ENDOTHERMIC GAS GENERATOR TROUBLESHOOTING AND GENERAL MAINTENANCE GUIDE

Written by

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IMPORTANT NOTE

This document is intended as a general overview of the typical maintenance and troubleshooting practices for endothermic gas generators. Of course, every generator is manufactured differently and therefore, it is ***strongly recommended*** that the operation manual or generator manufacturer be consulted for the exact procedure when performing any maintenance on this equipment. If a gas generator has been recently updated or retrofitted with a dew point sensor or fuel-injection control system, the following document serves to compliment the original equipment operation manuals. It is recommended that all equipment manufacturers be contacted to resolve any confusion regarding the maintenance requirements for a particular piece of gas generation equipment.

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Modern Endothermic Gas Generators

An endothermic gas generator is comprised of at least one heating system and a reaction supply system. The typical components of each system are identified on Figure #1. A general understanding of these basic components is useful when troubleshooting any gas generation problem. Therefore, below is a brief explanation of the each component and its usual function.

Heating System Overview

In a standard single hot zone generator, the heating system is typically composed of an industrial burner (*a*) or electric heating element (not shown), thermocouple (*b*), temperature controller (not shown), and burner control valve (*c*). The purpose of the heating system is to control the hot zone surrounding the reaction gas retorts (*f*) containing a nickel coated ceramic catalyst (*g*) to a temperature of at least 1900ºF. An over temperature controller and separate thermocouple (not shown) provide a safety check on the heating system to ensure that the generator remains below 2000 ºF.

Note: Some modern generators utilize separate hot zones for each retort. In this case, there will be a complete heating system and over temperature controller safety device for each additional retort.

Reaction System Overview

The reaction system starts with an air/gas mixing system (*d*) that produces a pressurized mixture of air and gas using either a carburetor or more precisely with a fuel-injection control system. The air/gas mixture then passes through a fire check valve (*e*). *(Normally, the air/gas mixture is too rich to be combustible. However, in the event the mixture becomes combustible, the fire check valve will prevent any flash back from occurring.)* The reaction gas is than introduced into to the heated retort (*f*) and passes through the catalyst (*g*) where a chemical reaction occurs that transforms the air-gas mixture into endothermic gas.

When the reaction is complete, the endothermic gas must pass through a gas cooler (*h*) which uses ambient air or water to bring the temperature of the endothermic gas below 300 ºF. The gas must be cooled quickly to prevent undesired chemical reactions that create carbon fallout. Once the endothermic gas is sufficiently cooled, the endothermic gas is either vented to a burn-off spool (*k*) or delivered through an endothermic gas header line (m) to the heat treating furnaces. A relief vent regulator (*n*) is typically provided before the retort that provides automatic venting in the event the retort input pressure rises above a safe operating range.

To ensure gas quality, a gas sample line is normally installed after the gas cooler. The gas sample is fed to either a zirconia oxygen probe system (*p*) or a carbon dioxide analyzer (not shown) which provides an electronic signal to a process controller (not shown). The process controller compares the actual gas quality with the desired set point and communicates any necessary air/gas ratio adjustments to the air/gas mixing system.

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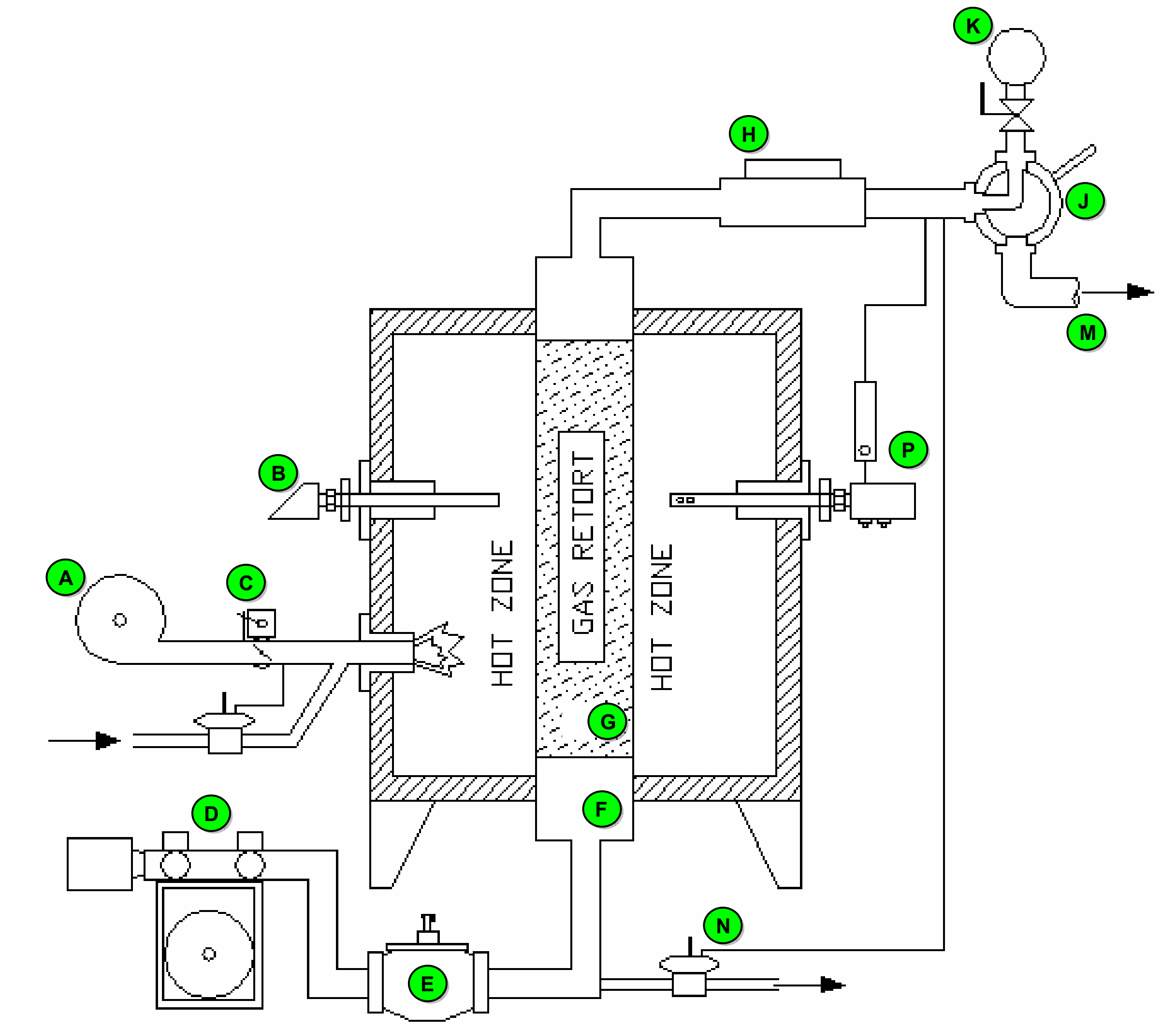
Figure 1

Typical Generator Components



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Typical Gas Generation Problems

While the gas generation process is rather straight forward, problems can be quite complicated to diagnose when they arise. This is especially true when seemingly conflicting information is reported. Of course, when addressing any problem, it is important to think logically and document the symptoms known before making any changes to the system. It can also be helpful to categorize the problems to help identify the required actions and tools required to resolve the issues.

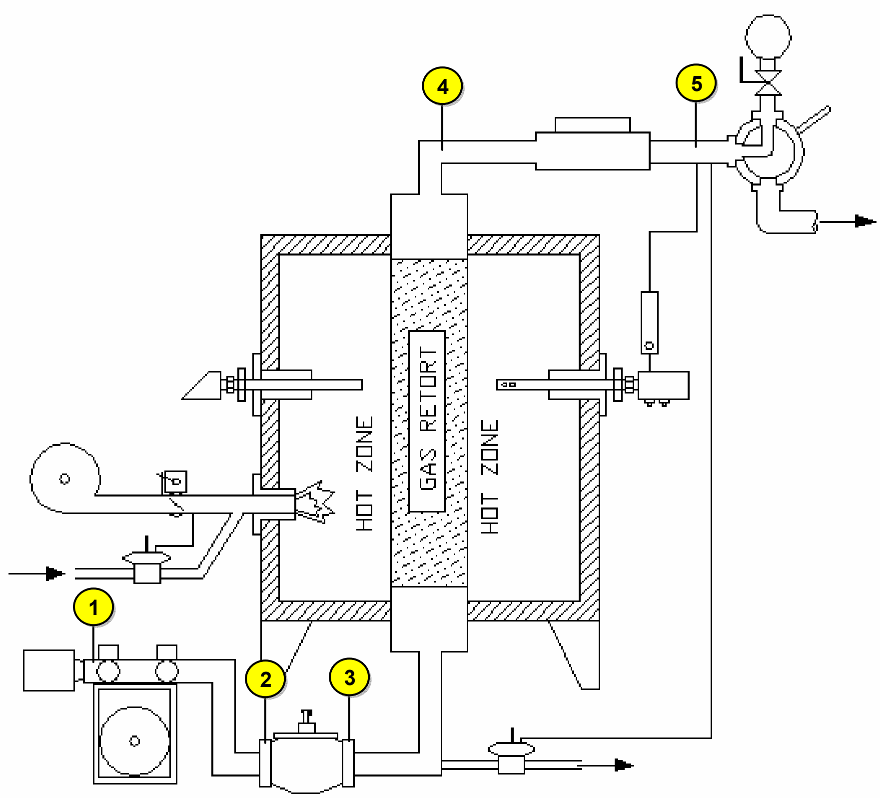
Typical Categories of Generator Problems

1. Flow and Pressure Delivery Issues
2. "Soot" or Gas Quality Problems

Troubleshooting Flow and Pressure Delivery Issues

If a gas generator can not provide the required amount of endothermic gas to a heat treating furnace, it important to begin thinking in terms flow restriction and pressure losses. Wherever the gas flow is restricted, the gas will show a loss of static pressure in the flow stream. A standard low pressure gauge or differential pressure monometer (0-60"wcg) is required to identify the location of these flow restrictions. In addition, a properly designed gas generator will provide pressure ports with isolation valves in a number of key locations to facilitate this process. Figure 2 identifies the key locations for these test ports.

IMPORTANT: While the following identifies a range of typical gas pressures at these points, it is much more important to document the difference between these pressure points. Any pressure loss that is larger than expected is a serious sign of a growing flow restriction that must be resolved.



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Critical Pressure Points

Point 1 (Reaction Gas Supply Pressure)
Modern Fuel-Injection mixing equipment requires a minimum of 70”wcg (2.5psig) supply gas pressure. When using a fuel-injection mixing system, if the air/gas ratio remains above the desired ratio setpoint, this is typically a sign that either the reaction gas supply pressure is not adequate to make the required flow rate or the mixing system pressure (Point 2) is higher than normal.

Point 2 (Mixing System Pressure) *(Normal Range: 30 - 40"wcg)*
The mixing system will normally pressurize the air-gas mixture to 30 - 45“wcg depending on the generator design. This pressure is controlled via a relief regulator or relief valve on the mixing system and can usually be adjusted manually during generator operation. If this pressure is below the normal operating range, it will result in a loss of output pressure and potentially a loss of generator capacity. However, care should be taken not to raise this supply pressure above the maximum pressure that any component on the generator is rated for. If this pressure is raised above the normal operating range, it will typically result in pump fatigue and could potentially produce a seal failure in the retort assembly. If more pressure is required to maintain generator output then the following pressure points should be checked.

Note: Some generators are designed to utilize a pressure regulator that is sensing and trying to control the generator outlet pressure at point D by modifying the mixing system pressure. Therefore, it is important to keep the sense line and control scheme in mind when making adjustments to this regulator.

Point 3 (Retort Inlet Pressure) *(Normal Range: 28 - 38"wcg)*
The retort inlet pressure should be only a 2 - 4”wcg lower than the mixture supply pressure measured at point 2. If the pressure measured at this point has dropped by more than this, the fire check valve is becoming dirty and must be cleaned as soon as possible. The fire check valve is typically contaminated when air filtration is not sufficient or when mixing pumps requiring lubrication are used. The lubrication can find its way into the fire check valve plugging the devices quickly. Modern generators utilizing a fuel-injection mixing system do not require lubrication and therefore, have significantly reduced the amount of cleaning required inside fire check valves.

Point 4 (Retort Outlet Pressure) *(Normal Range: 15 - 25"wcg)*
At full flow capacity, a properly designed retort with catalyst should have an outlet pressure only 12 - 16"wcg lower than the retort inlet pressure measured at point 3. When the pressure loss across the retort is larger than 18”wcg, it is a sign of a major problem building within that retort. Either the retort catalyst is becoming “sooted” up and requires a carbon burnout or the retort has developed a hole and is leaking the endothermic gas into the hot zone of the generator. Either problem is of immediate concern and should be addressed as soon as possible.

Point 5 (Generator Outlet Pressure) *(Normal Range: 12 - 22"wcg)*
At full flow capacity, a properly designed generator will provide 18”wcg with the pressure losses described above. If the outlet pressure is lower than expected, than it is recommended to begin checking the pressures from point 1 (above) and identify the location of the largest pressure loss. If this outlet pressure is more than 2”wcg lower than the retort outlet pressure measured at point 4 it is a sign that the cooler has a build up of carbon inside its tubes and must be cleaned as soon as possible. If the outlet pressure is larger than expected then it is advisable to reduce the inlet pressure at point 2 by making the proper adjustment to the relief regulator on the mixing system.

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Troubleshooting Gas Quality Problems

Recent innovations in fuel-injection and gas analysis equipment have provided the modern heat treatment professional with a number of useful tools to aid in troubleshooting gas generator problems. These tools can help to quickly identify any quality related issue within the gas generation process and provide the most direct course of action to prevent or resolve any issue.

Endothermic Gas Quality Troubleshooting Tools

1. Air/Gas Ratio (Historical Data if possible)
2. Oxygen Probe Data
3. Dew Point Analyzer
4. Three Gas Analyzer

Air/Gas Ratio

The air/gas ratio is the leading indicator of any change inside the endothermic gas generation process. Typically, a higher air/gas ratio will produce endothermic gas with a higher dew point. However, the air/gas ratio can change considerably to maintain the same dew point for a number of reasons as detailed below. Therefore, it is important to understand the normal ratio "*range*" associated with a particular generator so that it is easier to identify actual problems before they become major issues. The air/gas ratio is simply a description of the recipe being used in the gas reaction. This ratio is typically displayed prominently when the generator has a fuel-injection ratio control system. However, if the generator utilizes a carburetor/trim mixing package, the air/gas ratio must be calculated by looking at the mechanical flow meters on the generator and using the following equation:

Air/Gas Ratio Calculation

(Air Flow + Trim Air Flow) / (Gas Flow + Trim Gas Flow) = Air/Gas Ratio

Typical Air/Gas Ratio (40'F Dew Point)

Air / Natural Gas .... 2.60 - 2.80
Air / Propane Gas .... 7.60 - 7.80

If the dew point control system utilizes a trim gas solenoid that "pulses" additional trim gas into the reaction gas mixture using a time proportional scheme an additional calculation will be required to find the actual trim gas flow required in the Air/Gas Ratio equation above:

Time Proportional Trim Gas Flow Calculation

(same calculation can be used for trim air if needed)

(% Output on DP Controller) x (Trim Flow when Solenoid Open) = Trim Gas Flow Rate

It may seem obvious, but there are still a number of generators manufactured today that do not provide flow meters for all the gasses on the reaction mixing system. It should be understood that this is a serious disadvantage when trying to predict and troubleshoot gas generation problems.

Further, a fuel-injection system with true ratio control provides the easiest and most accurate way to document the actual air/gas ratio at any moment and does not require any manual calculations. In addition, modern controllers typically include a paperless chart recorder that will log this ratio for reference in generator troubleshooting.

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Generator Startup after Weekend Shutdown or Longer

During the first 30 minutes of a generator startup the dew point will remain high until all the residual oxygen within the ceramic catalyst has been reacted and the actual endothermic reaction begins to occur. It is recommended that the operator resist the urge to manually lower the air/gas ratio much lower than the last known air/gas ratio to produced endothermic gas at the desired dew point. After approximately 30 minutes, the primary endothermic gas reaction will begin and the dew point will drop dramatically to a stable value and continue to decrease slowly for the next 15-20 minutes.

In the event the dew point does not fall to the desired dew point after these events have occurred, then an air/gas ratio adjustment should be made to bring the dew point down manually. Once the dew point has fallen below the desired setpoint, the dew point controller should automatically begin adjusting the air/gas ratio to maintain the desired endothermic gas dew point.

Normal Reasons for Air/Gas Ratio Swing

The air/gas ratio can change significantly from month-to-month just to produce endothermic gas of the same dew point quality. These common ratio changes are actually a normal response to conditions that are not controlled of by the gas generation process.

Reasons for Normal Air/Gas Ratio Swing

“Peak Shaving” in Natural Gas Supply........Large Influence (8 - 15%)
Ambient Air Dew Point Changes ....Small Influence (1 - 5%)
New Catalyst “Seasoning”...........................Small Influence (1 - 5%)

The most obvious example of a “normal ratio swing” is between the summer and winter months. Over five years of data, it has been documented that a 10-12% higher air/gas ratio is required to produce endothermic gas of the same quality during the winter months. The primary explanation for this winter swing is due to “peak shaving” in the gas supply and dryer than normal ambient air conditions. Conversely, during the summer months, the ambient dew point can be significantly higher and therefore, a lower air/gas is needed to produce endothermic gas with the same dew point.

Another normal ratio swing occurs when new catalyst is installed. The initial air/gas ratio required will be slightly lower than normal and gradually rise to a normal operating range during the first 2 weeks of operation. During this time, the dew point of the endothermic gas will remain constant. The primary cause of this initial drift is presumed to be that there is additional oxygen resident within the inner cavities of the ceramic catalyst. This oxygen is slowly reacting with the air-gas mixture in the retort. Therefore, a small amount of additional gas is required until the catalyst has been completely “seasoned.”

It is important to note that during these “Normal” occurrences, the endothermic gas quality is not greatly affected. However, large “Peak Shaving” events can cause a significant change to the amount of Carbon Monoxide (%CO) in the endothermic gas. In this case, the “CO Factor” might need to be changed in the carbon controller at the furnace. Of course, this should be done after a proper shim test of the furnace atmosphere.

(For more information refer to the “Peak Shaving” note at the end of this document)

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Abnormal Reasons for Air/Gas Ratio Swing

After identifying the normal reasons for a ratio adjustment to occur, it is important to detail what abnormal situations might occur within a gas generator to cause an Air/Gas Ratio adjustment. The dew point being measured could remain under control or fall out of control depending on the severity of the underlying problem. Abnormal Air/Gas ratio changes are typically larger than normal swings and will typically require personal attention to resolve the underlying problem.

Reasons for Abnormal Air/Gas Ratio Swing

- "Dusting" or "Sooting" of the Catalyst
- Completely "Sooted" Catalyst
- Catalyst Nickel Depletion
- Too much Endothermic Gas Output
- "Carbon Fallout" (Failing Cooling System)
- Low Internal Retort Temperature
- Leak in Retort or Cooling System

"Dusting" or "Sooting" of the Catalyst

Soot is created on the catalyst when there is too much natural gas (or propane) introduced without enough air for proper reaction. Practical experience shows that carbon will begin to accumulate when the dew point of the endothermic gas produced falls below 20°F. The lower the dew point, the faster the accumulation will occur. During this time a small amount of unreacted methane (CH_4) will be found in the endothermic gas product and continue increase in concentration as the carbon continues to build-up on the catalyst. A three gas analyzer is useful to diagnose this problem as the normal gas constituents will be found with an unusually high CH_4 concentration of greater than 0.8%. During this time, the dew point controller will attempt to correct for this "Sooting" by automatically increasing the air/gas ratio. However, if the air/gas ratio reaches is maximum value and the dew point still remains low, then manual intervention will be necessary to "Lean Out" the Catalyst.

"Leaning Out" the Catalyst

The easiest way to clean the catalyst of a small amount of soot build-up from a low dew point situation and bring the dew point back under control is by manually increasing the air/gas ratio to 3.50+ parts air. This process introduces more oxygen into the retort which will react with the carbon on the catalyst to create carbon monoxide. Once the carbon is gone, the normal endothermic gas reactions will resume and the dew point will rise quickly. This process can take anywhere between 5 to 15 minutes depending on the amount of soot resident inside the retort and catalyst. During this time, the dew point might remain low and show little change. However, it is important to remain patient and allow the reactions to occur in the retort. Once the dew point rises above 10 or 15'F the dew point will begin to rise very quickly. When the dew point rises to a point above the desired setpoint, the air/gas ratio can be brought back to a more normal range and the dew point controller can then automatically control the dew point.

If the dew point falls quickly again, there might be additional soot on the catalyst. A second "lean-out" can be attempted however, this could also be a sign that there is simply too much soot accumulated on the catalyst and a full "Burn-Out" must be scheduled.

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Completely "Sooted" Catalyst

When an endothermic gas generator becomes completely unresponsive to air/gas ratio changes and will not recover during a "Leaning Out", it is a sign that the catalyst has become completely "Sooted" and will require a carbon "Burn Out." This operation will require the gas generator to be taken offline and therefore, this procedure must be scheduled with production.

"Burning Out" the Catalyst

A "Burn Out" is accomplished by stopping the air/gas mixture completely, reducing the generator temperature to 1500'F, and introducing a small amount of air flow (100 to 200_{CFH}) into each retort for an extended period of time (30-60 minutes or longer).

Since this carbon reaction creates a large amount of heat, it is important to keep watch on the temperature of the generator to ensure that there is no damage to the retort alloy. If the temperature rises by more than 50'F it is typically recommended that the burnout air flow is turned off until the temperature decreases back to the normal 1500'F. A three gas analyzer is useful when performing this procedure as it can identify when the CO and CO_2 concentrations fall to 0% which typically indicate that the carbon burnout is complete.

If after both of these procedures, the dew point never rises above a confirmed and verified 20'F even with a confirmed 3.50 air/gas ratio, then either the retort catalyst is completely plugged with carbon or the catalyst is completely depleted. In either event, it is advisable to get a three gas analysis of the output gas to confirm the presence of a large amount of unreacted methane CH_4 before reaching the ultimate conclusion that the catalyst must be changed.

As a precaution, most heat treatment facilities will schedule a "Burn-Out" procedure once or twice a month as preventative maintenance to ensure the removal of any soot on the catalyst and preventing a completely "Sooted" generator from interrupting production unexpectedly.

Nickel Catalyst Depletion

Endothermic gas is produced over a bed of 1900°F nickel coated ceramic catalyst. The nickel coating provides a highly reactive surface for the hydrocarbon gas to "crack" and react with the oxygen in the reaction air. However, this nickel coating will eventually wear over time due to oxidation and normal use. Catalyst life will depend greatly on usage and generator retort design, however, 2.0 years would be considered a normal life span for a properly designed and maintained generator. To ensure long catalyst life, to not expose the catalyst to a large amount of air flow. The excessive oxygen will severely oxidize the nickel and make it completely useless for producing endothermic gas. Therefore, during a "Burn Out" procedure, make sure that the air flow rates are sufficiently low to minimize the chance of damaging the catalyst.

Depleted catalyst will typically produce endothermic gas with a dew point between 40-70°F but remain completely unresponsive to any air/gas ratio changes. The problem can be easily diagnosed with a three gas analyzer as the CH_4 concentration will be in excess of 4.0%

The only solution to a depleted catalyst situation is to completely replace the catalyst per the generator manufacturer recommendations. *(Make a specific reference to the recommended fill level as specified by the manufacturer since it is usually not advisable to fill the catalyst to a level where it will be sitting outside of the heating zone as this can produce a carbon fallout situation.)*

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Too Much Endothermic Gas Output

There are specific equations that dictate how much endothermic gas can be produced through a retort of a given diameter and length filled with a certain amount of catalyst. In addition, the cooling system supplied with the generator is designed for a maximum amount of flow before the heat exchanging rate becomes insufficient. When either of these limitations is pushed beyond their limits, the endothermic gas quality will begin to suffer.

When "pushing" too much endothermic gas flow through a retort, the amount of unreacted methane will begin to rise. Once again, the best way to diagnose this issue is with the use of a three gas analyzer. The three gas analyzer will confirm that higher CH_4 and lower than normal CO_2 and CO values occur at the elevated flow rates. However, when flow rates are within the normal operating range of the retort, the three gas analyzer should not detect a noticeable change in gas constituents.

"Carbon Fallout" (Failing Cooling System)

If the cooling system is undersized, poorly designed, or becomes inefficient due to contamination it will not adequately stop the endothermic gas reactions from reversing. This is typically termed "carbon fallout" and will quickly fill all the pipes downstream of the gas generator will carbon soot.

Carbon fallout occurs quite quickly and naturally when the endothermic gas is between the temperatures of 900 and 1300°F. Therefore, to ensure that this gas does not dwell in the reactive temperature range too long, a properly sized cooling system will output endothermic gas between 200-300°F. The use of a laser thermometer is useful when determining if there are any cooling problems with a particular generator.

During carbon fallout, a three gas analyzer will indicate a lower %CO than normal and corresponding higher $\%CO_2$ concentration. This is because some of the carbon monoxide has actually decomposed into carbon soot and carbon dioxide.

It is recommended that the cooling system by cleaned inside and outside at least once annually to ensure an efficient transfer of heat from the endothermic gas. However, if the generator is using only a passive "fin" method, it would be highly advisable to upgrade to an active technology such as forced air or water jacket to help remove the heat from the endothermic gas as quickly as possible.

Low Internal Retort Temperature

The endothermic gas reaction occurs at temperatures above 1800°F. However, the reaction occurs faster and more completely at higher temperatures. Therefore, the typical generator temperature setpoint is between 1900-1950°F as this is the best balance between the alloy life of the retort and the chemical reaction time. However, during generator startup it is important to allow the retort to completely soak up to the operating temperature. In addition, when too much mixed gas is introduced into the retort, it can also cool the core temperature of the retort below the optimal reaction temperature.

When this occurs, the reaction becomes sluggish and incomplete. The result is very similar to "Sooted" catalyst in that the unreacted CH4 is higher than normal. It is typically advisable to allow the retort to soak for at least one hour at temperature before attempting to introduce the reaction gas mixture.

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Leak in the Retort or Cooling System

Obviously, any leak is a sign of a major problem and should be addressed immediately. Cooling system leaks are normally easier to identify than retort leaks. However, there are some signs that can warn an observant generator operator of the potentiality of a retort leak.

A small leak will typically not greatly affect the endothermic gas quality nor be readily diagnosable. However, any leak in a generator retort will begin to grow in size within a few days. Eventually, the measured dew point will begin to be effected and a lower than normal ratio will be required to maintain dew point. When the air/gas ratio reaches it's minimum value, the dew point will begin to rise. This is the primary sign of a retort leak.

As the leak becomes even larger, the output pressure of the retort and generator output will become lower than normal. In addition, a constant flame from the generator combustion vent (typically at the top of the heating zone) will become visible as the leaked endothermic gas burns in the presence of the ambient air at the top of the vent. At this time, the leak can be quite severe and the reaction system should be shut down as quickly as possible to prevent an unsafe situation.

A Note on "Peak Shaving"

While natural gas is primarily composed of methane gas (CH_4), to meet peek demand times in the winter, a gas supply company may introduce a mixture of other hydrocarbons (i.e. propane) into the natural gas supply. When this occurs the gas supplier will typically dilute the additional propane gas with an inert gas (i.e. nitrogen) to maintain a consistent heat quantity per volume (BTU/CF). In this way, the gas company can accurately claim that they do not "spike" the gas since the actual BTU value remains constant.

The result of this "peak shaving" is that the combustion systems and burners throughout the heat treatment facilities, and certainly at residential locations, will not be greatly affected. However, the chemical reaction required to produce endothermic gas and the desired atmosphere inside a heat treating furnace will definitely be affected by these changes. A properly tuned fuel-injection mixing system will account for these changes and automatically compensate the gas generator by introducing a larger amount of air flow to maintain the desired endothermic dew point quality.

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