Propylene

HIGHLIGHTS

Processes and technology status – Propylene is mainly a byproduct of two processes the steam cracking and fluid catalytic cracking (FCC). Due to high and increasing demand of propylene, the mentioned byproducts are not enough for the market and on purpose production technologies are developed as well such as propane dehydrogenation (PDH). Other main on purpose processes for propylene production are methanol to olefin (MTO), methanol to propylene (MTP) metathesis and Superflex technology. Moreover, bio- and CO_2-routs are green technologies for propylene production which are under development.

Cost – Various production routes impose different costs. Furthermore, feedstock costs play an important role on the propylene production specially in the case of PDH technology. Further details are available in this fact sheet for the main propylene production routes. For instant, price of PDH route is equal to 596.35 €$_{2007}$ /ton[1] of propylene [1].

Potential and barriers – Opportunities in front of propylene production are increase in propylene production and development of new feedstock resources such as shale gas in Europe. Weaknesses of propylene production plants are high feedstock and energy costs, high labor costs, high environmental and legislative cost. Moreover, threats ahead are imports of petrochemical derivatives, declining petrochemical production, closure of refineries and steam crackers.

Propylene – Propylene (C_3H_6) is one of the most important building blocks for the entire chemical industry and the raw material for plastic polypropylene, which is a common component mainly used in the automotive and textile industries, for plastic films for packaging and many other products.

The conventional propylene productions are byproduct streams from two chemical processes. The first one is the byproduct from the steam cracking of liquid feedstocks such as

[1] 817 USD$_{2007}$/ton of propylene. The values are converted from mean USD values to € in the reference year of 2007, based on 1 €$_{2007}$ = 1.37 USD$_{2007}$ [17]

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naphtha as well as gas oil and condensates to produce ethylene. The second source is byproduct from off-gases produced in fluid catalytic cracking (FCC) units in refineries.

The remainder of propylene is produced using on-purpose technologies such as propane dehydrogenation (PDH), methanol to propylene and olefin metathesis.

Process overview – There exist traditional and on-purpose methodologies for production of propylene. Currently, about 61% of propylene is produced in ethylene plants, 34% in petroleum refineries and less than 3% in on-purpose propylene-only production plants [2]. The supply percentage of propylene in 2007 are 63.3% from steam cracker, 27.9% from FCC unit, 4% from refinery splitters, 2.6% from PDH process, 1.9% from metathesis and 0.3% from other routs [3].

Production of propylene in Belgium

Propylene is being produced in Belgium at three different refineries/Petrochemicals namely the Total located in Antwerp, BASF in Antwerp and Borealis in Kallo. The overall produced propylene in Belgium was 1805000 tons/year by 2013 [4].

1- Propylene as by-products

1-1- By-product of steam cracker

The thermal steam cracking reaction is carried out in cracking furnaces at more than 1073 K as shown in figure 1. The steam cracking process suffers from coke formation and it significantly contributes to the emission of CO_2 into the atmosphere.

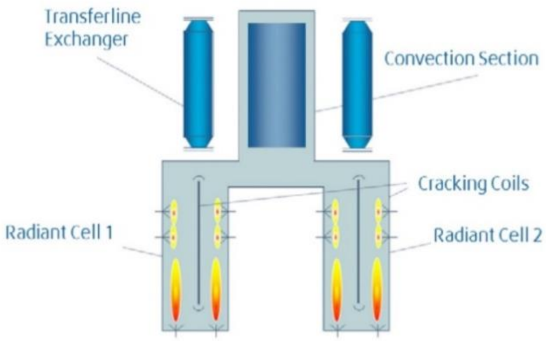

Figure 1. Cracking furnace [1]

Propylene yields at steam cracking vary between 1.5–18%, depending mainly on the feedstock and operating conditions [5]. 70 % of the Propylene was produced via steam cracking in 2007 [1].

The feedstock consumption for steam cracking are listed in table 1 based on the ethylene production [19]. The required feedstock for the naphtha-based steam cracker is reported to be 2.7 $t/t_{Ethylene}$ [19]. Moreover, yields of the propylene at steam cracker per ton of ethylene is 0.53 $t_{Propylene}/t_{Ethylene}$ [6]. Therefore, steam cracker naphtha input fo propylene production is equal to 5.09 $t_{Naphtha}/t_{Propylene}$.

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Table 1. Feedstock consumption for steam cracking production [19].

Steam cracking	Feedstock	$t/t_{ethylene}$
Ethane based	Ethane	1.2
Gas oil based	Gasoil	4.0
Naphtha based	Naphtha	2.7

Naphtha-based steam cracking needs 44 $kWh/t_{ethylene}$ electricity, ethane-based 140 $kWh/t_{ethylene}$ and gasoil-based 300 $kWh/t_{ethylene}$ [6]. Total energy consumption for ethane-based steam cracking is assumed to be 20.5 $GJ/t_{ethylene}$, for naphtha-based to 12 $GJ/t_{ethylene}$ and for gasoil-based to 25 $GJ/t_{ethylene}$ [6]. Moreover, total energy requirements of naphtha-based propylene production is reported to be 15.395 $GJ/t_{propylene}$ [7].

1-1-2- Electrification of steam cracking

Electrification can reduce CO_2 emission from steam cracker up to 90%. BASF expects the development of the first electrically heated cracking furnace by 2025 [8]. The innovative technologies of electrification are coil surrounding tubes for heat generation, and the Roto Dynamic Reactor (RDR) supplied by an electric motor [8].

1-1- By-product of FCC

A large proportion of Europe's propylene demand can be satisfied by steam cracking, but the rest is supplied from extraction from refinery Fluidized Catalytic Cracker (FCC) off gas [6] as shown in figure 2. Emission at FCC unit is related to the coke generation on catalyst which contributes to average 19% of $CO_{2,eq}$, for worldwide operations as it is released in 2000 [9].

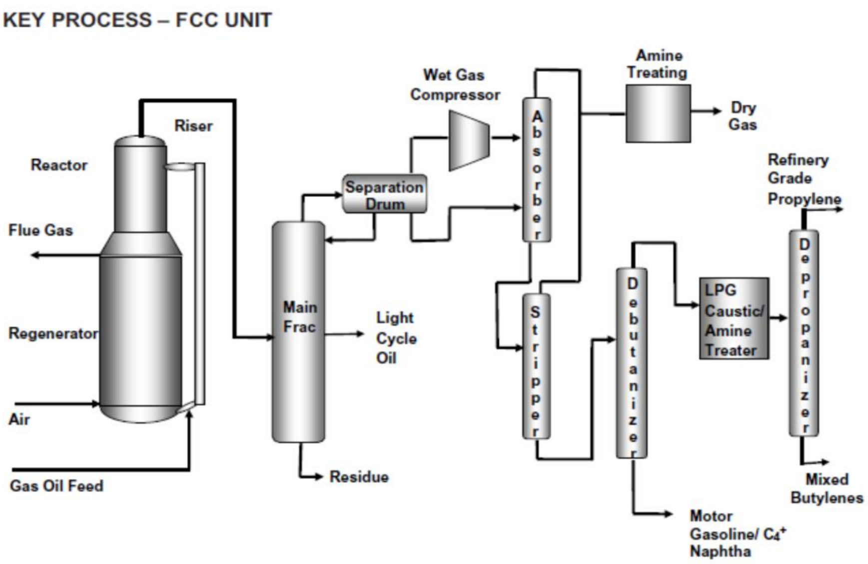

Figure 2. Fluid Catalytic Cracking BFD [10]

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2- On-purpose propylene production processes

2-1- Propane dehydrogenation (PDH)

PDH reaction, as shown in Eq. (1), is normally carried at high temperature with a relatively low pressure and in the presence of either a Platinum (Pt) or a Chromium (Cr) catalyst to achieve a reasonable conversion of propane into propylene.

$$C_3H_8 \rightarrow (Catalyst + Heat) \rightarrow C_3H_6 + H_2 \qquad \text{Eq. (1)}$$

The reaction of propane to propylene is endothermic in nature. Hence, firing of heaters are required to heat the process gas to roughly 600 °C to maintain catalyst activity and increase conversion. Propylene production rate is reported to be 1MT/ 1.2 MT propane feedstock for a typical OLEFLEX unit with platinum based catalyst ($1MT_{Propylene}$ / $1.2\ MT_{Propane}$).

Total energy requirements of a conventional PDH plant is reported to be around 0.145 kW for 1 kmol/h of feed [11] which is equal to 11.84 $GJ/t_{propane}$. Moreover, toal energy requirements of MTP based on propylene production is reported to be 2.502 $GJ/t_{propylene}$ [7]. The initial investment cost of PDH plant is 574.86[2] $€_{2015}$/t [12].

Three major greenhouse gas emission sources have been identified in the PDH process:

1. Natural gas combustion
2. Electricity consumption
3. Burning/flaring of waste streams

Emission Factors for Natural Gas Combustion for CO_2: 1.92[3] (t_{CO2}/t_{NG}[4]) [13]. For a plant with 30 year [12] life, the CO_2 emission coefficient is reported to be 0.81 (t_{CO2}/t) [12].

Borealis was producing propylene by conversion of propane at the dehydrogenation unit located in Kallo (Antwerp). The rate of product was 480,000 tons per year in 2003 [14].

2-2- Methanol to olefins (MTO) and methanol to propylene (MTP)

Total has developed olefin cracking process (OCP) in conjunction with UOP to boost further propylene which takes the heavier olefins from the MTO unit and converts them into lighter olefins, in particular propylene. The integrated MTO/OCP

[2] 1 $€_{2015}$ = 1,11 $\$_{2015}$ [17]
[3] 120,000 lb/scf, 1 Pound per cubic foot is approximately equal to 16.01846337 kilograms per cubic meter.

[4] NG = Natural gas

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(Methanol to olefins /olefin cracking process) process, which is being tested in a pilot plant in Feluy, Belgium, produces significantly more propylene than ethylene.

2-2-1- Significant Differences between MTO and MTP

MTO is designed to produce mainly ethylene as well as propylene while MTP output is mainly propylene and a smaller amount of gasoline. Moreover, the MTO uses a fluidized-bed reactor and MTP uses a fixed-bed reactor. The other important difference between the two processes is the feedstock. Plus, MTO can use crude methanol while the methanol for MTP has to be purified prior to the reaction. MTO and MTP process costa depends highly on methanol price. Figure 3 compares costs of propylene production through different technologies [7]. For the MTO and MTP processes, the CO_2 emission is reported as 13.4 and 12.7 ton/ton product respectively [16].

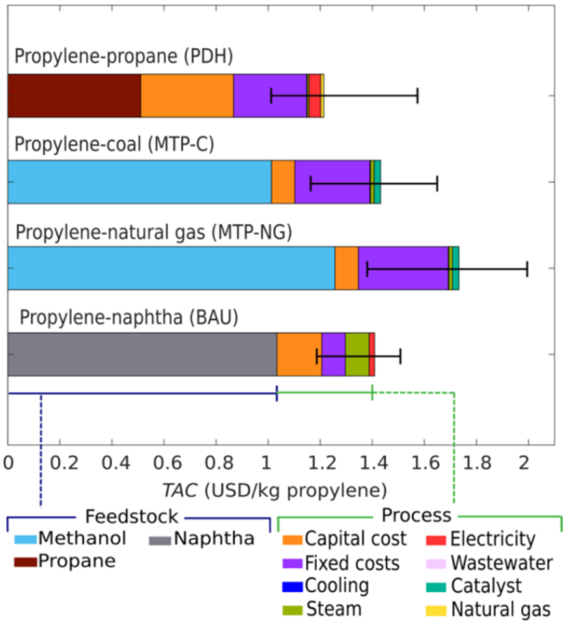

Figure 3. Total annualized cost (TAC) for each process alternative [7]

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Table of summary

Table 2. Summary table, key propylene data

Main production methods	Supply percentage in 2007	Feedstocks	Propylene yield
By-product from **steam cracker**	63.3 %	Naphtha, LPGs, gas oil	1.5–18 %
By-product from FCC	27.9%	Distillate fuel oil	25 - 40 %
PDH	2.6%	Light hydrocarbons - propane	35-40 %
MTP	- **	Purified crude methanol	50%
Energy requirements based on the type of feedstock	**Electricity**		**Total energy consumption**
Steam cracker (Naphtha-based)	44 ($kWh/t_{ethylene}$)		120 ($GJ/t_{ethylene}$)
FCC	1.7 $kWh/t_{propylene}$		0.95 $GJ/t_{propylene}$ fuel
PDH	1.843 $kWh/t_{propylene}$		10.35 ($GJ/t_{propylene}$)
MTP	NO ***		13.12 ($GJ/t_{propylene}$)
Costs			
Steam cracker	1230 ($€_{2020}$ /$ton_{propylene}$)		
FCC	- ****		
PDH route	574.86 ($€_{2015}$ /$ton_{propylene}$), 1053 ($€_{2020}$ /$ton_{propylene}$)		
MTP	1560 ($€_{2020}$ /$ton_{propylene}$), 10.35 ($GJ/t_{propylene}$)		

* Demand was growing faster than production in recent years and on-purpose production methodologies are required to fill the gap. Hence, the exact supply percentages via various propylene production methodologies are not available.

** New technology (MTO/MTP applications are gaining momentum and will fill the demand gap).

*** On-site electricity production is included which results in “No extra electricity demand” [7].

**** There is not cost data available for FCC unit based on the propylene production. Total capital cost for FCC unit construction is[5] 342.34 $MM€_{2015}$

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[5] The values are converted from \$ to € based on 1 $€_{2015}$ = 1,11 $\$_{2015}$, MM refers to million

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