AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/PC/79650--12

DE-AC22-87PC79650-12

CWS-FIRED RESIDENTIAL WARM-AIR HEATING SYSTEM

Quarterly Report for the Period May 1, 1989 – August 15, 1989

By
J.C. Balsavich, F.E. Becker, and L.A. Smolensky

September 1989

Work Performed Under Contract DE-AC22-87PC79650

Tecogen Inc.
A Subsidiary of Thermo Electron Corporation
Waltham, Massachusetts

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PATENT STATUS

This technical report is being transmitted in advance of DOE patent clearance and no further dissemination or publication shall be made of the report without prior approval of the DOE Patent Counsel.

TECHNICAL STATUS

This technical report is being transmitted in advance of DOE review and no further dissemination or publication shall be made of the report without prior approval of the DOE Project/Program Manager.

TR4415-132-89

DE-AC22-87PC79650-12

**CWS-FIRED RESIDENTIAL WARM-AIR
HEATING SYSTEM**

**Quarterly Report for Period
May 1, 1989 - August 15, 1989**

**By
J.C. Balsavich, F.E. Becker, and L.A. Smolensky**

September 1989

Work Performed Under Contract DE-AC22-87PC79650

**Prepared by
Tecogen Inc.
A Subsidiary of Thermo Electron Corporation
45 First Avenue
Waltham, Massachusetts**

TABLE OF CONTENTS

1. INTRODUCTION	1
2. WORK PERFORMED DURING THE FOURTH QUARTER OF PHASE II	2
2.1 LIFE TESTING OF THE THIRD-GENERATION FURNACE SYSTEM	2
2.1.1 Combustor Performance During Life Testing	5
2.1.2 Heat Exchanger Performance During Life Testing	29
2.2 MANUFACTURING PROTOTYPE DESIGN AND MANUFACTURING AND OPERATING COST EVALUATION	36
3. SUMMARY STATUS ASSESSMENT AND FORECAST	38

LIST OF ILLUSTRATIONS

2.1	Photograph of Third-Generation Furnace System	3
2.2	Heating and Cooling Load Hour Regions	4
2.3	Variation in Combustion During Life Testing of the Third-Generation Furnace	6
2.4	NO _x Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing	7
2.5	SO ₂ Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing	8
2.6	CO Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing	10
2.7	Ash Chemistry of Parent Coal and Fly Ash	11
2.8	Ash Chemistry of Parent Coal and Fly Ash	12
2.9	Combustor Ash and Slag Buildup with Time (41 Hours)	13
2.10	Combustor Ash and Slag Buildup with Time (53 Hours)	14
2.11	Combustor Ash and Slag Buildup with Time (92 Hours)	15
2.12	Combustor Ash and Slag Buildup with Time (115 Hours)	16
2.13	Combustor Ash and Slag Buildup with Time (148 Hours)	17
2.14	Combustor Ash and Slag Buildup with Time (166 Hours)	18
2.15	Combustor Ash and Slag Buildup with Time (186 Hours)	19
2.16	Combustor Ash and Slag Buildup with Time (200 Hours)	20
2.17	Head Liner Ash and Slag Buildup with Time (41 Hours)	21
2.18	Head Liner Ash and Slag Buildup with Time (53 Hours)	22
2.19	Head Liner Ash and Slag Buildup with Time (92 Hours)	23
2.20	Head Liner Ash and Slag Buildup with Time (115 Hours)	24
2.21	Head Liner Ash and Slag Buildup with Time (148 Hours)	25
2.22	Head Liner Ash and Slag Buildup with Time (166 Hours)	26
2.23	Head Liner Ash and Slag Buildup with Time (186 Hours)	27
2.24	Head Liner Ash and Slag Buildup with Time (200 Hours)	28
2.25	Variation in Heat Exchanger Effectiveness During Life Testing of the Third-Generation Furnace	30

LIST OF ILLUSTRATIONS (Continued)

2.26	Variation in Heat Exchanger Overall Heat Transfer Coefficient During Life Testing of the Third-Generation Furnace	31
2.27	Variation in Heat Exchanger Number of Transfer Units (Ntu) During Life Testing of the Third-Generation Furnace	32
2.28	Percent Decrease in the Heat Exchanger Number of Transfer Units (Ntu) During Life Testing of the Third-Generation Furnace	34
2.29	Variation in Heat Exchanger Gas-Side Pressure Drop During Life Testing of the Third-Generation Furnace	35
2.30	Assembly Drawing of Manufacturing Prototype Furnace	37

1. INTRODUCTION

The objective of the CWS-Fired Residential Warm-Air Heating System program is the development of an economically viable coal water slurry (CWS) fueled furnace that is competitive with current oil and natural gas systems. The program consists of two phases: the first phase was completed in July 1988, and the second phase, which is in progress at this time, is scheduled for completion in October 1989.

Under the first phase of the program, a novel state-of-the-art Inertial Reactor with Internal Separation (IRIS) combustor was designed and tested. With this combustor, the following program objectives were met:

- Combustion efficiencies in excess of 99 percent while burning CWS.
- Response time to full load in less than 5 minutes.
- Successful operation with input rates ranging from 60,000 to 240,000 Btu/hr.
- Steady-state furnace efficiencies in excess of 80 percent.

The second phase of this program is a logical continuation of the first phase. However, in contrast to the first phase, which concentrated basically on the development of the individual system components, the second phase focuses on evaluating the interaction between the individual components and system design optimization. Serious consideration is also given to life testing to identify areas where additional development may be needed. This report summarizes the results of the fourth quarter of Phase II.

During this reporting period, life testing of the third-generation furnace system was completed. During the life testing period, the unit operated for 200 hours and burned 1,758 pounds of CWS. This translated into an average input rate over the testing period of 87,200 Btu/hr. Throughout the testing period, no modifications to the system were required.

2. WORK PERFORMED DURING THE FOURTH QUARTER OF PHASE II

2.1 LIFE TESTING OF THE THIRD-GENERATION FURNACE SYSTEM

The purpose of life testing the third-generation furnace system was to operate the furnace with CWS for an extended period of time without any modifications to the system. When the system is monitored, changes in performance of the individual components with time can be noted, and areas for future development work can be recommended.

Before life testing began, the third-generation furnace, shown in Figure 2.1, was thoroughly cleaned. This included the removal of all ash from the combustor, transition box, heat exchanger, and baghouses. The unit was thoroughly cleaned so that baseline data could be obtained on all the components, and performance changes during the life-testing period could be monitored.

In determining the number of hours for the life-testing period, Figure 2.2 which shows the regional breakdown of heating and cooling hours in the continental United States was used. Figure 2.2 is broken down into 6 regions, ranging from region I with an average of 750 heating load hours to region VI with an average of 2,750 heating load hours. Typically, the number of hours that the furnace would be in operation during any of these regions is 60 percent of the heating load hours. This translates into 450 hours of furnace operation in region I and 1,650 hours of operation in region VI. As part of the specifications for the CWS-Fired Warm-Air Furnace, twice annual maintenance was allowed. If the scheduled maintenance period is broken down to divide the heating season in half, then the furnace must operate 225 hours in region I and 825 hours in region VI between service calls. In terms of the time involved in testing and associated information obtained, a life testing period of 200 hours was chosen. The 200-hour period represents 89 percent of the required operating hours between service calls in region I and 24 percent of the required operating hours between service calls in region VI. This should provide adequate data that can be extrapolated throughout all the regions.

In counting the number of hours in the life testing period, only the time when the unit was operating with CWS was included. The short furnace startup periods where the furnace operates on number 2 fuel oil were not figured into the life testing hours. The parent coal used in the CWS burned during the life testing period had the following specifications:

• Identification:	Upper Elkhorn number 3 seam
• Heating Value:	15,251 Btu/lbm
• Ash:	1.32 percent (by weight)
• Sulfur:	0.66 percent (by weight)

Figure 2.1 Photograph of Third-Generation Furnace System

Figure 2.2 Heating and Cooling Load Hour Regions

- Ash Fusion Temperatures:

Initial:	2150°F
Softening:	2300°F
Fluid:	2400°F
T-250:	2509°F

This coal was prepared in two different slurries used during the tests period. The first slurry was designated as UE3-204-MCW-F and contained 63.97 percent coal by weight. This fuel was burned for the first 35 hours of testing. The second slurry was designated as UE3-218-MCW-F and contained 65.29 percent coal by weight, and was used for the remainder of the test period.

2.1.1 Combustor Performance During Life Testing

During the 200 hours of the life testing period, the combustor burned 1,758 pounds of CWS. This translated into an average input rate over the testing period of 87,200 Btu/hr. Throughout the 200 hours of operation, the combustor operated on average with 22 percent excess air. With the exception of the occasional replacement of a startup oil burner nozzle, no modifications were made to the combustor.

The change in performance of the combustor over the testing period can best be characterized by examining the change in the combustion efficiency. Combustion efficiency was determined by the analysis of ash collected in the baghouses. Figure 2.3 shows how the combustion efficiency changed with time over the test period. Over the first 35 hours of operation, the combustion efficiency was on average 98.9 percent. During the next 93 hours of operation, the combustion efficiency varied between 98.2 and 98.5 percent, while for the remaining hours of the life testing period, the efficiency steadily increased. In fact the highest combustion efficiency obtained with the third-generation furnace, 99.1 percent, was obtained at the end of the 200-hour testing period. From this data it appears that combustor performance remains at least steady as hours of operation accumulate, and may possibly increase with time.

Throughout the life testing period, emission measurements were recorded. Figure 2.4 shows how NO_x emissions vary as a function of excess air for the third-generation furnace system. In referring to Figure 2.4, there is quite a bit of scatter in the data. However, like the second-generation furnace, NO_x emissions tend to reach a maximum when the unit is operated with about 30 percent excess air. Peak emission levels were on the order of 0.68 pound of NO_x per million Btu fired.

Sulfur dioxide emissions were also recorded. Figure 2.5 shows that SO₂ levels remain essentially constant over the range of excess air tested, with emissions being on the order of 0.5 pound of SO₂ per million Btu fired. The trend of SO₂ being fairly independent with excess air was also observed in the second-generation furnace.

Figure 2.3 Variation in Combustion During Life Testing of the Third-Generation Furnace

Figure 2.4 NO_x Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing

Figure 2.5 SO₂ Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing

In addition to both NO_x and SO_2 , carbon monoxide (CO) emissions were also recorded. Figure 2.6 shows how CO varies with excess air over the test period. Though there is quite a bit of scatter in the data, CO emissions are on average on the order of 0.1 pound of CO per million Btu fired.

In order to determine if any changes are occurring in the ash as the coal is burned, a complete ash chemistry analysis was performed on the fly ash collected in the baghouses. A comparison of the ash collected after combustion and the ash in the parent coal is shown in Figures 2.7 and 2.8. The comparison between the parent coal and the fly ash shows that for most components, there is only a slight change; however, this is not true for SO_3 . Analysis shows that there is a reduction of several percent in the amount of SO_3 . This reduction can be attributed to the fact that some of the sulfur in the ash is liberated as SO_2 .

Throughout the life testing period, the buildup of ash and slag on the segmented, silicon carbide partitions and head liner has been monitored. At various intervals, the combustor head was removed and photographs were taken to record how ash and slag built up over time. Figures 2.9 through 2.16 show the buildup of ash and slag on the upper and lower partitions, while Figures 2.17 through 2.24 show the buildup on the head liner.

The buildup that occurred on the upper and lower partitions tended to accumulate quickly at first, and then level off, as shown in Figures 2.9 through 2.16. The buildup on the upper partition was a very hard, slag-like material. This was expected since the upper chamber is the hottest section of the combustor, and the ash in the deep-cleaned coal used in the slurry has a very low fusion temperature.

The initial buildup in the lower chamber was a very fine ash that was not tightly bound to the partition. However, as time progressed and more buildup occurred in the lower chamber, the ash layer behaved as a very good insulator. This decreased the heat transfer out of the lower chamber into the water jacket. Due to this fact, the lower chamber ran hotter as time progressed, and a slag layer was formed on top of the ash layer.

The buildup that occurred on the silicon carbide head liner was a hard slag-like buildup, and appeared to be unaffected by time. This can be seen in Figures 2.17 through 2.24, where the buildup at 41 hours appears very similar to what was present at the end of the 200-hour test period. The slag buildup on the head liner was not unexpected since the head is in the hottest zone of operation in the combustor, and the ash in the fuel has such a low fusion temperature.

Figure 2.6 CO Emissions as a Function of Excess Air During Third-Generation Furnace Life Testing

Figure 2.7 Ash Chemistry of Parent Coal and Fly Ash

Figure 2.8 Ash Chemistry of Parent Coal and Fly Ash

Figure 2.9 Combustor Ash and Slag Buildup with Time
(41 Hours)

Figure 2.10 Combustor Ash and Slag Buildup with Time
(53 Hours)

Figure 2.11 Combustor Ash and Slag Buildup with Time (92 Hours)

Figure 2.12 Combustor Ash and Slag Buildup with Time
(115 Hours)

Figure 2.13 Combustor Ash and Slag Buildup with Time
(148 Hours)

Figure 2.14 Combustor Ash and Slag Buildup with Time
(166 Hours)

Figure 2.15 Combustor Ash and Slag Buildup with Time
(186 Hours)

Figure 2.16 Combustor Ash and Slag Buildup with Time
(200 Hours)

Figure 2.17 Head Liner Ash and Slag Buildup with Time
(41 Hours)

Figure 2.18 Head Liner Ash and Slag Buildup with Time
(53 Hours)

Figure 2.19 Head Liner Ash and Slag Buildup with Time
(92 Hours)

Figure 2.20 Head Liner Ash and Slag Buildup with Time
(115 Hours)

Figure 2.21 Head Liner Ash and Slag Buildup with Time
(148 Hours)

Figure 2.22 Head Liner Ash and Slag Buildup with Time
(166 Hours)

Figure 2.23 Head Liner Ash and Slag Buildup with Time
(186 Hours)

Figure 2.24 Head Liner Ash and Slag Buildup with Time
(200 Hours)

2.1.2 Heat Exchanger Performance During Life Testing

During the 200 hours of life testing, heat exchanger performance was carefully monitored. By measuring the gas and water inlet and outlet temperatures, as well as the water flow rate, the heat exchanger effectiveness, number of transfer units (Ntu), and overall heat transfer coefficient can be determined. By monitoring how these parameters change with time, the heat exchanger fouling characteristics can be determined.

The heat exchanger effectiveness is defined as the actual amount of heat transfer divided by the maximum amount theoretically possible. The change in heat exchanger effectiveness over the life testing period is shown in Figure 2.25. Initially the heat exchanger has an effectiveness in excess of 98 percent. However, this drops off rapidly over the first few hours of operation. As more hours of operation accumulate, the heat exchanger effectiveness decreases even further. Yet, after about 60 hours of operation, the rate of decrease in heat exchanger effectiveness is not as great as it was originally.

An interesting feature of Figure 2.25 is that after 186 hours of operation, there is a small step increase in the heat exchanger effectiveness. This increase is due to a problem that occurred with the startup oil burner nozzle. After testing several hours with CWS, the oil burner nozzle became fouled with ash, and would not atomize the fuel oil very well. When the oil eventually did ignite, there was a small "pop" in the furnace. While this minor explosion did not cause any damage, it did help clean the heat exchanger tubes.

One of the prime parameters in heat exchanger design is the overall heat transfer coefficient (U). A plot of the overall heat transfer coefficient, based on the tube inside area, is shown in Figure 2.26 for the 200-hour life testing period. Figure 2.26 shows an overall decrease in U over the first 60 hours of operation; however, from then on there appears to be no really noticeable decrease in U with time.

Though the overall heat transfer coefficient is traditionally used as an indication of heat exchanger fouling, in this application it is more desirable to use the number of transfer units (Ntu). By definition, the number of transfer units is defined as the product of the overall heat transfer coefficient multiplied by the heat exchanger surface area, and divided by the minimum heat capacitance of the two fluids in the heat exchanger.

It is more desirable to use Ntu as an indication of fouling because during the life testing period the flow rate of the gases through the heat exchanger varies slightly from data point to data point. This is due in part to the fact that the system pressure drop increases as the bag filters become fouled. Since the gas flow rate is imbedded in the definition of Ntu, it tends to remove some of the scatter in the data. In Figure 2.27 where Ntu is plotted as a function of time,

Figure 2.25 Variation in Heat Exchanger Effectiveness During Life Testing of the Third-Generation Furnace

Figure 2.26 Variation in Heat Exchanger Overall Heat Transfer Coefficient During Life Testing of the Third-Generation Furnace

Figure 2.27 Variation in Heat Exchanger Number of Transfer Units (Ntu) During Life Testing of the Third-Generation Furnace

it can be seen that there is a fairly smooth asymptotic decrease in heat exchanger performance with time.

To obtain an understanding as to how much the heat exchanger has fouled, the percent decrease in Ntu is plotted as a function of time in Figure 2.28. After the first 60 hours of life testing, the rate of fouling started to level off at a 65 percent reduction in Ntu . To put this into perspective, in order to obtain the same performance as when the heat exchanger was clean, 65 percent more surface area is required. Though this seems excessive, it must be realized that the amount of heat that would be recovered in this additional 65 percent surface area is only 20 percent of the total amount of heat recovered in the heat exchanger. This is due to the fact that though there has been a 65 percent reduction in Ntu , the heat exchanger gas exit temperature has risen only from about 210 to 500°F.

Heat exchanger pressure drop data has also been recorded during furnace life testing. This data is plotted in Figure 2.29 as a function of time. Initially, the heat exchanger gas-side pressure drop remained fairly low for the first 40 hours of operation. After that point there was a significant increase in the rate at which the pressure drop increased with time, until about 60 hours of operation. At this time the heat exchanger pressure drop had increased from a clean value of about 0.04 in. w.c. to over 0.2 in. w.c. From then on the heat exchanger pressure drop exhibited a somewhat cyclic behavior, with the pressure drop occasionally lowering and then rising again, with an overall trend to increase the pressure drop with time.

The periods of fluctuations in heat exchanger gas-side pressure drop tended to coincide with various startup cycles of the furnace. As the furnace was warming up on oil, ash from the heat exchanger tubes would occasionally be dislodged and collect in the baghouse. This occurred usually just at the beginning of startup on fuel oil.

From the time period of 60 to about 140 hours of operation, the gas-side pressure drop increased in a fluctuation manner to about 0.45 in. w.c. From about 145 to 180 hours of operation, the heat exchanger pressure drop leveled off. However, fluctuations at startup were still present. At 180 hours of operation, a sharp increase in pressure drop was observed. At this time the pressure drop increased from 0.45 to 0.66 in. w.c. over a six hour period. The pressure drop after this period of time decreased dramatically due to the small "pop" that occurred in the furnace on account of a fouled oil burner nozzle. For this reason it is difficult to say whether the trend of a rapid increase in pressure drop would have continued, or whether during the next furnace startup cycle, the heat exchanger pressure drop would have decreased as has been previously observed.

Figure 2.28 Percent Decrease in the Heat Exchanger Number of Transfer Units (Ntu) During Life Testing of the Third-Generation Furnace

Figure 2.29 Variation in Heat Exchanger Gas-Side Pressure Drop During Life Testing of the Third-Generation Furnace

2.2 MANUFACTURING PROTOTYPE DESIGN AND MANUFACTURING AND OPERATING COST EVALUATION

Preliminary drawings for a manufacturing prototype of the CWS-fired, warm-air furnace have been made and were sent to our manufacturing partner, Yukon Energy Corporation, for review. The manufacturing prototype was designed as a total warm air system, with cooling air replacing the water jacket that surrounds the combustor. In order to augment heat transfer from the combustor, cooling fins were incorporated in the design. An assembly drawing of the manufacturing prototype furnace is shown in Figure 2.30.

TF132-989

DATE	REV	BY	DESCRIPTION	DATE	REV	BY	DESCRIPTION
11/10	1	TEC	TECNOGEN INC	11/10	1	TEC	TECNOGEN INC
45 FIRST AVENUE BOSTON MA 02114 9048 617 552-1111 617 552-1112 617 552-1113 617 552-1114 617 552-1115 617 552-1116 617 552-1117 617 552-1118 617 552-1119 617 552-1120 617 552-1121 617 552-1122 617 552-1123 617 552-1124 617 552-1125 617 552-1126 617 552-1127 617 552-1128 617 552-1129 617 552-1130 617 552-1131 617 552-1132 617 552-1133 617 552-1134 617 552-1135 617 552-1136 617 552-1137 617 552-1138 617 552-1139 617 552-1140 617 552-1141 617 552-1142 617 552-1143 617 552-1144 617 552-1145 617 552-1146 617 552-1147 617 552-1148 617 552-1149 617 552-1150 617 552-1151 617 552-1152 617 552-1153 617 552-1154 617 552-1155 617 552-1156 617 552-1157 617 552-1158 617 552-1159 617 552-1160 617 552-1161 617 552-1162 617 552-1163 617 552-1164 617 552-1165 617 552-1166 617 552-1167 617 552-1168 617 552-1169 617 552-1170 617 552-1171 617 552-1172 617 552-1173 617 552-1174 617 552-1175 617 552-1176 617 552-1177 617 552-1178 617 552-1179 617 552-1180 617 552-1181 617 552-1182 617 552-1183 617 552-1184 617 552-1185 617 552-1186 617 552-1187 617 552-1188 617 552-1189 617 552-1190 617 552-1191 617 552-1192 617 552-1193 617 552-1194 617 552-1195 617 552-1196 617 552-1197 617 552-1198 617 552-1199 617 552-1200				45 FIRST AVENUE BOSTON MA 02114 9048 617 552-1111 617 552-1112 617 552-1113 617 552-1114 617 552-1115 617 552-1116 617 552-1117 617 552-1118 617 552-1119 617 552-1120 617 552-1121 617 552-1122 617 552-1123 617 552-1124 617 552-1125 617 552-1126 617 552-1127 617 552-1128 617 552-1129 617 552-1130 617 552-1131 617 552-1132 617 552-1133 617 552-1134 617 552-1135 617 552-1136 617 552-1137 617 552-1138 617 552-1139 617 552-1140 617 552-1141 617 552-1142 617 552-1143 617 552-1144 617 552-1145 617 552-1146 617 552-1147 617 552-1148 617 552-1149 617 552-1150 617 552-1151 617 552-1152 617 552-1153 617 552-1154 617 552-1155 617 552-1156 617 552-1157 617 552-1158 617 552-1159 617 552-1160 617 552-1161 617 552-1162 617 552-1163 617 552-1164 617 552-1165 617 552-1166 617 552-1167 617 552-1168 617 552-1169 617 552-1170 617 552-1171 617 552-1172 617 552-1173 617 552-1174 617 552-1175 617 552-1176 617 552-1177 617 552-1178 617 552-1179 617 552-1180 617 552-1181 617 552-1182 617 552-1183 617 552-1184 617 552-1185 617 552-1186 617 552-1187 617 552-1188 617 552-1189 617 552-1190 617 552-1191 617 552-1192 617 552-1193 617 552-1194 617 552-1195 617 552-1196 617 552-1197 617 552-1198 617 552-1199 617 552-1200

Figure 2.30 Assembly Drawing of Manufacturing Prototype Furnace

3. SUMMARY STATUS ASSESSMENT AND FORECAST

In this quarter, life testing of the third-generation furnace was completed. During this period, the furnace was operated for 200 hours on slurry, and burned 1,758 pounds of CWS. This translated into an average input rate over the testing period of 87,200 Btu/hr. Combustion efficiency for this period ranged from 98.2 to 99.1 percent, with no noticeable decrease in efficiency with time. During life testing, peak emissions on the order of 0.68 pound of NO_x per million Btu fired and 0.5 pound of SO₂ per million Btu fired were recorded.

Throughout the life testing period heat exchanger fouling data was recorded. While operating with CWS, the heat exchanger exhibits a rapid rate of fouling over the initial hours of operation; however, as time progresses fouling tends to level off. After about 60 hours of operation, the heat exchanger exhibited a decrease in the number of transfer units (Ntu) of 65 percent and remained around this value throughout the remainder of the life testing period.

During next quarter, an automatic control system will be incorporated into the furnace system, and cyclic testing will begin. In addition, a complete manufacturing cost estimate and operating cost evaluation on the CWS-fired warm-air furnace will be conducted.

**DATE
FILMED**

8 / 18 / 93

END