MASTER

DEMONSTRATION OF A NITROGEN BASED CARBURIZING ATMOSPHERE
(ENERGY CONSUMPTION OF THE ENDOTHERMIC GENERATOR)

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ABSTRACT

This first quarterly report details the energy consumption of an endothermic generator. Two different sized generators were studied and found to have basically the same energy usage characteristics. The energy consumption was found to be dependent on generator output, with less energy consumption per unit volume at higher outputs.

DESCRIPTION OF PROJECT

The first phase of this program was an analysis of the energy consumption of an endothermic generator. To obtain a comprehensive analysis, two different sized generators were evaluated over their normal operating ranges of temperature, dew point and rated output. The natural gas, air, electricity and water consumption were measured.

PROCEDURE

Setup

The first generator examined was a Surface Combustion endothermic generator rated at 2400 SCFH output. The generator was to be evaluated at three temperatures, three dew points and three flow rates. A statistical design (Box-Behnken) was used to reduce the number of tests required from 27 to 16.

Prior to beginning the test procedures, new catalyst and retorts were installed in the generator. The gas meters and flow meters were calibrated, and the generator was tested for leaks (see Appendix A).

The following test equipment was installed on the generator:

1. Diaphragm type gas meters on the:
 - a. Heating natural gas.
 - b. Reacting natural gas.
 - c. Total natural gas.
2. Waukee variable orifice type flow meters on the:
 - a. Input air.
 - b. Generator output.

3. High pressure gas regulator on the input natural gas line to reduce pressure fluctuations to the gas meters.
4. Temperature and pressure taps where necessary to correct the flow meters for temperature and pressure, and the gas meters for pressure.
5. A rotating type gas meter on the output of the generator as a cross-check on the Waukee flow meter. This gas meter failed after the fifth test run was disconnected and discarded.

The test setup is schematically shown in Figure 1. Appendix B gives nameplate data on the test equipment and generators. Natural gas information is given in Appendix C.

Each test consisted of a two hour run at a set temperature, flow rate and dew point. The temperature and flow were first adjusted to the desired setting. An infrared CO_2 analyzer was used to adjust the air to gas mixture to maintain a constant concentration of CO_2 in the output gas. This procedure maintained the D.P. at the desired level.

After allowing the generator to stabilize, the two hour test was begun. Gas meter readings, flow meter readings and associated data were taken at the beginning of each run, after the first hour and at the end of the test. The same test was performed at 1900° with no air or gas flow through the generator. This gave the idle heating requirement.

The above setup and procedure was basically duplicated for the 3600 SCFH generator. However, new catalyst and retorts were not installed in this case. A gas chromatograph was installed and gas concentrations of the output endothermic atmosphere were taken. Also, a KWH meter was installed on the pump motor to determine electrical consumption.

RESULTS

Table I summarizes the results obtained for the 2400 SCFH generator. The reacting natural gas consumed per unit of endo produced was essentially constant over the range of temperature, flow rates and dew points studied and had a mean value of 207.4 SCF per 1000 of endo produced. The standard deviation was 4.29 SCF or 2.1% of the mean. Since the accuracy of the Waukee flow meters was approximately $\pm 4\%$, the variation in reacting gas consumed with temperature flow and D.P. was not significant over the ranges evaluated. This reaction requirement was 13% less than the nameplate rating of 232 SCF/1000 endo, and 3% higher than the Metals Handbook value of 200 SCF/1000 endo.

The heating gas required to heat the generator is given in Table I and plotted against generator output in Figure 2. This data indicates that the generator has a certain basic heat loss and then requires additional heating gas based on output flow. At 1900°F the basic straight line equation for heating natural gas requirements calculated using the least mean squares method was 172.035 SCFH plus 51 SCF/1000 of endo produced. This agrees fairly well with actual idle natural gas consumption of 185 SCFH and the thermodynamic calculation which indicate that heating requirements should be approximately 49 SCF of natural gas/1000 SCFH of endo provided. Thermodynamic calculations are shown in

Appendix D. At full rated output the heating gas consumption of 294 SCF was 31% higher than the nameplate rating of 203 SCF, but 49% less than the Metals Handbook value of 600 SCF.

Table 2 and Figure 3 gives the same data for the 3600 SCFH generator. Since more scatter is evident in the data, the straight line fit does not give as realistic a depiction of the heating requirements.

However, when the data from both generators is combined, it is interesting that both generators operate at approximately the same overall efficiency with respect to natural gas consumption. This fact is shown dramatically in Figure 4, where total natural gas consumed (heating and reacting) to produce 1000 SCF of endo is plotted against generator output. This figure clearly demonstrates that for a given output, both generators consume approximately the same amount of natural gas. The generator nameplate ratings and the values given in the Metals Handbook are also shown in this figure.

Other minor energy related consumptions include cooling water consumption which averaged 4.2 gpm for the 2400 SCFH generator at 1/3 rated output and 6.7 gpm at 2/3 and full rated output. Electrical consumption was determined for the 3600 SCFH generator to be constant at 1.22 KWH/hr regardless of output.

CONCLUSIONS

In a well-maintained generator, the total output of the generator is the biggest factor in determining the energy consumed to produce a given volume of endothermic atmosphere. As the output increases, the natural gas required per unit of endo produced decreases dramatically. Since the amount of natural gas required for reaction is essentially constant over the normal operating ranges of temperature, dew point and flow rate, the decrease in natural gas consumption is due to the heating requirements.

The generators studied have a relatively high basic heat loss plus a smaller incremental heating requirement for each unit of endothermic atmosphere produced. Therefore, as output increases, the heating gas consumed per unit of atmosphere decreases. The natural gas required to produce a given volume of endo can vary as much as 54% depending on generator output.

NEXT PERIOD

During the next two months of the program, the total energy consumed by different heat treating furnaces on different production parts will be determined using endothermic atmosphere. At the conclusion of these tests, a similar comprehensive study of the nitrogen system will begin.

APPENDIX A

CALIBRATION OF GAS AND FLOW METERS

Test 1

Objective

These preliminary tests were designed to check the accuracy of the three Rockwell diaphragm type gas meters against each other and against the Waukee flow meters.

Setup

To the Process Gas vent of the 2400 SCFH endo generator, a Waukee flow meter was installed in series with the three Rockwell gas meters. Each gas meter was set up as in Figure 5 so that inlet and exhaust temperature and pressure could be measured. A second Waukee was installed on the inlet air as shown in Figure 1.

PROCEDURES

With the generator cold and with all natural gas off, the test was performed by energizing the Roots Positive Displacement Pump for a period of 60 minutes. This provided a constant flow of air through the test equipment.

Temperature, pressure and readings on the gas meters and flow meters were taken at the beginning, during and at the completion of the test. All flow volumes were corrected to 70°F and atmospheric pressure using the ideal gas laws and flow meter correction formulas.

APPENDIX A (Continued)

RESULTS

The maximum error between the three gas meters was 1.12% and between the gas meters and the output Waukee was 4.3%. However, due to a large discrepancy between the output flow and the input flow, air leaks in the generator were indicated. These were identified and eliminated by replacing two rubber sleeves attached to the Roots pump and closing off the CO₂ control valve. The next test was performed to insure the air leaks had been eliminated.

Test 2

Setup

Two of the Rockwell gas meters were removed from the output line of the generator and one was installed just prior to the inlet Waukee.

PROCEDURE

A fifteen minute run was performed in a similar manner as the previous test.

RESULTS

After correcting to standard conditions, the error between the Rockwell gas meters was 1.45%. The maximum error between the Waukees and gas meters was 3.3%.

CONCLUSIONS

The 2400 SCF generator was free from leaks and the flow equipment was of suitable accuracy.

APPENDIX B

EQUIPMENT INFORMATION

GAS METERS

Serial Number:	W72810T, W72926T and W72957T	3111876R
Type:	Rockwell #750 3-78	Rockwell R-3 Roto-seal
Capacity:	1600 CFH @ 2" differential 750 CFH @ 1/2" differential	3000 CFH
Pressure Max:	20 psi	125 psi
Temp. Compensation Good:	-30°F to 120°F	
Max. Operating Temp:	+165°F	200°F
Temp. Compensated to:	60°F	
Min. Operating Temp:		-50°F
Rangability:		20:1

GENERATORS

Surface Combustion 3600
 Serial #: BX-37309-1
 Size: S-3-N
 Capacity: 3600
 Temp. Max: 1950°F

	<u>Fuel</u>	<u>Reaction</u>
Cu. ft/hr	276	834
Pressure	20 psi	4-16 oz
Gas	Natural	Natural
BTU/ft ³	1,000	1,000

Surface Combustion 2400
 Serial #: BX-36813-1
 Size: S-2-N
 Capacity: 2400
 Temp. Max: 1950°F

	<u>Fuel</u>	<u>Reaction</u>
Cu. ft/hr	203	556
Pressure	20 psi	4-16 oz
Gas	Natural	Natural
BTU/ft ³	1,050	1,050

APPENDIX C
NATURAL GAS INFORMATION

Natural gas is supplied by Northern Indiana Public Service Company of Hammond, Indiana. No BTU rating is contractually guaranteed; however, the average BTU rating during the generator test period was reported to be 1,000 BTU's/SCF.

A typical natural gas composition (in percent by volume) at Metallurgical Processing as analyzed by a gas chromatograph:

91% CH₄
1.53% C₂H₆
.374% C₃H₈
4.94% N₂
.452% CO₂

APPENDIX D

THERMODYNAMIC CALCULATIONS OF ENDO PRODUCTION

In the endothermic generator retort, 1,000 SCFH of endo atmosphere is produced when 200 SCF (at 70°F and one atmosphere pressure) of natural gas reacts with 500 SCF of air. This is based on the equation:

Since natural gas composition varies with location and is not 100% CH₄, and air is 21% oxygen by volume not 20%, this equation is a simplification to facilitate subsequent calculations.

At 0°C (32°F) and atmospheric pressure (STP) the 200 SCF of CH₄ converts to 185.5 ft³ via the ideal gas equation:

$$\begin{aligned}
 \frac{VP}{T} &= \frac{V'P'}{T'} \\
 \frac{200 \text{ ft}^3 (1 \text{ Atm})}{530^\circ\text{R}} &= \frac{V' (1 \text{ Atm})}{491.69^\circ\text{R}} \\
 V' &= 185.5 \text{ ft}^3
 \end{aligned}$$

From the Janaf tables, the energy to heat the gases:

$$\Delta H^\circ_{1310} - \Delta H^\circ_{298}$$

$$\begin{array}{llll}
 \text{CH}_4 & - & 14.85 \text{ kcal/g-mole} \times 1 & = & -14.85 \\
 \text{O}_2 & - & 8.06 \text{ kcal/g-mole} \times 1/2 & = & -4.03 \\
 \text{N}_2 & - & 7.3 \text{ kcal/g-mole} \times 2 & = & -14.6
 \end{array}$$

-33.48 kcal/g-mole of CH₄ react.

APPENDIX D (Continued)

The energy liberated by the reaction:

$$\begin{aligned} \text{CH}_4 \Delta H_f^{1310} &= -21.99 \text{ kcal/g-mole} \\ \text{CO } \Delta H_f^{1310} &= +27.23 \text{ kcal/g-mole} \\ &+ 5.24 \text{ kcal/g-mole} \end{aligned}$$

$$-33.48 \text{ kcal/g-mole}$$

$$+ 5.24 \text{ kcal/g-mole}$$

$$-28.24 \text{ kcal/g-mole net energy required.}$$

$$= 28.24 \text{ kcal/22.4 liters} \times \frac{1}{.053 \text{ ft}^3/\text{liter}}$$

$$= 28.24 \text{ kcal/.79072 ft}^3$$

$$= 35.7 \text{ kcal/ft}^3 \times 185.5 \text{ ft}^3 =$$

$$= \frac{6,625 \text{ kcal}}{1,000 \text{ SCF endo}} \times 3.968 \text{ BTU/k-cal}$$

$$= \frac{26,288 \text{ BTU}}{1,000 \text{ SCF endo}} \div \frac{530 \text{ BTU's}}{\text{SCF of N.G. @ 1900°F (est.)}}$$

$$= \frac{49 \text{ SCF N.G.}}{1,000 \text{ SCF endo}}$$

Table 1

2400 SCFH Endothermic Generator
Data Summary

<u>Test #</u>	<u>Heating Nat. Gas SCFH</u>	<u>Reacting Nat. Gas SCFH</u>	<u>Total Nat. Gas SCFH</u>	<u>Endothermic Atm. Produced SCFH</u>	<u>Dew Point</u>	<u>Temp. OF</u>	<u>Reactant Nat. Gas 100/Endo</u>
1	253	323	578	1580	39	1900	20.4
2	207	168	374	793	30	1850	21.4
3	255	345	606	1610	10	1850	21.4
4	279	475	760	2230	31	1850	21.3
5	245	340	583	1632	39	1850	20.8
6	251	336	586	1631	32	1900	20.6
7	266	334	600	1651	38	1950	20.2
8	310	502	813	2457	30	1950	20.4
9	266	342	607	1689	11	1950	20.2
10	222	176	399	836	27	1950	21.1
11	247	330	584	1639	28	1900	20.1
12	218	185	403	900	39	1900	20.6
13	291	502	797	2432	40	1900	20.6
14	295	514	808	2445	11	1900	20.9
15	218	185	403	876	16	1900	21.11
16	250	326	578	1564	26	1900	20.8

TABLE 2

3600 SCFH ENDOTHERMIC GENERATOR DATA SUMMARY

Test #	Heating Nat. Gas SCFH	Reacting Nat. Gas SCFH	Total Nat. Gas SCFH	Endothermic Atm. Produced SCFH	Dew Point	Temp. °F	Reactant Nat. Gas 100/Endo
1	269	522	795	2483	27	1900	21.0
2	201	282	491	1269	28	1850	22.0
3	252	511	765	2387	12	1850	21.4
4	330	703	1032	3351	22	1850	20.9
5	241	499	733	2369	42	1850	21.1
6	269	531	799	2512	30	1900	21.1
7	317	527	846	2516	44	1950	20.9
8	396	692	1099	3353	28	1950	20.6
9	306	544	849	2598	14	1950	20.9
10	222	271	487	1191	27	1950	22.7
11	276	532	808	2542	32	1900	20.9
12	201	282	481	1282	40	1900	22.0
13	309	680	985	3194	39	1900	21.3
14	353	697	1043	3309	13	1900	21.1
15	201	290	494	1288	12	1900	22.5
16	271	529	808	2584	25	1900	20.5
1 repeat	285	534	816	2545	23	1900	20.9
2 repeat	208	297	498	1377	28	1850	21.6
8 repeat	396	706	1105	3488	31	1950	20.2

SCHEMATIC DIAGRAM SURFACE COMBUSTION Rx UNIT

FIGURE 1.

**HEATING GAS VS. ENDO OUTPUT
2400 SCFH-GENERATOR**

FIGURE 2.

HEATING GAS VS. ENDO OUTPUT 3600 SCFH GENERTOR.

FIGURE 3.

NATURAL GAS CONSUMED TO PRODUCE 1000 SCF OF ENDO

FIGURE 4.

GAS METER SCHEMATIC

FIGURE 5.