Use of Low Heating Value Natural Gas by Blending With Fuel Gas

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Abstract

The completion of a sweetening solvent change from Di ethanol Amine (DEA) into methyl Di ethanol Amine (MDEA) in sour gas sweetening units conducted off spec flash gas. Flash gas lined up directly from flash drums to incinerators in the sulfur recovery units (SRU), area was completely implemented in 2014. The flash drum gas is an off-spec gas with a high concentration of carbon dioxide. The fundamental objective is to use this low Btu, high CO_2 gas as a low cost fuel. Scrubbing the gas to remove the CO_2 makes it complicate and too costly to use as a fuel. However, if this gas could be blended with higher Btu spec gas typically supplied to incinerators, it would meet the objective of providing a lower cost fuel while volumetrically reducing the CO_2 content of the final mixture.

Fuel gases with large percentages of an inert gas such as Carbon Dioxide will have a ratio of rich-to-lean flammability limits less than that of natural gas. Flammability ratios of less than 2.2 to 1 based on volume at standard conditions (14.7 psia and 15 ^{o}C), may experience problems maintaining stable combustion over the full operating range of the combustion incinerator burners.

Burners can operate with fuel gases having a very wide range of heating values, but the amount of variation that a specific fuel system design can accommodate is limited, usually ± 5%. The fuel nozzles are designed to operate within a fixed range of pressure ratios and changes in heating values are accommodated by increasing or decreasing the fuel nozzle area or the fuel gas temperature. Since changing the fuel nozzle area is difficult, the temperature of the fuel gas is generally changed to accommodate significant changes in the heating values.

The project objective was to design and install a blending stations utilizing either Btu or Wobbe Index as the basis to blend the gases such that the resulting fuel would be a lower cost alternative, and meet burner firing requirements for the incinerator and environmental emissions limits. A temporary analyzer that could determine the composition of the natural gas in near real time mode was employed. The analyzer outputs, as well as other instrumentation, were brought into the plant's DCS for operator monitoring and control of the gas blending stations.

Our research of the Wobbe Index indicated that the preferred blending control mode should be based on the Wobbe Index. However, there did not appear to be any distinct advantage in using the Wobbe Index over the heating value or Btu. Since usually both Btu and Wobbe Index outputs are available from the gas analyzers, the logic configuration could developed such that the Operator select either Btu or Wobbe Index as the basis for controlling fuel gas blending.

The project evaluated two methods of blending, those being a single blending system at the plant gas yard or individual blending systems at each unit. However, the incinerators chose multiple blending systems because they intended to burn the blended gas only in the gas burners and felt the additional operability offset the cost of the additional blending stations.

This would allow the plant to determine which method gave them the best control of the blending stations. We know that the maximum limit of the Low Btu fuel gas is a 50% ratio, but the minimum limit (low flow) is set by blending system characteristics. To ensure trouble free start-ups, plant Operations prefers to start the burners of incinerator on Hi Btu fuel gas. Once the unit is online and operating reliability; at a given load, the Operator places the blending station in service.

The success of the blending station depends on the quality of the temporary analyzer signals. If the blending station analyzer fails, the blending control is automatically, or by Operator action, placed on flow control and the Hi Btu gas remains on pressure control. If the gas yard analyzer fails, the station is automatically placed on flow control (Low Btu gas) and pressure control (Hi Btu gas).

During the start-up phase of the project, both methods of controlling the blending stations were tested. There were no significant differences found between controlling based on Btu or Wobbe Index. Because the Wobbe Index is incremented in finer divisions, one would expect that finer blending control could be obtained, but for this application, very fine adjustments to the blending ratio are not necessary. The Low Btu gas on flow control is the default blending control method. This method was also tested, both as an Operator selected operational mode and as a default control mode when one of the analyzers fails.

The plant is currently operating on flow control mode, selected by the Operator, because the Low Btu gas can yet provide enough gas to justify blending based on Btu or Wobbe Index.

Keywords

Fuel Gas, Gas Blending, Btu, Wobbe Index, Natural Gas, Heating Value

BACKGROUND

THE ALTERNATIVE FUEL SOURCE

The off-spec flash gas is prevalent throughout the flash drum in gas sweetening units. The off-spec flash gas is produced at the five same units, but has been considered too costly because it had to be "scrubbed" to remove the diluent, carbon dioxide, before being considered.

Our research has confirmed that the high-carbon dioxide flash gas could be used as a fuel gas in gas burners on a blended basis. This means that the off-spec gas could now be transported without the prior need to remove the carbon dioxide at the flash drum. This would significantly reduce the cost of fuel gas to the plants.

THE PLANT STATISTICS

The gas Plant began operation in 1985. The plant is rated at 50 million standard cubic gas per day (MMSCMD) and is composed of five gas sweetening trains. Each trains has flash drum that produced flash gas. The plant has three sulfur recovery units (SRU) which consumed fuel gas in incinerator with three burners. The burners presently fires pipeline quality (Hi Btu) gas rated at an average of 1,000 – 1,025 Btu/scf provided from gas pipeline. The mixture passes through a knock-out separator in the gas yard before being sent to the plant via a common header.

The plant central control system is an Ovation Distributed Control System (DCS) supplied by yokogawa Process Management. The DCS is integrated with the Combustion supplied by L.D. duiker with the equipment, for the purpose of remote start/stop of the burners, monitoring of data, and collecting historical data in a historian. There is gas metering but no fuel composition analysis at the gas yard and no fuel composition analysis at any of the units.

THE PROJECT

DESIGN CRITERIA

To fully appreciate the scope of the project, the design parameters must first be discussed:

A gas sample of the Low Btu gas from the flash gas has the following fractional analysis:

Table 1 – flash gas Sample Fractional Analysis

Component	Mol%
N_2	0.81
CO_2	30
CH_4	67.6
C_2H_6	0.85
C_3H_8	0.38
C_4H_{12}	0.21
C_5^+	0.15
H_2S	100 ppmv
Total	100

Calculated Specific Gravity = 0.82

Btu / cu ft (@14.65 psia, 60^{o} F) = Calculated Gross Wet = 888, Calculated Gross Dry = 904

Table 2 specifies the allowable limits for the fuel properties and constituents for L.D. Duiker burners.

Table 2 – Fuel Gas Specification

FUEL PROPERTIES	**MAX**	**MIN**
Gas Fuel Pressure	Varies with unit and combustor type	Varies with unit and combustor type
Gas Fuel Temperature, °F		
Lower Heating Value, Btu/scf	None	100-130
Modified Wobbe Index (MWI) - Absolute Limits - Range Within Limits	54 +5%	40 -5%
Flammability Ratio	2.2:1	
Constituent Limits, mole %		
Methane	100	85
Ethane	12	0
Propane	12	0
Butane + higher paraffins (C4+)	5	0
Hydrogen	Trace	0
Carbon Monoxide	Trace	0
Oxygen	Trace	0
Total Inerts (N_2+CO_2+Ar)	**15**	0
Aromatics (Benzene, Toluene etc.)		0
Sulfur	100 ppmv	0

Burner Limits

The L.D. burners are unable to burn 100% Low BTU. In addition to the potential of generating excessive NO_x and CO emissions, fuel gases with large percentages of inert gases such as carbon dioxide, nitrogen will have a ratio of rich-to-lean flammability limits less than that of natural gas. Low flammability ratios may cause the burners to experience problems maintaining stable combustion over the full operating range of the burner. Therefore, a gas blending system is required to ratio the two sources of gas to prevent combustion instability and the generation of excessive CO and NO_x emissions. The intent is to burn as much of the Low Btu gas as possible since it is available at a more attractive price than Hi Btu gas.

By calculation, we know the blended gas streams ratio could be a high as 50/50. As indicated in the Fractional Analysis table above, the flash gas is 15% Carbon dioxide and the Hi Btu gas contains approximately 1% Nitrogen. If the gas is blended 50/50, the total carbon dioxide content would be 15%. This is the maximum carbon dioxide limit recommended by L.D.Duiker for the burners. Table 2 specifies L.D. Duiker allowable limits for fuel properties and constituents. This then sets the upper limits for the design project.

METHODS OF LIMITING CARBON DIOXIDE INTRODUCTION

Although the ultimate goal is to use as much of the Low Btu gas as possible, we must control the amount of Carbon dioxide introduced to the burners. It is simply a matter of controlling the blending of two fuel gas streams. It is easier to blend based on hydrocarbon content than inert gas content because it is relatively easy to determine the Btu content. Our investigation found that several analyzers were available that could provide real-time or near real-time analysis for hydrocarbons. One analyzer we investigated could provide real-time analog outputs for Btu as well as for Wobbe Index.

The heat of combustion, also known as heating value or calorific value of a fuel, is the amount of energy generated by the complete combustion of a unit mass of fuel. The US system of measurement uses British Thermal Units (Btu) per pound or Btu per standard cubic foot when expressed on a volume basis. The heating value of a gas fuel may be determined experimentally using a calorimeter in which fuel is burned in the presence of air at constant pressure. The products are allowed to cool to the initial temperature and a measurement is made of the energy released during complete combustion. All fuels that contain hydrogen release water vapor as a product of combustion, which is subsequently condensed in the calorimeter. The resulting measurement of the heat released is the higher heating value (HHV), also known as the gross heating value, and includes the heat of vaporization of water. The lower heating value (LHV), also known as the net heating value, is calculated by subtracting the heat of vaporization of water from the measured HHV and assumes that all products of combustion including water remain in the gaseous phase. Both the HHV and LHV may also be calculated from the gas compositional analysis using the procedure described in ASTM D 3588.

This is important to understand because the caloric value or the higher heating value is used in the calculation of Wobbe Numbers (Wobbe Index). Goffredo Wobbe, an Italian physicist, observed in1927:

- Given constant pressure and orifice size, the heat output of a burner is proportional to the flow volume per time
- The flow velocity through a given orifice size at constant pressure is proportional to the specific gravity of the gas

The calorific value or heating value, of a gas is proportional to its specific gravity.

Wobbe developed a numerical index that provided that if two fuel gases have identical Wobbe numbers, they will deliver the same amount of heat.

The Wobbe Number can be defined by

$$\mathbf{WI = CV / \sqrt{SG}}$$

Where: WI = Wobbe Index number (Although expressed in Btu/scf or MJ/Sm3 (mega joules per standard cubic meter), WI is generally expressed without units to limit confusion with heating value units.)
CV = Caloric Value (Higher Heating Value)
SG = Specific Gravity

Gas burners do not operate with condensing exhaust systems and it is a common practice for the gas burners industry to utilize the LHV when calculating the overall cycle thermal efficiency. Therefore, L.D. Duiker uses a modified version of the Wobbe Index.

L.D. Duiker calculations use a Modified Wobbe Index (MWI):

$$\mathbf{MWI = LHV / \sqrt{SGgas * Tgas}}$$

This is equivalent to:

$$\mathbf{MWI = LHV / \sqrt{(MWgas / 28.96) * Tgas}}$$

Where: LHV = Lower Heating Value of the Fuel Gas (Btu/scf)
SGgas = Specific Gravity of the Fuel Gas relative to Air
MWgas = Molecular Weight of the Fuel Gas
Tgas= Absolute Temperature of the Fuel Gas (º Rankine)
28.96 = Molecular Weight of Dry Air

It is clear that since the Wobbe Index is an indicator of the interchangeability of fuel gases; it can be used to control blending of fuel gases. Since the Wobbe Index and the Btu value of fuel gases make similar curves, either could be used to control blending of fuel gases; thereby, controlling the amount of carbon dioxide in the blended fuel.

Alternatively, the classic flow control method could also be used, whereby, the Low Btu gas could be placed on flow control at a selected flow rate less than 50% of the needed fuel flow rate and the Hi Btu gas supply placed on pressure control. This is the simplest method of controlling the blend, but certainly not the optimum.

SINGLE BLENDING STATION VS. INDIVIDUAL GT BLENDING STATIONS

The project evaluated two methods of blending, those being a single blending system at the plant gas yard or individual blending systems at each unit. A neighboring plant that has a different version of L.D. Duiker burners utilizes a single blending station and feeds the blended gas to their gas burners. However, the gas plant chose multiple blending systems because they intended to burn the blended gas only in the gas incinerators and felt the additional operability offset the cost of the additional blending stations.

The benefits from utilizing multiple blending systems:

- The burners, although designed to the same specifications and considered identical, have individual operating characteristics that may require the blend to be unit specific.
- Operational availability of all units is of utmost importance. The operation of any of the units may be limited by its combustion or CO and NO_x characteristics. Individual blending would allow any limiting of the blend mix to affect only that unit without imposing the same limit on the other units.
- A central blending system represents a single point of failure that could require all units to revert to Hi Btu gas, curtailing use of the low cost Low Btu gas.
- A multiple blend system offers the ability to tune each unit and its blend depending upon changing unit characteristics. Self-tuning or Neural Network may even be utilized later to maximize unit flexibility and operability.

BLENDING SYSTEM DESIGN

The primary reason for success of a good blending system is the selection of a good gas analyzer that can provide the outputs required in real-time. We identify the projects in two steps;

Step1: (one year ago till now)

Taking the samples and analysis it as off line by lab equipments. The Gas Chromatography (GC) analysis the gas each day and the ratio regulated by trim valves.

Step 2: (planned for 2016)

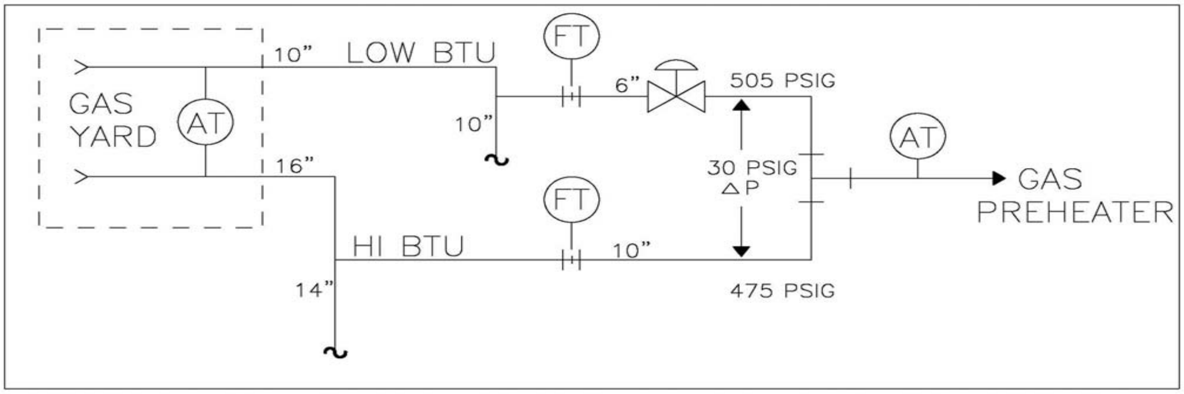
For this application, the COSA 9600 Btu Analyzer was chosen. This analyzer provides the following features important to this project:

Analyzer features fast response time and high accuracy

- Provides analog outputs for both Btu and Wobbe Index
- Contains no moving parts, hence low maintenance requirements
- Flameless, the gas/air mixture is burnt catalytically in an oven that utilizes a zirconium oxide Oxygen sensor in the oven
- Can be purged for use in Class 1 Division 1 or Class 1 Division 2 locations as defined in the National Electrical Code (NEC) ANSI/NFPA 70.
- Capable of analyzing multiple streams, thus reducing the number of analyzers required
- Accepts sample gas from a Genie Probe Regulator, whose features are:
    - Provides a representative gas sample
    - Removes all entrained liquids in a sample gas
    - Protects analyzers against liquid damage
    - Probe housing can be installed in a pressurized line
    - Housing includes a foot valve in its base so the probe can be inserted in a pressurized line

In addition to a fuel gas analyzer at each SRU blending station, the overall design includes a fuel gas analyzer at the gas yard. The gas analyzer utilized in the gas yard is the dual stream version, eliminating the need for multiple analyzers. The Hi Btu and Low Btu gas supply samples are switched to the analyzer. This analyzer is used to provide a feed forward signal to the blending stations. The analyzers at the discharge of the blending stations are used to bias the blending station for the proper blended gas introduced to the gas burners. These analyzers provide data to the DCS to control the flow of Low Btu gas. The blending station control logic resides in the plant DCS.

Figure 3 – Blending System Flow Diagram



The actual blending of the gases is accomplished in a "T" downstream of the Low Btu flow control valve. See Figure 3. In order to properly mix the fuel gases, a 30 psi minimum differential is maintained between the two gas supplies at the blending stations. The DCS sends a pressure set point to a PLC at the gas yard to control the Low Btu gas pressure at the blending station 30 psi higher than the High Btu gas pressure. See Figure 4. The blending stations are rather simple and do not require a valve in the Hi Btu fuel gas lines at the blending stations. These blending stations do not require an elaborate skid arrangement and can be fabricated in the field utilizing pre-fabricated spool pieces to maximize the use of existing fuel gas piping.

PROGRAMMING

Fuel gases with large percentages of an inert gas such as carbon dioxide will have a ratio of rich-to-lean flammability limits less than that of natural gas. Flammability ratios of less than 2.2 to 1 based on volume at standard conditions (14.696 psia and 59^{o}F), may experience problems maintaining stable combustion over the full operating range of the combustion burners. Combustion burners can operate with fuel gases having a very wide range of heating values, but the amount of variation that a specific fuel system design can accommodate is limited, usually ± 5%. The fuel nozzles are designed to operate within a fixed range of pressure ratios and changes in heating values are accommodated by increasing or decreasing the fuel nozzle area or the fuel gas temperature. Since changing the fuel nozzle area is difficult, the temperature of the fuel gas is generally changed to accommodate significant changes in the heating values. The combustion burners control system provides a signal to the DCS indicating poor combustion characteristics. Since, the intent is for the blending station to be capable of introducing as much of the low cost Low Btu gas as possible to the gas burners, the DCS first decreases the fuel gas temperature to improve combustion before reducing the amount of the Low Btu fuel.

We know that the maximum limit of the Low Btu fuel gas is a 50% ratio, but the minimum limit (low flow) is set by blending system characteristics. To ensure trouble free start-ups, plant Operations prefers to start the gas burners on Hi Btu fuel gas. Once the unit is online and operating reliability; at a given load, the Operator places the blending station in service.

The success of the blending station depends on the quality of the analyzer signals. If the blending station analyzer fails, the blending control is automatically, or by Operator action, placed on flow control and the Hi Btu gas remains on pressure control. If the gas yard analyzer fails, the station is automatically placed on flow control (Low Btu gas) and pressure control (Hi Btu gas).

The blending station logic configuration is programmed into the plant DCS. There is a small Allen Bradley PLC in the gas yard that the DCS interfaces with for data gathering and controlling the gas yard. The Control Room Operator HMI is used for Operator monitoring and control of the Blending Stations. Graphics were developed to provide the Operator a visual presentation of all the data related to the blending stations. The graphic shown below depicts only two of the four Sulfur Recovery units. The other two were added in the second phase of the project.

RESULTS

Our research of the Wobbe Index indicated that the preferred blending control mode should be based on the Wobbe Index. However, there did not appear to be any distinct advantage in using the WobbeIndex over the heating value or Btu. Since both Btu and Wobbe Index outputs are available from the gas analyzers, the logic configuration was developed such that the Operator could select either Btu or Wobbe Index as the basis for controlling fuel gas blending. This would allow the plant to determine which method gave them the best control of the blending stations.

During the start-up phase of the project, both methods of controlling the blending stations were tested. There were no significant differences found between controlling based on Btu or Wobbe Index. Because the Wobbe Index is incremented in finer divisions, one would expect that finer blending control could be obtained, but for this application, very fine adjustments to the blending ratio are not necessary. The Low Btu gas on flow control is the default blending control method. This method was also tested, both as an Operator selected operational mode and as a default control mode when one of the analyzers fails.

The plant is currently operating on flow control mode, selected by the Operator, because the Low Btu gas supplier cannot yet provide enough gas to justify blending based on Btu or Wobbe Index.

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