ENGINEERING PRACTICE

VOLUME 10 NUMBER 43

MARCH 2024

IACPE

INTERNATIONAL ASSOCIATION OF CERTIFIED PRACTICING ENGINEERS

WWW.IACPE.COM

In This Issue

Volume 10 | Number 43

SPECIAL FEATURES

04 **Current New Carbon Footprint Fuels and Future Generation of the Global Bunkering Fuels (Sustainable Decarburization Approach)**
Hamid Reza Seyed Jafari, Babak Danesh, Ms.Esra Kayhan, Seyed Mohammad Reza Seyed Jafari

11 **The BTX Market as Alternative to Reduce the Exposure of Down-stream Players to the "Red Ocean" of Gasoline Market**
Dr. Marcio Wagner da Silva

27 **Concrete Coating for Natural Gas Pipelines**
Jayanthi Vijay Sarathy

31 **Design Guidelines For Propylene Splitters Efficiencies**
Karl Kolmetz CPE—KLM Technology Group
Contributing Authors: Timothy Zygula, Andrew Sloley, Randy Miller, Brian Clancy-Jundt, Daniel Summers

40 **View from Rock Bottom**
Ron Cormier

Current New Carbon Footprint Fuels and Future Generation of the Global Bunkering Fuels

(Sustainable Decarburization Approach)

Hamid Reza Seyed Jafari, Babak Danesh, Ms.Esra Kayhan,
Seyed Mohammad Reza Seyed Jafari

Introduction

Considering that about 2.2% of the total emission of carbon dioxide (as the main harmful greenhouse gas) in the entire global transportation industry and the statistics of 2022 were related to the maritime field (the total emission of carbon dioxide released at this year is 36.6 billion tons) .The International Maritime Organization (IMO) has been under a lot of pressure from international organizations and institutions supporting the environment to take action to reduce the increasing trend of the world's seas and oceans in the field of managing pollutant and greenhouse emissions caused by non-renewable fossil oil products. Note that more than hundreds of thousands of small and large passenger, commercial and fishing vessels are active in the world's waters, which introduce a significant amount of CO2, SOX, NOX and other pollutants only into the atmosphere.

It should be noted that the emission of sulfur dioxide gas in 2010 was about 10 million tons. Therefore, in the last few years, the United Nations International Maritime Organization (IMO)has decided to establish serious and strict regulations and recommendations to reduce the emission of such harmful gases into the atmosphere by requesting the improvement of marine fuels in various areas, including reducing the emission of harmful sulfur oxide gas, including from January 1, 2020, by establishing regulations the international fleet active in designated international waters and ports to use fuel oil (refinery oil product)with a maximum sulfur content of 0.5% by weight, as well as planning the development and use of non-renewable better quality oil products in line with the approvals of the United Nations Climate Change Conferences (COP) and international conventions with a perspective 2030 AD and the following decades until 2100 AD , finally proceeded using marine fuels without carbon such as H2 gas , NH3 gas.

As the most important example, in the 21st United Nations Climate Change Conference (COP21), the Paris Agreement of the United Nations was approved by 196 countries, known as the Paris Agreement, in 2015 AD , (note: COP28 did as climate change conference in United Arab Emirates on 30 Nov - 12 Dec 2023). Under the framework of the United Nations Convention on Climate Change (UNFCCC), which is related to reducing emissions are greenhouse gases, the member states must plan in such a way that by managing the upgrade and type and replacement of their fuels (preferably renewable and carbon sequestration) to prevent the emission of greenhouse gases and other harmful gases to the earth's atmosphere in order to prevent the warming of 1.5 degrees Celsius by the end of the year 2100 AD.

Current of marine fuel

As mentioned, considering the adverse environmental consequences of the climate change crisis in recent years, which the main cause of global is warming due to the emission of greenhouse gases (GHG) causing by the combustion of fossil fuels.

To understand about the adverse effects of greenhouse gases (GHG);it points out that greenhouse gases (CO2;NOX;CH4;…), are caused by the combustion of fossil fuels in various sectors of industry, transportation, etc… When sunlight enters the earth with short wavelength and absorb by ground and photosynthesis processes, Then it wants to return by the long wavelength warms from the surface of the earth, but these greenhouse gases act like a shield preventing the sunlight leaving from the earth and causing the sun's heat to be trapped inside the earth's atmosphere and intensifying the gradual increase in the warming of the earth. Gradually it causes climate change and climate crisis in which causes shifts in seasons, sudden rains, severe droughts, and violent and sudden storms and so on.

On this basis, in the Paris meeting of the United Nations, 2015, all countries are strictly required in their annual national action plans to reduce carbon and greenhouse gas production, especially through the management of the production and consumption of their fossil fuels in all areas, by replacing them with clean, renewable, and carbon-free fuels (known as: net zero carbon emission plan in energy transition period).

One of the important sectors that produces greenhouse gases in the world is the maritime transport sector (about 2.2% of the total carbon dioxide gas produced in the world) and according to January 2023 statistics reported, only about 105,500 giant commercial sea fleets and about 80% of the world's transportation of cargos, are in the sea waters of the world. These heavy sea fleets, including oil tankers, container carriers, and passengers, mainly use various fuels such as fuel oil, marine diesel (blending of gas oil and heavy fuel oil), liquid petroleum gas(LPG), liquefied natural gas (LNG), and methanol. It should be noted that smaller ones such as fishing boats uses gasoline as their fuel.

Marine fuels such as liquid gas (LPG) or liquid natural gas (LNG) and methanol that are currently being used in shipping have a much lower carbon content than fuel oil in their compositions (large chain of carbon & hydrogen as hydrocarbons). A molecule of fuel oil has normally a side chain of 70 carbons, but LNG is the liquefied CH_4 methane gas that has only one carbon with 4 hydrogen atoms, or LPG is a combination of propane (C_3) or butane (C_4) that has a maximum of 4 carbons in each molecule. Therefore, if these compounds burn, they produce only one molecule of carbon dioxide or a maximum of 4 molecules of carbon dioxide, so they can be considered as a much cleaner fuel than petroleum and distillate fuels to produce CO_2 gas (as a major of greenhouse gas).

Heavy Fuel oil (HFO) is used for heavy vessels that do not need high speed, but they need a lot of power, and distillate fuel (DM) is used for semi-heavy vessels. For these two groups of fuel, ISO (International Organization for Standardization) has defined a standard called ISO 8217. In this standard, these two main fuels (HFO & DM) are classified according to their physical and chemical characteristics (density, sulfur content, viscosity and...) for use in marine engines. They have been classified as examples of fuel oil (RM: residual marine) into classes and grades A, B, D, E, G and K. Which is RMA; RMB; RMD is shown. Distillate marine fuels (DM: diesel marine) are also expressed as DMA, DMB, DMZ, and DMX, which are marked with grades A to Z in this marine fuel ISO standard. It should be noted that the maximum amount of sulfur allowed for each of these fuels is different and considering to the latest version of International Maritime Organization (IMO) regulations according to the MARPOL treaty (MARPOL, marine pollution) and is a mandatory by all the international shipping lines of the world, especially in the areas and ports under the control of pollution monitoring (ECA : Emission Control Area of sea onshore & offshore) and in case of non-observance from shipping lines, it is subject to serious crimes & financial penalties. Anyway, this causes the cost of transportation to become expensive and the fuel price of these shipping lines to increase. For example, the amount of sulfur oxide (SOX), based on the requirement of IMO (2020), and should be stopped from 30,000 ppm sulfur in marine HFO since January 1, 2020. It means, the amount of sulfur in fuel oil, which has been 30,000 ppm so far, should be replaced with 0.5 weight %, i.e. 5,000 ppm, and this regulation may be continued probably by 2030, then after 2030, its value should be reduced to one tenth of a percent (0.1 wt.%), i.e. 1000 ppm. However, currently, in some international waterways, the permissible limit of sulfur in this fuel is 1000 ppm.

Currently 1000 commercial and passenger ships in the world are using liquefied natural gas (LNG) engines in addition to 5000ppm fuel oil engines. It should be noted that this fuel produces 30% less greenhouse gas than heavy fuel oil (HFO), and it is non-sulfur content too. Also currently, in 120 ports of the world, ships with methanol engines are provided with fuel service of methanol (MeOH) from these ports, and interestingly, in September 2023, Maersk, one of the world's shipping line giants, as the leader of its first huge commercial container ship, which only It uses methanol fuel, exploitation and optimization.

Different types of shipping

A large amount of petroleum products, crude oil, petrochemical and gas products are moved by the sea fleet in the world, so it is necessary to know the types of ships in addition to their fuel. There are as follows:

1. Container Shipping:

- Containerships transport goods in standard containers, making it efficient for intermodal transportation (by ship, rail, and truck).
- These ships carry a wide range of cargo, from consumer goods to industrial products.
- Containerization revolutionized global trade by simplifying cargo handling and reducing costs.

2. Bulk Carriers:

- Bulk carriers transport bulk commodities such as coal, iron ore, grains, and minerals.
- They have large holds for loose cargo and are essential for raw material supply chains.
- Types include dry bulk carriers (for solid cargo) and liquid bulk carriers (for liquids like oil and gas).

3. Tankers:

- Oil tankers transport crude oil, petroleum products, and chemicals.
- Gas carriers transport liquefied natural gas (LNG) and liquefied petroleum gas (LPG).
- Tankers play a critical role in energy distribution.

4. Roll-on/Roll-off (Ro-Ro) Ships:

- Ro-Ro vessels transport wheeled cargo (cars, trucks, trailers) that can be driven on and off the ship.
- Commonly used for vehicle transportation.

5. Ferries and Passenger Ships:

- Ferries carry passengers, vehicles, and sometimes cargo across short distances.
- Cruise ships provide leisure travel experiences, often with entertainment, dining, and amenities.

6. Specialized Vessels:

- Includes reefer ships (for refrigerated cargo), livestock carriers, and heavy-lift ships (for oversized cargo).
- These cater to specific cargo requirements.

7. Breakbulk and General Cargo Ships:

- Breakbulk ships handle non-containerized cargo, such as machinery, steel, and project cargo.
- General cargo ships transport various goods not suited for containers.

8. Multipurpose Ships:

- These versatile vessels can carry both containers and breakbulk/general cargo.
- Adaptability makes them useful for diverse cargo types.

9. Inland Waterway Vessels:

- Operate on rivers, canals, and lakes.
- Includes barges, push boats, and tugboats.

10. Offshore Support Vessels:

- Serve offshore oil and gas platforms.
- Examples: supply vessels, anchor handling tugs, and platform supply vessels.

Existing marine fuel sulfur regulations

1. IMO 2020 - Cutting Sulphur Oxide Emissions:

- On January 1, 2020, a new limit on the sulphur content in fuel oil used on board ships came into force. Known as “IMO 2020”, this rule limits the sulphur in fuel oil to 0.50% m/m (mass by mass) for ships operating outside designated emission control areas. This is a significant reduction from the previous limit of 3.5%.
- Within specific designated emission control areas, even stricter limits apply (0.10% m/m). These areas include the Baltic Sea, the North Sea, the North American area, and the United States Caribbean Sea area.
- The reduction in sulphur oxide (SOx) emissions from ships has major health and environmental benefits, particularly for populations living close to ports and coasts. SOx emissions harm human health, cause respiratory and cardiovascular diseases, and contribute to acid rain and ocean acidification.
- Most ships now use very low sulphur fuel oil (VLSFO) to comply with the new limit, resulting in improved air quality and environmental preservation.

2. MARPOL Regulations:

- The International Convention for the Prevention of Pollution from Ships (MARPOL) regulates fuel oil quality. It sets provisions in Annex VI, addressing issues like flashpoint.
- Additionally, the International Convention for the Safety of Life at Sea (SOLAS) covers safety aspects related to fuel oil.

3. Future Developments:

- Amendments to MARPOL Annex VI are expected to designate the entire Mediterranean Sea as an emission control area for Sulphur Oxides (SOx-ECA) and particulate matter. These amendments are set to take effect from May 1, 2025.

Next Generation of clean marine fuel

According to the international environmental conventions and global decision making for prevention of global warming and climate crisis, we should go towards the development of production and consumption of clean and renewable fuels in the middle and long term of the end of the current century instead of non-renewable (fossil) fuels. The exact meaning of this sentence is that our current fossil fuels in the maritime industry (HFO, Diesel, LPG, LNG ;….) are a chain of carbon and hydrogen, and they produce carbon dioxide in the combustion chambers of any type of internal engine combustion. In this new approach of fuel consumption (carbon-free fuel), we must produce and use fuels in future that does not have carbon (net zero carbon emission) and it is known as energy transition. Currently H2 & NH3 are produced by the base of methane gas (fossil base) in reformer units but regarding to new generation of clean fuel these two gases shall be produced based on renewable energy (solar , wind , …) and water with the electrolysis technology, then they are known as : green hydrogen (GH2) and green ammonia (GNH3).

These types of clean fuels (carbon free) shall be considered as the new generation of fuels in next decades, then it needs the commercial and construction new design of these types of engines in transportation sector transportation, in all its categories such as: ground, air and marine. It has already started since few decades before but has accelerated sharply now due to combat of climate crisis. Hydrogen and ammonia are also the best samples of carbon free type of fuels, because they do not produce carbon dioxide as a hard greenhouse gas due to their combustion.

Economic market size of marine fuel

It is worth mentioning that based on the functional statistics of the bunkering fuel market in 2020 AD, it was 109.6 billion dollars annually, which is expected to reach 164.9 billion dollars in 2030 AD, in which mainly of it, is related to low-sulfur fuel oil& diesel, liquid petroleum gas (LPG), liquefied natural gas (LPG), gas oil, and methanol and gasoline.

Also, based on international sources, it is predicted that the fuel production volume of the main competitor of our country (the United Arab Emirates in Fujairah port) will be around 2.01 million barrels by the end of 2024 AD, and it is decided to increase it to 2.25 million barrels by the beginning of 2029 AD.

How technologically to neutralize and control GHG of marine fuel in commercial ship?

On the other hand, the installation of some auxiliary equipment in the commercial ships can significantly help to reduce or neutralize the emissions of GHG emitted from the chimneys of these ships. Systems like as:

1. Installation of important carbon dioxide (CO2) capture system known as, CCS: carbon capture storage.

2. Installation of the Adblue system to neutralize the nitrogen dioxide (NOX) known as, SCR: selective catalyst reduction.

Marine emission trading scheme (ETS)

1. International emissions trading system (ETS)

The nature of the pollutant emission plays a very important role when policymakers decide which framework should be used to control pollution. CO2 acts globally, thus its impact on the environment is generally similar wherever in the globe it is released. So, the location of the originator of the emissions does not matter from an environmental standpoint. The policy framework should be different for regional pollutants (e.g. SO2 and NOx) because the impact of these pollutants may differ by location. The same amount of a regional pollutant can exert a very high impact in some locations and a low impact in other locations, so it matters where the pollutant is released. The 2005-launched ETS works as a “cap and trade” scheme where emitters of CO2 in certain sectors (industry, building…) have to purchase allowances to cover their carbon emissions during the relevant trading period. The number of allowances at any one time are fixed, but they generally reduce each year, so that emissions within the EU also fall. The European Union (EU) established the EU Emissions Trading System (EU ETS) in 2005 as the cornerstone of its strategy for cutting emissions of carbon dioxide (CO□) and other greenhouse gases at least cost. The EU ETS is the world's first major carbon market and remains by far the biggest today. This pioneering system operates through a cap-and-trade model, where allowances permit the holder to emit 1 ton of CO□. Under this scheme, a maximum cap is set on the total amount of greenhouse gases that can be emitted by all participating installations. These allowances are auctioned or allocated and can be traded, allowing the system to find cost-effective ways to reduce emissions without significant government intervention.

2. Starting emission trading system (ETS) marine fuel sector

Starting on January 1, 2024, the EU Emissions Trading System (EU ETS)—the world's largest carbon market introduced in 2005—will begin to apply to the maritime transport sector. This extension marks a significant shift for the maritime logistics industry, creating both challenges and opportunities for sustainability and innovation. Let's delve a little into the details:

- Scope and Coverage: The EU ETS will encompass 50% of emissions from voyages starting or ending outside the EU and 100% of emissions between two EU ports or when ships are within EU ports.It applies to all large ships with a gross tonnage of 5,000 and above, regardless of their flag.
- How It Works: The EU ETS operates through a cap-and-trade system, aiming to reduce greenhouse gas emissions. Emissions are monitored, reported, and verified. Shipping companies will need to use allowances to cover their emissions.

  The system will gradually cover more emissions: 40% in 2024, 70% in 2025, and 100% in 2026.
- Practical Implementation: Companies will report emissions through the THETIS-MRV platform. They can open Maritime Operator Holding Accounts to manage allowances.
- Compliance Responsibility: Shipping companies are responsible for complying with obligations under the MRV (Monitoring, Reporting, and Verification) and ETS (Emissions Trading System) and Non-compliance for example with 5,000 GT trading within EU waters, irrespective of flag) can lead to penalties and expulsion orders.

References

https://unfccc.int/cop28?gad_source=1&gclid=CjwKCAiAloavBhBOEiwAbtAJOx176AvWJrf9YhfRQG8ndwZtHGHzaAP8B2_jYtPKDb84Aa4RP_-BvhoClU8QAvD_BwE2 ,2023

https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-default.aspx ,2024

https://www.imo.org/en/KnowledgeCentre/ConferencesMeetings/pages/Marpol.aspx

https://en.wikipedia.org/wiki/Emissions_trading

www.clydeco.com

https://www.jas.com

https://insurancemarinenews.com/insurance-marine-news/the-eu-emission-trading-system ,2022

https://climate.ec.europa.eu/system/files,2016

https://fsr.eui.eu/eu-emission-trading-system-eu-ets ,2021

https://www.epa.gov/sites/default/files/2015-10/documents/420b14097.pdf,2015

https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020 ,2020

https://www.imo.org/en/MediaCentre/PressBriefings/pages/02-IMO-2020 ,2021

https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets ,2023

Authors

Hamid Reza Seyed Jafari, , PhD candidate in technology transfer management(IAU), is a senior technical advisor of deputy planning of petroleum ministry in Iran in downstream oil & gas & petrochemical with more than 35 years' experience with B.Eng. Degree in Chemical Engineer from Petroleum University (PUT), M.Eng. Degree in Industrial Engineer (IUST) , Doctorate Business Administration diploma (UT), Economic & Management in Downstream Oil& Gas diploma from French Institute of Petroleum (IFP energies School) in France . He has expert in switching non – renewable to renewable and biofuel energies in refineries and petrochemical sectors in energy transition in different sectors (industry, transportation, building, power plant, biofuels…) to mitigate climate crisis.

Babak Danesh, is project director in SDT Energy Company in Turkey and expert in decarburization development technology especially in renewable energy of wind. He is also active and involved in ISTU University in Turkey and his academic fields are in electrical & renewable wind energy.

Ms.Esra Kayhan, is director in SDT Energy Company in Turkey and expert in decarburization development technology especially in green hydrogen and algae fuel. He is also active and involved in ISTU University in Turkey and her academic field is chemical engineering.

Seyed Mohammad Reza Seyed Jafari is a B.Eng. Chemical Engineer and MBA with more 7 years' experience in HSE of oil & gas sectors & IT.


TrayHeart
Tower Internals Design
TrayHeart is a professional software that performs hydraulic calculations for all types of tower trays, random and structured packings and liquid distributors. The development of **TrayHeart** started in 1998 and was continued jointly by universities, companies of the chemical industry and tower internals suppliers. **TrayHeart ...**
is based on multiple calculation models and large databases of packings, float valves, fixed valves, bubble caps, and liquid distributor templates
is a supplier-independent tool. There are no preferred product placements or promoted designs
considers static dimensions, manways and fastenings
offers an interactive 3D-view for all designs
can be used for single stage, profile and data validation calculations
has a unique, logical and multi-lingual user interface, with multiple input and output options
applies hundreds of online queries to check the feasibility and limits of the calculated designs
is a well introduced software many companies have relied on for more than 20 years
has extensive documentation and is licensed on annual basis
For more information:
www.welchem.com
service@welchem.com
WELCHEM
PROCESS TECHNOLOGY

The BTX Market as Alternative to Reduce the Exposure of Downstream Players to the "Red Ocean" of Gasoline Market

Dr. Marcio Wagner da Silva

Introduction and Context

According to some recent forecasts, the petrochemical market tends to rise in the next years and, in middle term, will be responsible by a major part of the crude oil consumption over passing the transportation fuels this fact have been made the refiners to looking for closer integration with petrochemical assets through the maximization of petrochemical intermediates in their refining hardware as a strategy to ensure better refining margins and higher value addition to the crude oil. Figure 1 presents an overview of the trend of growing to the petrochemical market in middle term.

Some of the most promising petrochemical intermediates are the aromatics benzene and p-xylene. The maximization of aromatics in the refining hardware is possible through the installation of catalytic reforming technologies associated with aromatics separation unit. The catalyst applied to catalytic reforming units has a fundamental role in the aromatics yield and consequently to allow the achievement of profitable and reliable operation.

In the current scenario of the downstream industry, the refiners are facing to important trends, the petrochemicals maximization as a strategy to ensure added value to the processed crude oil and the hydrogen question, which the refiners are facing a growing demand and environmental restrictions related to the CO2 emissions of the traditional steam reforming generation route. In this sense, the catalytic reforming units can develop a fundamental role in the strategy of some refiners.

Beyond the aromatics production, in markets with surplus of gasoline, some alternatives like blend the heavier fraction of naphtha with diesel and jet fuel can be an interesting strategy, but this alternative presents limitations due to the middle distillates specifications like volatility and Reid Vapor Pressure (RVP). In this case, technologic routes capable of managing naphtha molecules aiming to direct these streams to petrochemical intermediates can ensure closer integration with petrochemical assets as well as higher added value to refiners.

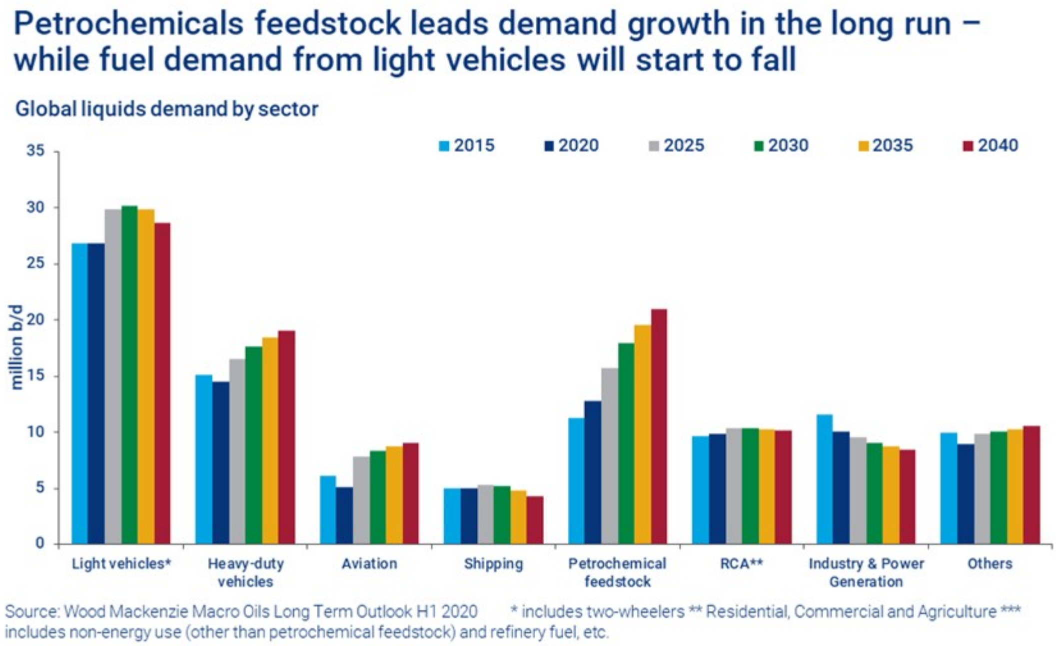


Figure 1: Growing Trend in the Demand by Petrochemical Intermediates (Wood Mackenzie, 2020)

Again, being a high demand and most profitable market, the alternative to convert naphtha to petrochemicals should be a trend to refiners inserted in markets with gasoline surplus in the next years. According to data from Wood Mackenzie Company (2021), the highly integrated refiners can add from US$ 0,68 to US$ 2,02/ bbl. Still according to Wood Mackenzie, the Asian Market presents the major concentration of integrated refining plants.

It's interesting to quote the potential competitive imbalance of the downstream industry in the short term due to the growing demand for petrochemicals. Based on data from 2019 the total capital investments in crude to chemicals refineries is 300 billion US dollars and 64 % of this investment was made by Asian players, to reinforce this trend Figure 4 present a comparison between the relation of crude oil distillation capacity and the integrated refinery capacity for each continent.

Figure 2 shows that the Asian players have a superior integration capacity of their refining assets in comparison with another continents, as mentioned above, this can be translated in a significant competitive advantage to the Asian players and a great potential o competitive imbalance of the downstream market considering the recent forecasts which indicates growing demand for petrochemicals. Furthermore, it's possible to see the power of the China in the Asian and global downstream market.

As presented in Figure 3, the petrochemicals demand tends to drive the crude oil demand for the next years.

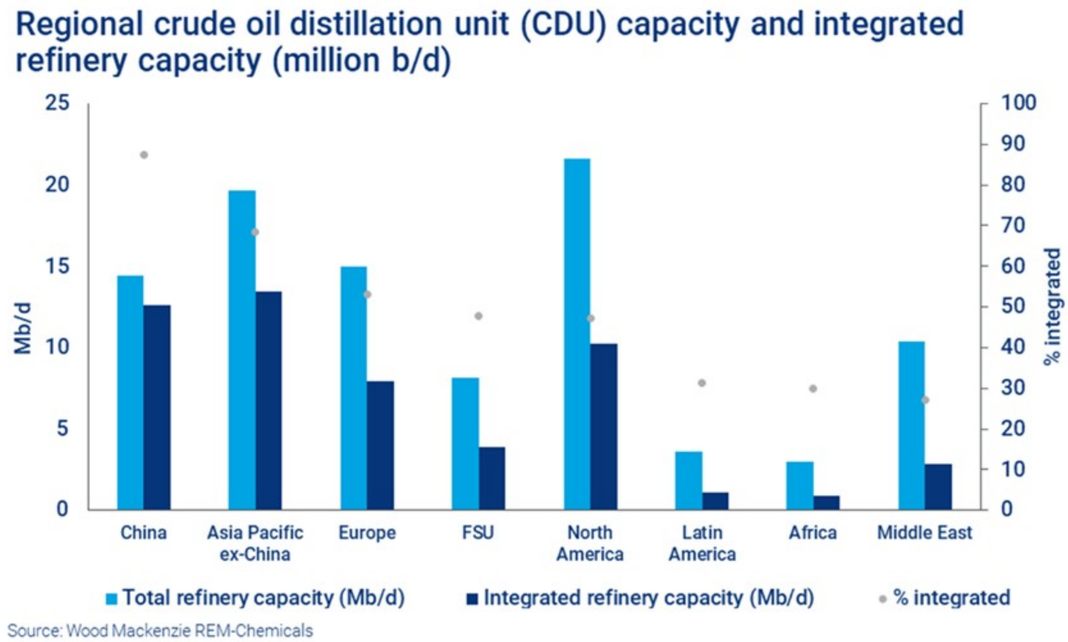


Figure 2: Crude Oil Distillation Capacity and Integrated Refinery Capacity for Each Continent (Wood Mackenzie, 2023)

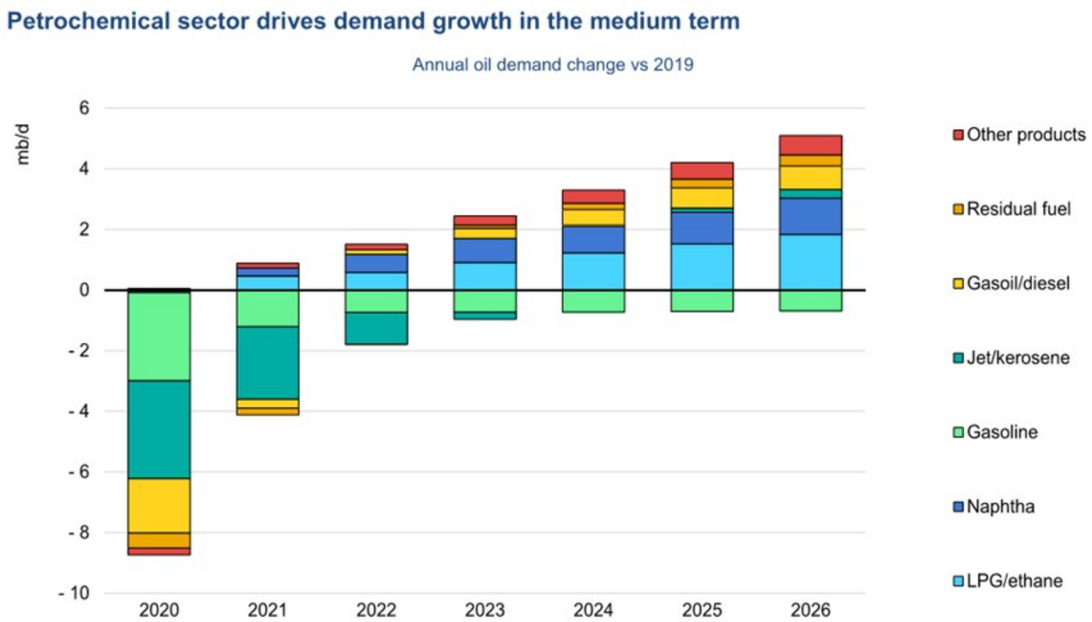


Figure 3: Growth of Petrochemicals as Driver for Crude Oil Consumption (IEA, 2021)

Additionally, it's important to quote that the gasoline demand will be sustained by the developing economies, as presented in Figure 4.

This fact tends to restrict the consumer market which tends to offer lower refining margins, another great advantage to refiners capable of converting naphtha to petrochemicals against gasoline.

Based on the description above it's possible to apply the article published by W. Chan Kim and Renée Mauborge called "Blue Ocean Strategy" in Harvard Business Review, to classify the competitive markets in the downstream industry. In this article the authors define the conventional market as a red ocean where the players tend to compete in the existing market focusing on defeat competitors through the exploration of existing demand, leading to low differentiation and low profitability. The blue ocean is characterized by look for space in non-explored (or few explored markets), creating and developing new demands and reaching differentiation, this model can be applied (with some specificities once is a commodity market) to the downstream industry, considering the traditional transportation fuels refineries and the petrochemical sector.

Due to his characteristics, the transportation fuels market can be imagined like the red ocean, where the margins tend to be low and under high competition between the players with low differentiation capacity. On the other side the petrochemicals sector can be faced like the blue ocean where few players are able to meet the market in competitive conditions, higher refining margins, and significant differentiation in relation to refiners dedicated to transportation fuels market. Figure 5 presents the basic concept of blue ocean strategy in comparison with the traditional red ocean where the players fight to market share with low margins.

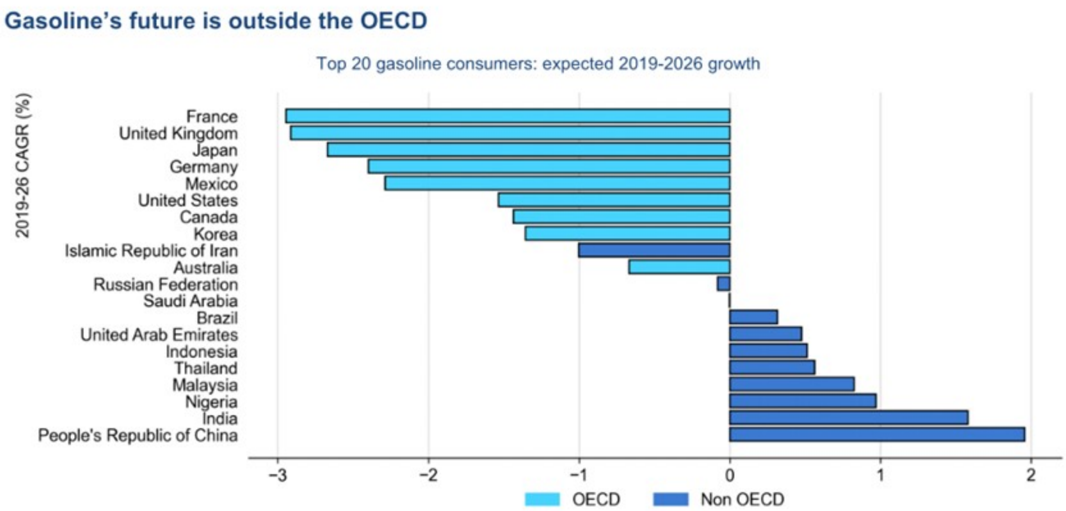


Figure 4: Growth of Gasoline Demand for the Next Years (IEA, 2021)

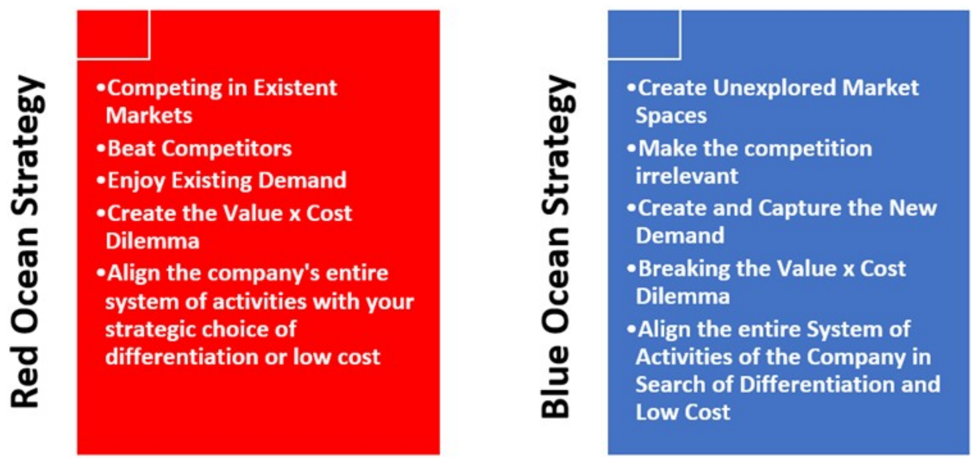


Figure 5: Differences between Blue and Red Ocean Strategies (KIM & MAUBORGNE, 2004)

As presented above, the market forecasts indicates that the refiners able to maximize petrochemicals against transportation fuels can achieve highlighted economic performance in short term, in this sense, the crude oil to chemicals technologies can offer even more competitive advantage to the refiners with capacity of capital investment.

Can be difficult to some people to understand the term "differentiation" in the downstream industry once this is a market that deal with commodities, but the differentiation here is related to the capacity to reach more added value to the processed crude oil and as presented above, nowadays this is translated in the capacity to maximize the petrochemicals yield, creating differentiation between integrated and non-integrated players.

Considering 2022 as the base year, the petrochemical market size reached a total value of USD 523,56 billion with an expected compound annual growth rate (CAGR) of 5,4 % between 2022 and 2030 as presented in Figure 6.

Based on these data, the petrochemical market size can reach a total value of close USD 800 billion in 2030, reinforcing the attractiveness of the petrochemical market for the refiners under a scenario where the transportation fuels show in contraction demand and hostile scenario due to the necessity to reduce the carbon intensity of the energetic matrix.

Considering just the aromatics solvent market (Benzene, Toluene, and Xylenes) the CAGR expected between 2021 and 2030 is 4,8 % leading the aromatics solvent market size reach USD 8,1 billion in 2030 still according to Precedence Research data.

Maximizing Added Value to the Processed Crude – Petrochemical Integration

The focus of the closer integration between refining and petrochemical industries is to promote and seize the synergies existing opportunities between both downstream sectors to generate value to the whole crude oil production chain. Table 1 presents the main characteristics of the refining and petrochemical industry and the synergies potential.

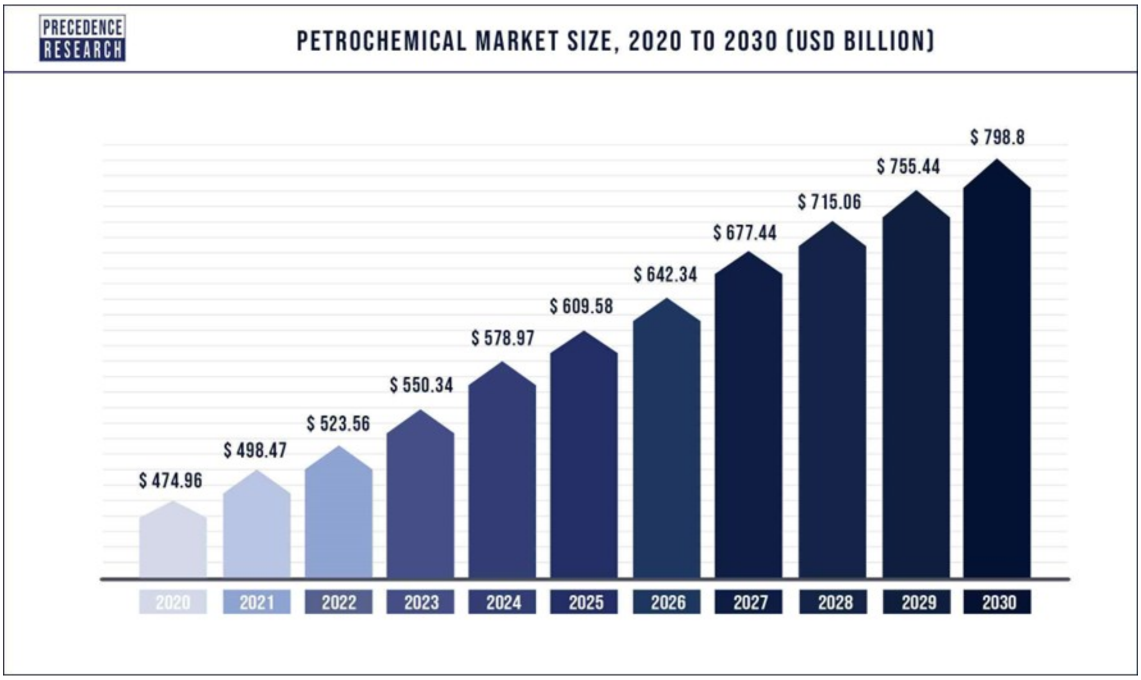


Figure 6: Petrochemical Market Size Forecast 2022-2030 (Precedence Research, 2022)

Table 1 – Refining and Petrochemical Industry Characteristics

Refining Industry	Petrochemical Industry
Large Feedstock Flexibility	Raw Material from Naphtha/NGL
High Capacities	Higher Operation Margins
Self Sufficient in Power/Steam	High Electricity Consumption
High Hydrogen Consumption	High Availability of Hydrogen
Streams with low added Value (Unsaturated Gases & C2)	Streams with Low Added Value (Heavy Aromatics, Pyrolysis Gasoline, C4's)
Strict Regulations (Benzene in Gasoline, etc.)	Strict Specifications (Hard Separation Processes)
Transportation Fuels Demand in Declining at Global Level	High Demand Products

As aforementioned, the petrochemical industry has been growing at considerably higher rates when compared with the transportation fuels market in the last years, additionally, represent a noblest destiny and less environmental aggressive to crude oil derivatives. The technological bases of the refining and petrochemical industries are similar which leads to possibilities of synergies capable of reducing operational costs and add value to derivatives produced in the refineries.

Figure 7 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

Process streams considered with low added value to refiners like fuel gas (C2) are attractive raw materials to the petrochemical industry, as well as streams considered residual to petrochemical industries (butanes, pyrolisis gasoline, and heavy aromatics) can be applied to refiners to produce high quality transportation fuels, this can help the refining industry meet the environmental and quality regulations to derivatives.

The integration potential and the synergy among the processes rely on the refining scheme adopted by the refinery and the consumer market, process units as Fluid Catalytic Cracking (FCC) and Catalytic Reforming can be optimized to produce petrochemical intermediates to the detriment of streams that will be incorporated to fuels pool. In the case of FCC, installation of units dedicated to produce petrochemical intermediates, called petrochemical FCC, aims to reduce to the minimum the generation of streams to produce transportation fuels, however, the capital investment is high once the severity of the process requires the use of material with noblest metallurgical characteristics.

The IHS Markit Company proposed a classification of the petrochemical integration grades, as presented in Figure 8.

According to the classification proposed, the crude to chemicals refineries is considered the maximum level of petrochemical integration, where the processed crude oil is totally converted into petrochemical intermediates.

Catalytic Reforming Technologies – Naphtha to BTX

The main objective of the Catalytic Reforming unit is to produce a stream with high aromatics hydrocarbons content that can be directed to the gasoline pool or to produce petrochemical intermediates (benzene, toluene, and xylenes) according to the market served by the refiner, due the high content of aromatics compounds the reformate can significantly raise the octane number in the gasoline, in the current scenario this a less attractive route.

A typical feedstock to the catalytic reforming unit is the straight run naphtha, however, in the last decades due to the necessity to increasing the refining margin through installation of bottom barrel units, hydrotreated coke naphtha stream has been consumed like feedstock in the catalytic reforming unit.

The catalyst generally employed in the catalytic reforming process is based on platinum

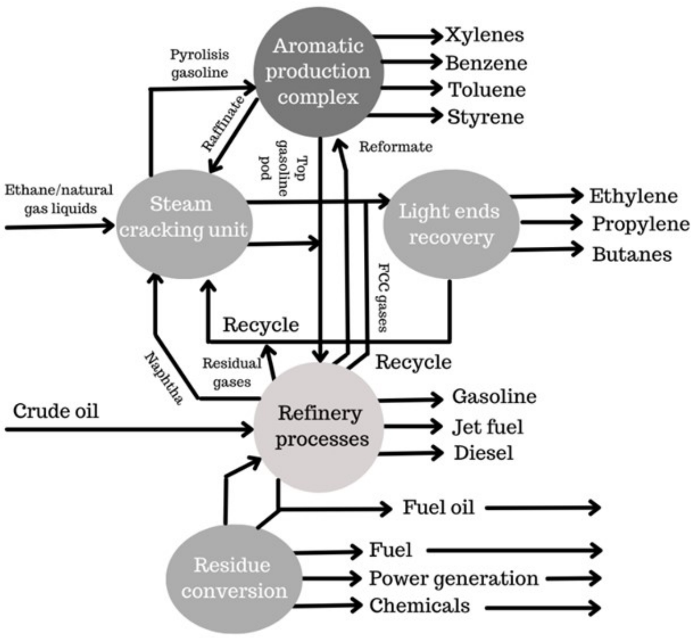


Figure 7: Synergies between Refining and Petrochemical Processes

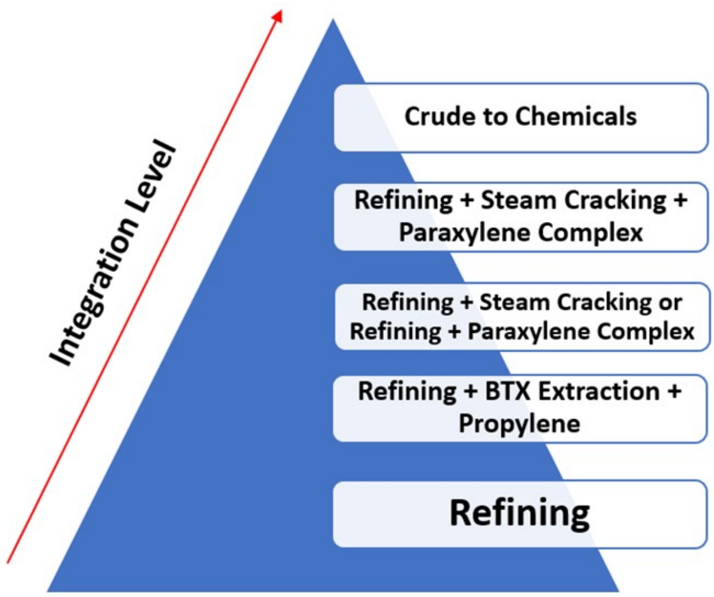


Figure 8 – Petrochemical Integration Levels (IHS Markit, 2018)

(Pt) supported on alumina treated with chlorinated compounds to raise the support acidity. This catalyst has bifunctional characteristics once the alumina acid sites are active to molecular restructuring and the metals sites are responsible for hydrogenation and dehydrogenation reactions.

The main chemical reactions involved in the catalytic reforming process are:

- Naphthene Compounds dehydrogenation;
- Parafinns Isomerization;
- Isomerization of Naphthene Compounds;
- Paraffins Dehydrocyclization;

Among the undesired reactions can be cited hydrocracking reactions and dealkylation of aromatics compounds.

Figure 9 presents a basic process flow diagram for a typical semi-regenerative catalytic reforming unit.

The naphtha feed stream is blended with recycle hydrogen and heated at a temperature varying 500 to 550 oC before to enter in the first reactor, as the reactions are strongly endothermic the temperature fall quickly, so the mixture is heated and sent to the second reactor and so on. The effluent from the last reactor is sent to a separation drum where the phases liquid and gaseous are separated.

The gaseous stream with high hydrogen content is shared in two process streams, a part is recycled to the process to keep the ratio H2/ Feed stream the other part is sent to a gas purification process plant (normally a Pressure Swing Adsorption unit) to raise the purity of the hydrogen that will be exported to others process plants in the refinery.

The liquid fraction obtained in the separation drum is pumped to a distillation column wherein the bottom is produced the reformate and in the top drum of the column is produced LPG and fuel gas.

The reformate has a high aromatics content and, according to the market supplied by the refinery, can be directed to the gasoline pool like a booster of octane number or, when the refinery has aromatics extraction plants is possible to produce benzene, toluene, and xylenes in segregated streams, which can be directed to petrochemical process plants. The gas rich in hydrogen produced in the catalytic reforming unit is an important utility for the refinery, mainly when there is a deficit between the hydrogen production capacity and the hydrotreating installed capacity in the refinery, in some cases the catalytic reforming unit is operated with the principal objective to produce hydrogen.

The main process variables in the catalytic reforming process unit are pressure (3,5 – 30 bar), which normally is defined in the design step, in other words, the pressure normally is not an operational variable. The temperature can vary from 500 to 550 oC, the space velocity can be varied through feed stream flow rate control and the ratio H2/Feed stream that have a direct relation with the quantity of coke deposited on the catalyst during the process. To semi-regenerative units, the ratio H2/Feed stream can vary from 8 to 10, in units with continuous catalyst regeneration this variable can be significantly reduced.

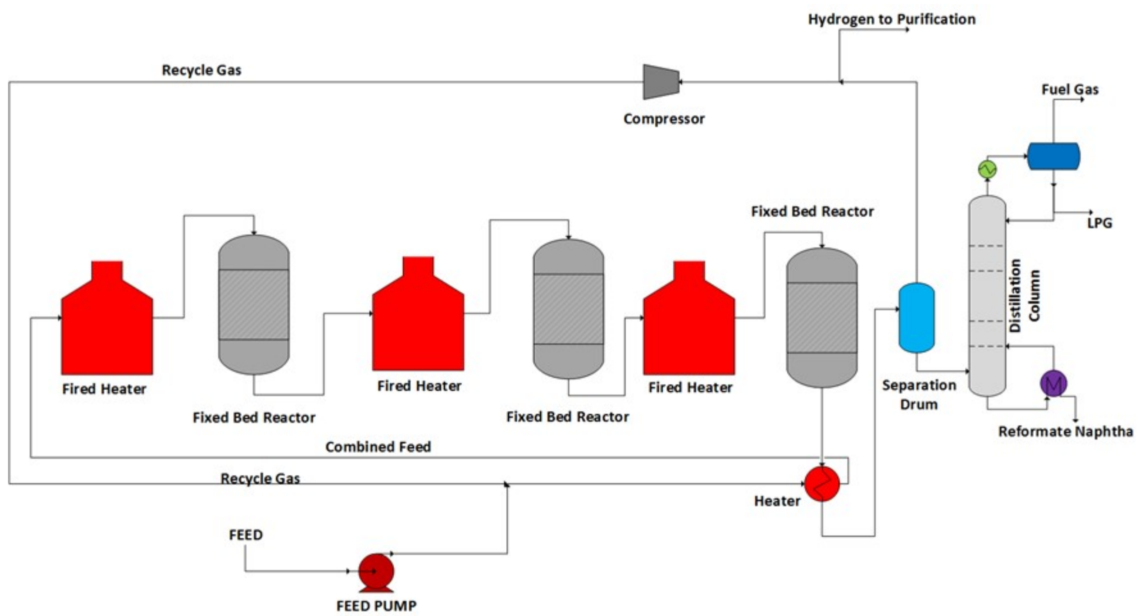


Figure 9: Typical arrangement to Semi-regenerative Catalytic Reforming Process Unit

Due to the process severity, the high coke deposition rate on the catalyst and consequently the quick deactivation leaves short operational campaign periods to semi-regenerative units that employ fixed bed reactors.

To solve this problem some technology licensors developed catalytic reforming process with continuous catalyst regeneration steps.

The process Aromizing™ developed by Axens company apply side by side configurations to the reactors while the CCR Platforming™ developed by UOP apply the configuration of stacked reactors to catalytic reforming process with continuous catalyst regeneration. Figure 10 presents a flow diagram to Aromazing™ catalytic reforming unit.

Both technologies are commercial and some process plants with these technologies are in operation around the world. Figure 11 presents a basic process flow diagram to CCR Platforming™ developed by UOP Company.

In the regeneration section the catalyst is submitted to processes to burn the coke deposited during the reactions and treated with chlorinated compounds to reactivate the acid function of the catalyst.

Despite the higher capital investment, the rise in the operational campaign and higher flexibility in relation to the feedstock to be processed in the processing unit can compensate for the higher investment in relation of the semi-regenerative process.

The catalytic reforming technology gives a great flexibility to the refiners in the gasoline production process, however, in the last decades there is a strong restriction on the use of reformate in the gasoline due to the control of benzene content in this derivate (due to the carcinogenic characteristics of this compound). This fact has reduced the application of reformate in the gasoline formulation in some countries. Furthermore, the operational costs are high, mainly due to the catalyst

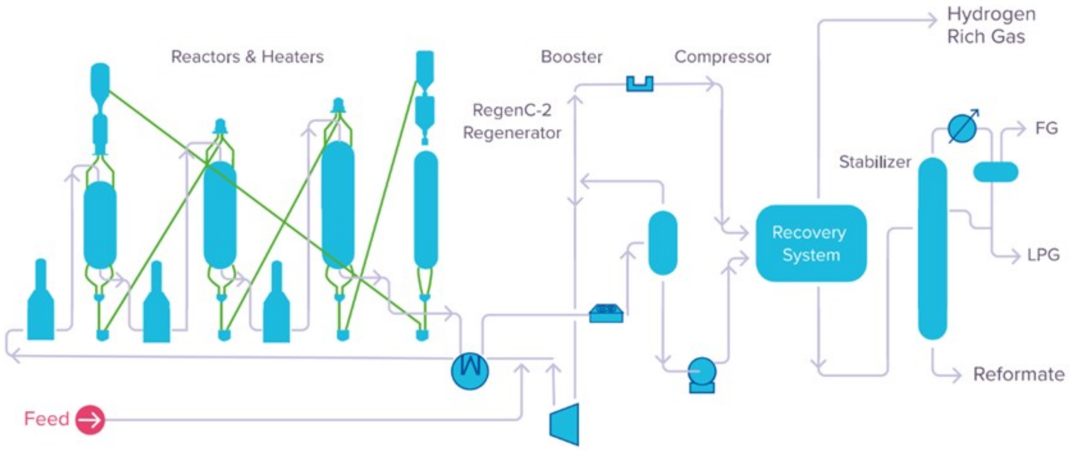


Figure 10 : Aromizing™ Reforming Technology by Axens Company

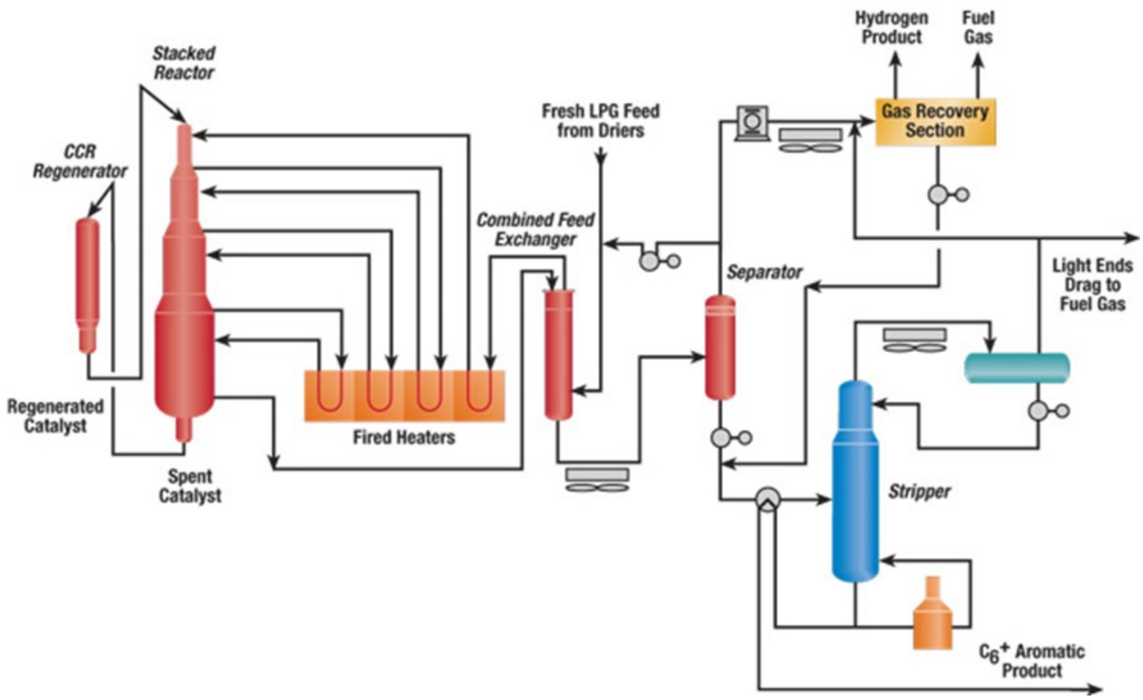


Figure 11: CCR Platforming™ Reforming Technology by UOP Company

replacement and additional security requirements linked to minimize leaks of aromatics compounds.

Catalytic Reforming Catalysts

The catalysts applied to naphtha reforming are based on platinum carried on high purity alumina, in many cases is applied ruthenium or germanium as promoters to the catalyst activity. The catalyst has dual function, the metal site is responsible by hydrogenation and dehydrogenation reactions while the acid function, determined by the chlorine content, is responsible by the molecular arrangement reactions like paraffin cyclization, isomerization, and hydrocracking.

In some formulations, can be added Tin (Sn) to the catalyst, especially in most severe operating conditions. The tin promotes a better dispersion of platinum leading to a more selective catalyst to aromatics like xylenes, reducing the coke deposition and gases production.

As aforementioned, the main disadvantage of the semi regenerative catalytic reforming units is the relatively short operating cycles due to the catalyst deactivation. The main deactivation mechanisms to catalytic reforming catalysts are the poisoning due to the contaminants in the feed, pore plugging, chemical attack to the structure, sintering, and leaching due to the catalyst cracking leading to fines production.

Regarding contaminations, the sulfur and nitrogen are temporary poison to catalytic reforming catalysts and normally the content of these contaminants is controlled through the feed hydrotreating, it’s important to quote that in some cases sulfur and nitrogen can be purposefully added to the feed to keep under control the acid function of the catalyst. Permanent poisons are quoted metals like Lead (Pb), Silicon (Si), Mercury (Hg), Copper, (Cu), Vanadium (V), etc. Poisoning involves the selective adsorption in the active sites to the detriment of reactants. The metal contamination involves the chemical bond of the contaminant with platinum leading to metal alloy with activity loss, especially to dehydrogenation reactions.

The sintering is normally caused by high temperatures as well as excessive water concentration in the feed and is related to the agglomeration of metal particles reducing the active surface area.

The most common deactivation mechanism in catalytic reforming units is the coke deposition that leads to pore plugging with drastic reduction of the catalyst activity. In catalytic reforming units that rely on catalyst regeneration sections like the CCR Platforming™ by UOP Company and Aromizing™ by Axens Company, the catalyst is subjected to a sequence of process aiming to restore the catalyst activity. The first step is a controlled burning process to burn the coke deposited over the catalyst, in the sequence the catalyst crosses the oxychlorination section where is added chlorine to restore the acid function, and normally is applied perchlorethylene as chlorine source. Following the catalyst regeneration process, the catalyst is dried and cooled before to back to the process.

Due to their formulations, the catalytic reforming catalyst presents a high cost and adequate management actions are fundamental to maximize the catalyst lifecycle.

Aromatics Separation Section – Ensuring Maximum Added Value to the Naphtha

As aforementioned, in markets where there is demand, the production of petrochemical intermediates is economically more advantageous than the production of transportation fuels, especially in countries with easy access to lighter oils. The production and separation of aromatics are processes with great capacity of adding value to crude oil.

The aromatics production complex is a set of processes intended to produce petrochemical intermediates from naphtha produced in the catalytic reforming process or by pyrolysis process. An aromatics production complex can take on different process configurations, according to the petrochemical market to be served, an example is shown in Figure 12.

The naphtha rich in aromatics, produced in catalytic reforming or pyrolysis units (in some cases from both), is fed to an extractive distillation column where the separation of aromatic compounds is conducted, which are withdrawn in the extract phase, are recovered at the bottom of the column while the non-aromatic compounds are withdrawn from the top in the raffinate phase. The aromatics are separated from the solvent in the solvent recovery column and directed to the fractionation section of aromatics where the essentially pure benzene and toluene streams and xylenes blend are obtained. The raffinate is sent to a wash column and the non-aromatic hydrocarbons are usually sent to the refinery's gasoline pool.

The process shown in Figure 12 involves only physical separation steps, that is, the process yields in each stream depend on the concentration of this compound in the feed stream.

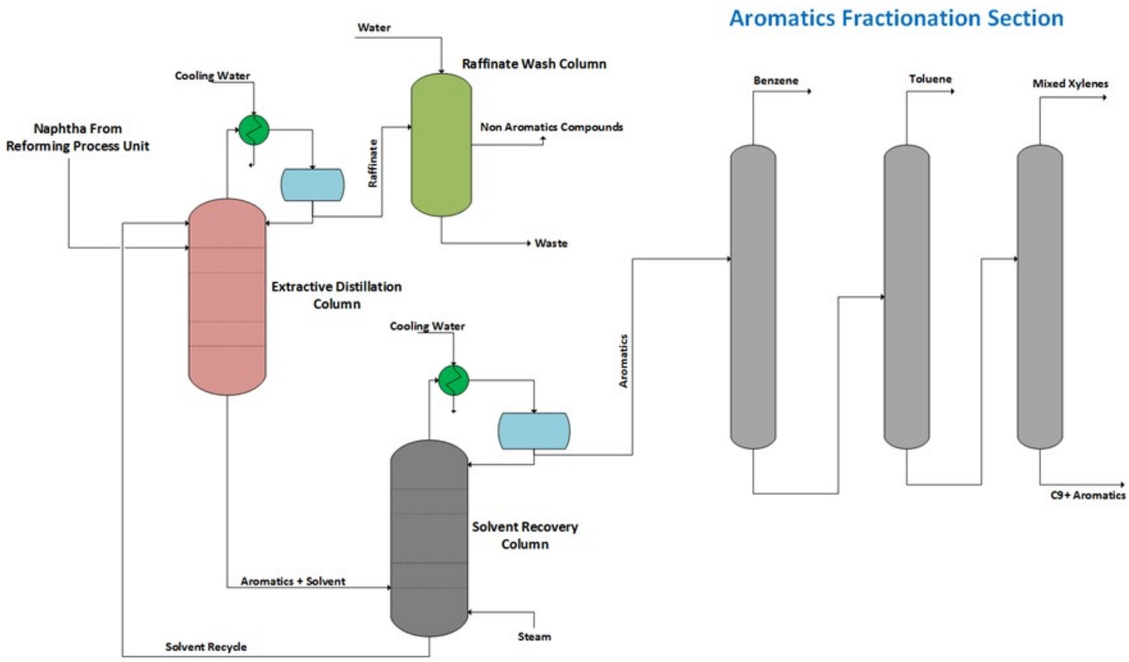


Figure 12: Basic Process Configuration for a Typical Aromatics Separation Unit

The growing demand for high-quality petrochemical intermediates and the higher added value of these products have made it necessary to develop conversion processes capable of converting lower interest aromatics (Toluene) into more economically attractive compounds (Xylenes).

Aromatics separation, mainly xylenes, is a great challenge to modern engineering. The similarities between the molecules make the separation through simple distillation extremely hard, for this reason, several researchers, and technology licensors dedicate their efforts to develop new processes which can lead to pure compounds with lower costs. A basic scheme for a xylene separation process is shown in Figure 13.

The xylenes blend is fed to a distillation column where the ethylbenzene is separated in the top and sent to styrene production market while the bottom stream is pumped to another column where the mixture of Meta and Para-xylenes is withdrawn in the top and the Ortho-xylene and heavier compounds are removed in the bottom.

Ortho-xylene is separated from heavy aromatics in another distillation column while the Meta and Para-xylene are fed to a crystallization process, where is obtained a stream with a high concentration in Meta-xylene and the residual stream is directed to an isomerization unit, aiming to promote the conversion of residual Meta and Orto-xylenes in Para-xylene. The aromatics production units are normally optimized to maximize the Para-xylene production because this is a petrochemical intermediate with higher interest, this compound is raw material to produce terephthalic acid that is used to produce PET (Polyethylene terephthalate). Figure 14 presents the chemical arrangement of the xylenes isomers.

To raise the production of higher commercial and economic interest compounds (P-Xylene and Benzene), technology licensors developed several processes to convert streams with low added value in these compounds. One of the main developers of this technology is the UOP Company, the PAREX™ process apply the separation through adsorption to obtain high purity P-xylene from xylenes blend.

Another UOP technology is the ISOMAR™ process, which promotes the xylenes isomerization to Para-xylene raising the recovery of this compound in the aromatic complex. TATORAY ™ process was developed to convert toluene and heavy aromatics (C9+) in benzene and xylenes through transalkylation reaction. Another economically attractive technology is the SULPHOLANE ™ process that applies liquid-liquid extraction operations and extractive distillation to reach high purity aromatics separation from hydrocarbon mixture.

The UOP Company developed an integrated aromatics complex aiming to maximize the production of benzene and P-xylene, which lead to a higher profitability for the refiner. A UOP Aromatics Complex scheme is presented in Figure 15.

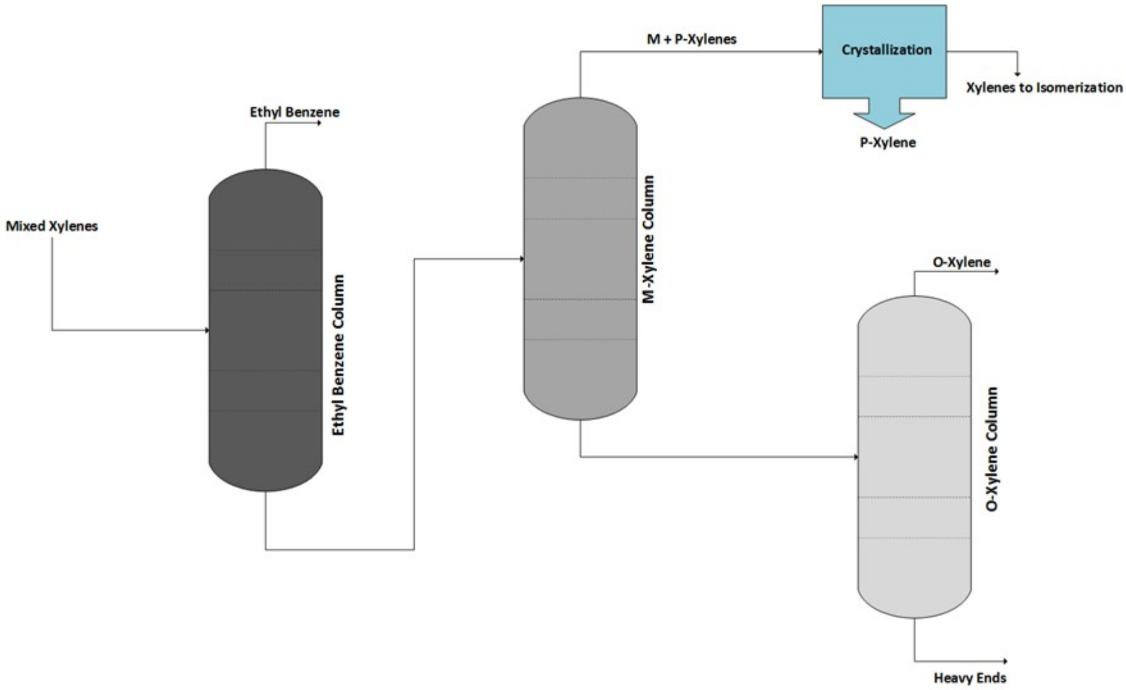


Figure 13: Basic Process for Xylenes Separation

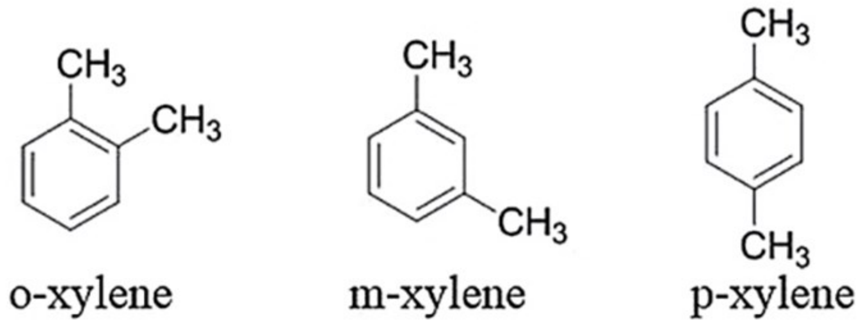


Figure 14: Chemical Arrangement of the Xylene Isomers

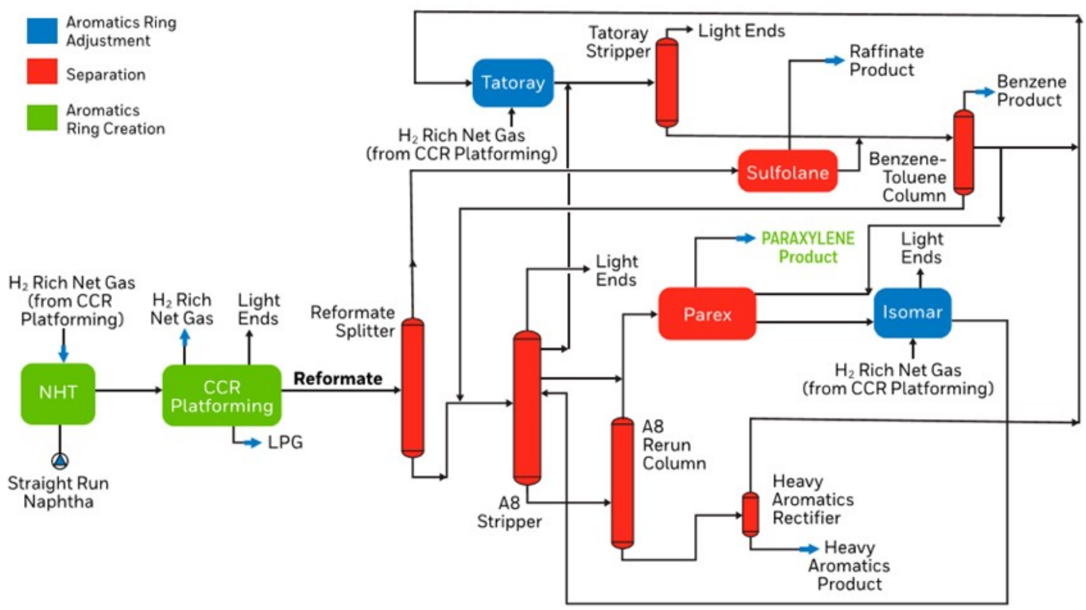


Figure 15: Aromatics Complex by UOP Company

Other companies have attractive and efficient technologies to produce high purity aromatics, the Axens Company license an aromatics production complex also based on separation and conversion processes, called ParamaX™ that can be optimized to produce P-xylene. This process is presented in Figure 16.

The ParamaX™ technology offers the possibility of Cyclohexane production (Raw material to synthetic fibers) through benzene hydrogenation beyond raise the production of this component through toluene HydroDealkylation (HDA).

As aforementioned, the capital investment to installation of aromatics production complexes is high, however, the obtained products have high added value and rely on great demand, and even the compounds with low interest can be commercialized with high margin. In countries with easy access to light oil reserves as Saudi Arabia and United States (Tight Oil) the installation of these process plants is even more economically attractive. As presented in Figure 15, the main reactions carried out in the aromatics production process aiming to improve the yield of benzene and xylenes are the toluene transalkylation presented in Figure 16 and the toluene disproportionation, presented in Figure 17.

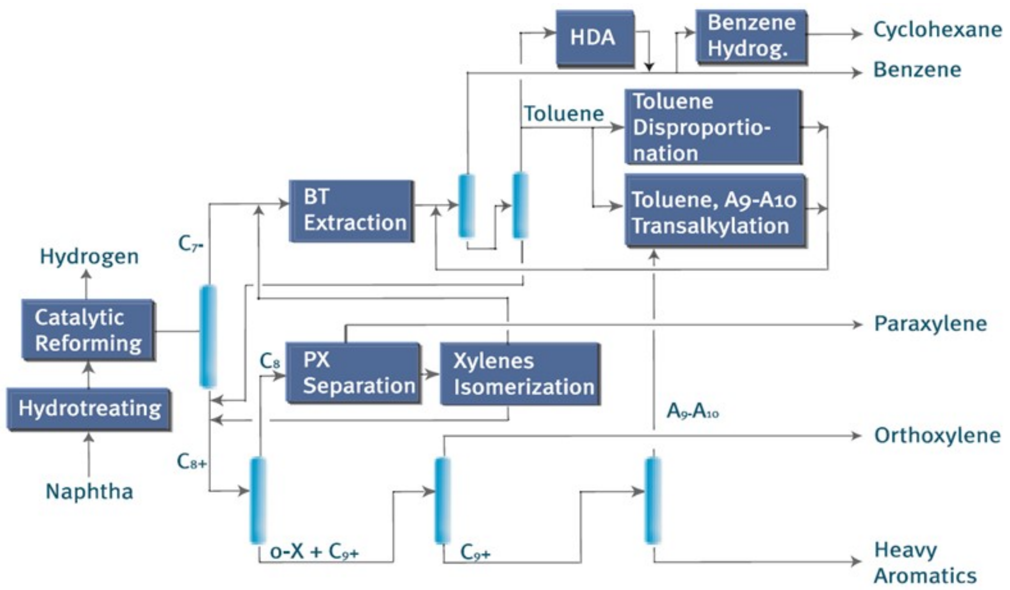


Figure 16: Schematic Process Flow Diagram for ParamaX™ technology, by Axens Company.

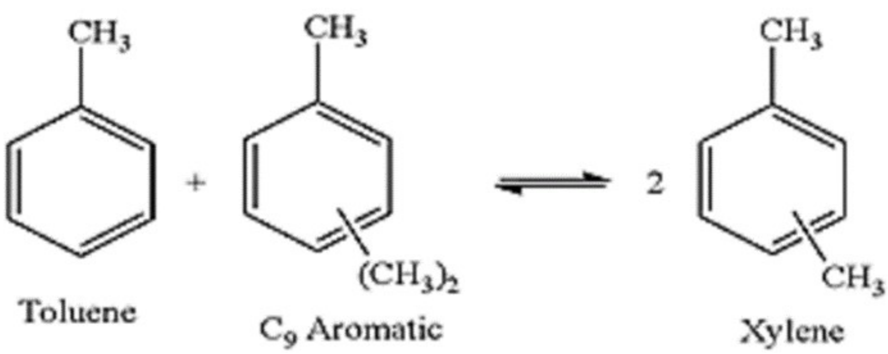


Figure 16 – Toluene Transalkylation Reaction

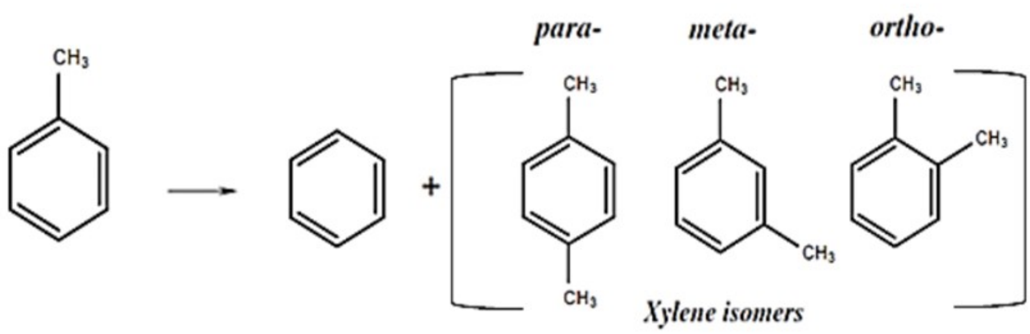


Figure 17: Toluene Disproportionation

It's important to quote that all technologies have molecular management processes to improve the yield of p-Xylene, the most added value aromatic. Recent forecasts indicate the great potential growth of the BTX market in the next years, as presented in Figure 18.

Considering the data from Figure 18 the market size of the BTX market can reach a total value of USD 11,25 billion in 2032 under a compound annual growth rate (CAGR) of 4,6 % between 2023 to 2032. This data reinforces the relevance of the BTX market, especially considering the hostile scenario imposed to fossil fuels like gasoline which is the most conventional destiny of naphtha in non-integrated refineries.

The Synergy between Aromatics Production Complex and Steam Cracking Units

As presented in Figure 1, light aromatics and olefins presents growing demand and high added value when compared with gasoline, in this sense, maximize the yield of these petrochemical intermediates in the refining hardware can ensure high economic result to refiners, despite the high capital spending and operation costs related to a more complex refining hardware.

Among the synergy possibilities between steam cracking and aromatics production complexes is the use of pyrolysis gasoline produced in the steam cracking units as feed stream to aromatics production complex, improving the refinery capacity to produce aromatics against gasoline. By his turn, the raffinate stream from aromatics complex can be used to improve the olefins yield in steam cracking units, mainly ethylene and propylene.

An example of refining configuration relying on the synergy between aromatics production complex and steam cracking units is presented in Figure 19.

Considering the recent trend of reduction in transportation fuels demand followed by the growth of petrochemicals market makes the synergy between aromatics production complex and steam cracking units an attractive way to maximize the petrochemicals production in the refining hardware and achieve closer integration between refining and petrochemical assets, a growing trend in the downstream industry.

As aforementioned, facing the current trend of reduction in transportation fuels demand at the global level, the capacity of maximum adding value to crude oil can be a competitive differential to refiners. Due to the high capital investment needed for the implementation that allows the conventional refinery to achieve the maximization of chemicals, capital efficiency becomes also an extremely important factor in the current competitive scenario as well as the operational flexibility related to the processed crude oil slate.

The Role of Catalytic Reforming Units in the Refineries Hydrogen Balance

Demand for hydrogen raised strongly in the last decades following the necessity of

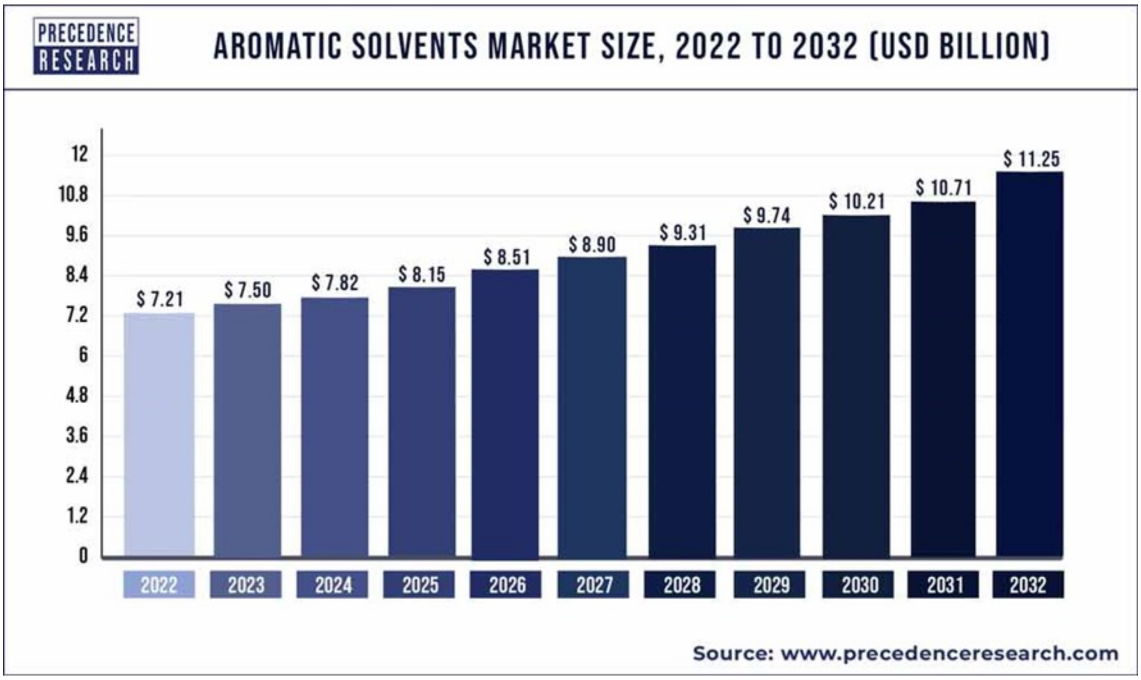


Figure 18: Evolution of Aromatics Market Size 2023 to 2032 (Precedence Research, 2023)

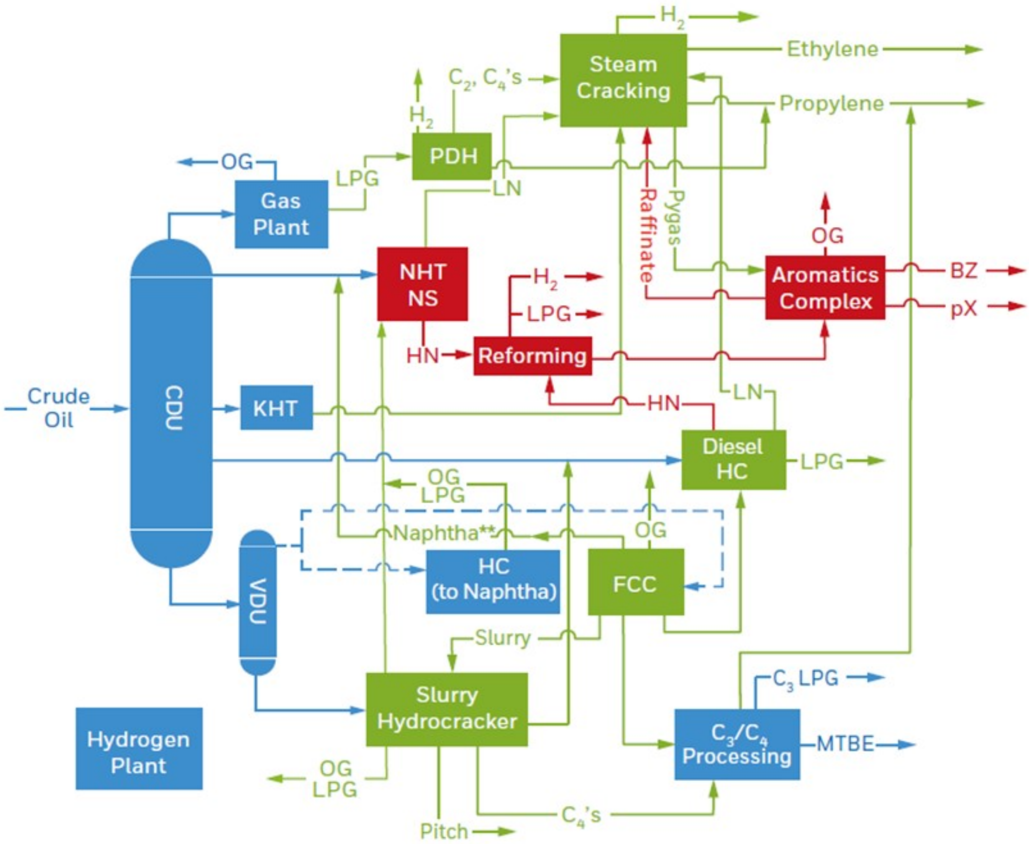


Figure 19: Integrated Refining Scheme Base on Aromatics Complex and Steam Cracking Units (UOP, 2019)

hydrotreatment units installations in refineries to comply with the pressure to reduce the content of contaminants like sulfur and nitrogen in the petroleum derivates and consequently minimizing the environmental impact caused by fuels burn. This scenario became the hydrogen one of the most important production inputs in modern refineries and adequate hydrogen management actions reach strategic character to keep under control the operating costs and refining margins, contributing to economic sustainability in the downstream industry.

The hydrogen matter is one of the most important questions to the future of downstream, the growing participation of renewable raw material in the refining hardware as a decarbonization strategy tends to raise even more the hydrogen consumption. The renewable streams have a great number of unsaturations and oxygen in his molecules which lead to high heat release rates and high hydrogen consumption, this fact leads to the necessity of higher capacity of heat removal from hydrotreating reactors aiming to avoid damage to the catalysts. The main chemical reactions associated with the renewable streams hydrotreating process can be represented as below:

$R\text{-}CH{=}CH_2 + H_2 \rightarrow R\text{-}CH_2\text{-}CH_3$ (Olefins Saturation)

$R\text{-}OH + H_2 \rightarrow R\text{-}H + H_2O$ (Hydrodeoxigenation)

Where R represents a hydrocarbon.

These characteristics lead to the necessity of higher hydrogen production capacity by the refiners as well as quenching systems of hydrotreating reactors more robust or, in some cases, the reduction of processing capacity to absorb the renewable streams. In this point it's important to consider a viability analysis related to the use of renewables in the crude oil refineries once the higher necessity of hydrogen generation implies in higher CO2 emissions through the natural gas reforming process that is the most applied process to produce hydrogen in commercial scale.

$CH_4 + H_2O = CO + 3H_2$ (Steam Reforming Reaction - Endothermic)

$CO + H_2O = CO_2 + H_2$ (Shift Reaction - Exothermic)

This fact leads some technology licensors to dedicate their efforts to look for alternative routes for hydrogen production in large scale in a more sustainable manner. Some alternatives pointed can offer promising advantages:

- Natural Gas Steam Reforming with Carbon Capture – The carbon capture technology and cost can be limiting factor among refiners.

- Natural Gas Steam Reforming applying biogas – The main difficulty in this alternative is a reliable source of biogas as well as their cost.
- Reverse water gas shift reaction (CO2 = H2 + CO) – One of the most attractive technologies, mainly to produce renewable syngas.
- Electrolysis – The technology is one of the more promising for the near future.

Refiners and technology developers are looking for alternatives to produce hydrogen on an industrial scale with lower CO2 emissions and some attractive routes have been considered as competitive in the future.

Despite the advantages of the green production routes of hydrogen, they are still in development and poor attractive to the most part of the refiners, in the current scenario the refiners to look for more efficient operations aiming to optimize the hydrogen balance the refining hardware as well as apply CO2 capture technologies (the blue route), in this sense an attractive alternative is to apply technologies capable to recovery hydrogen from refinery off-gases and apply control strategies capable to minimize the hydrogen losses to flare system.

As exposed above the hydrogen generation is a key matter to refiners, and refineries that rely on Catalytic Reforming units apply the hydrogen produced in this process unit to compose a relevant part of the hydrogen network becoming an important internal source of hydrogen. In some markets, where the demand for petrochemicals is lower, the main relevance of the catalytic reforming to the refining hardware is the hydrogen generation against the production of light aromatics. Figure 20 presents an example of hydrogen network in a crude oil refinery with high hydroprocessing capacity.

In refineries with bottlenecked hydrogen generation units, the hydrogen from catalytic reforming units is fundamental to ensure the compliance with the current quality and environmental regulations, becoming a fundamental enabler to profitable and reliable operations of the refining hardware. Nowadays, it's not uncommon to find refiners operating catalytic reforming units with the main objective to hydrogen generation, especially to refiners that operate with octane giveaway in the gasoline pool.

Closing the Sustainability Cycle – Plastics Recycling Technologies

As described above, we are facing a continuous growing of petrochemicals demand and a great part of these crude oil derivatives have been applied to produce common use plastics. Despite the higher added value and significant economic advantages in comparison with transportation fuels, the main side effect of the growth of plastics consumption is the growth of plastic waste.

Despite the efforts related to the mechanic recycling of plastics, the increasing volumes of plastics waste demand most effective recycling routes to ensure the sustainability of the petrochemical industry through the regeneration of the raw material, in this sense, some technology developers have been

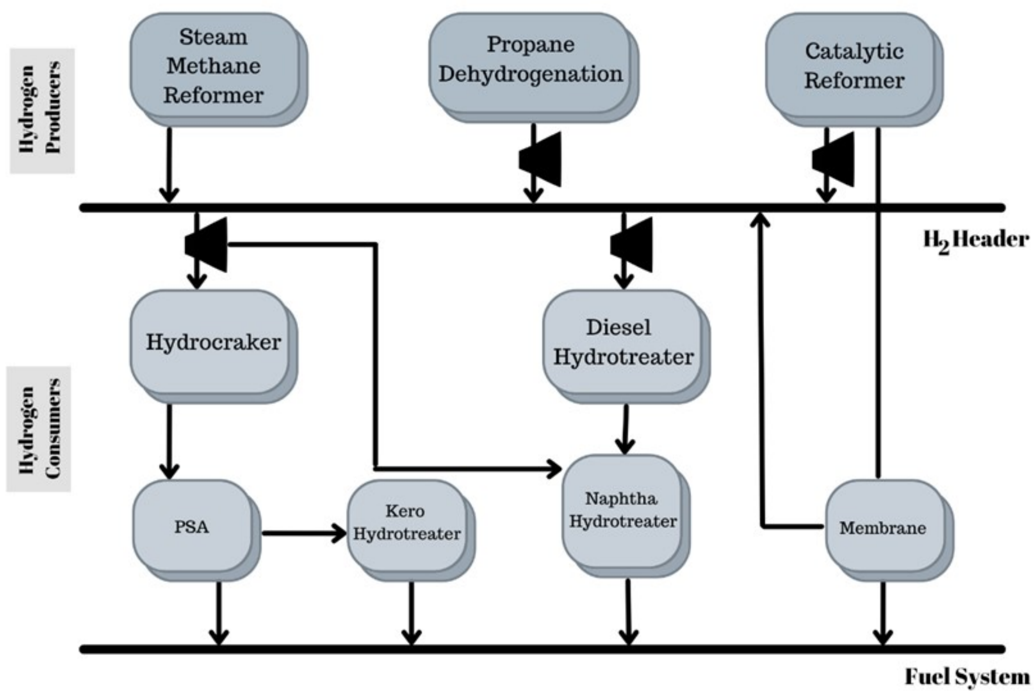


Figure 20: Example of Hydrogen Network to a Crude Oil Refinery (LAFLEUR, 2017)

dedicated investments and efforts to develop competitive and efficient chemical recycling technologies of plastics.

One of the most applied technologies for plastics recycling in the catalytic pyrolysis where the long chain polymeric are converted into smaller hydrocarbon molecules which can be fed to steam cracking units to reach a real circular petrochemical industry. Another route is the thermal pyrolysis of plastics, is this case, it's possible to quote the Rewind™ Mix technology developed by Axens Company.

Another promising chemical recycling route for plastics in the hydrocracking of plastics waste, in this case the chemical principle involves the cracking of carbon-carbon bonds of the polymer under high hydrogen pressure which lead to the production of stable low boiling point hydrocarbons. The hydrocracking route present some advantages in comparison with thermal or catalytic pyrolysis, once the amount of aromatics or unsaturated molecules is lower than the achieved in the pyrolysis processes, leading to a most stable feedstock to steam cracking or another downstream processes as well as is more selective, producing gasoline range hydrocarbons which can be easily applied in the highly integrated refining hardware.

The chemical recycling of plastics is a great opportunity to technology developers and scientists, especially related to the development of effective catalysts to promote depolymerization reactions which can ensure the recovery of high added value molecules like BTX. More than that, the chemical recycling of plastics is an urgent necessity to close the sustainability cycle of an essential industry to our society.

Conclusion

The search to add maximum value to processed crude oil is a constant among the refiners, especially considering the competitive scenario faced by the downstream market, in this sense, the flexible refining technologies like Catalytic Reforming and aromatics recovery section can offer a significant competitive advantage.

Installation of aromatics production units can significantly raise the profitability to refiners inserted in markets with high demand for petrochemical intermediates and surplus in gasoline, this fact is especially true in the current scenario where the transportation fuels consumption suffered drastic reduction due to the economic crisis caused by the COVID 19. The catalytic reforming technologies can develop a fundamental role in the downstream industry to allow profitable and reliable operations to refiners both to maximize petrochemicals and allow closer integration with petrochemical assets and ensure a positive contribution to the hydrogen balance, reducing the necessity to higher capacity of traditional steam methane reformers with consequent lower CO_2 emissions. These advantages can be even more relevant in a market with a great gasoline surplus aiming to ensure higher added value to the processed crude.

The synergy between refining and petrochemical processes raises the availability of raw material to petrochemical plants and makes the supply of energy to these processes more reliable at the same time ensures better refining margin to refiners due to the high added value of petrochemical intermediates when compared with transportation fuels. The development of crude to chemicals technologies reinforces the necessity of closer integration of refining and petrochemical assets by the brownfield refineries aiming to face the new market that tends to be focused on petrochemicals against transportation fuels, it's important to note the competitive advantage of the refiners from Middle East that have easy access to light crude oils which can be easily applied in crude to chemicals refineries. As presented above, crude oil to chemicals refineries is based on deep conversion processes that requires high capital spending, this fact can put under pressure the refiners with restrict access of capital, again reinforcing the necessity to look for close integration with petrochemical sector aiming to achieve competitiveness.

Despite the benefits of petrochemical integration, it's fundamental to take in mind the necessity to reach a circular economy in the downstream industry. To achieve this goal, the chemical recycling of plastics is essential. As presented above, there are promising technologies which can ensure the closing of the sustainability cycle of the petrochemical industry.

References

Advances in Catalysis for Plastic Conversion to Hydrocarbons – The Catalyst Group (TCGR), 2021.

CHANG, R.J. – Crude Oil to Chemicals – Industry Developments and Strategic Implications – Presented at Global Refining & Petrochemicals Congress (Houston, USA), 2018.

Deloitte Company. The Future of Petrochemicals: Growth Surrounded by Uncertainties, 2019.

DOMERGUE, B.; LE GOFF, P. Y.; ROSS, J. Octanizing Reformer Options. PTQ Magazine, 2006.

GARY, J. H.; HANDWERK, G. E. Petroleum Refining – Technology and Economics.4th ed. Marcel Dekker., 2001.

GELDER, A.; BAILEY, G. The Future of Petrochemicals: A Tale of Two Transitions, Wood Mackenzie, 2020.

International Energy Agency (IEA). Oil 2021: Analysis and Forecast to 2026, 2021.

KIM, W.C.; MAUBORGE, R. - Blue Ocean Strategy. Harvard Business Review, 2004.

LAFLEUR, A. Use and Optimization of Hydrogen at Oil Refineries. Shell Company, Presented at DOE H2@Scale Workshop – University of Houston, 2017.

OYEKAN, S.O. Catalytic Naphtha Reforming Process. 1st ed. CRC Press, 2019.

SILVA, M. W. – More Petrochemicals with Less Capital Spending. PTQ Magazine, 2020.

VU, T.; RITCHIE, J. Naphtha Complex Optimization for Petrochemical Production, UOP Company, 2019.

ZHOU, T.; BAARS, F. Catalytic Reforming Options and Practices. PTQ Magazine, 2010.

Author

Dr. Marcio Wagner da Silva is Process Engineer and Stockpiling Manager on Crude Oil Refining Industry based in São José dos Campos, Brazil. Bachelor's in chemical engineering from University of Maringa (UEM), Brazil and PhD. in Chemical Engineering from University of Campinas (UNICAMP), Brazil. Has extensive experience in research, design and construction to oil and gas industry including developing and coordinating projects to operational improvements and debottlenecking to bottom barrel units, moreover Dr. Marcio Wagner have MBA in Project Management from Federal University of Rio de Janeiro (UFRJ), in Digital Transformation at PUC/RS, and is certified in Business from Getulio Vargas Foundation (FGV).

Concrete Coating for Natural Gas Pipelines

Jayanthi Vijay Sarathy

Submerged natural gas pipelines that run through wetlands such as marsh lands and river crossings tend to get dislodged and float in the waters due to buoyancy. To prevent them from getting dislodged, iron weights are strapped on to the pipeline with galvanized bolts to counter buoyant forces.

Figure 1. Bolt On Weights on Pipelines [1]

With time, concrete to increase pipeline weight, was employed to reduce costs. An alternative approach was to use set-on weights which are single pieces of concrete set over the pipeline (Fig 2).

However, some of the downside of using pipeline weights is the damage it can do to coatings. A pipeline is often coated with fusion bonded epoxy (FBE) which offers protection by acting as a physical barrier to corrosion. Additionally, pipelines are also offered cathodic protection to prevent corrosion. With weights added, the ensuing friction can scrape off / damage the pipeline coatings thereby exposing the fresh metal to corrosion. In case there is a loss of contact between the cathodic protection current and the pipeline, the situation can once again exacerbate corrosion.

Figure 2. Set On Weights on Pipelines [2]

The following article covers how to estimate the concrete coating required to overcome buoyancy effects.

General Notes

1. The stability of a pipeline against buoyancy depends on the resisting forces, (i.e., pipeline weight and back filled soil) and the upthrust forces due to buoyancy.
2. For this article, the skin friction acting between filled top and adjacent soil and the pipeline is neglected.
3. The safety factor against pipeline buoyancy is at least ≥ 10%.
4. When laying pipelines, if water is found to seep through the soil during excavation

and trenching, sufficient dewatering measures need to be employed to keep the trench dry.

5. Cover depth refers to how deep below the ground level a pipeline is placed. This can often vary between 1m to 1.5m.

6. The soil layers are not always uniform along the pipeline route & the layers of soil which are closer to ground level is taken as superficial layers. To cover the top of the pipe, saturated soil is added to lose soil as back fill.

7. The unit weight of compact backfill varies from location to location and depends on the grain size, specific gravity of the soil and level of compaction. Since the backfill is not necessarily uniform throughout the pipeline route, for the unit weight of dry backfill above the water table, average values of dry soil density is taken.

8. Factor of Safety is taken to account for any uncertainties like poor installation, natural calamities, and unexpected loads. Therefore, the principle on which the pipeline is coated with concrete should be the downward forces must be greater than the factor of safety times the upward buoyant force.

Problem Statement

For the current article, a 48” pipeline [OD 1219.20 mm] with a wall thickness [WT] of 12.7 mm is chosen. The material of construction is carbon steel with a density [rpipe]of 7,850 kg/m3 and is coated with Polyethylene [PE] to prevent corrosion. The coating thickness [CT] is taken as 3 mm with a density [rCT] of 950 kg/m3. The water density [rW] is taken 1,025 kg/m3.

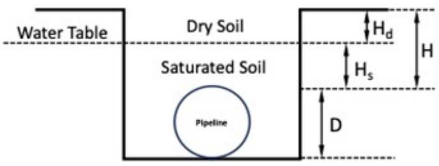


Figure 3. Pipeline in Soil Schematic

The concrete density [rC] is taken as 2,500 kg/m3 with a block length [L] and spacing [S] of 1.5 m and 3.5 m respectively. For this article, a bulk weight of 1,800 kg/m3 by the backfill soil and saturated soil density of 1900 kg/m3 is assumed. The submerged unit weight therefore becomes, 1900 – 1025 = 875 kg/m3.

For this exercise, the dry soil height and the saturated soil height is taken as 0 m. Therefore, the total cover height (Hs + Hd) is 0 m.

To estimate the thickness [Tc] of set on weight of the concrete, assuming a value of 300 mm, the calculations are made as follows,

$$Pipe\ Buoyancy = \frac{\pi}{4}[OD + (2 \times CT)]^2 \times \rho_w \times [S - L] \quad (1)$$

$$= \frac{\pi}{4}\left[\frac{1219.2 + (2\times3)}{1000}\right]^2 \times 1025 \times [3.5 - 1.5] \quad (2)$$

$$Pipe\ Buoyancy = 2{,}417\ kg \quad (3)$$

$$Concrete\ Weight\ Buoyancy = \frac{\pi}{4}[OD + (2 \times CT) + (2 \times T_c)]^2 \times \rho_w \times L \quad (4)$$

$$= \frac{\pi}{4}\left[\frac{1219.2 + (2\times3) + (2\times300)}{1000}\right]^2 \times 1025 \times 1.5 \quad (5)$$

$$Concrete\ Weight\ Buoyancy = 4{,}023\ kg \quad (6)$$

$$Total\ Buoyancy = 2{,}417 + 4{,}023 = 6{,}440\ kg \quad (7)$$

$$Pipeline\ ID = OD - [2 \times WT] \quad (8)$$

$$ID = 1219.2 - [2 \times 12.7] = 1193.8\ mm \quad (9)$$

$$Bare\ Pipeline\ Weight = \frac{\pi}{4}[OD^2 - ID^2] \times \rho_{pipe} \quad (10)$$

$$= \frac{\pi}{4}\left[\left[\frac{1219.2}{1000}\right]^2 - \left[\frac{1193.8}{1000}\right]^2\right] \times 7850 = 378\ \frac{kg}{m} \quad (11)$$

$$Coating\ Weight = \frac{\pi}{4}[(OD + 2 \times CT)^2 - OD^2] \times \rho_{CT} \quad (12)$$

$$= \frac{\pi}{4}\left[\left[\frac{1219.2 + (2\times3)}{1000}\right]^2 - \left[\frac{1219.2}{1000}\right]^2\right] \times 950 = 10.9\ \frac{kg}{m} \quad (13)$$

$$Pipeline + Coating\ Weight = 378 + 10.9 \quad (14)$$

$$Pipeline + Coating\ Weight = 388.9\ \frac{kg}{m} \quad (15)$$

$$Concrete\ Weight = \frac{\pi}{4}\left[\left(OD + (2 \times CT) + (2 \times T_c)\right)^2 - \left(OD + (2 \times CT)\right)^2\right] \times \rho_c \quad (16)$$

$$= \frac{\pi}{4}\left[\left(\frac{1219.2 + (2\times3) + (2\times300)}{1000}\right)^2 - \left(\frac{1219.2 + (2\times3)}{1000}\right)^2\right] \times 2500 \quad (17)$$

$$Concrete\ Weight = 3{,}594\ \frac{kg}{m} \quad (18)$$

$$Total\ Weight = [388.9 \times 3.5] + [3594 \times 1.5] \quad (19)$$

$$Total\ Weight = 6{,}752\ kg \quad (20)$$

$$Factor\ of\ Safety = \frac{Total\ Weight}{Total\ Buoyancy} \quad (21)$$

$$Factor\ of\ Safety = \frac{6752}{6440} = 1.0484\ or\ 4.84\ \% \quad (22)$$

Estimating the factor of safety by including the soil weight,

$$Soil\ Weight = [[Bulk\ weight \times OD \times H_d] + [Submerged\ Unit\ weight \times OD \times H_s]] \times [S + L] \quad (23)$$

$$Soil\ Weight = \left[[[1800 \times 1.2192 \times 0] + [875 \times 1.2192 \times 0]] \times [3.5 + 1.5]\right] = 0\ kg \quad (24)$$

The safety factor with soil weight contributing,

$$SF_{soil} = \frac{Soil\ Weight + Total\ Weight}{Total\ Buoyancy} \quad (25)$$

$$SF_{soil} = \frac{0+6752}{6440} = 1.0484\ or\ 4.84\% \quad (26)$$

The upward force therefore that is acting on the pipeline is,

$$Upward\ Force\,[F_s] = Total\ buoyancy - Total\ Weight - Soil\ weight \quad (27)$$

$$F_s = 6440 - 6752 - 0 = -312\,\frac{kg}{m} \quad (28)$$

Conclusion

With a net upward force of -312 kg/m, the pipeline with its concrete coating of 300 mm is expected to be stable against buoyant forces.

However, with the factor of safety [Fs] at 4.84%, the condition of Fs ≥ 10% is not satisfied. Hence the concrete thickness must be increased to meet factor of safety requirements.

Therefore, repeating the calculations for a concrete thickness of 328 mm, the required factor of safety, Fs ≥ 10% is satisfied. The concrete unit volume for 328 mm thickness is,

$$Concrete\ Volume = \frac{Total\ Weight - (Pipeline + Coating\ Weight \times Block\ Spacing)}{Concrete\ Density} \quad (29)$$

$$Concrete\ Volume = \frac{7363-(389\times 3.5)}{2500} = 2.4m^3 \quad (30)$$

References

https://allanedwards.com/about-us/

https://www.mmpipeline.com/pipeline-integrity-project/

https://ccppa.ca/flotation-of-buried-pipe/

https://epcmholdings.com/pipeline-buoyancy/

Author

Vijay Sarathy holds a Master's Degree in Chemical Engineering from Birla Institute of Technology & Science (BITS), Pilani, India and is a Chartered Engineer from the Institution of Chemical Engineers, UK. His expertise over 10 years of professional experience covers Front End Engineering, Process Dynamic Simulation and Subsea/Onshore pipeline flow assurance in the Oil and Gas industry. Vijay has worked as an Upstream Process Engineer with major conglomerates of General Electric, ENI Saipem and Shell.

Annexure

Set on Weights on Pipelines					
Outer Diameter [OD]	1219.2	mm	Pipe Buoyancy	2,417	kg
Pipe Wall thickness	12.7	mm	Concrete Weight Buoyancy	4,273	kg
Inner Diameter [ID]	1193.8	mm	Total Buoyancy	6,690	kg
Pipe Density	7,850	kg/m^3	Bare Pipeline Weight	378	kg/m
Pipeline Coating	PE		Coating Weight	10.94	kg/m
Coating Thickness	3	mm	Pipeline + Coating Weight	389	kg/m
Coating Density	950	kg/m^3	Concrete Weight	4,001	kg/m
Set on Weight			Total Weight	7,363	kg
Block Length	1.5	m	Soil Weight	0	kg
Block Spacing	3.5	m	Upward Force	-672	kg/m
Concrete Density	2,500	kg/m^3	Safety Factor [Fs]	1.1005	-
Water Density	1,025	kg/m^3	Safety Factor [Fs] with soil	1.1005	-
Concrete Thickness	328	mm	Concrete Volume	2.40	m^3
Soil Data			Check		
Bulk Weight	1,800	kg/m^3	Upward Force	Stable	
Saturated Weight	1,900	kg/m^3	Safety Factor >= 10%	Meets Safety Factor	
Submerged Weight	875	kg/m^3	Note:		
Hd	0	m	Use Goal seek to increase Concrete thickness until Safety Factor > 1.1 and Upward Force < 0 kg/m		
Hs	0	m			
H=Hs +Hd	0	m			

Design Guidelines For Propylene Splitters Efficiencies

Karl Kolmetz CPE—KLM Technology Group
Contributing Authors: Timothy Zygula, Andrew Sloley, Randy Miller, Brian Clancy-Jundt, Daniel Summers

Introduction

Actual field tray efficiencies are affected by many factors. These include;

a) tower pressure
b) geometry and design of contacting equipment,
c) flow rates and flow paths of the liquid and vapor streams,
d) composition and properties of the vapor and liquid streams.

All these items can affect tray efficiencies and there are field examples were some have greatly impacted tray efficiencies. This paper will review some case studies and develop some design best practices.

We would like to thank our contributing authors who had added knowledge for this paper and support in our career. We would also like to thank Robert Miller and Simon Xu for their help and support.

Propylene Splitter Distillation Fundamentals

Propylene is a colorless, gaseous hydrocarbon. It is a petrochemical feedstock used primarily in the manufacture of plastics via polypropylene or cumene. It is also used to produce propylene oxide, acrylic acid, oxo alcohols and isopropanol. There are four grades of propylene that are sold; research grade (99.99% minimum purity); polymer grade (99.5% minimum purity); chemical grade (93-94% minimum purity); and refinery grade (60-70% purity).

There are over 250 Propylene Splitters all over the world. Most Ethylene Plants and large refineries have Propylene Splitters. They are the largest and tallest twin distillation columns in an Ethylene Plant.

Distillation is the separation of key components by the difference in their relative volatility, or boiling points. It can also be called fractional distillation or fractionation. Distillation is favored over other separation techniques such as crystallization, membranes or fixed bed systems when;

1. The relative volatility is greater that 1.2,
2. Products are thermally stable,
3. Large rates are desired,
4. No extreme corrosion, precipitation or sedimentation issues are present,
5. No explosion issues are present,
6. Low scale up cost factors - capacity can be doubled for about 1.5 additional cost,
7. Suitable for heat integration.

Close boiling mixtures may require many stages to separate the key components. For vapor and liquid equilibrium a K- value is defined for each species i by,

$$K_i = Y_i / X_i$$

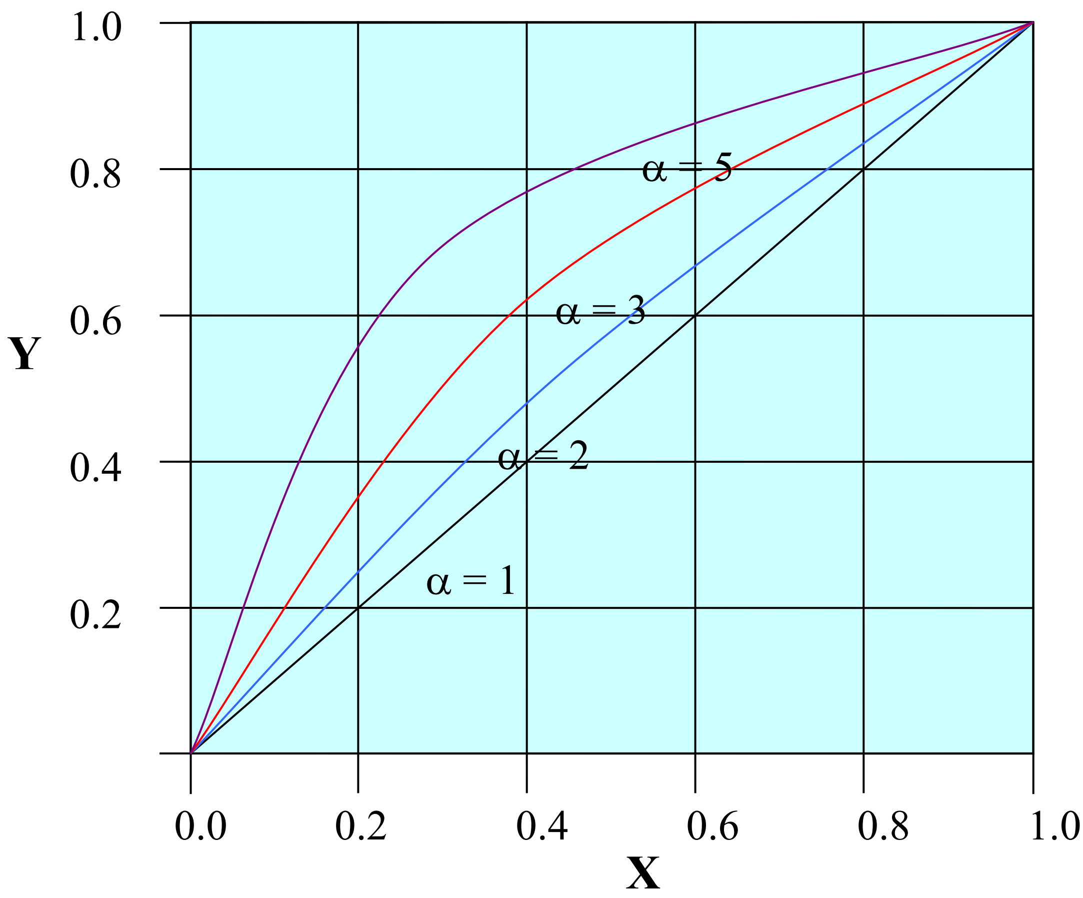
where Y is the mole fraction in the vapor phase and X is the mole fraction in the liquid phase. (1)

For vapor liquid separation operations, an index of the relative ease of separation for two chemical species i and j is given by the relative volatility alpha defined as the ratio of their K values

$$\alpha_{ij} = K_i / K_j = P_i / P_j$$

P_i and P_j are the vapor pressures of components i and j at a given temperature.

The number of theoretical stages required to separate two species to a desired degree is strongly dependent on the value of this index. The greater the departure of the relative volatility from a value of one, the fewer the equilibrium stages required for a desired degree of separation.



Knowing the relative volatility for a system is also useful in determining the amount of separation possible. A relative volatility of 1.0 indicates that both components are equally volatile and no separation takes place via normal distillation. When the relative volatility is low, less than 1.05, separation becomes difficult because a large number of stages are required. The higher the relative volatility, the more separable are the two components; this connotes fewer stages in a distillation column in order to effect the same separation between the overhead and bottoms products. Lower pressures increases relative volatilities in most systems.

The choice of the best application should be based on the life cycle cost. The life cycle cost is the initial capital cost of the plant along with the first ten years operating and maintenance cost. The life cycle cost should include a reliability factor, which is very important in designing any process plant equipment, reactors or separation equipment. Improved reliability has a very large impact on return on investment (ROI).

Many life cycle cost only review energy, but not solvent, adsorbent, or catalyst cost because of accounting rules and this can lead to skewed economic decisions. Accounting rules which list some items as capital cost and other items as operating expense need to be totaled or a skewed life cycle cost can be generated. A partial list would include;

1. Capital
2. Catalyst
3. Solvents
4. Energy
5. Maintenance
6. Industry average on stream factor (95% - 20 days per year)

For distillation the largest life cycle cost would be energy and maintenance concerns. Distillation is typically the single largest consumer of utilities in a chemical plant or refinery, and also the largest producer of finished product in most facilities. For energy cost a review of tray and packing efficiencies is warranted. For maintenance cost a review of reliability and simplicity is warranted. Distillation may be the most economical and is the most utilized globally to obtain improved purity products.

Some general estimates of tray efficiency might be

Demethanizer 65% Air Separation 90%
Deethanizer 70% C2 & C3 Splitter 85%
Depropanizer 75% Stabilizer 80%
Debutanizer 80% Hydrocarbon/Water 15%
Depentanizer 80% EB/Styrene 90%
Low alpha Aromatics 80% Alcohol - Water 75%
High alpha Aromatics 70% Amine Contactor 33%

This data is for crossflowing trays and SRK Property Package. Best to compare on an equal basis. There is a general trend in this data. If the boiling points are close together like in a C2 and C3 Splitter (low alpha k), the separation will require many stages, but each stage will have a relatively high efficiency. If the boiling points are far apart like hydrocarbon and water (high alpha k) the separation will require few stages, but each stage will have a relativity low efficiency. A benzene water stripper might only require 5 to 7 stages in a simulation, but 30 trays in the field because of the low tray efficiency.

General Tray Efficiency

There are several general tray efficiency models. O'Connell Type Correlations can be used to predict the overall column efficiencies, many of which were developed in the 1940s and 1950s.

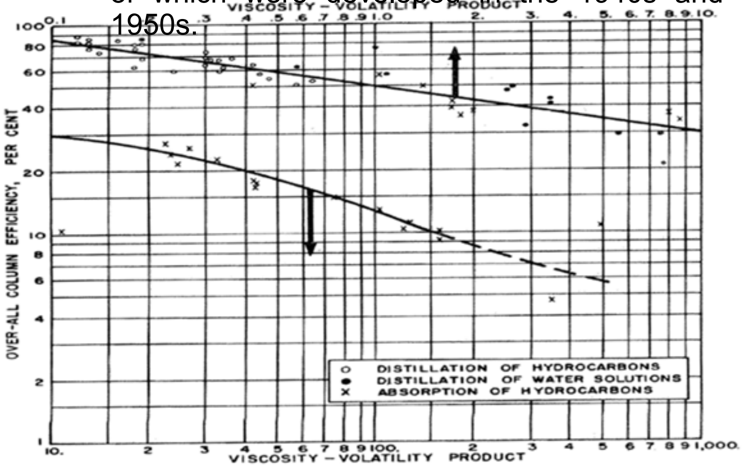


Figure 2.7: Lockhart and Leggett's augmented O'Connell correlation (Adapted from: Lockhart, F. J., and Leggett C. W. . (1958). *Advances in Petroleum Chemistry and Refining, 1*, 323-326)

One of the very first overall tray efficiency was the O'Connell Equation from 1946.

$$Eo = 49.2 (\alpha \mu) -0.245$$

μ is viscosity of feed
α is relative volatility
both at average tower temperature.

when viscosity and/or relative volatility are increased tray efficiency is decreased.

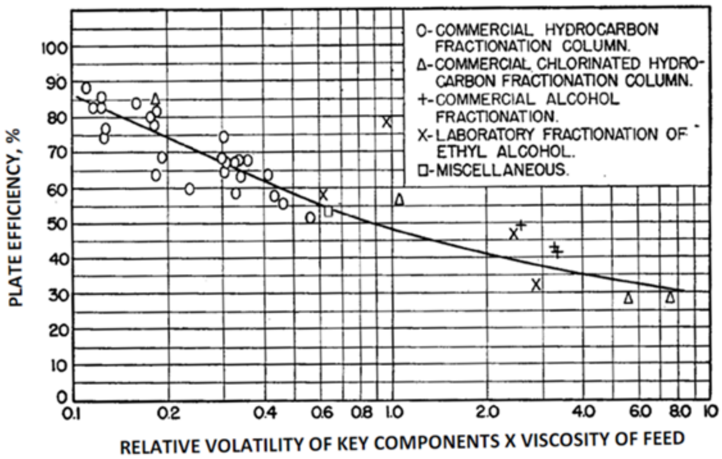
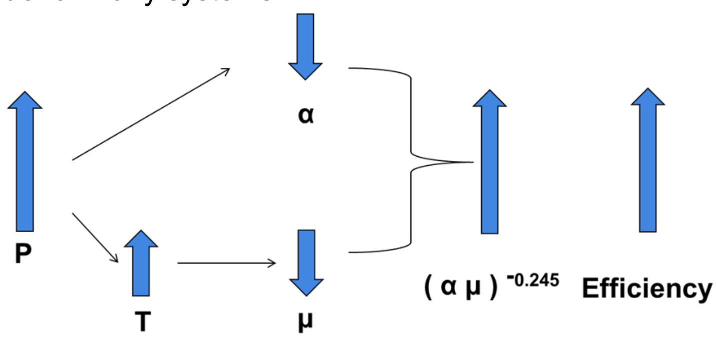


Figure 2.2: O'Connell correlation (Adapted from: O'Connell, H. E. (1946). Plate efficiency of fractionating columns and absorbers. *Transactions of the American Institute of Chemical Engineers, 42*(4), 741-755)

The Effect of Tower Pressure on Efficiency

For a fixed system (e.g. a C3 splitter), efficiency might go up with increased operation pressure as shown in the O'Connell Equation. This is true for many systems.



This pressure effect can be seen in C3 Splitters from the O'Connell Equation and Field Data.

PSIG	O'Connell	Field Tray Efficiency	
250	88	75-85+%	Numerous Papers
150	84	70-80%	Observed data
100	81	65-75%	Observed data
57		66%	AIChE 2011
50	75	60-70%	Observed data

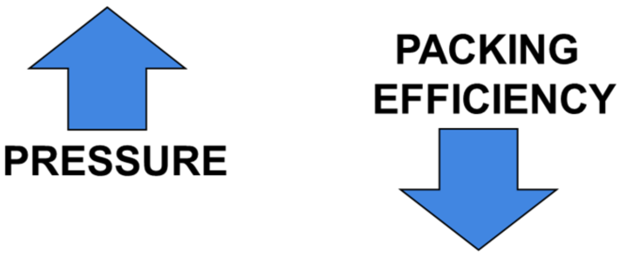
The is data is for cross flowing trays and SRK Property Package. At very close alpha Ks there can be a large difference in property packages, as much as 5 to 10%. PR might be a more accurate property package, but make sure you are comparing apples to apples.

The end result is what counts – does the tower meet capacity and product purities. Each good vendor utilizes a tuned model that give the proper end result.

There are over 200 C3 Splitter's in operation. O'Connell correlation works well for predicting the effect of pressure on efficiency.

Folklore and Myths can proclaim that lower pressure gives higher efficiencies – you need to review your system data – may not be true. This myth may have been developed from packing data, where HETP is much higher at lower pressures.

The field data for trays confirms that as pressure increases the efficiency increases. This is not the case for packing. There are two ideas of why this might be happening.



The first idea - some studies have showed that at higher pressures there appeared more liquid hold up on the packing, creating a larger boundary layer – leading to lower efficiency.

The second idea - there is a relationship between the vapor density / the liquid density and packing efficiency. At higher pressure the densities become closer together, leading to backing mixing effect of the liquid by the vapor - leading to lower efficiency.

Geometry and Design of Contacting Equipment
Once the preliminary tower diameter has been set the internals can be chosen. The task of choosing the type of tower internal to use is very important. The type of column internals used dictates a column's efficiency and capacity. All of the modeling and careful design work will mean nothing if the wrong type of column internals is chosen

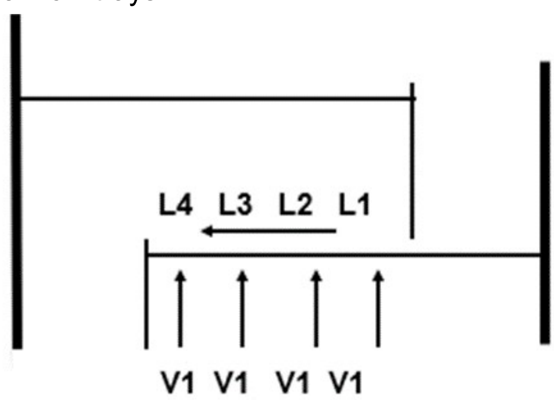
The types of internals that have been used in propylene splitter columns are:

- Conventional Cross Flowing Trays
- Dual Flow Ripple Trays
- Packing
- High Capacity Trays
- Multiple Downcomer Trays

Conventional Multi-Pass Trays
Conventional multipass trays are typically used when a column is initially designed. Four pass or six pass trays are usually used because of their ability to handle high liquid loads like seen in propylene fractionation. The downside to using multipass trays is the reduction in separation efficiency that is experienced due to the reduction in active area and path flow length.

Great care must be taken when sizing downcomers in high-pressure distillation applications. The difference between vapor and liquid densities becomes smaller and separation of vapor from liquid in a downcomer becomes more difficult. This can result in increased aeration back-up and possible premature downcomer flooding. (2)

General Tray Efficiency may be determined by several formulas. There are two types of tray efficiency. There is the point efficiency and path flow efficiency. The point efficiency is where V1 meets L1. This is what is seen in dual flow trays.



V1 meets L1 – about 60 % Efficiency. Then L1 becomes L2. Then V1 meets L3 – about 65% Efficiency

Cross Flow Tray Efficiency >= Point Efficiency

$$E_{oq} = \frac{(Y_n - Y_{n-1})}{(Y^{o}_n - Y_{n-1})}\ \text{point}$$

Point Efficiency

$$E_{MV} = \frac{y_j - y_{j+1}}{y^{*}_j - y_{j+1}}$$

Overall Tray Efficiency

Where

$$y_j^* = K\, x_j ,$$

x_j ***is liquid composition at DC outlet.***

Dual Flow Ripple Trays

Dual Flow Ripple Trays were installed in a few Propylene Splitters in the 1960s and in the 1990s. The challenge of dual flow trays are the hydraulic instability. The top of a distillation column will move as much at two feet in a wind storm. This movement at the top will cause the liquid to start down one side of the column and the vapor traveling up the opposite side of the column with limited mass transfer.

Dual Flow Ripple Trays Case Study

In a Malaysian ethylene plant, a two-column in series C3 Splitter was constructed to produce polymer grade (99.50 wt %) propylene. The towers were equipped with 258 dual flow trays. The trays are corrugated into a sinusoidal wave, with alternate trays installed with the waves at right angle.

Typical Dual Tray Loading Schematic

Notice:

1. **Froth Height**
2. **Rain Space**
2. **Corrugated Tray Deck**

The propylene service was commissioned in late 1999. It achieved both the nameplate capacity and propylene product quality. Unfortunately, the propylene loss in the propane recycle stream was observed to be significantly higher than the original design heat and material balance. This has resulted in an overall loss in propylene yield, higher purchased energy in the pyrolysis furnace and to a smaller extent, reduced the on-stream factor of the recycle propane gas pyrolysis furnace zone.

During a high load test carried out in July 2000, data was collected to pinpoint the high propylene loss was attributed to lower tray efficiency. By means of simulation to match the plant operating analyses, the efficiency was determined to be in the range of 45%. This is a significantly difference from the 65 - 70% tray efficiency assumed in the design. The tower effectively has less equivalent stages of fractionation and unable to achieve the desired separation. The average propylene in the propane recycle was averaging 45%, much higher that the designed 8%.

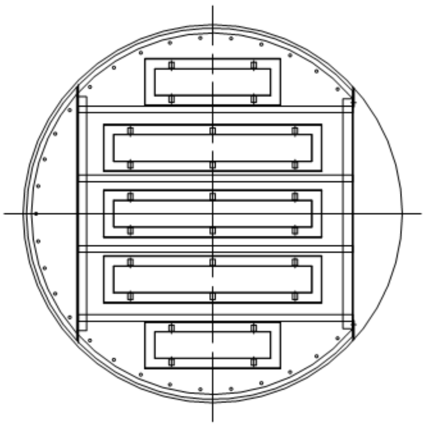
A gamma scan on the tower was carried out prior to a shutdown in early 2001 to eliminate potential tray damage. The scan showed all the trays were still intact. However, the liquid density profile showed mal-distribution occurring after the first 30 trays of each column. The decision was made to inspect the column on the results of the gamma scan.

The tower was opened for inspection during the February 2000 turnaround. The trays are were intact and level but large 6” I-beams and U-Channels were found laid perpendicular across the centerline of each tray. The I-beams and U-Channels effectively divided each tray into four quadrants.

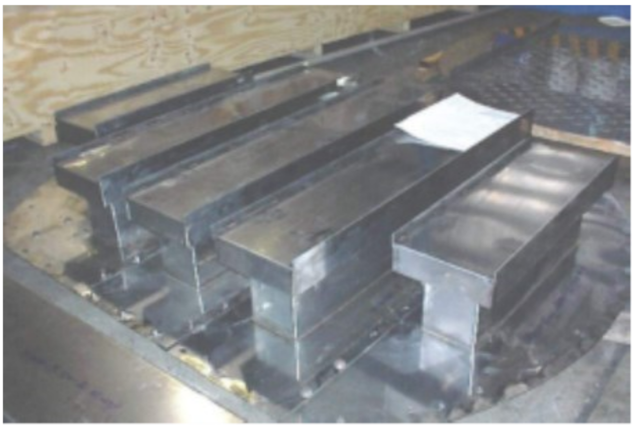
If the liquid flow was inconstant across the four quadrants, the gas flow will follow the path of least resistance further reducing the fractionation efficiency. A top of a column will move in a typical meteorological disturbance. This movement will cause the hydrologic load to migrate among the four quadrants. If any hydrologic flow instability were developed it would remain down the column. This hypothesis is consistent with the results from the gamma scan.

A decision was made to install six vapor and liquid re-distributors every thirty trays to correct any mal-distribution that had occurred in the column. Additionally the U-Channel was constructed in three parts and the middle part of the U-channel was removed on each of the 14th and 15th trays between the re-distributors.

Schematic of Typical Re-Distributor Tray



Picture of Typical Re-Distributor Tray



Results
With the addition of these vapor and liquid re-distributors the tray efficiency of the column was increased 10% resulting in improved fractionation, even with the total reduction in the number of fractionation trays. The propylene in the propane recycle was reduced from 45% to below 10%. The tower maximum capacity before was 112%, and has presently run as high as 115% without reaching a limit.

Structured / Random Packing
There were two towers where structured packing was installed in Propylene Splitter Service and they were quickly replaced with the original trays. The structured packing was unable to meet the required product purity.

Structured packing was successful in very high pressure services like air separations, and low pressure applications like vacuum towers. It would be a logical assumption to expect that a medium pressure application (200 psig), like a propylene splitter would be an ideal application for structured packing. Both towers under preformed.

In the refinery where I worked in Houston, an alky debutanizer was converted from trays to random packing. Again a medium pressure application where random packing would be a logical assumption. The tower under preformed and the original trays were reinstalled.

What was discovered in these failures was that the pressure was not as important as the density difference between the vapor and liquid phases. If the vapor and liquid phase were very close in density, the vapor would back mix the vapor leading to low efficiency. In high pressure air separation there is a large difference in vapor and liquid density. In low pressure application there is a large difference in vapor and liquid density.

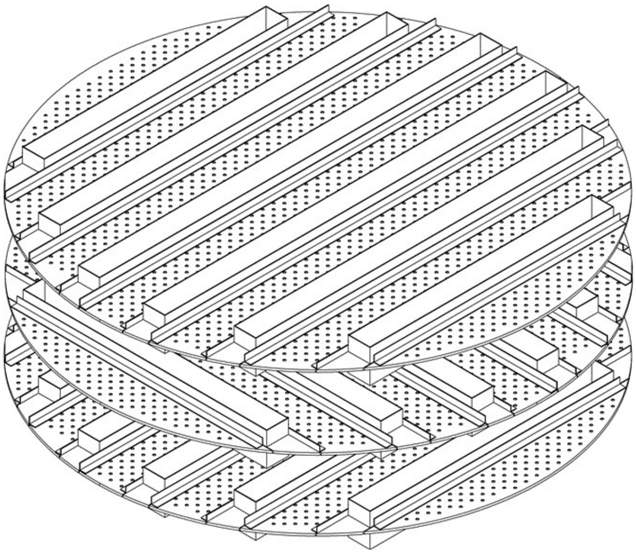
In medium pressure applications, above 150 psig (10 bar) the vapor and liquid density become close together and efficiently of the packing (HEPT) is reduced. It is seen in both structured and random packing applications. Low liquid-density/vapor-density ratios tend to create backflow in packed beds. Capacity and purities are often much lower than expected. Above a vapor density of 1.5 lb/ft3, packing may not be recommended. General guidelines are for the vapor to liquid ratio to be above 10.

There is some documentation that has packing utilized in low pressure C3 Splitters.

Multi-Downcomer Trays
Multi-Downer trays are used for large liquid loads, particularly when the volumetric ratio between vapor and liquid rates is low. These situations occur in medium to high-pressure distillation, in absorption and stripping, and in direct contact heat transfer applications.

Multi-Downcomer trays can be used at close tray spacing. This will allow a reduction in both height and diameter of a new column compared to a column fitted with conventional multi-pass trays. Vessel shell costs can be significantly reduced with the use of Multi-Downcomer trays. When retrofitting an existing column with Multi-Downcomer trays, a significantly greater number can be installed, providing increased product purities and recoveries, as well as reduced reflux ratio for reduced energy consumption and/or increased column capacity.

The use of Multi-Downcomer trays has often reduced the number of columns needed in difficult separations, such as the fractionation of propylene-propane.



Copyright A.W. Sloley, 2018. Used with Permission

Multiple Down Comer tray has less path flow length and lower efficiency. One rule is to keep the Path Flow Length above 450 mm (18 inches) to maintain good as possible efficiency. Efficiency is greatly reduced below 450 mm.

The question everyone ask - How much less efficient? You can hear numbers from 2% to 20% according to who you ask. One time a MD Salesman told me the efficiency loss was only 2%. Another time a cross flowing tray Salesman told me it was 20%.

The good news is that we have real data. There is some published efficiency data on Multiple Down Comer Trays

Date	Aug 92	June 95
Tower	C2 Splitter	C3 Splitter
Pressure	290 PSI	250 PSI
Reflux	237,834 kg	1,400,000 lb/hr
Trays	155	325
Capacity Gain	25%	35%
Efficiency	74%	74%

One might expect that a crossflowing tray at this pressure to be about 85% efficient.

Multiple Down Comer Trays – Best Practices

Understand there is a loss in tray efficiency – but because than may be installed on 18" trays spacing or less, you can install more trays and possibility increase overall tower efficiency – based on the reflux to stages curves. For the same tower shell diameter, capacity increase can be greater than 35%. If designed properly there can be an efficiency and capacity increase.

Design of a Propylene Splitter
High Pressure Verses Low Pressure Splitters

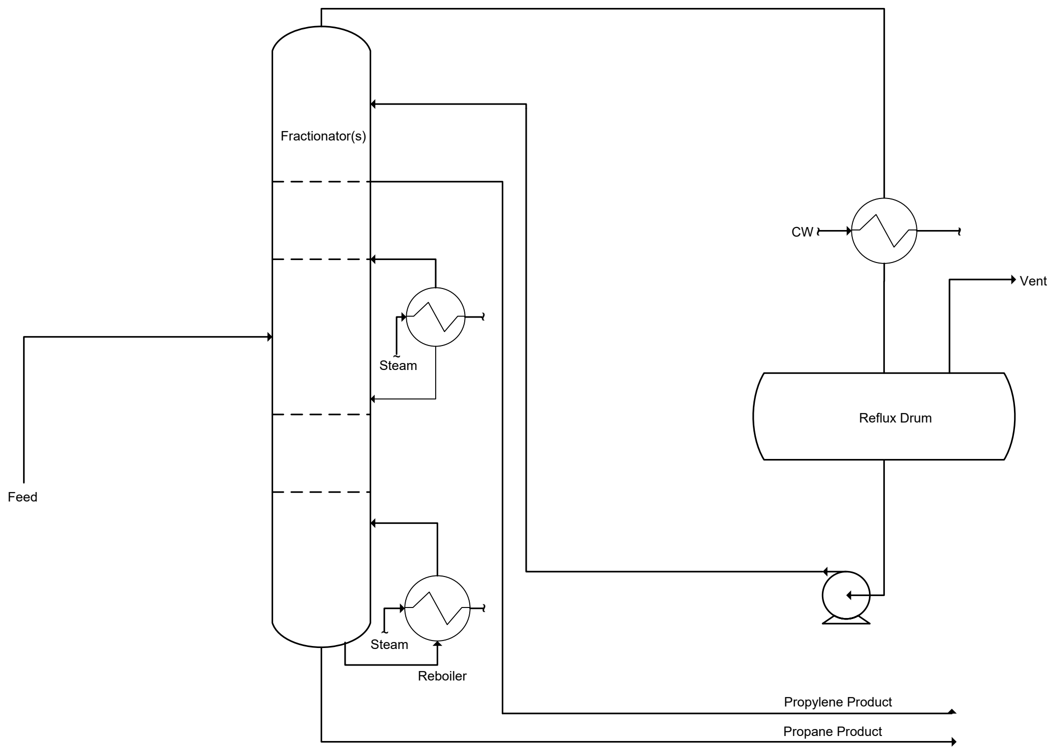
Determining the design of a Propylene Splitter requires an understanding of the simulation model used to generate the internal loads and physical properties, vapor and liquid equilibrium data utilized, tray hydraulics, and how the selection of the internals will affect the actual efficiency of the installed equipment in the field.

The typical design of a propylene splitter is not complex and there are two general variations in design. The first is a called high-pressure system, and the second is called a low pressure heat pumped system. A high-pressure system is designed to utilize cooling water as the source to cool the overhead vapor, and a high pressure is needed to condense the propylene vapor at ambient temperatures of about 40 degrees C.

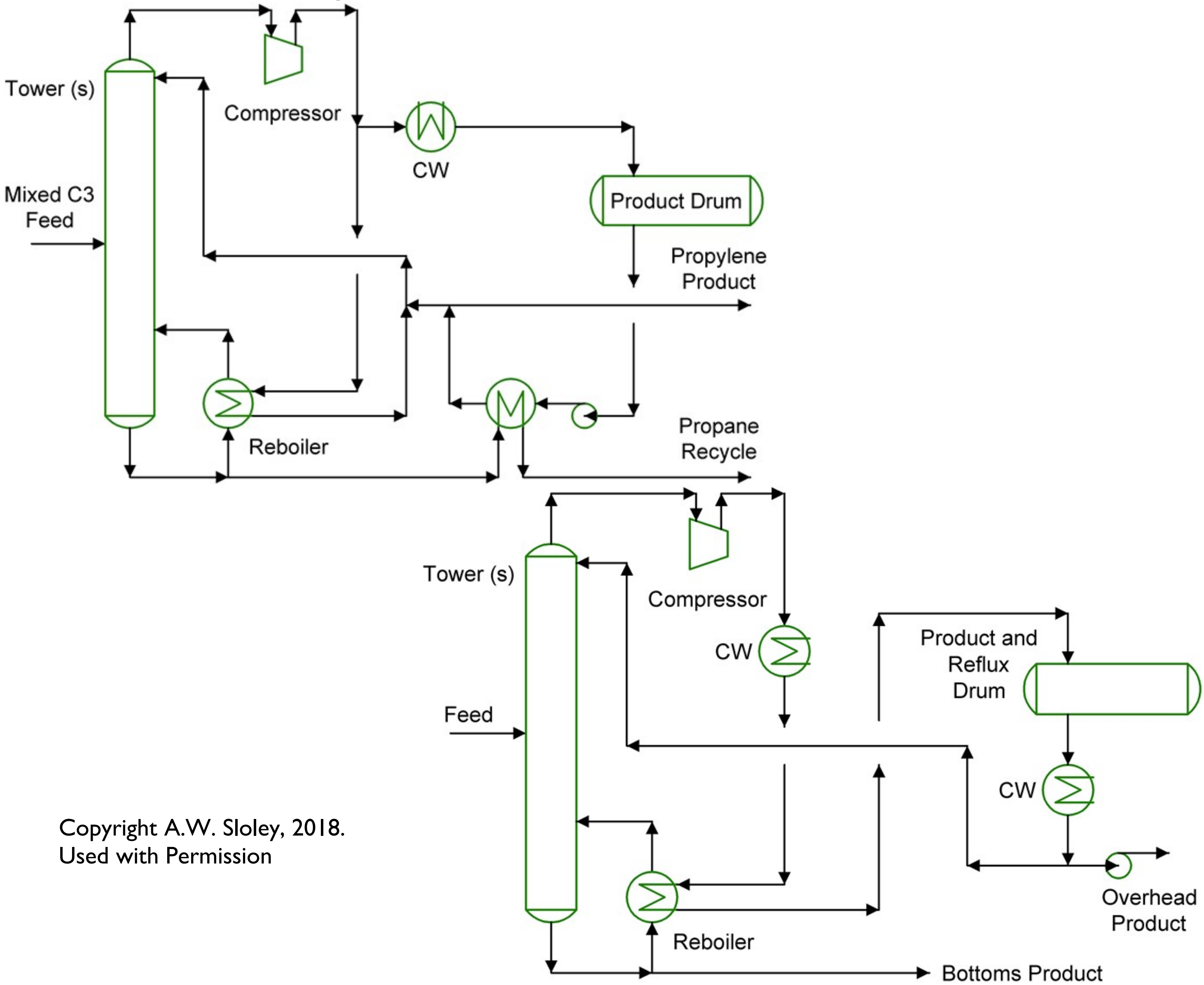
A heat pump system utilizes a compressor to reduce the tower pressure to allow the distillation column to be smaller in height, but larger in diameter. In most distillation application, relative volatilities can be improved by lowering the pressure. This results in lower number of stages required and reflux ratios, but at the cost of higher energy requirements of the compressor.

A good rule of thumb is that if the propylene system is associated with an ethylene plant, in which there is typicality an abundance of quench water that can be used to heat the C3 Splitter reboiler, a non-heat pump system may be the best choice. If no source of sufficient low-grade heat is available, for example in a refinery FCC unit, a revamp, or a propane dehydrogenation unit, then the use of a Heat Pump may be the economical choice. One should perform an economic analysis utilizing the six factors mentioned in the life cycle cost above.

High Pressure Systems



Low Pressure Heat Pumped Systems



There is a wide range of pressure choices for Propylene Splitters from 50 PSIG to 300 PSIG. What might be guidelines to choose the best pressure?

High Pressure Splitters

Advantages

- Ability to utilize cooling water for overhead condenser
- Ability to utilize medium level heat – there is a surplus in an Olefin Plant
- Higher Individual Tray Efficiency

Disadvantages

- Capital Cost – thicker tower shell and foundation

Low Pressure Splitters

Advantages

- Capital Cost – thinner tower shell and foundation
- Energy – if there is not a surplus of medium level heat – the compressor heat can utilized for the energy
- Lower reflux ratio – combination of J-T effect and relative volitivity
- Fewer stages – combination of J-T effect and relative volitivity
- Ability to utilize Packing

Disadvantages

- Capital, Energy and Maintenance Cost of a compressor
- Larger Tower Diameter

You may need a study to determine best pressure for your Splitter - one vendor recommends 90 PSIG and a second vendor recommends 110 PSIG.

- 90 PSIG is lower capital but higher energy cost
- 110 PSIG is high capital but lower energy cost.

Conclusions

Field efficiency of trayed towers, may increase with operational pressure, as shown in the O'Connell correlation and field data. Field efficiency of packed towers, from the data appears to going down with increasing operational pressure. Proper design and selection of trays, packings and internals are critical for success of distillation towers.

References

1. Kolmetz, K. and Zygula, T. M., "Resolving Process Distillation Equipment Problems" 5th Regional Ethylene Producers Technical Committee Meeting, Johor Bahru, Malaysia, (2000), Engineering Practice Magazine, Volume 3 Number 9 April 2017

2. Kister, H. Z. "Distillation Design", McGraw-Hill Book Company Inc., New York, 1992.

3. Zygula, T. M., Dautenhahn, P. C. Ph.D., P.E. "The Importance Of Thermodynamics On Process Simulation Modeling" AIChE Spring National Conference, March 2001, Houston, Texas.

4. Pilling, Mark, Column Efficiency – What to Expect and Why, Prepared for Presentation at 4th Topical Conference on Separations Science and Technology, November 1999 Session T1006 – Distillation Hardware and Application I

5. Kolmetz, K and Zygula T.M., "Guidelines for Propylene Splitters" Engineering Practice Magazine, Volume 1, Number 1 April 2015

6. Kolmetz, K, "The Economic Advantage Added by Specialized Knowledge of Distillation Fundamentals" Engineering Practice Magazine, Number 3 Volume 10

7. Kolmetz, K, "Technology Review 2017 – Steady State Process Simulation of Distillation Columns, Engineering Practice Magazine, Volume 3 Number 11

View from Rock Bottom: Trouble On the Continent!…What Will European Chemicals Need to Win?

Ron Cormier

Hello from sunny Mexico! The first quarter of 2024 is nearly behind us and while most parts of the industry are doing fairly well, one not-so-good-thesis continues to lag with the chemicals business in northwest Europe….we take look at the situation and what might be done.

During the first decade of the new century, the petrochemical business in North America was largely thought to be losing its competitive edge. Natural gas supply was diminishing, and price was forecast around $8-10+/mscf for the foreseeable future. To combat these possible feedstock supply spikes, the industry had built its ethylene basis on high cap-ex cost, flex-fed crackers, on the belief that oil vs. gas feeds provided advantaged economics. These units could crack heavy feeds all the way down to gas oil, if LP margin models dictated. Firms like Dow Chemical, Lyondell, and Chevron Phillips were sourcing condensates from as far afield as North Africa, then deep-sea sailing these cargos to the US Gulf Coast. Even such measures didn't seem to provide enough edge at the time.

Chemical firms in the Middle East had cheap and abundant oil, plus access to associated natural gas for conversion of their chemical basics—clearly the leading economic cost choice. Firms in the Far East remained mostly dependent on refinery naphthas, though supply and economics were lesser issues vs. those of North America. Those continent's feedstocks had emerged to provide better value from start to finish vs NorAm…hydrocarbon feedstock costs, minimal regulatory compliance cost limitations, petrochemical conversion chain tech which provided valuable co-products, product distribution chains which were shorter, and finally consumer demand which added up as the hands-down favorite.

Then Mitchell Energy, et.al., in North America commercialized new horizontal extraction techs for oil/gas/liquids-containing shales. This phenomenon boosted a resurgence in the USA, a "lightening" of ethylene crack slates/hardware, and a return to preeminence as the world's advantaged producer and exporter, when the "shale gale" blew in. Now in the century's mid-second decade, dire circumstances have disadvantaged Europe's conversion chain cost.

The global chemical industry is going through difficult times relative to geopolitical tensions, inflation, sustainability pressures, supply-chain interruptions, and demographic challenges which have greatly complicated its operations. On top of these issues, the European chemical industry is facing an existential threat. Prices of natural gas—the primary feedstock for the industry—have risen 420% compared with average prices in Europe in 2010-2020. Meanwhile, Asian and North American markets have faced significantly lower increases of about 105% and up to 50%, respectively. The higher global prices are primarily the result of the industry moving away from lower-cost Russian gas. Going forward, companies must build on Europe's intrinsic strengths and play offense in sustainability, while pursuing consolidation and functional excellence.

The current level of gas prices is putting the competitiveness of the European chemical industry at risk. The cost of materials and labor is increasing throughout the industry and EBITDA margins are declining, though diversified companies are less exposed to this effect. Several commodity chemicals companies have already started to reduce or shut down production capacity in Europe. Further, gas shortages are likely to persist until 2025. While gas prices are expected to fall from current levels, they could remain above pre-crisis levels with continuing high volatility.

European manufacturers are importing building blocks to make plastic from overseas as energy prices make domestic production too costly, notes Bloomberg. The last time European petrochemical plants processed so little of their favorite feedstock, Sweden's ABBA was the most popular band on the continent, and the Fall of Saigon had marked the end of the Vietnam War. It was 1975, and the region was still reeling after the first oil crisis. Nearly half a century later, the industry is dying.

Europe keeps consuming voracious amounts of foams, paints, resins and all other product petrochemical factories make. Now though, it is just replacing indigenous production with imported material. Europe's consumption of naphtha will drop in 2024 to a nearly 50-year low, down 40% from its peak.

On average, a European person consumes around 150 kilograms of plastic a year, more than twice the global average of 60 kilograms, according to the EEA. Plastics are everywhere, from food packaging to construction materials, from mobile phones to clothes. The petrochemical industry runs largely on two feedstocks: natural gas and naphtha, with the latter being a byproduct of refining oil, similar in some ways to gasoline. With processing so low, steam crackers are operating at uneconomical rates.

Because of their enormous, fixed costs, steam crackers prefer to run as close to capacity as they can throughout the year. Anything below 90% is a source of concern; 85% is bad, and 80% is seen as catastrophic. In recent quarters, however, they have run at loss-making rates of between 65% and 75% of their capacity.

In private, industry executives say they can only lose money for so long — so closures look certain in 2024. The IEA said that it is increasingly difficult to see how the continent's petrochemical industry can recover its previous strength. European companies are adapting accordingly. When BASF met investors a couple of weeks ago, its executives wanted to talk about anything but their home base. Look at their slide presentation….most featured is the construction of a $10B new plant in Zhanjiang, China.

Across European chemical companies, the proportion of spending on new projects into Asia has jumped by about 50% during the past decade and a half, according to estimates by Jefferies Financial Group Inc., an investment bank.

How does that translate to the economy? Before the pandemic, Europe's chemical trade balance with the rest of the world was typically in the black to the tune of $40B. Last year, the surplus narrowed to just $2.5B. Although it's likely to recover somewhat, the outlook for 2024 is somber, Bloomberg concludes.

Sources of competitiveness for the European chemical industry

While Europe has been disadvantaged historically in terms of feedstock, labor cost, and capital, its chemical industry has done remarkably well. In the 20 years from 2000 to 2020, the European chemical industry has delivered the same total return to shareholders (TRS) as its North American counterparts, and a higher TRS than its Asian ones. The lower capital cost in Asia has been driven by overall higher subventions. The European chemical industry has only fallen behind since 2020, when natural gas prices began rising even before the Russian invasion of Ukraine.

So, if the European chemical industry has lacked a structural advantage, why has it been doing relatively well? And can the sources of this strength be leveraged in the future? Europe offers chemical and other companies four intrinsic strengths that are difficult to replicate: ingenuity, size and stability, diversity, and sustainability, which must be emphasized to remain alive.

How European chemical companies can remain competitive.

Continuing to operate in the same way that they have for the past 20 years—that is, cutting costs to remain competitive—will not be enough for European chemical companies to secure their futures. It will require a transformation and redefinition of the industry, and fast execution and agility.

Short term: European chemical companies can take immediate steps to address efficiency and productivity, while preparing for the major shifts to come in the middle and long term.

Renew functional excellence….natural gas prices are expected to fall by 2026, but, even then, they may remain above historical averages. Under these circumstances, European businesses would do well to be at the forefront of efficiency and effectiveness to achieve a solid and stable base on which to build other initiatives. History shows that chemical companies can save up to 10 to 20% on energy spending and 10 to 40% on the energy they use, while achieving up to 10 to 20% in throughput improvements and 10% in yield increases, via digitization, analytics, and enterprise agility.

Strengthen resilience in the physical supply chain…safeguarding operations will be paramount. This includes securing access to energy through a combination of contractual and physical hedging, as well as gaining access to raw materials and identifying critical alternative feedstocks that might be, or become, scarce.

Review the existing strategy considering current value-pool shifts….the changes in energy supply, sustainability regulations, global supply chains, and other factors could spur a major shift in value pools. Decarbonization of power, low-carbon mobility, circular products and packaging, and low-carbon agriculture and food supply are just a few of the new value pools. Each of these areas could generate market sizes of $500B to $1T USD by 2025, and each one could require new chemical products. Companies can consider reassessing their product portfolios—what to keep, what to decarbonize, what to relocate, and what to sell—and reevaluate the strategic options linked to these new growth levers in Europe.

Identify new business-building opportunities…developing new sustainable solutions will require not only decarbonizing existing assets but also building new businesses, for example, in circularity or green and blue businesses in bio- or hydrogen-based feedstocks. Scaling these businesses will take time and the full top- and bottom-line impact will only become apparent in the middle to long term. Therefore, it will be important to identify opportunities, develop business blueprints, and design ambitious scale-up plans early on.

Medium term: In the medium term, European chemical companies can consider shifting their focus to decarbonization, building new businesses, developing functional capabilities, and bulking up through consolidation and M&A.

Decarbonize operations…European companies will have to decarbonize their own operations, both for compliance reasons and to satisfy their customers' needs. As noted above, many downstream companies, especially brand owners in consumer-focused industries, have announced ambitious targets and commitments to reducing Scope 3 carbon emissions.

As these industries are all customers of chemical companies, it will be critical that chemical companies decarbonize their own operations.

Build and start to scale new businesses…once companies have identified opportunities to pursue, they can start to build and scale them. Analysis shows that leaders in green business building share several key success factors, with the first being the most important:

- Lead with a game-changing ambition, balanced with speed and execution.
- Sign up captive demand before scaling. In many cases, there are long-term off-take agreements and even invitations to customers to invest in the business upfront to further align interests.
- Secure a cost advantage by identifying a scaling breakpoint to reach viability as quickly as possible.
- Assess technological pathways for maturity and performance at scale before committing bigger resources.
- Create business ecosystems by collaborating with players in the value chain (when obtaining commitments from suppliers and customers).

Develop functional capabilities…European companies can consider upgrading their capabilities in pricing, branding, marketing, and go-to-market to capture premiums for sustainably made chemical products. Market indications are that temporary premiums will be available, given expected green chemical supply shortages due to high demand from consumer and automotive companies. But being a first mover will be critical as green resources, like renewable feedstock, may be scarce.

Capture synergies and economies of scale… industry consolidation and M&A could improve competitiveness through synergies and economies of scale. Each management team will likely think differently about this situation—some will want to exit the market and sell, while others will seize the opportunity and seek to buy (consolidation). Players could also consider expanding horizontally or integrating businesses further upstream or downstream (M&A).

Long term: Europe's chemical companies should consider doubling down on green business building and partnerships to capture new value pools while strengthening positions in attractive value chains. Chemical players have a variety of investment options from which to choose to strengthen and maintain their competitiveness, especially in areas like decarbonization and circularity. A knowledge advantage in decarbonization, toxic-free environments, and sustainability commercialization can protect the home business and a competitive strategic advantage as regulations catch on in other geographic markets.

Finally: European chemical businesses can take several strategic measures to mitigate the impact of higher feedstock costs and enhance their competitiveness:

Invest in Research and Development (R&D): Focus on developing innovative technologies and processes that reduce reliance on traditional feedstocks and promote the use of alternative, sustainable feedstock sources such as bio-based materials, renewable energy sources, and waste-to-feedstock conversion methods.

Optimize Supply Chain Efficiency: Streamline supply chain operations to minimize costs related to transportation, storage, and logistics. Implement digital technologies, data analytics, and supply chain visibility tools to improve efficiency and responsiveness to market fluctuations.

Embrace Circular Economy Practices: Adopt circular economy principles by promoting recycling, reuse, and resource recovery. Develop closed-loop systems where waste materials from one process become feedstock for another, reducing raw material consumption and waste generation.

Diversify Feedstock Sources: Explore diverse feedstock sourcing strategies, including strategic partnerships, long-term contracts, and regional sourcing initiatives. Diversification can help mitigate risks associated with supply disruptions and price volatility in specific feedstock markets.

Enhance Energy Efficiency: Invest in energy-efficient technologies and processes to reduce energy consumption and associated costs in feedstock production, transportation, and manufacturing operations.

Focus on Specialty and High-Value Products: Shift focus on specialty chemicals, high-value-added products, and niche markets where pricing dynamics are less impacted by raw material costs. Develop customized solutions and value-added services to differentiate from competitors.

Collaborate and Innovate: Collaborate with industry peers, research institutions, and government agencies to drive innovation, share best practices, and collectively address common challenges such as feedstock costs, sustainability, and regulatory compliance.

Sustainable Practices: Integrate sustainability into core business strategies by implementing eco-friendly practices, reducing greenhouse gas emissions, and adopting circular design principles throughout the product lifecycle.

Strategic Pricing and Cost Management: Implement strategic pricing strategies based on market dynamics, cost structures, and value propositions. Continuously monitor and optimize costs across all operational areas to maintain competitiveness. By adopting a multifaceted approach that combines innovation, sustainability, operational efficiency, strategic partnerships, and market-driven strategies, European chemical businesses can navigate higher feedstock costs effectively and strengthen their position in the global market.

Hang in there Europe! Until May's edition of EPM and VRB, we bid you health and happiness!

Footnotes: BASF, 2023 shareholder report 2/2024; Bloomberg: Europe's petrochemical industry is heading for death row, 11/2023; EEA, various reports January, 2024; IEA, various reports January, 2024; Jefferies Financial Group Inc., Asian and European Chemical Segment Various Reports, 2024; McKinsey & Company, authors Cetinkaya, Klei, Seitz, and Winkler, 2023 various reports; WIkipedia, ABBA Tops the Charts, 1974-1982; Wood Makenzie, Ltd. Consulting interviews, January-March, 2024

IACPE
INTERNATIONAL ASSOCIATION OF
CERTIFIED PRACTICING ENGINEERS

IACPE.COM