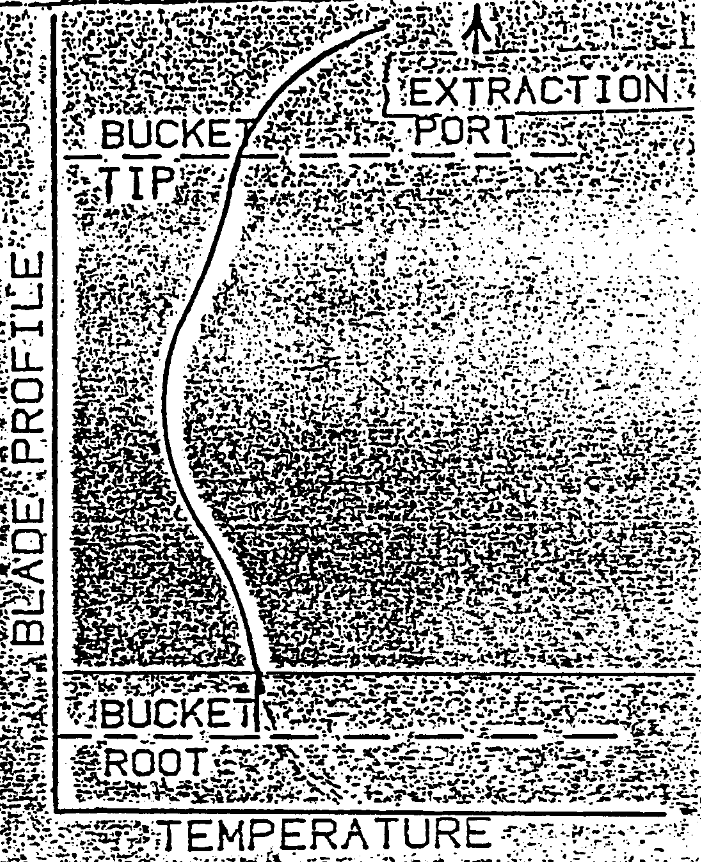


FIG. 7
BLADE PROFILE

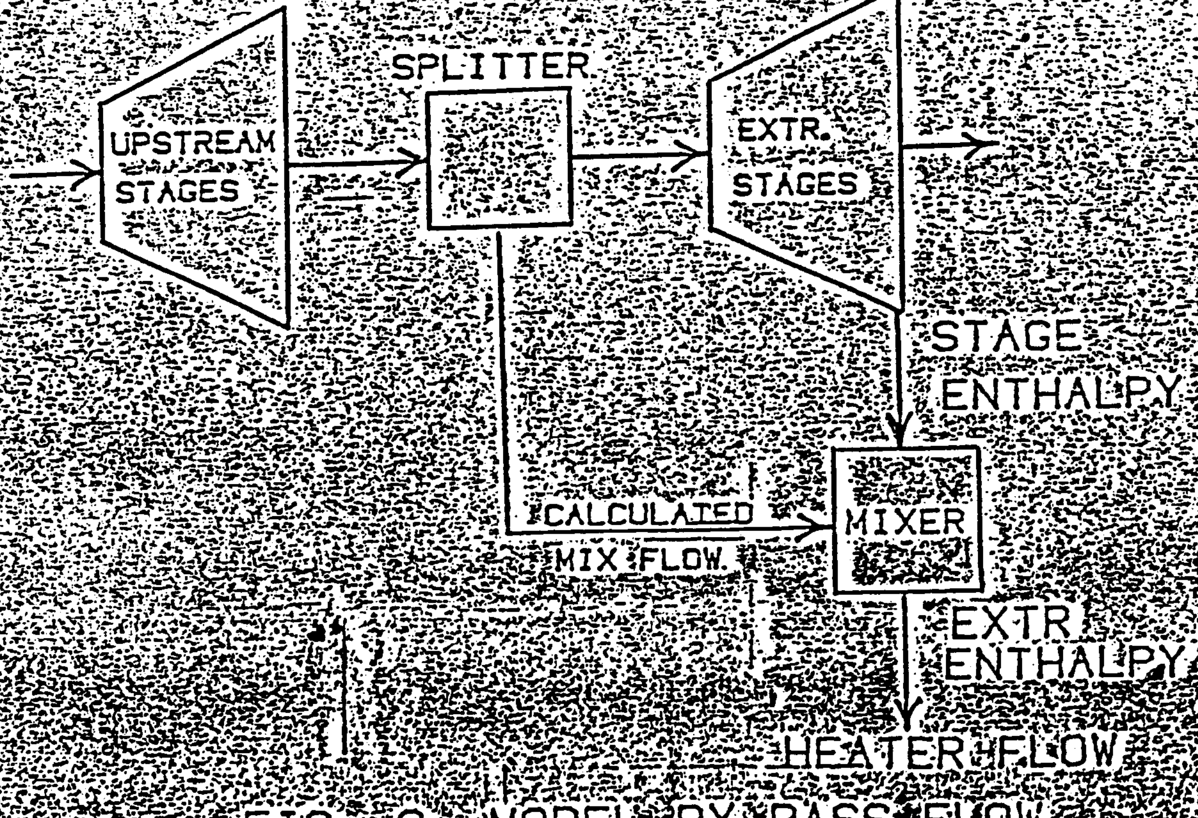


FIG. 8 MODEL BY PASS FLOW

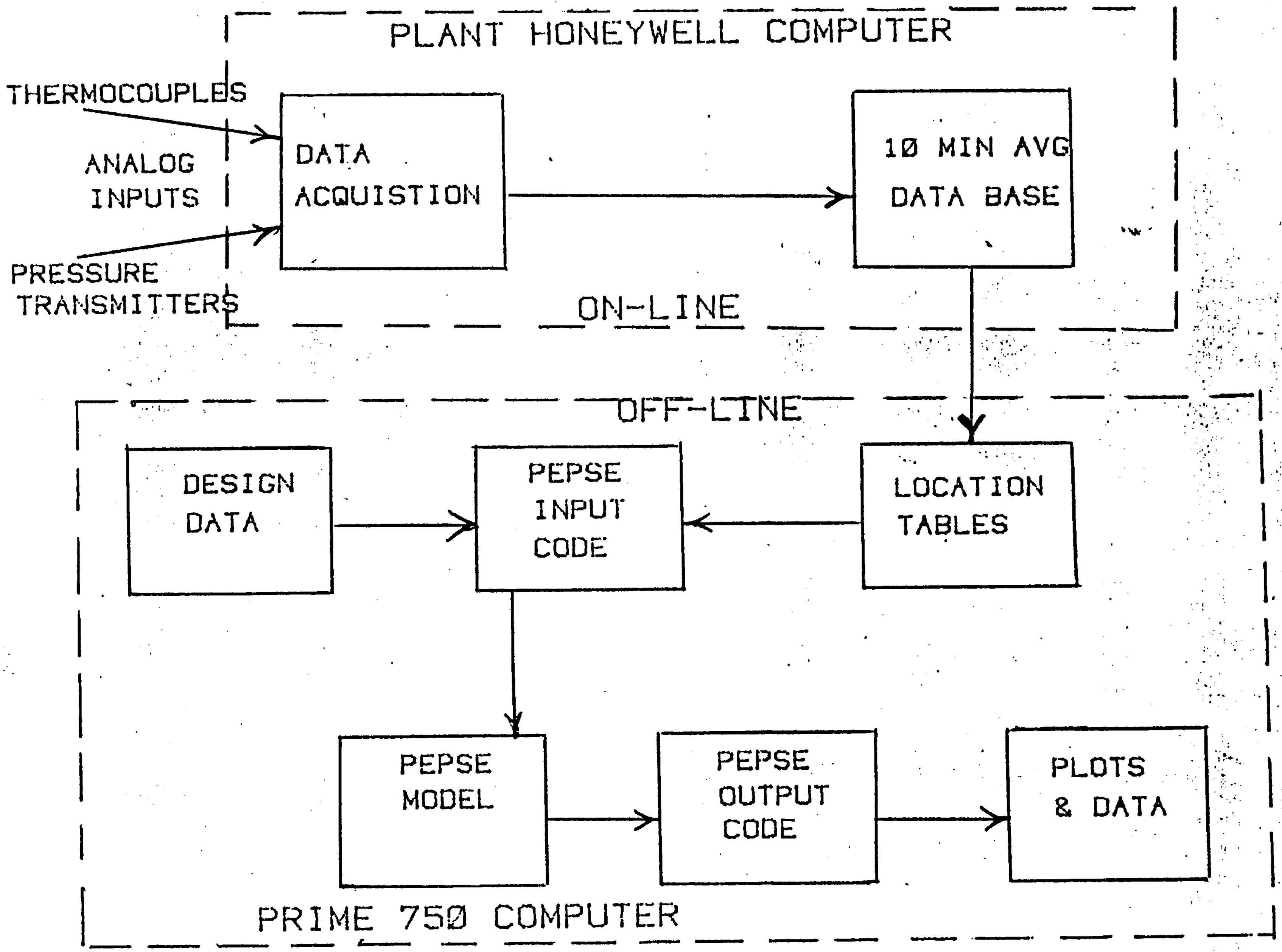


FIG. 9 TEST DATA FLOW CHART

RECOVERABLE HEAT RATE & MEGAWATTS

1st INTERMEDIATE TURBINE EFFICIENCY

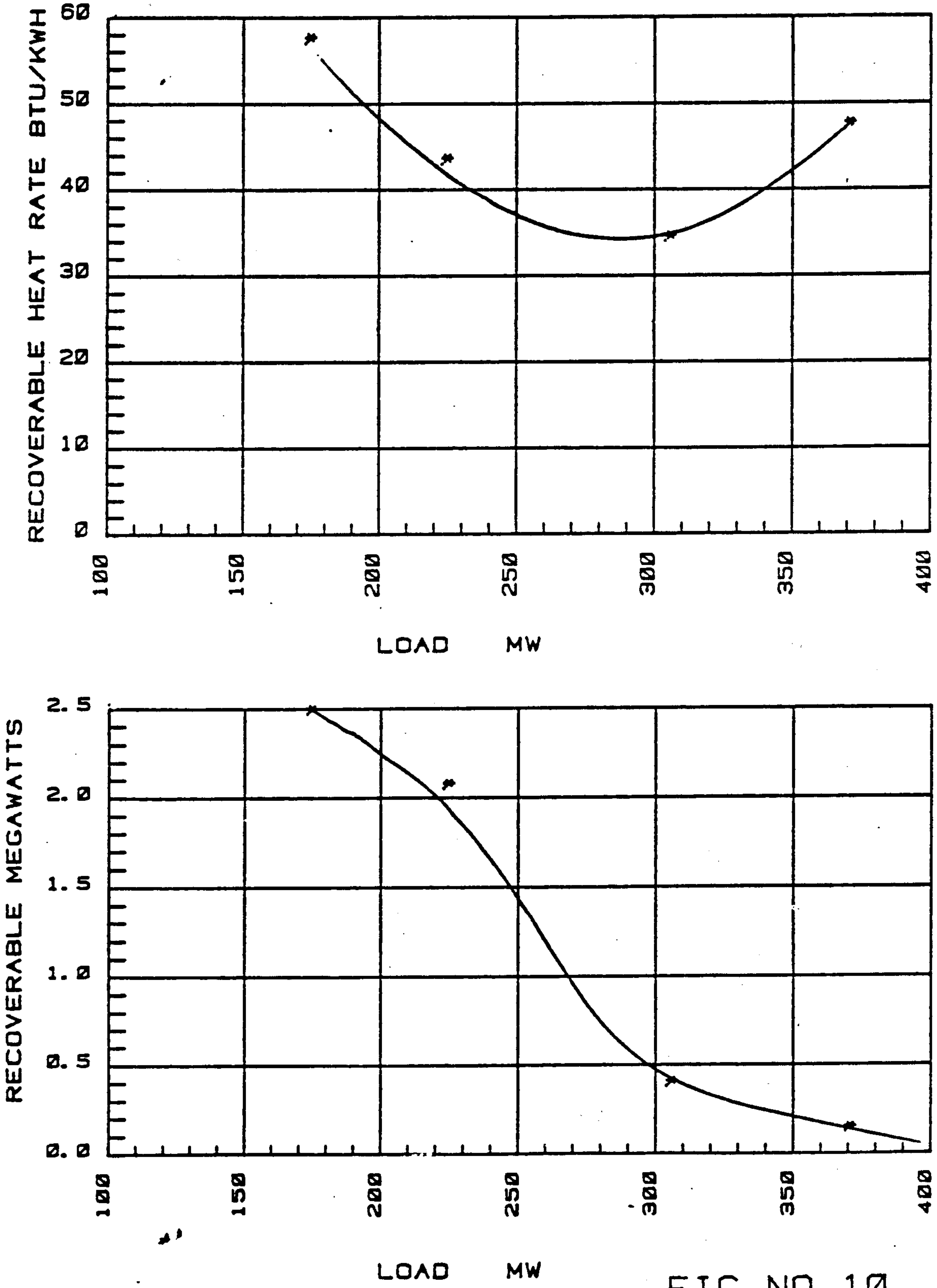


FIG NO 10

PRI. 2nd REHEAT BOWL FLOW VS. Q/√(P/V) & PRESS.

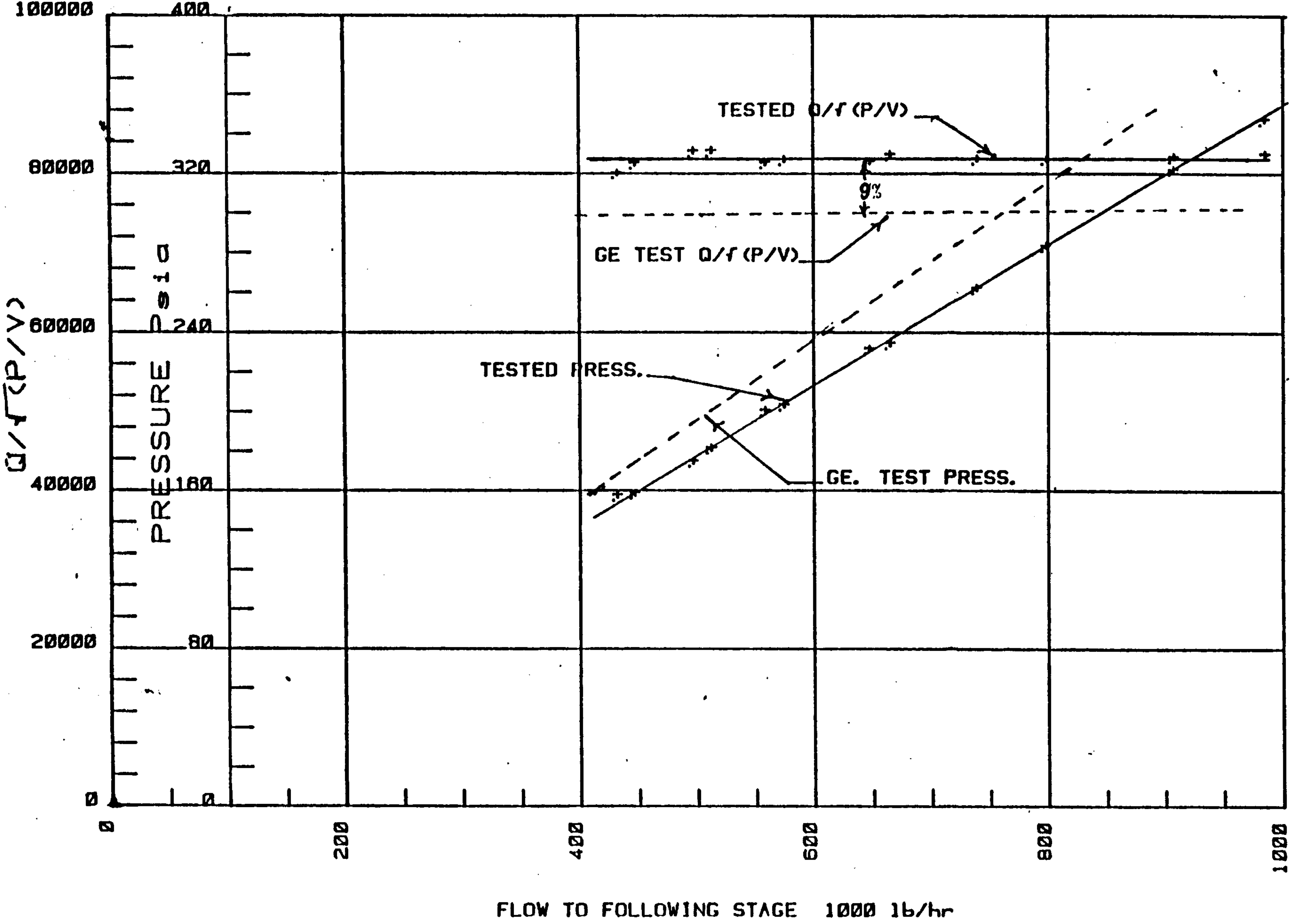
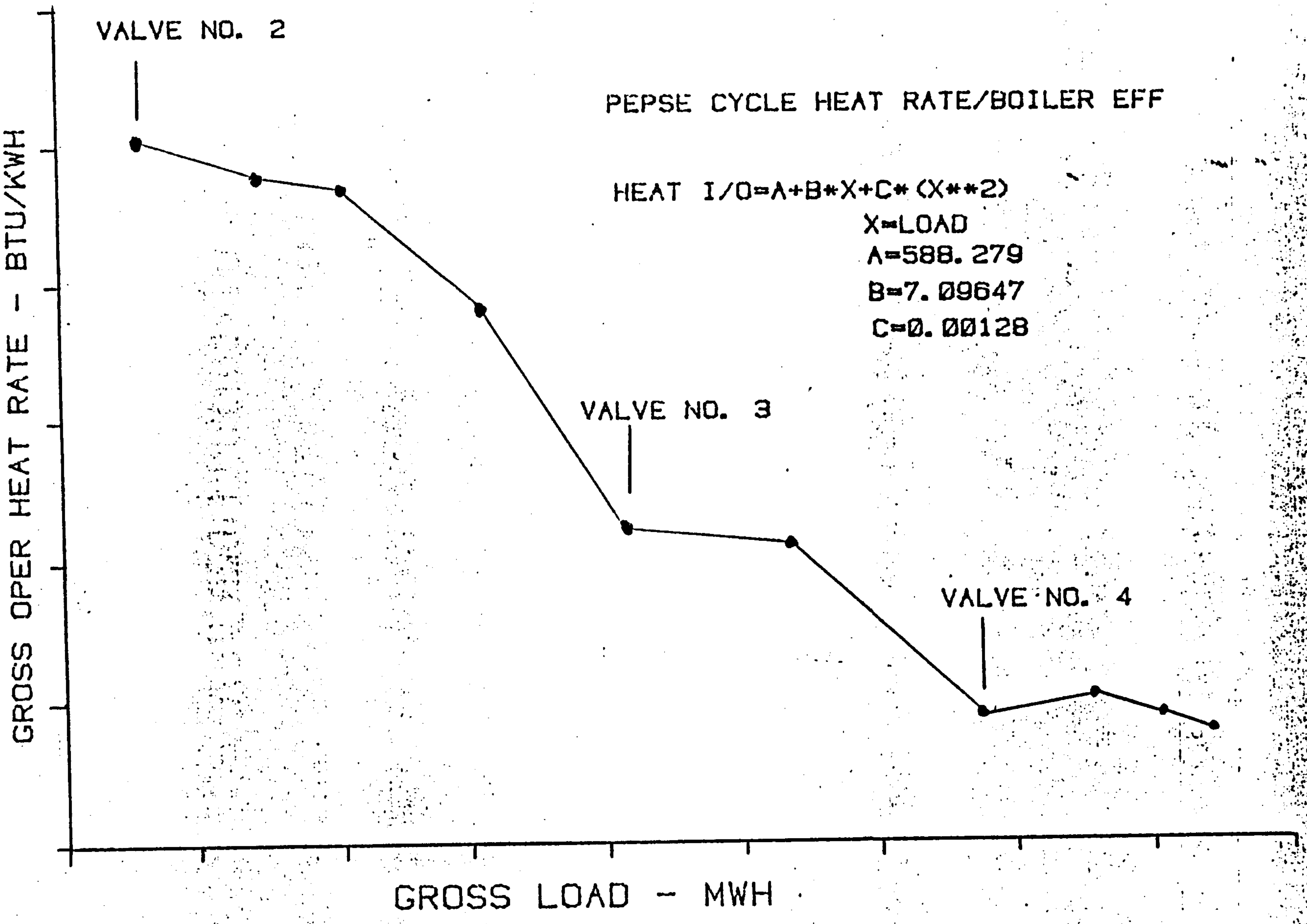


FIG NO 11

FIG. NO. 12

MORG NO. 2 TESTED HEAT RATE

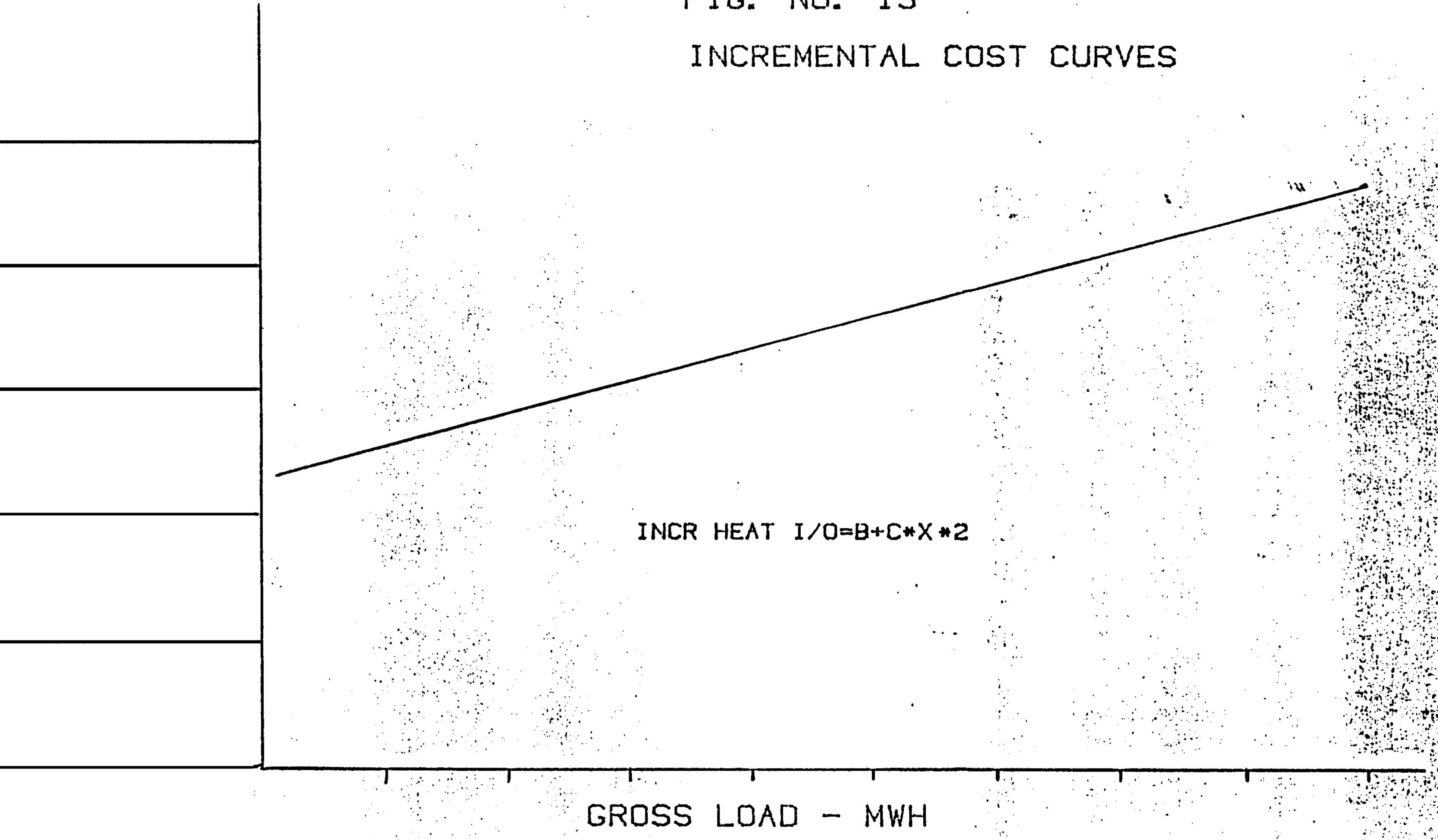


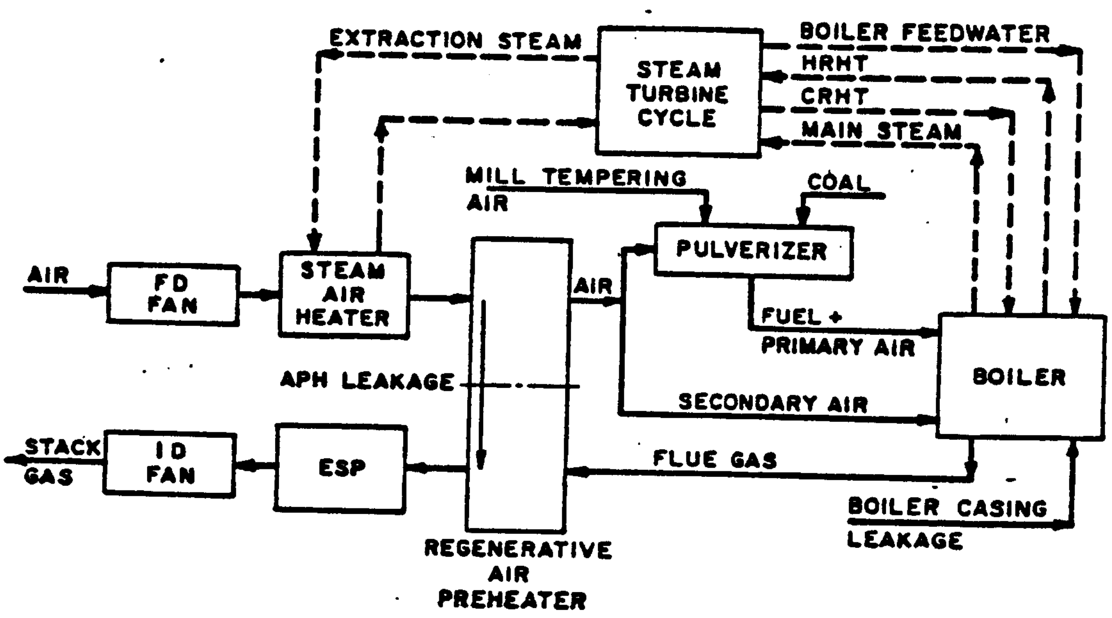
PEPSE CYCLE HEAT RATE/BOILER EFF

HEAT I/O=A+B*X+C*(X**2)
X=LOAD
A=588.279
B=7.09647
C=0.00128

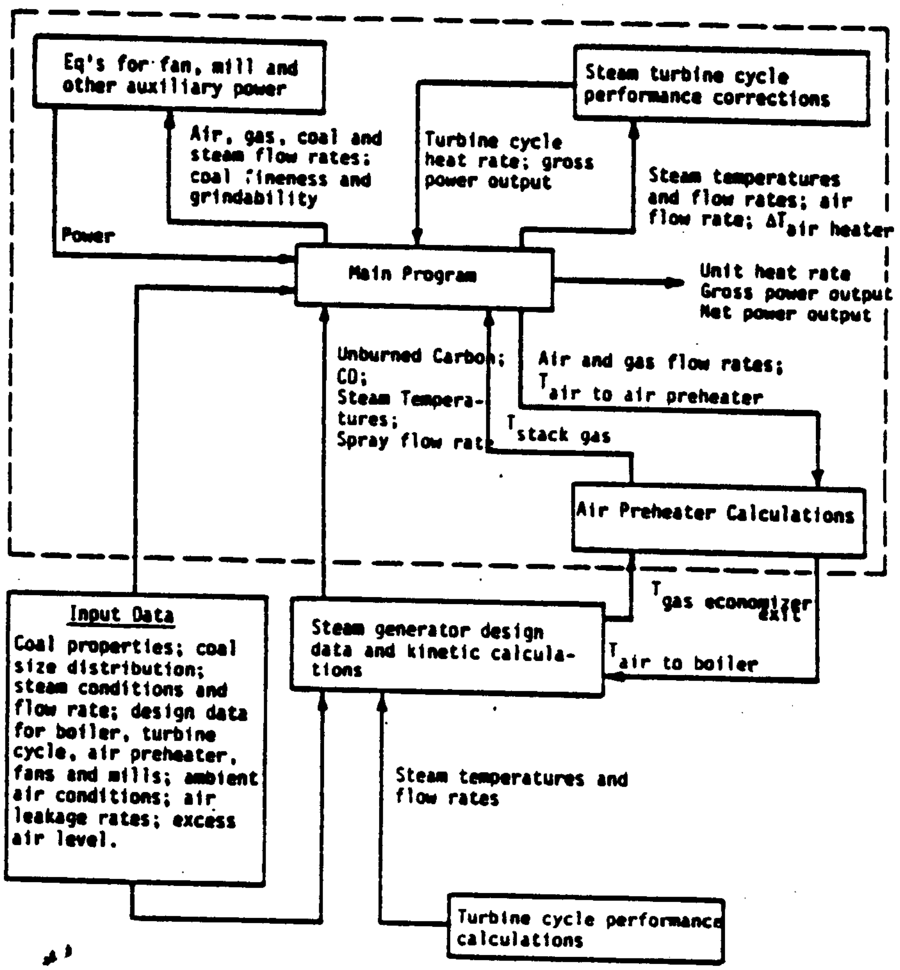
FIG. NO. 13

INCREMENTAL COST CURVES



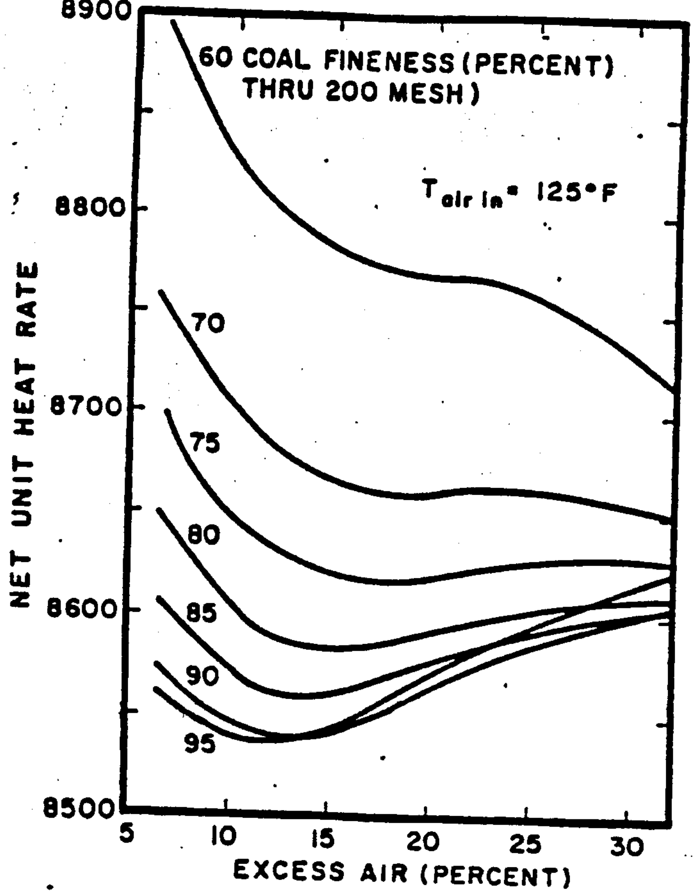


Sketch of Power Plant Modelled by Parametric Analysis

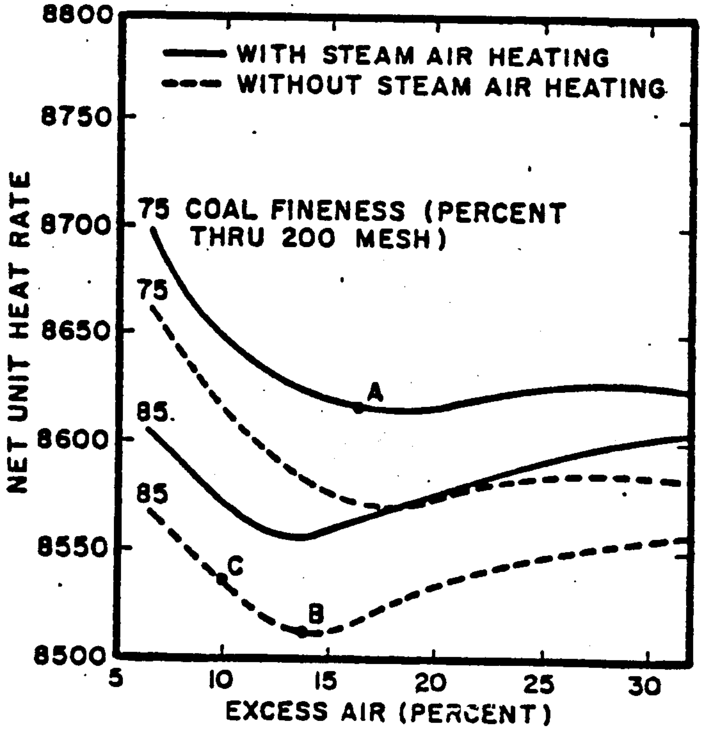


Structure of Parametric Analysis Computer Program

FIG 13A



Computed Variations of Net Unit Heat Rate with Excess Air - Illinois #6 Coal



Computed Variations of Unit Heat Rate with Excess Air and Exit Gas Temperature - Illinois #6 Coal

FIG NO 14

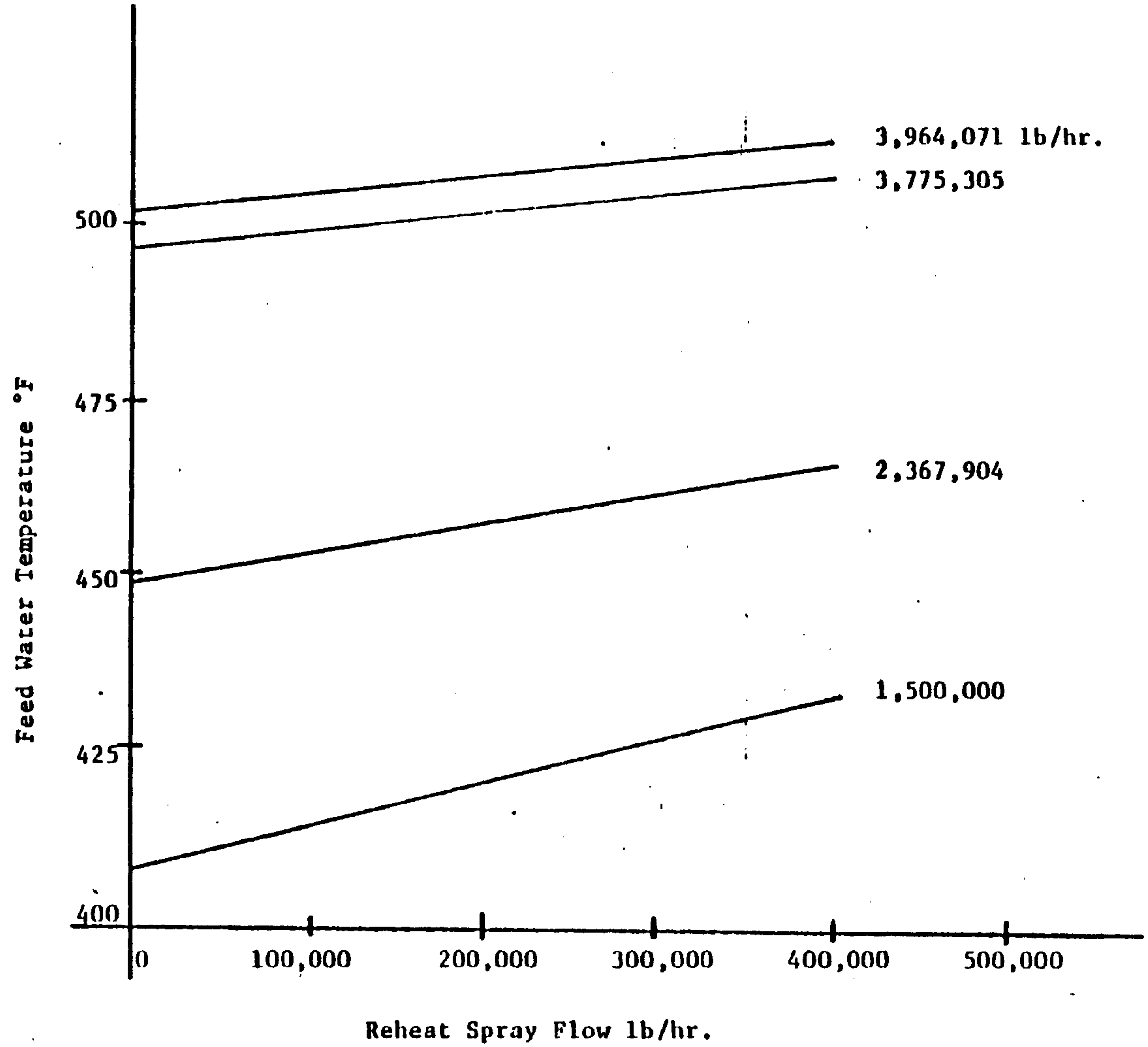

3,964,071 lb/hr.
3,775,305
2,367,904
1,500,000
500
475
450
425
400
Feed Water Temperature °F
0
100,000
200,000
300,000
400,000
500,000
Reheat Spray Flow lb/hr.

FIG NO 15