Optimization of fired heater control utilizing the residual oxygen measurement principle

©Hobre Instruments BV - A.J. Mouris
November 2009

Background

Tighter emission regulations and high energy costs pose new challenges to control systems for fired heaters. Rapid changes in fuel gas heating value, air demand and composition are typical for applications in oil refineries, chemical plants and many other sites. Traditional feedback control based on temperature and stack oxygen and combustibles measurement is not fast enough to deal with fast changes effectively. This shortcoming is typically addressed by controlling the excess air set point with a certain safety margin. Unfortunately, whereas this approach prevents the emission of unburned components, it increases the CO_2 emission due to poorer fuel economy: air is heated unnecessarily and heat transfer efficiency is reduced. Moreover, NOx formation is promoted as a result of the higher oxygen level in the combustion process. For these reasons feed forward control of the air/fuel ratio is gaining more attention. Proper selection and installation of the fuel gas property analyzer and using the right control parameters is essential to get the best results.

Control parameters

Control system philosophy of fired heaters varies depending on the requirements and design of the heater or boiler. However, in all cases the thermal load of the furnace and the air/fuel ratio are two critical parameters that must be monitored and controlled.

Control of the heat load

Depending on the control system design the Wobbe Index, the heating value and gas density may be required as input(s). The heating value is the amount of heat produced when a unit volume or mass of fuel is burned stoichiometrically. The higher heating value includes the heat of condensation of the water formed in the combustion process, the lower heating value does not. The Wobbe Index (defined as the heating value of a gas divided by the square root of its' specific gravity) is a measure of the interchangeability of fuel gases when introduced into a heater via a burner with a fixed differential pressure. Two gases with the same Wobbe Index will deliver the same amount of heat into a combustion process per unit of time regardless of the composition. To clarify the concept consider following fuel gas cases:
Case 1. 40% methane and 60% hydrogen (by volume)
Case 2. 58% methane and 42% nitrogen
The lower heating value by volume of these two gases is the same, i.e. 20.82 MJ/Nm3. The Wobbe Index however is 40.55 MJ/Nm3 for mix number 1 and 24.39 MJ/Nm3 for mix number 2! This means that the amount of heat delivered per unit of time through the same burner will be 40% lower in the second case!

Control of air/fuel ratio

The combustion air flow supplied to an industrial furnace is typically linked to the fuel gas flow. In smaller installations this may just be a mechanical link, in larger installations air and fuel gas temperature and pressure are taken into account. If large fluctuations in the fuel gas composition are expected, the signal from a Wobbe Index analyzer or calorimeter is used for correcting the air/fuel flow ratio. Typically the assumption is that there is a proportional relationship between heating value and air demand. Whereas this is correct for hydrocarbon bases fuel gases like natural gas, for fuel gases containing significant percentages of

hydrogen, olefins, carbonmonoxide and/or oxygen this approach fails. Take for example following fuel gas cases:
Case 1: 100% hydrogen
Case 2: 88,5% methane and 11,5% nitrogen
The Wobbe Index for both gases is the same, i.e. 40,9 MJ/Nm3. The Combustion Air Requirement Index (CARI) however, which is defined as the stoichiometric air demand divided by the square root of the relative gas density, is 9.0 for Case1 and 10.9 for Case 2. This means that if the fuel gas composition changes from hydrogen poor to hydrogen rich composition the excess air may be controlled 20% too high! Please note that in stead of Wobbe Index and CARI a similar case can be construed for heating value and air demand, this follows from the definitions:

$$\text{Wobbe Index} = \text{Heating Value}/\sqrt{(\text{Specific Gravity})}$$

$$\text{CARI} = \text{Air demand}/\sqrt{(\text{Specific Gravity})}$$

Residual oxygen content analysis

In a typical residual oxygen content analyzer sample gas is continuously mixed with combustion air under controlled conditions followed by catalytic combustion in an electrically heated furnace. The residual oxygen content in the flue gas is measured with an accurate and reliable zirconium oxide sensor. In the control unit following combustion parameters are calculated from the oxygen signal and the (optional) density signal: Wobbe Index, Combustion Air Requirement Index (CARI), Calorific Value (or BTU) and specific gravity.

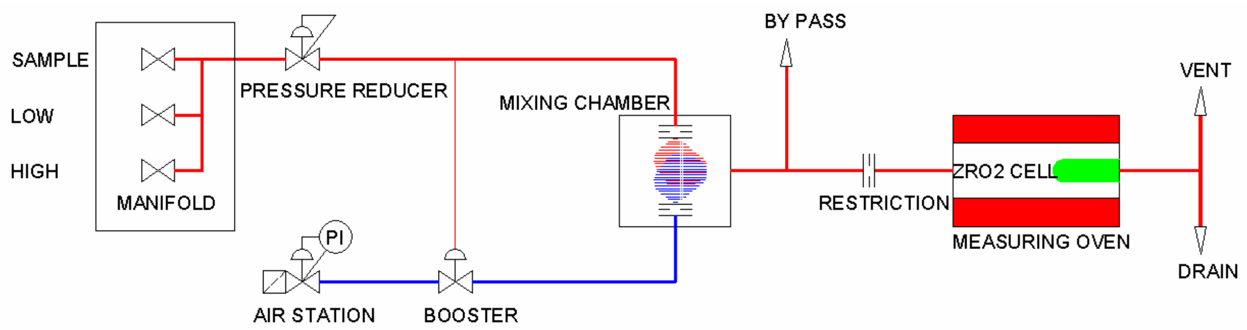

Fig.1 Schematic typical residual oxygen content analyzer

The concept was first explored in the USA but the European gas distribution companies Gaz de France and Dutch Gasunie have really optimized the benefits. Their prime objective was to develop an instrument that was as fast as possible for optimizing natural gas blending operations to meet grid entry specifications. However, in the last decade the technology has also proven to be very suitable for fuel gas, vent gas, flare gas, biogas and steel plant off gas applications.

Instrument installation and selection

When it is decided to install an analyzer for measuring the heating value and/or Wobbe Index for feed forward fuel and air/fuel ratio control, following requirements should be fulfilled:
1. The analyzer should be as fast as possible.
It makes no sense to install a calorimeter with a 20 seconds response time if changes occur within seconds. The WIM Compas F has a response time of less than 5 seconds for a 90% response to a step change in sample composition - lag or "dead" time included.
2. Signal noise should be as low as possible.

High signal noise levels will require smoothening of the signal, typically by averaging. As a consequence the response from the control system to a step change will be slower. The WIM Compas F has a repeatability of 0.05% of measured value!

3. Local installation close to sample tap point.

Ideally the fuel gas heat value and air demand signal should be available before the fuel gas leaves the burner tip. This means that the travelling time of the fuel gas from sample tap point to the burner should be longer than the travelling time from sample tap point to the analyzer *plus* the analyzer response time. The WIM Compas F can be installed outdoor in hazardous area as close as possible to the sample tap point.

4. The sample handling system should have minimal internal volume.

Although a fast loop theoretically can compensate for any dead volume in the system this will result in excessive venting and/or flaring of fuel gas. The WIM Compas F has an integrated sample conditioning system and requires no additional external sample handling.

5. A combustion air requirement signal should be available.

As outlined above the heating value or Wobbe Index can be poor indicators for the air demand in fuel gas applications. The WIM Compas F is based on the residual oxygen content principle and stores separate calibration lines for Wobbe Index/Heating Value and CARI/Air Demand.

6. Rangeability of the analyzer should match all possible cases

Typically the analyzer should be able to handle large fluctuations in the fuel gas composition. The WIM Compas F can analyze fuel gases of all possible compositions in the 0-120 MJ/Nm3 (0-3000 BTU/SCF) range without the risk for flame-out or overheating.

7. Thorough application review

Each application is different and proper review is essential. Issues that should be considered include:

- Calibration gas selection - the "right" calibration gases give best accuracy in all cases, do not contain many components (not more than 2 preferably) and allow sufficient filling pressure even when ambient temperature may be low.
- Parameters measured - For the WIM COMPAS, CARI and Wobbe Index are standard outputs; Specific Gravity, Heating Value and Air Demand are standard options.
- Fuel gas hydrocarbon and/or water dew point - It is not uncommon that fuel gas is taken form a knock-out vessel. Care must be taken that no condensation takes place in sample lines or inside the analyzer. The WIM COMPAS sample handling compartment is heated to 60°C as a standard but can be heated up to 150°C if required.
- Sulfur content and presence of other corrosive components - Wrong material selection can rapidly corrode and clog an analyzer. Proper component selection and analyzer design enables continuous operation even when more than 10% sulfur is present!
- Overall response time - A lag time analysis from sample probe tip to analyzer signal output should be provided to ensure compliance with the requirements. This is especially important when high pressure gas lines must be analyzed.
- Ambient temperature range and hazardous area certification requirements - Must of course be considered. The WIM COMPAS F is certified for ATEX Zone1 and FM Cl.1 Div2. Its' epoxy coated stainless steel enclosure is IP65/NEMA4x design and suitable for hostile environmental atmospheres

Literature:

- API RP 556, First Edition, May 1997
- CONTROLLING FIRED HEATERS, © Walter Driedger, P. Eng., 2000 May 20.
First published in Hydrocarbon Processing, April 1997.
- Physical Properties of Natural Gases, N.V. Nederlandse Gasunie, 1980