Operating Experience on Residual Fuel Oil with A W251 Combustion Turbine

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This paper describes the actual operating experience of a current technology combustion turbine, burning residual fuel, operating under actual utility conditions. The objective of the program was to demonstrate that combustion turbines utilizing air-cooled blades and vanes were capable of performing in an economical, reliable and satisfactory manner to meet the demands of a utility company in normal daily cyclical duty. Included in the program was an evaluation of a fuel treatment plant with associated fuel-handling requirements, resistance to corrosion of numerous blade and vane alloys both with and without protective coatings, plus optimization of a turbine cleaning system to remove turbine blade path deposition.


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OBJECTIVES

This paper describes the actual operating experience of a current technology combustion turbine burning residual fuel operating under actual utility conditions. The objective of the program was to demonstrate that combustion turbines utilizing air-cooled blades and vanes were capable of performing in an economical, reliable, and satisfactory manner to meet the demands of a utility company in normal daily cyclical duty. Included in the program was an evaluation of a fuel treatment plant for the removal of sodium and an additive system for the inhibition of vanadium plus the associated fuel handling requirements involved in the use of a residual oil.

The conclusions at the time of preparing the paper were entirely satisfactory and additional data to be presented at the ASME Conference is expected to fully confirm these initial conclusions.

BACKGROUND

For many years, there has been published data concerning the corrosion experience obtained using heavy fuel oils both from laboratory testing and field installations. In virtually all of the field installations, this experience has been confined to earlier vintage combustion turbines in which the turbine inlet temperatures were modest by comparison to those being manufactured today (1).

The changing world situation in the supply of fuel oils available for power generation has re-emphasized the need to be able to successfully operate combustion turbines with whatever grade of fuel oil that may be available at any particular location or time. Primary concern shown in the existing literature has been with the corrosive effects on the blade path components when operating on heavy fuel, whereas the subject of this paper also includes the practical operation of a turbine generating plant. This, thus, covers items such as fuel treatment, fuel handling, reliability, and availability, power fall-off due to deposits, effectiveness of turbine cleaning, as well as the evaluation of various materials and coatings from a corrosion sensitivity point of view.

The program developed for this investigation was jointly participated in by the utility, E.B.E.S. – Mol in Belgium, A.C.E.C, the supplier of the generating plant, including the design and specifications for the fuel handling and treatment systems, and Westinghouse Electric Corporation, Generation Systems Division, who was the manufacturer of the combustion turbine engine. The original concept of the program was to demonstrate to the E.B.E.S. Utility Company the practicality of operating a combustion turbine generating plant on residual fuel oil as part of their normal generating capability. In addition, various fuel grades, additives, and hot flow path components would be evaluated under operating conditions over a period of several thousand hours. As the program progressed, some of the detail features were modified to conform to the utility operating requirements. At the time of manuscript submission, over 1000 hr actual operating experience on the residual oil had been successfully completed and the program should have concluded at about 2500 hr at the time of the ASME Conference in 1978.

INSTALLATION

The basic installation for this evaluation program comprised an A.C.E.C. – Westinghouse W251 Econopac. This consists of a filtered air inlet system, a Westinghouse W251 combustion turbine, and an exhaust system which was modified to the customer requirements to provide a 45-m high...
exhaust stack. The open air cooled A.C.E.C. generator produced a nominal 33,000 kw at ISO conditions. The basic installation operated for approximately 400 hr on gas and No. 2 distillate oil prior to the commencement of this heavy fuel program.

The fuel handling and treatment plant consists of a bulk fuel storage tank of about 6000 cu m feeding both steam turbine and combustion turbine installation. The fuel treatment system consists of a three-stage electrostatic water wash system capable of handling 10 tons of fuel per hour with a treated maximum sodium plus potassium content of 0.5 ppm for an input of 55 ppm. The vanadium inhibition system uses an additive with a design level capable of handling 100-ppm vanadium.

The treated fuel is pumped to two storage tanks of 1000-cu m capacity each, thus allowing turbine operation from one storage tank while treated fuel is pumped to the other tank. The fuel forwarding system then pumps the fuel to the main fuel pump of the combustion turbine. A smaller, 100-cu m storage tank is used for No. 2 distillate oil for start-up and shutdown purposes.

The fuel forwarding system consists of dual filters, dual fuel pumps, and steam heating of the fuel. The fuel heating is to about 250 F and is controlled by a viscometer so that a fuel viscosity of 70 SSU is maintained at the fuel nozzle to ensure correct atomization for combustion. The installation included the ability to operate on natural gas with automatic transfer from gas to fuel oil upon the loss of gas pressure. Limited operation on gas took place during the running of this evaluation program.

W251 COMBUSTION TURBINE

The combustion turbine incorporated into the Econopac plant at the E.B.E.S. site of Hol is the Westinghouse W251 (Fig. 1). This engine consists of an 18-stage axial flow compressor with a three-stage turbine. The combustion system comprises eight individual combustor baskets with a dual fuel, gas and oil, fuel nozzle assembly. The combustion baskets consists of a primary basket where the combustion process takes place, followed by a secondary basket where dilution air is added and then a transition piece to the inlet of the first-stage vane segments. Ignitors are installed in two of the baskets with cross-flame tubes fitted between the baskets for cross-ignition and four ultraviolet flame detectors in two baskets at the opposite end of the basket chain. Atomizing air at 15 psi is used for starting purposes only. In order to ensure the air passages are always free in the atomizing air nozzles after the atomizing air has been turned off, a continuous low pressure, low flow purge system is incorporated using compressor discharge air.

The standard combustor basket design was retained without change for the operation on the heavy fuel. This consists of a series of Hastelloy X rings with cooling strips between each ring. This provides the required film cooling of the walls to maintain the metal temperatures at acceptable levels (Fig. 2).

The turbine consists of three stages of rotating blades and three stages of stationary vane segments. The first two stages of vane segments are internally air cooled and one stage of rotating blades is also air cooled. The materials...
Table 1

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary combustor basket</td>
<td>Hastelloy X</td>
</tr>
<tr>
<td>Secondary combustor basket</td>
<td>Hastelloy X</td>
</tr>
<tr>
<td>Transition piece</td>
<td>Hastelloy X</td>
</tr>
<tr>
<td>1st stage vane segment</td>
<td>X45</td>
</tr>
<tr>
<td>1st stage blade</td>
<td>Cast U500</td>
</tr>
<tr>
<td>2nd stage vane segment</td>
<td>X45</td>
</tr>
<tr>
<td>2nd stage blade</td>
<td>Forged U520</td>
</tr>
<tr>
<td>3rd stage vane</td>
<td>X45</td>
</tr>
<tr>
<td>3rd stage blade</td>
<td>Forged Inco X</td>
</tr>
</tbody>
</table>

The row 2 vane segment cooling uses metered, cooled, and filtered combustor shell pressure being fed into an insert within the hollow vane core. The cooling air from the insert bathes the inner surface of the vane and returns to main flow path through holes in the trailing edge of the vanes. Thus, the total cooling air used for row 1 and row 2 vane segments and row 1 turbine blades are all reintroduced into the main flow path, reducing the performance loss which would otherwise result (Fig. 5).

FUELS

The basic fuel specification used for all of the current Westinghouse - ACEC turbines has been developed over the years to allow unrestricted operation at base and peak firing temperatures without the problems or corrosion of the flow path components. This specification is based upon both practical experience and exhaustive laboratory testing of various materials and fuel contaminants. In order to achieve acceptable component parts life, the fuel contaminants, such as vanadium, sodium, potassium, lead, and calcium, must be controlled in the fuel. In addition, contaminants can be introduced through air ingestion or by water injection, and these sources are additive to that within the fuel.

The fuel oil specification, as covered by ASTM specification ASTM D-2880-76, classifies and defines four types of combustion turbine fuels; however, the Westinghouse requirements do vary from this specification in certain areas based upon experience. Table 2 summarizes the Westinghouse fuel specifications.
program was defined to allow design of the fuel system and fuel treatment plants to be made. The basic requirements were for the system to be capable of handling fuel to the limits as given in Table 3.

The temperature-viscosity curve of this fuel compared to No. 2 distillate oil is shown in Fig. 6. In order to achieve the guaranteed treated fuel quality, a three-stage electrostatic precipitator was designed and supplied by the Petrolite Company in France and Tretolite KI-16 additive injection system incorporated. Typical average fuel quality received during the test program had an analysis as shown in Table 4.

FUEL ANALYSIS

An essential feature of a controlled program to investigate the corrosion resistance of turbine materials is having an accurate knowledge of the fuel quality being used. To achieve this, a double beam atomic absorption spectrophotometer was installed at the site and operated by the customer's personnel.

Four automatic fuel-sampling systems were incorporated into the fuel treatment plant to allow samples to be taken before the first stage and after the first, second, and third stages of the fuel treatment plant. Representative samples can be obtained over varying periods of time from half an hour up to six hours. In addition, a bottom sediment and water monitor was incorporated in the treatment plant.
Table 2 Summary Specifications for Gas Turbine Fuels

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>MAXIMUM LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>70 SSU for Ignition</td>
</tr>
<tr>
<td></td>
<td>100 SSU for Combustion</td>
</tr>
<tr>
<td>Bottom Sediment and Water</td>
<td>1.0%</td>
</tr>
<tr>
<td>Vanadium (untreated)</td>
<td>0.5 ppm (wt.)</td>
</tr>
<tr>
<td>Sodium and Potassium (treated)</td>
<td>0.5 ppm (wt.)</td>
</tr>
<tr>
<td>Calcium</td>
<td>10 ppm (wt.)</td>
</tr>
<tr>
<td>Lead</td>
<td>2 ppm (wt.)</td>
</tr>
<tr>
<td>Sulfur</td>
<td>No Restriction</td>
</tr>
</tbody>
</table>

In order to be sure of the calibration of the equipment and that satisfactory repeatability of results was obtained, a series of fuel samples were analyzed by several independent laboratories. These demonstrated that accurate results were consistently obtainable at the utility site without having to rely on other laboratories.

As an example, a typical fuel analysis, as obtained during one of the 500 hr of operation on heavy oil, is summarized in Table 5.

TEST PROGRAM AND MATERIALS

The basic test program commenced after a full performance acceptance test was carried out on No. 2 distillate oil and natural gas. Upon completion of the installation acceptance, the fuel system was modified for operation on the heavy fuel and the fuel treatment plant commissioned. The test program was designed to initially operate for 100 hr at about 50 percent of base load. At this temperature level, all corrosion problems should be avoided, and the test running was designed to prove out the reliability of the total plant and fuel treatment systems. During this period of time, various minor problems were discovered and corrective actions taken to ensure a satisfactory operation during the actual testing.

The following phases of the test program were each of 500 hr operation with increasing load or metal temperatures using a controlled fuel input quality and an additive for vanadium inhibition. If time permitted, then alternative additives, different fuel contaminant levels, and different fuel qualities would be tested.

During the program, accurate records of the turbine components, turbine performance, and fuel quality would be continuously monitored. The opportunity was taken during this test to include
Table 4

<table>
<thead>
<tr>
<th>Component</th>
<th>Average</th>
<th>Extremes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>14.4 ppm</td>
<td>9.8 - 24.2 ppm</td>
</tr>
<tr>
<td>K</td>
<td>0.19 ppm</td>
<td>0.1 - 0.53 ppm</td>
</tr>
<tr>
<td>Mg</td>
<td>4.56 ppm</td>
<td>1.7 - 11.3 ppm</td>
</tr>
<tr>
<td>Pb</td>
<td>1.3 ppm</td>
<td>0.8 - 1.6 ppm</td>
</tr>
<tr>
<td>V</td>
<td>77.5 ppm</td>
<td>61 - 90 ppm</td>
</tr>
<tr>
<td>Density @ 15°C</td>
<td>0.9569</td>
<td>.9330 - .9638</td>
</tr>
</tbody>
</table>

ADDITIVE RATIO

In order to maintain an accurate determination on the quality of the fuel being burned in the turbine, daily fuel samples were taken. These were analyzed for vanadium and magnesium to ensure that the required ratio of magnesium to vanadium was maintained throughout the test program. In addition, a more complete analysis was carried out about once per week. With this virtually full-time effort devoted to the fuel analysis, it was possible to perform the controlled test program.

During a typical 500-hr test run, a total of 121 fuel samples were analyzed. The results
of these analyses showed that on all but eight occasions the magnesium to vanadium ratio was maintained at the required level of a minimum of 3 to 1. This thus shows that when operating with fuels requiring additives for vanadium inhibition, it becomes important to maintain daily checking so that any deviations can be quickly corrected. During this period of time the minimum ratio found was 2.7 and the maximum value being 4.8, with the overall average being 3.4 to 1.

An investigation was included in this program to determine the uniformity of distribution of the additive within the 1000-cu m day storage tank. Samples of fuel were regularly taken at various depths from the top of the tank and analyzed.

This data confirms that there is no gross settling of the magnesium additive over the period of one 500-hr series of tests. However, the length of time which the fuel remained within the tank was generally only a matter of a few days.

METAL TEMPERATURES

Some of the components of the gas path of the hot section were equipped with thermocouples. A primary combustor basket had 12 thermocouples installed to measure the metal temperature distribution. The corresponding secondary combustor basket had 10 thermocouples fitted while the transition piece had 12 thermocouples. One row 1 vane segment downstream of the instrumented combustors had 15 thermocouples on the suction side, pressure side, and one on the leading edge. The results obtained allowed a comparison of the metal temperatures to be made with different fuels.

PRIMARY BASKETS

In the primary zone of the combustor baskets, metal temperatures were measured on heavy fuel which were on average about 7 percent higher with peaks up to 15 percent higher for the hot spots than those measured on No. 2 oil at base load. These differences are due to the higher radiation of a heavy fuel flame.

SECONDARY BASKETS

In the zone of the dilution holes, metal temperatures were about 5 percent higher for heavy fuel while downstream of the dilution holes of the baskets, the metal temperatures were about the same for heavy fuel and No. 2 fuel oil.

TRANSITION PIECES

As the heat transfer due to radiation is small in the transition pieces, similar temperatures for both fuels were found.

FIRST ROW VANE SEGMENTS

There was virtually no temperature difference measured for both fuels on the Row 1 vane segments on either the pressure or suction sides.

Careful inspections were made of all of the baskets every 250 hr. The deterioration as a function of time has been plotted and compared with typical charts for use on No. 2 fuel oil.

After 1000 hr, it was found that some local basket deterioration had occurred which had not been experienced before; however, during the initial operation, the deposits were not totally removed as the water wash system was not operational. The buildup of deposits works as a heat sink which increases metal temperatures and started the local deterioration of the metal.

A careful and regular removal of the basket deposits will prevent further basket deterioration as was proven with the later operation.

POWER FALL-OFF - WATER WASHING

As mentioned previously, the test unit was a W251 Econo-pac which was in operation on No. 2 oil and gas for about one year before it was converted for use on heavy fuel.

The main changes on the longitudinal were the installation of some test components including materials and coatings. After the first 100-hr low load run to resolve the system problems, there was a large deposit buildup in the primary zone of the combustors and on the swirlplates. The deposits were easily removed manually. During the first 500-hr run at 70 percent load, the buildup was smaller, and during the next 500-hr run at 90 percent load, the deposit buildup was even smaller. Analysis of the deposits showed them to be the result of the magnesium additive for vanadium inhibition. Visual inspections as well as performance tests have proved that the deposit buildup was greatest during the first 150 hr and then stabilizes slowly afterward. Compared with the performance tests for the original commissioning of the unit in 1975, it was found that a power loss due to heavy fuel operation of 4 percent after 150 hr, 7 percent after 250 hr, and 8 percent after 500 hr without intermediate loadings.
washing had occurred. The heat rate increased, respectively, 2.5, 5, and 5.5 percent. The original performance commissioning test was with the turbine in a new and clean condition; however, some minor additional deterioration was evident due to, for instance, a fouled compressor as no cleaning was done, plus the normal losses due to reduction in component efficiency with time.

REMOVAL OF DEPOSITS

The daily operation of the unit was normally to start at 6:00 a.m., shutdown at 12 noon, restart at 2:00 p.m. and shutdown at 11:00 p.m. This thermal cycling was expected to have an effect on the removal of the deposits, but it proved to be less than anticipated and was, in fact, hardly measurable.

Running on gas for a short period was found to have a cleaning effect but it did not completely remove the deposits. The deposits are water soluble; thus, a water washing system is the most effective way to remove the deposits.

WATER WASHING

The water skid injects water at low flow rate and pressure through the existing atomizing air system into the combustors, while the unit is brought to ignition speed by the starting device. It was found that a first washing reduced the power fall-off from 8 to 1 percent and the loss of efficiency from 5 to 1 percent.

RELIABILITY

In the total generating capacity of an electric company, a simple cycle combustion turbine is a unit with relatively low utilization time, typically about 20 percent. The availability and reliability are, therefore, of very high

Fig. 7 Power fall-off reference to initial heavy fuel operation

Fig. 8 Efficiency reduction referenced to initial heavy fuel operation
importance as it is unacceptable to not have it available when needed for peaking service. That is the point of view of an electric utility. For interest, therefore, some of the problems experienced during this test program on heavy fuel are mentioned briefly.

Starting Problems

During the initial 1100 hr on heavy fuel, a total of 506 starts were recorded, of which 288 (57 percent) were good and 218 (43 percent) were aborted for various reasons. These results include the initial turbine plant commissioning plus the heavy fuel program start-up period including the test programs on the fuel and control systems. The failed starts were thoroughly analyzed and can be divided as follows:

<table>
<thead>
<tr>
<th>Failed starts due to:</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Diesel-engine problems</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>2 Fuel circuit</td>
<td>50</td>
<td>23</td>
</tr>
<tr>
<td>3 No ignition</td>
<td>100</td>
<td>46</td>
</tr>
<tr>
<td>4 No acceleration (stagnates at 1800 rpm)</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>5 Loss of the flame or too high temperature of gases</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>6 Starts on gas</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

Problems 1 and 6 do not relate to the use of heavy fuel and will not be discussed. The other points are in some form related to the use of heavy fuel and are mentioned briefly.

2 Fuel-Circuits. Some parts of the fuel circuit are common to the distillate fuel oil and the heavy fuel; however, the starts are always made on light fuel. Several modifications were needed to obtain a stable pressure control, especially during transfer from distillate to heavy fuel.

3 No Ignition. There were three major reasons for no ignition:

- Fuel flow too low
- Atomizing air insufficient
- Ignitors.

Fuel flow too low — After several failed starts, it was established that the fuel flow was not sufficient, the reason being that the minimum flow through the throttle valve was lower than designed due to some residual heavy fuel in the distillate fuel lines even after flushing the system from the previous shutdown. This residual heavy oil reduced the effective flow area of the throttle valve. The problem was solved by making a bypass around the throttle valve which was now fully closed, with the bypass orifice to ensure the correct ignition flow.

Atomizing air — When using heavy fuel, it was established that the atomizing air passages became clogged by carbon during operation. This was solved by installing a low positive pressure in the atomizing air system by comparison to the pressure of the combustion basket to continuously purge the passages. 100 g/cm² (1.5 psi) was sufficient to obtain satisfactory results.

Ignitors — The normal electrodes used when burning light fuel became dirty on heavy fuel causing ignition problems. These ignitors were replaced by a high energy system which then gave reliable operation.

4 No Acceleration (Stagnates at 1800 rpm). This was initially thought to be a fuel flow regulation problem, but the reason was found to be the same as the low flow problem referred to earlier as "no ignition."

5 Loss of the Flame or Too High Temperature of gases. The reason for loss of flame was found to be a lack of atomizing air. A change was made to increase the time the atomizing air was used. This increase in time is required due to the presence of some residual heavy fuel in the light fuel circuit.

All of these changes resulted in a high certainty that the starts are reliable and a starting reliability of in excess of 95 percent was achieved.

Reliability During Running

Some of the problems experienced during running on heavy fuel caused a shutdown of the combustion turbine or a transfer to light fuel and are summarized as follows:

Clogging of the Fuel Oil Filters. To protect the flow divider requires a filter of 5 microns; however, experience showed that this filter rapidly became clogged with the heavy fuel being used.

Filters of 50 microns were fitted after the booster pump but before the heater for the heavy fuel. This has given acceptable results with no necessity to change the filter during extended periods of operation and no flow divider problems.

The Transfer from Light Fuel Oil to Heavy Fuel Oil. Initially, the change over from distillate to heavy fuel was done very slowly by mixing the two fuels and heating according to a viscosity measurement. This kind of transfer gave good results since the temperature variation occurred very slowly. However, the unacceptably large amount of expensive light fuel oil needed
to start and stop the machine (4500 l) required a change to the complete fuel circuit in order to economize the use of light fuel. With the changes, the transfer now occurs in 2 min. and reduces the usage of distillate fuel. This system allows a start and stop operation requiring less than 1200 l of distillate fuel. This is, of course, an important economy taking into account the price difference in Europe between light and heavy oil. The transfer will take place at about 4000 rpm compared to the initial transfer being made after connection to the network.

**Viscosity Control.** Some difficulties remain with the viscosity control of the heavy fuel oil. The reason is the blockage of the capillary of the viscosity meter due to the presence of the vanadium inhibitor. After about 80 hr, the viscosity measurement becomes unreliable. During the last 500 hr, no shutdowns were recorded on heavy fuel. Occasionally, an automatic transfer to light fuel due to faulty operation of protective devices occurred for reasons such as temperature of fuel, too low air pressure, no steam pressure, or low level of fuel tanks.

The operation after the initial teething problems has proved to be reliable both during starting, shutdown, and normal operation.

**ECONOMIC FACTORS**

In Europe, the fuel prices are in a completely different proportion to those in the United States, where the price difference between light and heavy fuel oil is about 10 percent. In Europe, and certainly in Belgium, the price difference is about 65 percent.

- Price of heavy fuel oil: 300 Bfrs/Goal ($8.33/G Cal)
- Price of light fuel oil: 500 Bfrs/Goal ($13.89/G Cal)

For this reason in Europe, it is interesting and economically justified to perform some tests on heavy fuel.

The price of heavy fuel must be increased by the price for the treatment system. These costs can be divided as follows:

With the hypothesis of a running time of 2000 hr at 10 tons/hr and vanadium content in the fuel of 50 ppm:

1. **Variable costs**
   - **Chemical products:**
     - Inhibitor: 10.7 fr/Goal ($0.30/G Cal)
     - Demulsifier: 2.3 fr/Goal ($0.06/G Cal)
     - Electrolyte: 0.3 fr/Goal ($0.008/G Cal)
   - Water: 13.3 fr/Goal ($0.37/G Cal)
   - Electricity: 0.55 fr/Goal ($0.015/G Cal)
   - Steam: 2 fr/Goal ($0.05/G Cal)
   - **Total**: 17 fr/Goal ($0.47/G Cal)

2. **Cost of operation, maintenance and laboratory personnel**: 3 fr/Goal ($0.08/G Cal)

3. **Total variable cost**: 20 fr/Goal ($0.55/G Cal)

To obtain a complete comparable cost, the investment cost must be taken into account, but this is a fixed cost and, consequently, dependent of the total running time of the equipment.

Generally speaking, the treatment cost is about 15 percent of the cost of heavy fuel (345 fr/G cal [$9.58/G cal]), and this price is much lower than the price of light fuel oil.

The use of heavy fuel in the gas turbine also requires extra costs:

- Steam to heat the heavy fuel to obtain the right viscosity
- The fouling of the turbine with a deposit on the blades necessitating a regular water washing of the turbines
- Maintenance of the fuel filters
- A frequent inspection of the fuel nozzles and combustion chambers
- A maintenance program that is expected to be about twice the normal program by burning distillate fuel oil.

Some of the aforementioned extra costs are easy to measure; other ones are more difficult since other unknown parameters influence the costs, for example: the number of starts, the average running time for every start, and the ambient environment.

At the Mol power plant of E.B.E.S., it is considered that after the test program of 2500 hr on heavy fuel, it will be possible to accurately predict the extra costs and to determine the optimum maintenance program.

**CONCLUSIONS**

At the time of manuscript submission, the following conclusions were made which will be
confirmed at the presentation of the paper in April 1978.

1 A current technology combustion turbine plant can operate satisfactorily on residual oil in normal utility cyclic operation.
2 With a carefully designed and developed system, high starting reliability and availability can be achieved.
3 Performance deterioration due to deposit buildup in the flow path stabilizes after about 200 hr and is independent of load.
4 Thermal cycling has negligible effects on restoration of performance.
5 Water washing on a regular basis is effective in restoration of performance.
6 No visual corrosion of components was observed but detailed metallurgical analysis was not complete.
7 At this particular location, it was economically advantageous to operate on residual oil fuel.

REFERENCES