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Coriolis Meters Improve the Efficiency of Hydrogen Production Process

Introduction

Cost-effective production of hydrogen has become a significant concern in the refining industry. The need for deeper hydrotreating and for the processing of heavier and higher sulfur crude slates is driving the demand for reliable hydrogen and steam availability.

Precise control of the steam-to-carbon (S/C) ratio in the hydrogen production process can have a major impact on the efficiency of the facility. Running the S/C ratio closer to target and running the facility consistently can significantly reduce operating costs, with a potential payback period of less than a week. Possible results from replacing the existing hydrocarbon measurement technology with Micro Motion® include:

- Decreased capital investment for new units
- Decreased maintenance costs
- Decreased energy costs
- Increased safety
- Increased throughput

Background

Steam Methane Reforming (SMR) technology is the primary process for high-purity hydrogen production. This process involves introducing preheated natural gas (or another hydrocarbon stream such as Refinery Off Gas) with steam across a catalyst to produce a 75-80% hydrogen stream composed primarily of hydrogen and carbon monoxide, then purifying this effluent, using either an MEA scrubber or a PSA unit, to produce 99%+ hydrogen. See Figure 1.

Two reactions occur in the SMR:

- First, the reforming reaction that converts hydrocarbon feedstock to carbon oxides and H_2

$$C_nH_m + nH_2O + \text{heat} \longrightarrow n\,CO + (n/2 + n)\,H_2$$

- Second, the shift reaction that converts CO produced during the reforming reaction to carbon dioxide and additional H_2

$$CO + H_2O \longrightarrow CO_2 + H_2 + \text{heat}$$

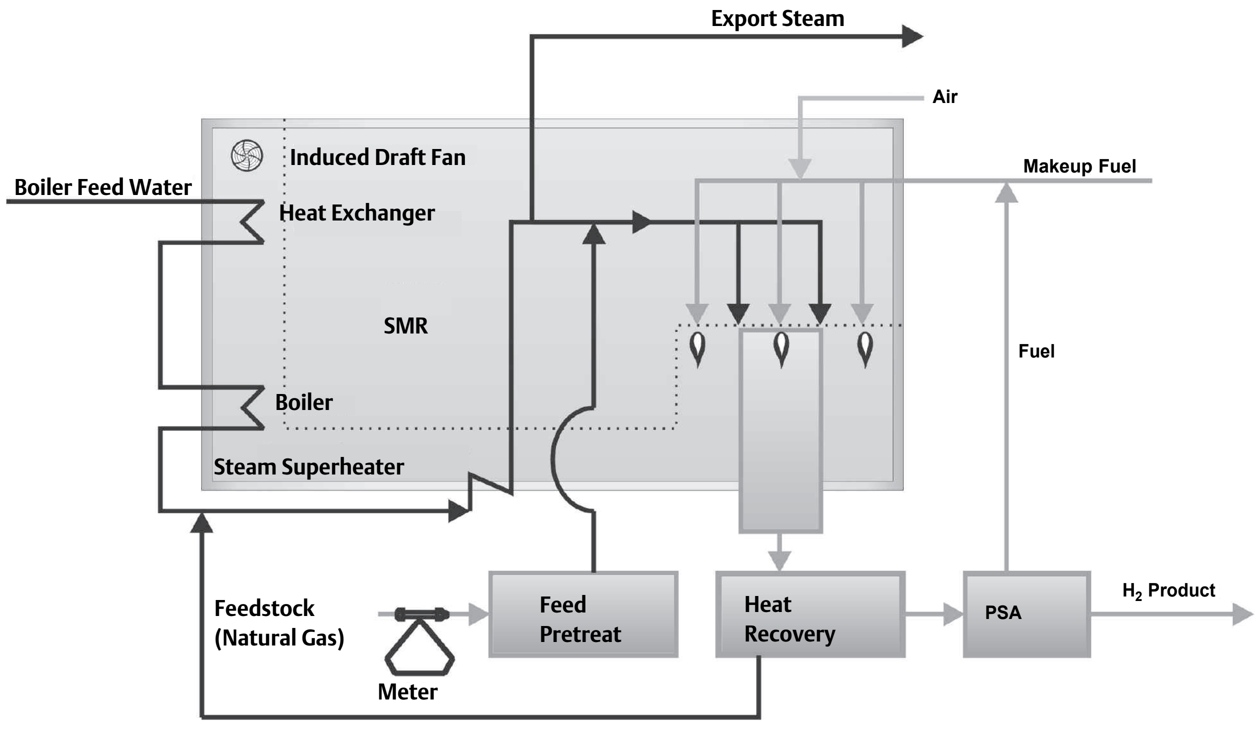

Figure 1. Hydrogen Production in SMR Unit

The S/C ratio is one of the most important process measurement areas for an SMR. The minimum S/C ratio is dependent on the feedback, but must typically be above 3:1 to prevent carbon deposit formation on the catalyst. For insurance, most hydrogen producers run the S/C ratio between 3.2:1 and 3.7:1. Any change in the composition of the feedstock requires a corresponding change in the amount of steam, and this is where the difficulty lies.

In most SMR units, the S/C ratio is controlled using differential pressure measurement, corrected for temperature and pressure, plus an analyzer (typically a gas chromatograph or a mass spectrometer) to calculate the molecular weight (MW) and determine the carbon weight contribution of the feed stream. This approach is expensive both in terms of the initial capital cost of the instruments and analyzer and in terms of the operations and maintenance required for the analytical devices.

This technology has additional drawbacks:

- Because calibration of the dP meter is highly dependent on fluid properties, changes in the composition of the feed stream will be a significant source of error.
- If the composition of the feed stream changes rapidly, response time problems can occur.

As a result, many operators run their SMR units at S/C ratios considerably above target, to provide a margin of safety that can compensate for changes in composition.

An alternative to the volumetric flow measurement and analical devices is to use a Micro Motion Coriolis meter to measure the mass flow of the gas directly and to ratio the steam accordingly.

Accuracy of Orifice / dP Technology

Orifice plate differential pressure technology is well understood and has an expected error of 1-2% (the orifice plate itself has an inherent error of 0.5% as a starting point) if the measurement is compensated for temperature and pressure, as is typical in custody transfer applications. Typical orifice plate installations for process quality metering will have even higher errors, as these systems are normally not temperature-or pressure-compensated. Composition changes in the fluid being measured will lead to further errors because the calibration is strongly dependent on the fluid properties.

If the hydrocarbon stream has a fairly constant MW, the mass flow can be estimated by assuming a fixed MW or density and applying temperature and pressure compensation to the orifice plate/dP transmitter installation.

If the MW of the hydrocarbon stream is not constant, an analyzer is required to determine the stream composition and MW. Minimum error of the volumetric meter, for changing composition of the process fluid, is 2%. The required S/C ratio must be calculated by extracting the carbon mole weight value from an analyzer. Mass spectrometers may be able to update this value every few seconds, while gas chromatographs can require up to 15 minutes to update.

Accuracy of Coriolis Technology

The new technology utilized in this application is a Coriolis mass flow meter from Micro Motion, who holds a patent on this application, US Patent No.: US 6,758,101 B2, titled "Steam to Carbon Ratio Control in Steam Reforming of Hydrocarbons."

Coriolis meters measure mass directly: the measurement is not affected by density or composition changes, and the calibration holds across all process fluids — liquid or gas. Micro Motion's ELITE® Coriolis meter has a rated flow accuracy of 0.35% on gases. Because the hydrocarbon string typically changes by 1 carbon per 2 hydrogen, the mass measurement from the ELITE meter can provide a very good estimate of the carbon weight for any hydrocarbon stream.

Accuracy of the ELITE meter was tested at a site where the composition of the natural gas stream changed significantly during the testing period:

- Methane range: 77.5% to 89%
- Ethane range: 6.8% to 15.23%
- Inerts:
  - Nitrogen fluctuated by +/- 0.185%
  - Carbon dioxide fluctuated by +/- 0.567%

An ELITE meter with a gas chromatograph was assumed to provide the most accurate data, so this technology was used as a reference for two test technologies: an orifice plate with a gas chromatograph, and an ELITE meter configured with a fixed MW value. The gas chromatograph was set to look for most hydrocarbons from methane to C_{6+}, plus CO_2 and N_2. The objective was to control the S/C ratio to within +/- 0.1.

During the two-month testing period:

- The maximum error of the ELITE meter with a fixed MW value was 0.02, compared with the reference technology.
- The maximum error of the orifice / dP system with the gas chromatograph was 0.2 compared with the reference technology — 10 times greater than the ELITE meter with a fixed MW value.

In these tests, no attempt was made to compensate for changes in the inerts. In production installations, testing is recommended to determine whether or not compensation for inerts must be implemented. For example, calculations performed during this study indicate that if the concentration of nitrogen changes by 3%, with a corresponding change in the methane concentration, the S/C ratio in this process will change by 0.1 points, and a nitrogen analyzer might be recommended.

Benefits

The economic benefits of tighter control of the S/C ratio are significant, both in terms of reduced fuel consumption and in terms of increased export steam credit. Reducing the variability in the S/C ratio by 0.2 points could increase plant efficiency by as much as 8 BTU/SCF of H_2 produced. With natural gas at $5.50 per MMBTU, an H_2 plant with a capacity of 80 MMSCFD would realize savings of close to $1.3 million a year.

Additional economic benefits of utilizing the Micro Motion meter instead of traditional measurement technologies include lower capital costs for new unit designs:

- Gas chromatograph analyzer and orifice plate technology: $50,000
- Mass spectrometer and orifice plate technology: $130,000
- Coriolis meter: less than $20,000

It is well recognized that gas chromatographs and mass spectrometers are expensive to maintain. In addition, when the analyzers are down for maintenance, the unit must run in a conservative, less efficient mode.

Conclusions

Tighter control of the steam-to-carbon ratio in the Steam Methane Reforming unit will result in significant increases in the efficiency of the unit. Coriolis direct mass flow technology allows the user to control this ratio more accurately, especially under changing conditions of the hydrocarbon feed stream. This significantly reduces fuel costs, equipment costs, and maintenance costs.

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