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$_2$S), removing one atom of sulfur for each reaction. Once separated from the hydrocarbons, the H$_2$S 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.

The reforming reaction is:

\[
\text{Methane, } \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2
\]

\[
\text{Ethane, } \text{C}_2\text{H}_6 + 2\text{H}_2\text{O} \rightarrow 2\text{CO} + 5\text{H}_2
\]

\[
\text{Propane, } \text{C}_3\text{H}_8 + 3\text{H}_2\text{O} \rightarrow 3\text{CO} + 7\text{H}_2
\]

\[
\text{Butane, } \text{C}_4\text{H}_{10} + 4\text{H}_2\text{O} \rightarrow 4\text{CO} + 9\text{H}_2
\]

The shift reaction is:

\[
\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2
\]

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
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 stream-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.
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.