Originally appeared in:
HYDROCARBON PROCESSING®
August 2007 issue, pgs 72–72
Used with permission.
www.HydrocarbonProcessing.com

Coriolis flowmeters improve hydrogen production

Accurate steam-to-carbon ratio control provided efficient operation

W. HOGLEN, Air Products and Chemicals, Allentown, Pennsylvania, and **J. VALENTINE,** Emerson Process Management, Micro Motion Division, Boulder, Colorado

Refinery-based hydrogen production from natural gas (NG) is typically a challenge to make the most efficient use of resources to produce product at levels that help facilitate safe, steady and profitable refinery operation.

The recent application of Coriolis flowmeters in an innovative and patented Air Products and Chemicals process has greatly improved the ability to maintain efficient operation despite a common and longstanding hardship (Fig. 1). NG supplies vary in their composition. For some uses, this variation is of little or no consequence. However, until now it has been a cause of higher maintenance costs and reduced efficiency in hydrogen production. The new equipment and process have improved the ability to function at or near peak efficiency despite the inconsistent NG supply.

Hydrogen uses. Refineries need large amounts of hydrogen to perform several hydrocarbon processing duties. Recently, the largest consumer of hydrogen in refining is the process that removes sulfur from crude oil. Clean fuels laws regulate the amount of sulfur present in transportation fuels. For example, the permissible amount of sulfur in gasoline has fallen from 500 parts per million (ppm) to 30 ppm in recent years; similarly, diesel fuel could once contain 1,000 ppm, but can now contain only 15 ppm. Hydrogen reacts with hydrocarbon-containing sulfur to produce hydrogen sulfide (H_2S), removing one atom of sulfur for each reaction. Once separated from the hydrocarbons, the H_2S is further processed to form elemental sulfur.

Basic hydrogen production process. A reforming hydrogen plant is a discrete, autonomous system built and operated onsite that converts NG (or another hydrocarbon stream such as refinery off gas) and steam into hydrogen and carbon dioxide, with the reaction heat used to produce additional steam (Fig. 2).

The two reactions that occur in the hydrogen generation process are reforming, which uses steam to convert the hydrocarbons (methane, ethane, propane, and butane) to carbon monoxide and hydrogen and shift, which combines steam (some leftover from the reforming reaction) with the carbon monoxide to form carbon dioxide and hydrogen. Excess steam produced in the process is sold to the host facility.

FIG. 1 Using Coriolis meters improved the ability to maintain efficient operation.

The reforming reaction is:

Methane, $CH_4 + H_2O \rightarrow CO + 3H_2$

Ethane, $C_2H_6 + 2H_2O \rightarrow 2CO + 5H_2$

Propane, $C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$

Butane, $C_4H_{10} + 4H_2O \rightarrow 4CO + 9H_2$

The shift reaction is:

$CO + H_2O \rightarrow CO_2 + H_2$

While the shift reaction is the same regardless of the original chemical makeup of the NG, the amount of steam required for the reforming reaction can vary widely depending upon the number of carbon atoms per molecule of the gas (i.e., one molecule of steam is required for each carbon atom, but there can be from one to four atoms).

Traditional volume/analytical measurement. The traditional method for determining the NG carbon weight uses

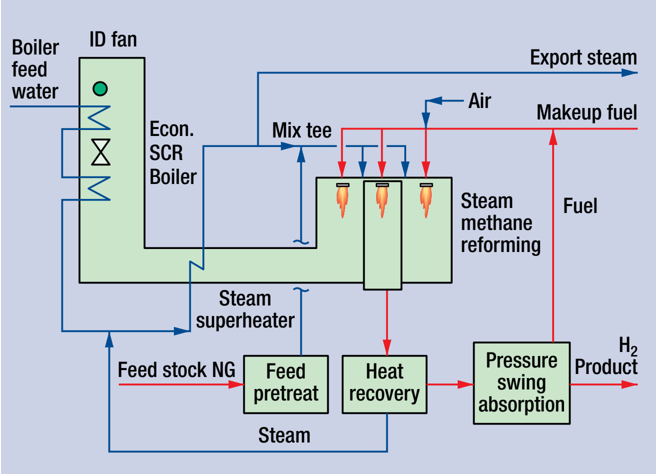

FIG. 2 A reforming hydrogen plant converts natural gas and steam into hydrogen and carbon dioxide.

a volumetric flowmeter (typically orifice plate, differential pressure) and an analytical reading from a gas chromatograph or mass spectrometer. Then calculations are performed to determine the actual mass flow, the number of carbon moles in the gas stream and ultimately the carbon mole flow. Once the carbon mole flow is known, the amount of steam required for reforming can be determined.

Using too little steam for the amount of carbon in the feed gas reduces catalyst life and the overall plant production level, and can lead to a plant shutdown, an extremely costly consequence.

Similarly, though not as acutely impactful, systematic use of too much steam leads to plant inefficiency, reduces the amount of export steam and increases the level of capital investment by requiring a larger plant than would be needed in an optimally efficient system. A large 80-MMscfd hydrogen plant could save one-half-million dollars per year with a 1.0–1.5 Btu per scf hydrogen efficiency increase given a cost of $6.50 per MM Btu of NG. For optimal performance, the ratio must be maintained to within ±0.1 of the ideal steam-to-carbon ratio.

Given the variable nature of the NG composition, the technology used to measure it must be accurate at all conditions. A sudden increase in the carbon mole flowrate must be matched by a precisely metered change in the steam rate. However, in the absence of an extremely accurate carbon mole flow measurement, an excess of feed steam is required to ensure that there is enough so that the steam-to-carbon ratio is greater than the target ratio, thereby avoiding a ratio detrimental to the process. The traditional system averages to only within approximately ±0.2 of the ideal steam-to-carbon ratio.

The capital investment in the traditional method can be very significant. Differential pressure orifice plate flowmeters are not particularly expensive, but quality analytical measurement equipment is. In addition, routine maintenance must be performed regularly to ensure reliable, accurate measurement results. When maintenance is being performed hydrogen production still must continue. However, without an accurate analytical measurement, the steam ratio must be artificially increased to overcome any unexpected spike in the carbon mole flow.

Using Coriolis flowmeters to measure actual mass flow. Coriolis flowmeters measure the actual mass flow by taking advantage of the Coriolis effect. Simply stated, the inertial effects caused by a fluid flowing through a tube are directly proportional to the mass flow of the fluid. In a Coriolis flowmeter, vibration is induced in the gas-filled flow tube(s), and then the mass flowrate is captured by measuring the difference in the vibration phase between one end of the flow tube and the other. Coriolis flowmeters are well-suited to virtually any process because they are very accurate, require little or no maintenance and have no moving wetted parts.

Because they measure mass flow directly and very accurately, and are less expensive to purchase and maintain, Coriolis mass flowmeters appear to be a good solution.

Impurities in the NG stream. One potential drawback to using the mass flow measurement alone for determining the carbon mole flowrate is the presence of other heavier elements in the NG supply. Typically there can be varying amounts of nitrogen (N_2) and carbon dioxide (CO_2) in NG supplies. By measuring mass alone, it is impossible to distinguish the N_2 and CO_2 from carbon.

Testing and operating facilities. Though Air Products has been using Coriolis flowmeters for a wide range of applications in recent years, the first attempts to use them on a hydrogen plant NG feed gas line were performed in 2004–2005 in a test facility in Wilton, England. In this case, a 3-in.-diameter Coriolis flowmeter was installed in the feed gas supply between the compressors and the feed preheater.

Test results from the Wilton, England, facility confirmed the viability of the Coriolis flowmeter measurement solution. Even though the NG methane concentration fluctuated from 78% to 89% and the ethane ranged from 7% to 15%, the maximum error in the steam-to-carbon ratio, calculated using the Coriolis meter's mass flow measurement and a fixed molecular weight value, was 0.02 units of steam. This is far better than the traditional method's ±0.2 and the requirement of ±0.1.

The facility also had a relatively stable percentage of the heavier inert gases: N_2 percentage varied by only 0.2% and CO_2 by 0.6%. While the mass of the inert gases had to be determined and calculated out of the steam-to-carbon ratio, the relative stability of the percentages ultimately eliminated any concerns. Had the variation been more volatile, the solution may have needed some additional considerations. For example, calculations performed during this study indicated that if the N_2 concentration changes by 3%, with a corresponding change in the methane concentration, the steam-to-carbon ratio in this process will change by 0.1 points, and a nitrogen analyzer might be recommended.

Two other facilities are now operating using the Coriolis meters to control the NG feed for the steam-to-carbon controls. One facility is located in Sarnia, Canada using three 6-in. meters and one in Edmonton, Canada using three 4-in. meters. The meters are in series and report their results using a 2-out-of-3 voting system. Having the three meters in series causes some pressure drop; however, doing so provides safety assurance and reliability in the event of a meter failure.

A test is underway in Convent, Louisiana, where a 6-in. meter is being used on a highly variable refinery offgas feed to the steam-to-carbon circuit.

Based on these results from above, the Coriolis mass flowmeter is well suited for this application for changing hydrocarbons in a NG stream. The flowmeters perform well for both the regulatory and shutdown circuits in a 2-out-of-3 voted circuit for an NG stream that has either a fixed inert stream or an N_2 concentration that does not fluctuate by more than 3% lower than its design basis. **HP**

Win Hoglen is a lead process controls engineer at Air Products and Chemicals. He has a patent for valve leak detection on PSA units and a white paper on the above subject. He has over 15 years of experience in the production of hydrogen. Mr. Hoglen has an MBA degree with a concentration in management of technology from Lehigh University and a BS degree in electrical engineering from Drexel University. Mr. Hoglen is a regular member of ISA and can be reached at hoglenws@airproducts.com.

Julie Valentine is the industry marketing manager at Emerson Process Management, Micro Motion Division. She holds several patents on applying Coriolis technology and has written numerous articles and white papers on the utilization of Coriolis technology within the refining industry. Ms. Valentine has a BS degree in chemical engineering from the Colorado School of Mines and is a member of the NPRA and AIChE. She can be reached at julie.valentine@emersonprocess.com.