Never Say Never, North American GTL on the Horizon

Distributed plants enabled by microchannel process technology

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1. Background

Gas-to-liquids (GTL) is at its root an arbitrage opportunity. The process is a hardware solution that converts one commodity – natural gas – into another – petroleum fuels. When market conditions are favorable, oil prices are high and gas prices are low, the process can be a cash machine. While this is clear to any trader, few traders or others ever foresaw the conditions in North America being right for GTL. Three factors have changed the equation and now enable this arbitrage opportunity. First, the ability to tap abundant shale gas has caused a gas glut, keeping prices low. Second, unrest in Middle East and growing demand from China and India has boosted oil prices. Lastly, new technology is enabling attractive process economics for smaller scale GTL facilities. This paper will introduce one such technology – microchannel process technology – and describe its application to GTL.

2. Aims

This paper will inform the audience about microchannel process technology and its application to GTL. Microchannel technology and associated super-active catalysts offers a number of salient benefits that enable cost effective production of synthetic fuels from smaller-scale facilities. These include intensifying the key processes so that smaller, relatively light equipment can produce commercially significant quantities of ultra-clean synthetic fuels. Also noteworthy is the operational advantages offered by microchannel Fischer-Tropsch (FT) reactors, which possess the best attributes of fixed and slurry bed reactors as well as some unique advantages unto itself. This paper will also discuss the developmental status of the technology, highlighting the results from recent field demonstrations and an engineering study currently underway.

3. Methods

The gas-to-liquids (GTL) process is seen as an advantaged route for monetizing natural gas because it produces infrastructure compatible fuels. These fuels, which are one-to-one replacements for petroleum derived fuels, are produced in processes based on FT synthesis, which is named for its German inventors. The key components of the GTL process benefit from the process intensification offered by microchannel technology, resulting in smaller, less costly processing hardware; thus, enabling cost effective production of synthetic fuels from smaller facilities, appropriate for associated and distributed gas resources. The products from FT processes can be upgraded into diesel or synthetic paraffinic kerosene, or simply blended with crude oil for transport to the world market.

The GTL process consists of two or three major components, depending on the desired end product, as well as a number of supporting units. The first main component is a reformer to convert the natural gas into carbon monoxide (CO) and hydrogen (H_2), also known as synthesis gas or syngas. A handful of reforming technologies are on the market, but the most common routes are steam methane reforming (SMR) and partial oxidation (POX)/autothermal reforming (ATR). In a SMR reactors methane (CH_4) reacts with steam at high temperatures (typically >800°C) over a catalyst to produce the syngas. Heat for the highly endothermic SMR reaction is typically provided by combusting natural gas and tail gas from other parts of the process. The syngas resulting from SMR commonly has a H_2:CO ratio around 3:1, which too high for cobalt based FT reactors. This ratio can be adjusted by separating off some of the H_2 or using a reverse water gas shift reaction to adjust down to 2:1, which is ideal for cobalt based FT. POX/ATR reformers are simpler and use oxygen rather than steam as the oxidant. They can be tuned to produce syngas with a 2:1 ratio, however the need for pure oxygen limits siting options, notably offshore, and presents operational issues, especially for smaller scale plants.

The second major component is FT synthesis. This unit converts the syngas into long chain hydrocarbons by passing it over an iron or cobalt catalyst. The FT reaction operates best at elevated pressure (20-40 bar) and temperature (210-285°C). FT reactors come in two basic types – fixed bed and slurry bed. Fixed bed reactors have a solid catalyst that stays in the reactor. The catalyst in slurry bed reactors is suspended in a liquid through which the syngas bubbles. Slurry bed reactors and associated catalyst recovery systems are more complex, but have operational advantages, since they eliminate the need to shutdown the reactor to change the FT catalyst and have improved stability. However, slurry beds are challenged by the need to filter catalyst fines out of the product stream.

A third optional step in the GTL process is hydrocracking. The synthetic crude product from an FT reactor consists of straight-chain (paraffinic) hydrocarbons with 5 to 50 carbons or more. A substantial portion of FT products (waxes) are solid at room temperature. Using standard refinery hydrotreating processes, these waxes can be cracked into diesel and jet fuel, which are cleaner and in many ways outperform their petroleum counterparts. Alternatively, the additional upgrading step – and the price premium for synthetic fuels – can be forgone in favor of a less capital intensive process where the syncrude is blended into co-produced crude oil.

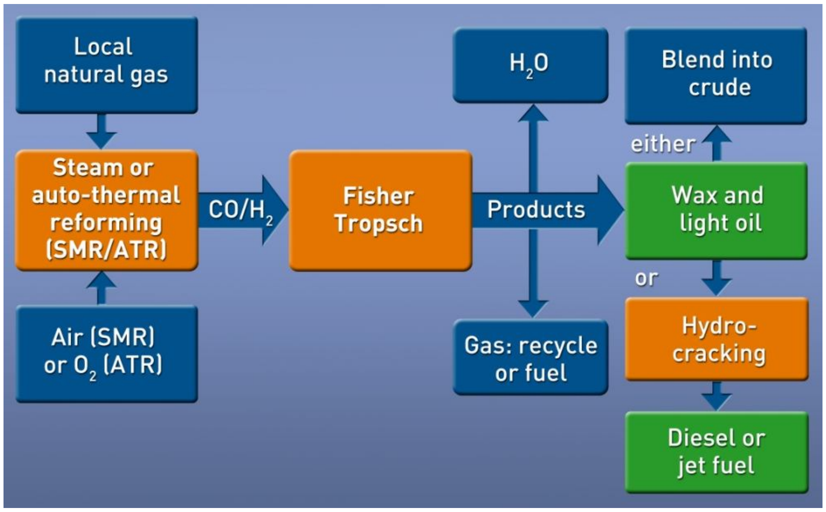

Figure 1. Gas-to-liquids process block flow diagram

Microchannel process technology offers process intensification, in the form of enhanced heat and mass transfer, to a wide range of chemical reactions, including SMR, FT and hydrocracking. Of these, the microchannel FT reactor is the most developed and will be the focus of this paper. Figure 2 below shows a schematic of a microchannel reactor, which has a fixed bed of catalyst packed into small passages and is cooled by water in cross-flowing channels.

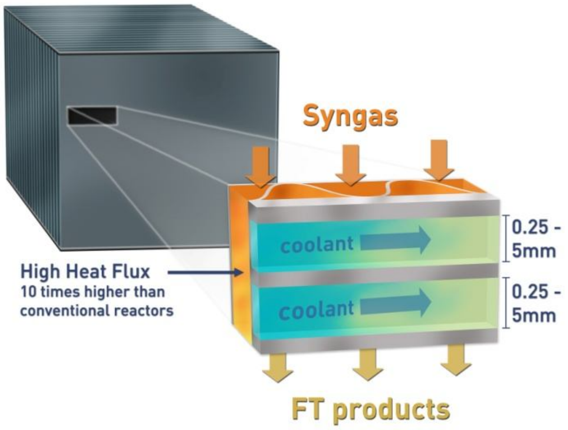

Figure 2. Microchannel FT Reactor Schematic

Described below are the advantages of the microchannel approach to FT and how it compares to convention fixed and slurry bed reactor.

1. <u>High per pass conversion</u> – A combination of microchannel technology reactor architecture with a highly active and selective catalyst enables over 70% per pass conversion of CO, compared to 50-65% in conventional reactors with cobalt catalysts; iron based catalyst have even lower rates per pass conversion. This high per pass

conversion minimizes recycle and allows for two-stage, no recycle configurations, which can greatly reduce capital and operating costs.

2. Robust to changing conditions/upsets – The improved heat transfer properties of microchannel architecture enables reactors to maintain a steady temperature, even during rapid changes in syngas composition. Conventional fixed bed reactors tend to cool rapidly or develop hot spots during process upsets. Due to the thermal mass of the slurry, slurry bed reactors also can be robust to upsets.
3. High product purity – The products of all FT processes is very high quality, but the paraffinic waxes from slurry bed reactors can be gray due to the presence of catalyst fines. This is due the attrition of catalyst particles suspended in the slurry and the failure of the catalyst recovery system to filter them out. Fixed bed designs, both conventional and microchannel, maintain all the catalyst in the reactor and produce very pure synthetic products.
4. High reactor productivity – Reactor productivity (bpd/ton) is an important metric for an FT process as it correlates with capital cost and can limit, or enable, process siting options. Due to improved heat and mass transfer performance, microchannel reactors achieve reactor productivities beyond that of commercially available fixed and slurry bed reactors, and they do so at far smaller scales. This enables cost effective synthetic fuel production from distributed scale facilities.
5. Modularity/Configuration flexibility – Due to FT reaction kinetics and the limitations of conventional reactor technology, traditional fixed and slurry bed reactors must be very large to achieve attractive process economics. The need for large reactors can limit process configuration options, especially in distributed plants. Smaller microchannel FT reactors are modular and can be arranged in multiple configurations (1-stage,1-stage recycle, 2-stage, etc.) to minimize capital cost, improve conversion or otherwise optimize plant economics.

4. Results

Compared to conventional tube style reactors, the reaction passages in microchannel FT have orders of magnitude smaller characteristic dimensions, which greatly improve heat and mass transfer. This reactor design enables optimal temperature control across the catalyst bed which maximizes catalyst activity and life, and leads to far higher reactor productivity. Microchannel FT reactors, utilizing an advanced catalyst (provided by Oxford Catalysts) have performed well in both lab and field tests. These reactors have operated steadily, achieving over 70% carbon monoxide (CO) conversion, minimal catalyst deactivation, and methane make below 10%. All of this was done in small scale reactors that match or beat the productivity of world-scale reactors.

An FT catalyst developed specifically for microchannel reactors is able to achieve catalyst productivities that are orders of magnitude higher than for more conventional systems (see Figure 3). In multiple tests, this catalyst has achieved productivities of more than 1500 kg/m^3/h. In contrast, conventional fixed-bed reactors typically operate at 100 kg/m^3/h, while slurry-bed reactors operate at 200 kg/m^3/h.

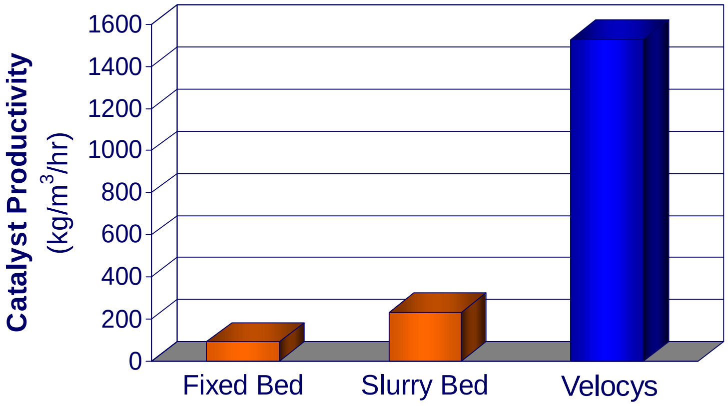

Figure 3. Fischer-Tropsch catalyst productivity comparison

High levels of catalyst activity are often associated with poor stability and rapid deactivation. This is not the case for the Oxford catalyst, which recently passed 9,000 hours of operation without needing to be regenerated or replaced. Data from this long-duration test is shown in Figure 4 below. Throughout the run, the temperature was incrementally increased to maintain 70% CO conversion. Despite this high conversion, the deactivation rate was very low, starting at about 0.08%/day at the start of the run and decreasing to 0.03%/day as it neared end of run conditions. Selectivity to methane was good, below 10% for most of the run, only increasing significantly during a process upset. During the entire run, which exceeded one year, no regeneration was needed.

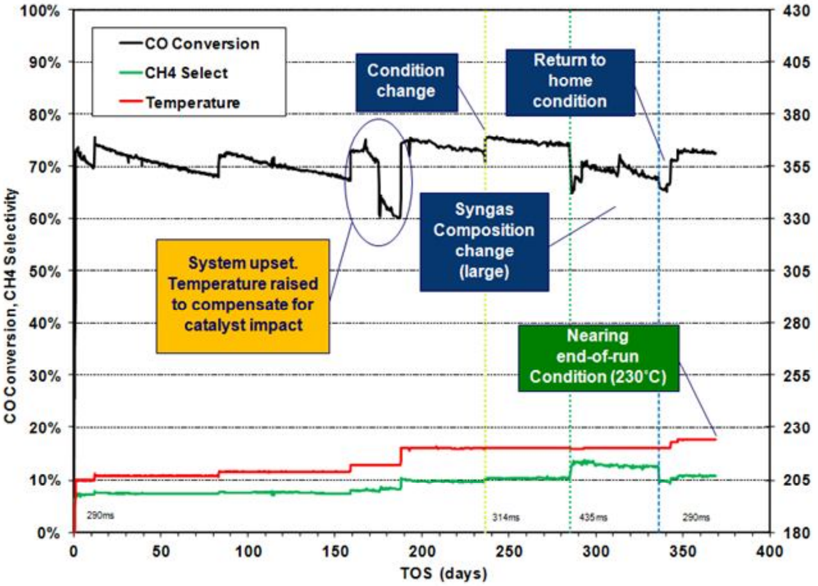

Figure 4. Results from long duration catalyst test

Like commercially available conventional fixed bed reactors, microchannel FT reactors are cooled by the partial boiling of water. However, the improved heat transfer properties of microchannel architecture make it possible to achieve near isothermal conditions, which maximizes catalyst activity while prolonging catalyst life. The image in Figure 5 shows the thermal profile of a microchannel FT reactor results. Across the entire device, which was a slice of a commercial scale reactor, the temperature varied by only +/- 2°C, a degree of thermal control previously thought only possible in a slurry bed reactor.

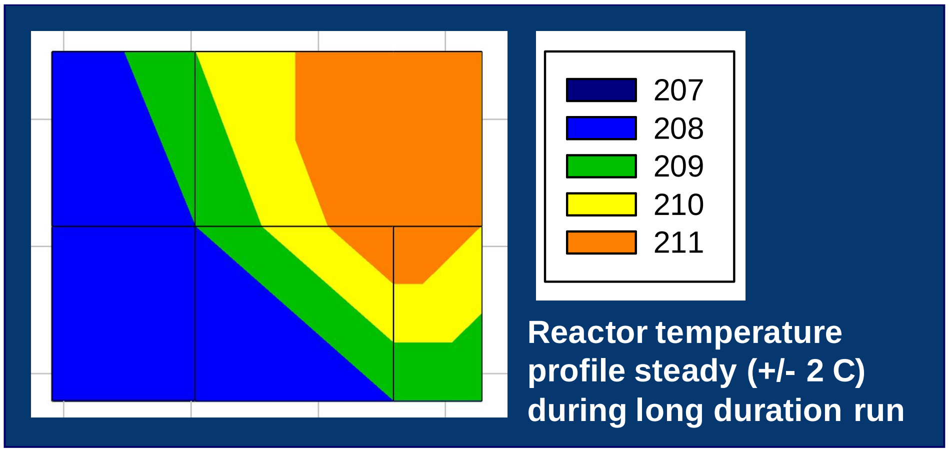

Figure 5. Microchannel reactors demonstrate excellent thermal control

In parallel with the technical efforts to design the reactors and catalyst, engineers have worked on manufacturing this new type of reactor using low cost, commercially available methods. Their efforts have resulted in the design of an initial commercial scale reactor with a nameplate capacity of 25 barrel/day (bpd). Multiple 25 bpd reactors have been built and sold to pioneering companies looking to demonstrate synthetic fuel processes. Figure 6 shows a 25 bpd reactor and a conceptual drawing of a 130 bpd reactor.

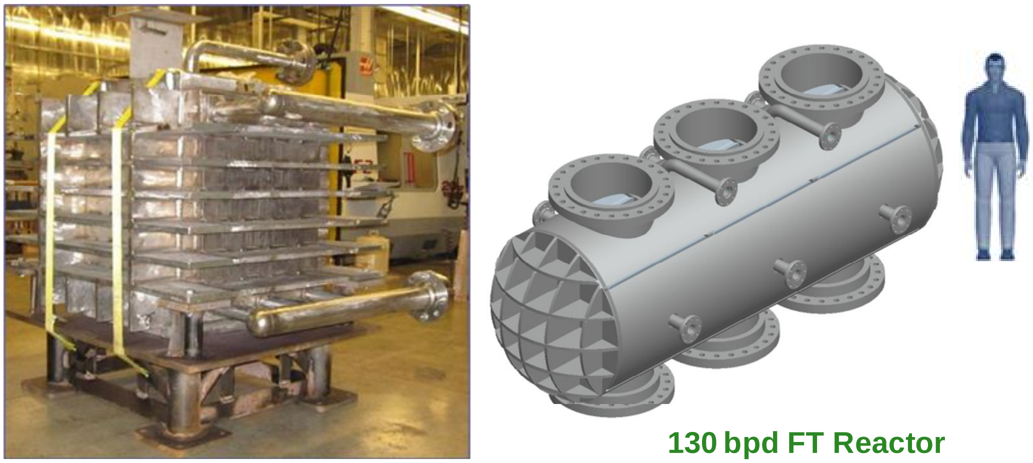

Figure 6. Fabricated 25 bpd microchannel FT reactor and 130 bpd concept

In addition, a 130 bpd microchannel reactor has been designed and will be built in 2012 This larger microchannel reactor is designed specifically for commercial scale GTL facilities in the

1,000 to 5,000 bpd range. Despite its relatively small size, the 130 bpd reactor has a reactor productivity, defined as bpd of production divided by weight of reactor, higher than the far larger reactors used in competing commercial FT processes, as shown in Figure 7.

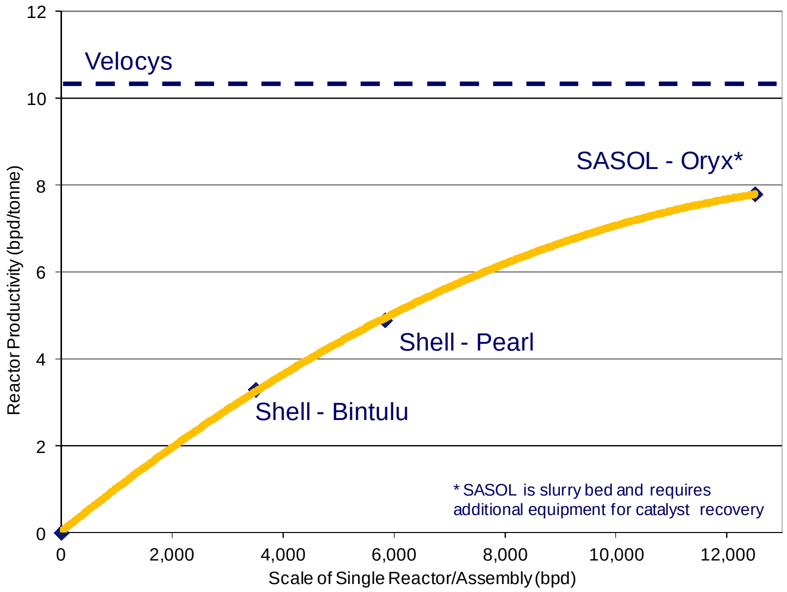

Figure 7. Microchannel Fischer-Tropsch technology offers improved reactor productivity

5. Summary/Conclusions

A sharp increase in unconventional gas production has created a large and sustained spread between the prices of natural gas and oil. This presents an unprecedented opportunity for GTL in North America. However, the distributed nature of shale gas and other unconventional discoveries requires that GTL solutions for this region be of a smaller scale than existing and planned plants used to exploit large stranded gas reserves, such as those in the Middle East and Africa. By intensifying SMR, FT and hydrocracking, microchannel process technology offers a solution that permits large-scale economics in smaller facilities; thereby opening the door to smaller scale GTL in North America and other locations around the world.

Positive results from experiments and field demonstrations have led to the first sales of commercial-scale, 25 bpd microchannel FT reactors as well as inclusion of the technology in multiple engineering studies for GTL plants, including some specifically for converting abundant North American shale gas into ultra-clean synthetic fuels.