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SPECIAL REPORT: Process Control and Information Systems
Ethanol-based production of ethylene, ethylene oxide (EO) and ethylene glycol (EG) dates back to the 1960s. The process is commercially proven and has been extensively applied industrially. Recent trends in small, purpose-built EO-only plants with no nearby source of ethylene, and the consumer push for bio-monoethylene glycol (MEG)-based green packaging, have created new opportunities for this once-thought-to-be-obsolete know-how technology.

**ETHANOL TO ETHYLENE**

Industrial ethanol dehydration catalysts were developed in the 1960s. By the 1980s, the first commercial ethanol-to-ethylene (E2E) process was licensed. While newer catalysts are touted to be more active than alumina-based catalyst, the proven alumina-based catalyst is very selective and is suitable for high, one-pass conversion applications that reduce capital investment and use a simpler process. The overall dehydration proceeds, then, according to the overall reaction:

\[
C_2H_5OH \rightarrow C_2H_4 + H_2O
\]

**FIG. 1** is a simplified diagram of the E2E process. In 2006, a 60-Mtpy E2E unit was licensed in Brazil. Later in 2010, three 60-Mtpy E2E units were licensed by TCI-Sanmar, in Port Said, Egypt. The first of these three units was successfully commissioned in March 2014 (**FIG. 2**). The TCI Sanmar plant uses imported ethanol feedstock, as it has no local ethylene sources to feed the downstream and existing vinyl chloride monomer (VCM) units at this site.

**INTEGRATED ETHANOL-TO-EO/EG TECHNOLOGY**

**FIG. 3** illustrates an integrated process for producing EO or EG. The bio-ethanol feed is dehydrated under appropriate conditions to produce ethylene. Heat integration is maximized to increase overall processing efficiency. Ethylene purification can accommodate either ethylene-specific applications or downstream uses such as EO/EG.

Especially in the case of EO/EG applications, it is imperative to either clean up the bioethanol or to purify the intermediate ethylene product to protect sensitive silver-based, high-selectivity EO catalyst. Most EO operators will use the most cost-advantaged ethanol. While cost-effective ethanol is adequate for fuel applications, it is a less-than-perfect choice for chemicals application, mostly due to the inherent and varying sulfur content of an agricultural-based feedstock. It remains to be seen what advantages clean generation II cellulosic-based ethanol will bring to the table.

**Industry applications.** As shown in **FIG. 4**, once ethylene has been produced, it can then be used for purified EO (PEO) and MEG production. The basics of EO and EG production are well known in the industry, and have been exhaustively documented in the past. The EO/EG process can be supplied on a flexi-feed basis to accommodate bio-derived ethylene or petro-based ethylene. This technology has been applied to some ethanol-based plants in China, which are now in commercial operation. China has been home to several recent ethanol-based projects, and nine different units have been licensed over the past five to six years. Four of the licensed units use flexi-feed, and three plants were commissioned between 2011 and 2013. At present, the process design package (PDP) for a green EO plant is being finalized for a US installation. The plant should be operational within the next couple of years.

**Process advantages.** The integrated process offers several processing advantages, such as:**

**FIG. 1.** A simplified diagram of the E2E process.

**FIG. 2.** The TCI Sanmar plant in Port Said, Egypt.
Petrochemical Update

- Single-pass conversion with no recycling of reactor effluents
- High ethylene yield

Ethanol-based production of ethylene, EO and EG dates back to the 1960s. The process is commercially proven.

- No requirement for intermediate ethylene storage
- Energy integration to minimize operating expense (OPEX)
- Flexi-feed option—the ability to switch between bio- and petro-based ethylene to meet varying market demand and feedstock pricing constraints
- Ability to produce excess bio-ethylene suitable as on-spec feedstock for other downstream products such as VCM and high-density polyethylene (HDPE)
- Fiber-grade MEG product that is indistinguishable from that produced from petro-based ethylene.

Installations. In 1986, the world’s first fully integrated ethanol-to-EG plant was licensed in India, and it became fully operational in 1989. Today, this plant is the world’s largest single-site producer of green MEG, with a capacity of more than 150 Mtpy. Ethanol at this plant is either made onsite by fermentation, or it is imported from Brazil, depending on product-specific requirements.

GREEN MEG DRIVERS

Green MEG is enjoying a huge upside in the market due to consumer demand for green packaging. For example, Coca-Cola’s PlantBottle™, packaging features a polyethylene terephthalate (PET)-based bottle that is about ⅔ bio-derived, which has been widely deployed in the US and internationally. Other consumer product companies are, likewise, making plans for their own green packaging. Green plastics have been used in automotive applications by companies such as Toyota, and green PE-film packaging has also had some limited commercial application. Expectations are that green MEG as used in PET applications, could reach as high as ⅔ of the total global MEG production by the year 2018, as shown in FIG. 5. Will this be a certainty? Not necessarily, but it surely is possible, given current trends within the industry. Other drivers include lack of local ethylene supply for small purpose-built plants, as well as the looming notion that EO transport by rail could eventually be severely limited.

Process economics. While, undoubtedly, bio-based ethylene cannot compete with present US Gulf Coast-based ethylene production costs, on a global basis, it can be competitive depending upon the local cost of ethanol production or the purchase price. Depending on the local ethylene cost, which, in

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<th>TABLE 1. Economics for a bio-ethylene plant</th>
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<td>Usages</td>
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<tr>
<td>Ethanol, Mt/Mt</td>
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<td>MP steam, Mt/Mt</td>
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<td>Power, kW/Mt</td>
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<td>Total, $/Mt</td>
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<td>Ethylene market price, $/Mt</td>
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1) Per Mt of ethylene
2) With ethylene purification
3) Ethanol cost = $525/Mt- $700/Mt

FIG. 3. Flow diagram of an integrated ethanol-to-EO/EG process.

FIG. 4. Flow diagram of an integrated ethanol-to-EO/EG and MEG production.

FIG. 5. Green MEG market potential, 2010-2018.
some imported cases, is quite expensive, the ethanol-based process with feedstock costs ranging between $525/ton and $700/ton can be competitive, as summarized in Table 1.

THE BIOREFINERY

The concept of a so-called biorefinery has been proposed for several years now. It is now gaining ground in various parts of the world, including North America. The new ethanol-to-EO/EG process is an ideal candidate for an ethanol-based biorefinery. It provides synergy with both upstream and downstream units in the refinery, and yields appreciable savings in both CAPEX and OPEX. An inherent capability of this process is its ability to provide for excess bio-ethylene that can expand the refinery’s product portfolio beyond EO and its derivatives to include other high-value products such as VCM and HDPE.

FIG. 6 shows a typical biorefinery as envisioned based on the fermentation of sugar cane. This same concept, however, could just as easily be imagined for ethanol made from second-generation cellulosic-based ethanol.

OUTLOOK

Ethylene and EO/EG from ethanol, while somewhat of a niche play, is enjoying renewed popularity in the industry due to local infrastructural issues, EO transport concerns, and the push for green packaging. The new integrated process is well proven and commercially demonstrated by a number of industrial applications. Economics can be favorable, using GEN I ethanol priced at $700/ton or less. It remains to be seen how much more competitive this process could be if there is breakthrough pricing for second-generation ethanol in the future. This flexible process can be the basis for conventional products such as ethylene, EO or MEG—or, in the alternative, it can be used as a link for many other industrially important derivative products, including alkoxylates, ethanolamines or glycol ethers. The process can be seamlessly integrated with other process units in a biorefinery with appreciable cost advantages.

ACKNOWLEDGMENT

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NOTES

1 Scientific Design’s (SD’s) ethanol-based process for producing ethylene, EO and/or EG dates back to the 1960s with their development of industrial ethanol dehydration catalyst. By the 1980s, SD had developed and licensed a commercial ethanol-to-ethylene process. In 1986, SD licensed the world’s first integrated ethanol-to-EG plant. Recently, with renewed interest in bio-based technologies, SD has licensed its integrated EO/EG process for nine plants in China and is in PDP development stage for one in US.

2 SD made the decision to sell the E2E technology to Chematur AB in 1988. However, in 2005, SD signed an agreement with Chematur to sub-license the technology and jointly collaborate on new projects.

3 SD integrated process for producing EO or EG.