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## SPECIAL FEATURES

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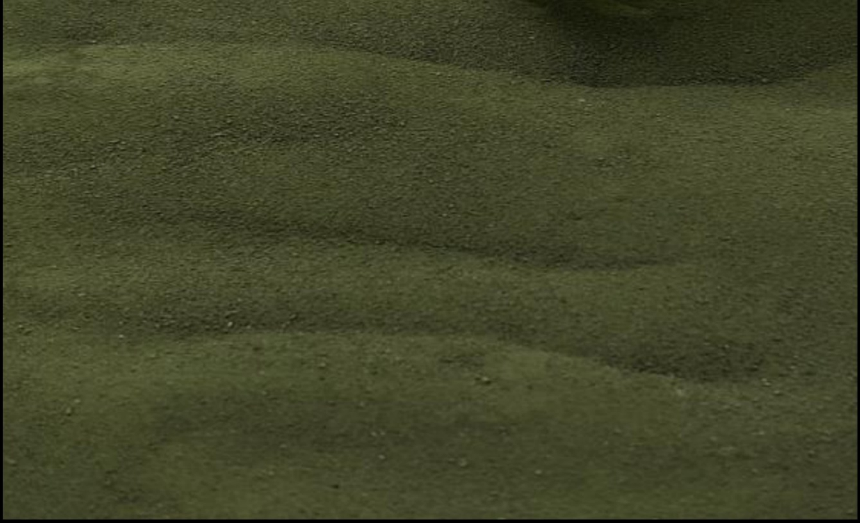

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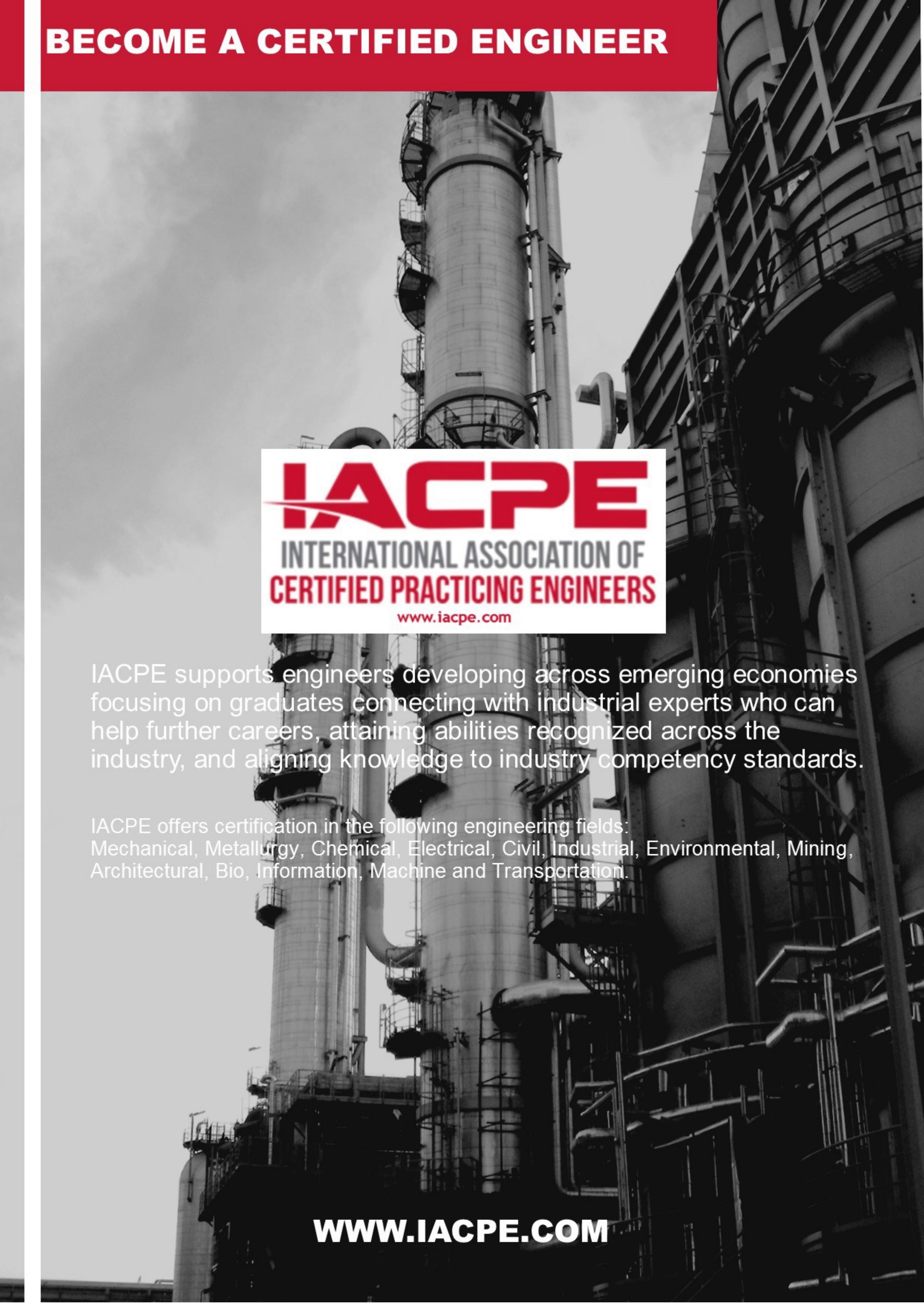
# Letter from the Editor

Hope you are doing well.  Here is some wisdom from a farmer:

- Your fences need to be horse-high, pig-tight and bull-strong.
- Keep skunks, bankers, and politicians at a distance.
- Life is simpler when you plow around the stump.
- A bumble bee is considerably faster than a John Deere tractor.
- Words that soak into your ears are whispered, not yelled.
- The best sermons are lived, not preached.
- If you don't take the time to do it right, you'll find the time to do it twice.
- Don't corner something that is meaner than you.
- Don’t pick a fight with an old man. If he is too old to fight, he’ll just kill you.
- It doesn’t take a very big person to carry a grudge.
- You cannot unsay a cruel word.
- Every path has a few puddles.
- When you wallow with pigs, expect to get dirty.
- Don't be banging your shin on a stool that's not in the way.
- Borrowing trouble from the future doesn't deplete the supply.
- Most of the stuff people worry about isn’t never going to happen anyway.
- Don’t judge folks by their relatives.
- Silence is sometimes the best answer.
- Do not interfere with something that is not bothering you none.
- Timing has a lot to do with the outcome of a rain dance.
- If you find yourself in a hole, the first thing to do is stop digging.
- Sometimes you get, and sometimes you get got.
- The biggest troublemaker you’ll ever have to deal with watches you from the mirror every morning.
- Always drink upstream from the herd.
- Good judgment comes from experience, and most of that comes from bad judgment.
- Letting the cat out of the bag is a whole lot easier than putting it back in.
- If you get to thinking you’re a person of some influence, try ordering somebody else’s dog around.
- Live a good, honorable life. Then when you get older and think back, you’ll enjoy it a second time.
- Live simply. Love generously. Care deeply. Speak kindly. Leave the rest to God.
- Most times, it just gets down to common sense.

All the best,
Karl



# Integrated Refining Schemes: Reviewing the Mind Map of the Downstream Players

Dr. Marcio Wagner da Silva

## INTRODUCTION AND CONTEXT

Just like any other business, the central objective of the crude oil refining industry is to maximize profitability, to achieve this objective the refiners need to ensure meeting quality requirements and, mainly, compliance of environmental regulations.

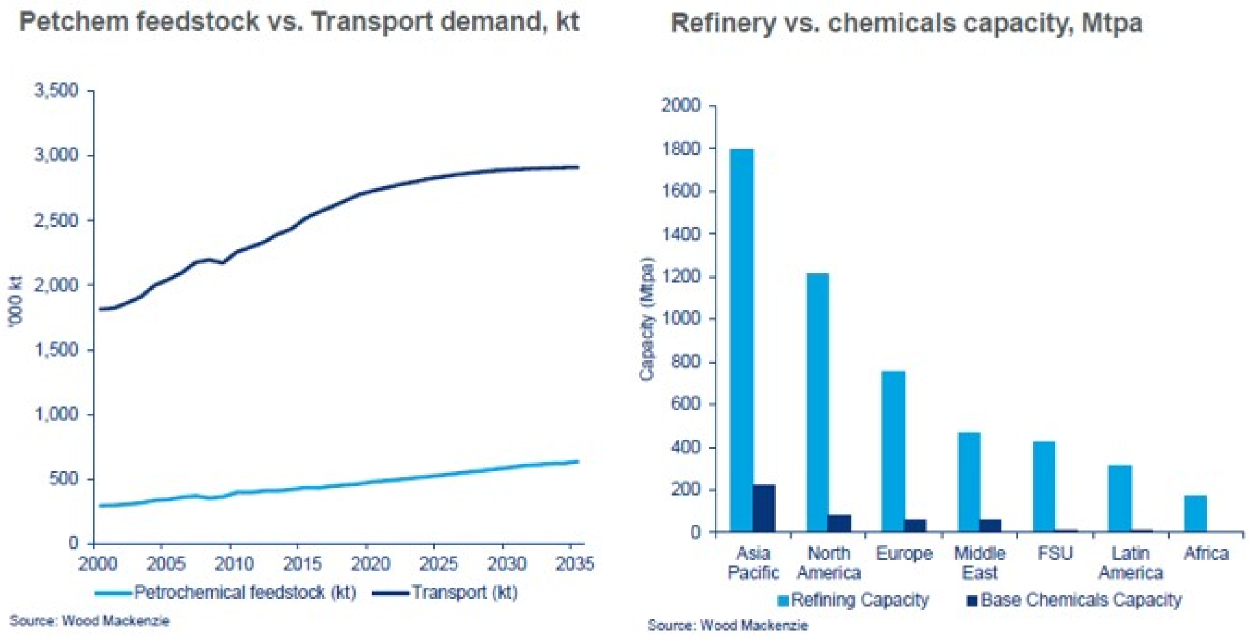
Refineries conception or refining scheme adopted by refiners depends on the market that will be attended aim to define what derivative will be maximized (diesel, gasoline, lubricants, etc.) as well as quality and environmental requirements that these derivatives need meet and, of course, the crude oil which will be processed. As generally known, heavier crude oils need a higher conversion and treating levels, raising the processing costs.

The comparison between different refineries is a hard task given that each operational unit attends distinct markets and different specifications, however, some standard refining schemes were defined over the years in the sense to allow the comparative studies. Refining scheme is the sequence of process units through the crude oil is submitted aim to produce desired derivatives meeting the quality and environmental requirements.

Currently, the downstream industry faces a transition period where the focus of the players is changing from transportation fuels to petrochemicals aiming to ensure maximum added value to processed crude oils as well as to allow the growth of low carbon energies in the global energetic matrix.

The newest threat to refiners is the reduction of the consumer market, in the last years became common, news about countries that intend to reduce or ban the production of vehicles powered by fossil fuels in the middle term, mainly in the European market. Despite the recent forecasts, the transportation fuels demand is still the main revenues driver to the downstream industry, as presented in Figure 1, based on data from Wood Mackenzie Company.

According to Figure 1, the transportation fuels demand represents close to five times the demand by petrochemicals as well as a focus on transportation fuels of the current refining hardware, considering the data from 2019. Despite these data, is observed a trend of stabilization in transportation fuels demand close to 2030 followed by a growing market of



Petchem feedstock vs. Transport demand, kt

Source: Wood Mackenzie

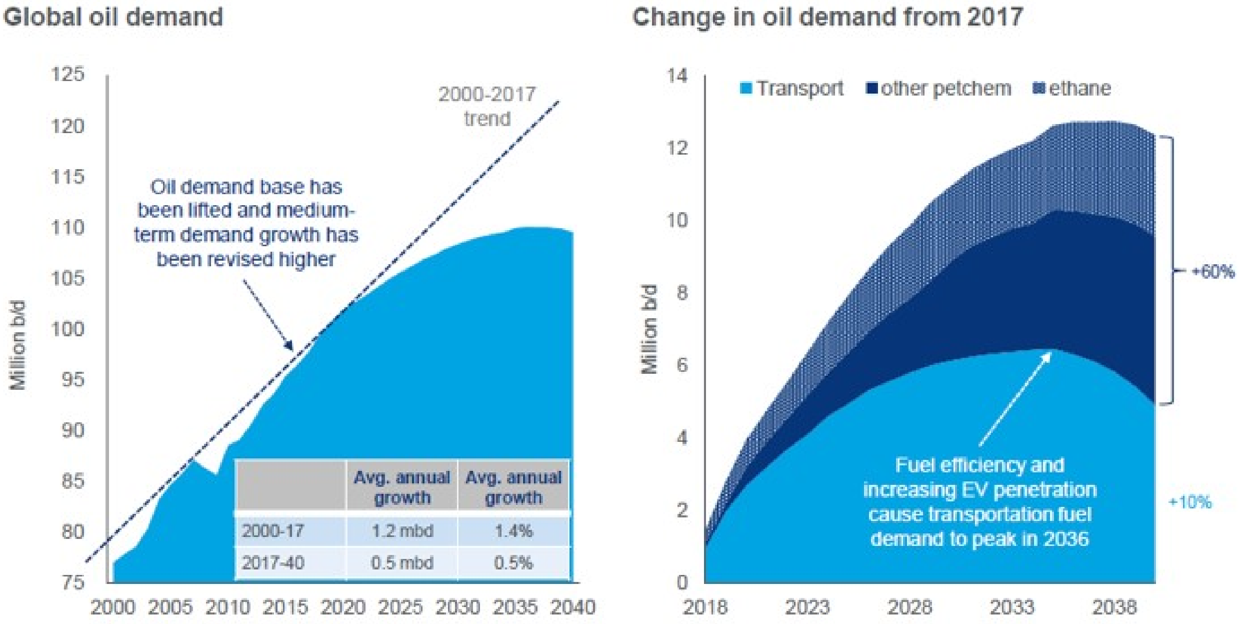
Refinery vs. chemicals capacity, Mtpa

Source: Wood Mackenzie

Figure 1 – Relation of Petrochemical Feedstock/Transportation Fuels Feedstock and Installed Capacity (Wood Mackenzie, 2019)

petrochemicals. Still according to Wood Mackenzie data, presented in Figure 2, is expected a relevant growth in the petrochemicals participation in the global oil demand.

The improvement in fuel efficiency, growing market of electric vehicles tends to decline the participation of transportation fuels in the global crude oil demand. New technologies like additive manufacturing (3D printing) have the potential to produce great impact to the transportation demands, leading to even more impact over the transportation fuels demand. Furthermore, the higher availability of lighter crude oils favors the oversupply of lighter derivatives that facilitate the production of petrochemicals against transportation fuels as well as the higher added value of petrochemicals in comparison with fuels. According to Figure 3, the demand by petrochemicals raised in the recent years and can be an attract way to refiners keep his protagonism in the market, it’s fundamental to quote that the refiners relying on petrochemicals face a kind of edge during the mobility crisis due to the COVID 19 pandemic.


Global oil demand

Change in oil demand from 2017

Figure 2 – Change in the Profile of Global Crude Oil Demand (Wood Mackenzie, 2019)

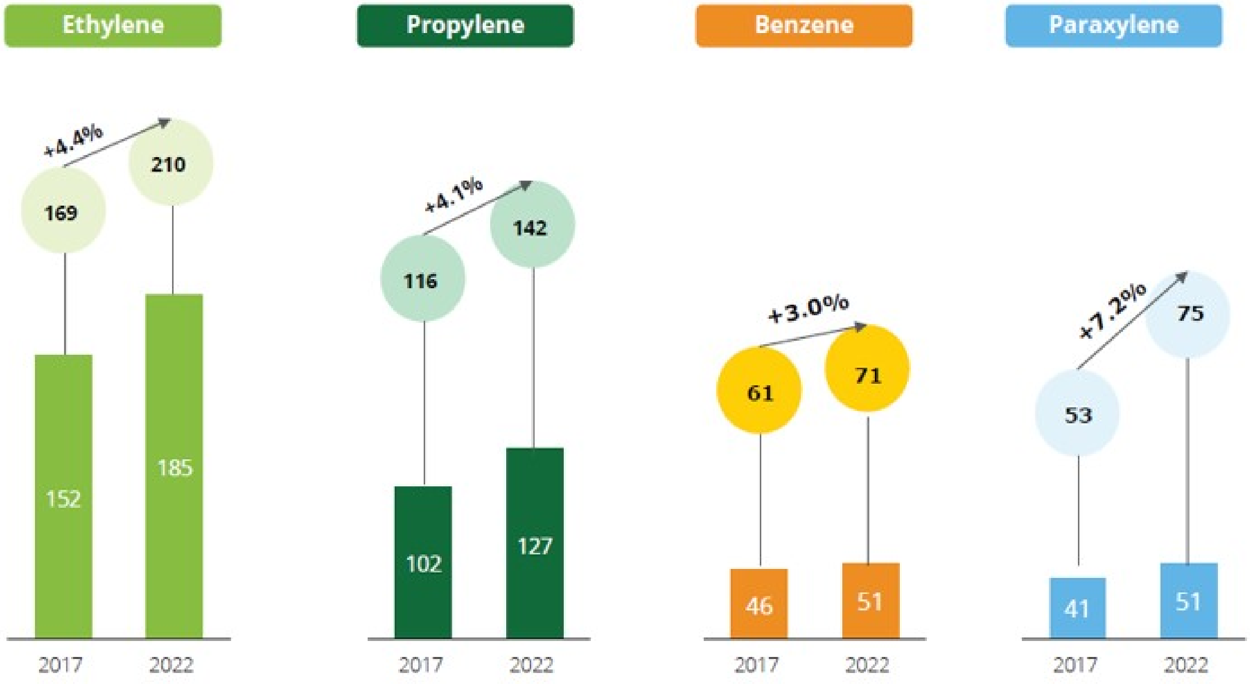


Figure 3 – Growing Trend in the Demand by Petrochemical Intermediates (Deloitte, 2019) - *Note: Bars represent total demand (million metric tons or MMT), circles represent total capacity (MMT).*

According to data presented in Figure 3, is expected a significant growth in the market of light olefins like ethylene and propylene, and refining hardware capable to maximize the yield of these petrochemical intermediates can offer significant competitive advantage through closer integration with petrochemical assets and higher value addition to processed crude oil.

The contraction of the transportation fuels market and the growing market of petrochemicals as well as their higher added value is the main driving force to closer integration between refining and petrochemical assets, leading the refiners to promote a focus change in the crude oil refining industry. This scenario leads the refiners to modify his refining hardware aiming to maximize the petrochemicals against transportation fuels, creating a deep change in the traditional refining configurations.

## WHAT IS THE 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.

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 lead to possibilities of synergies capable to reduce operational costs and add value to derivatives produced in the refineries.

Figure 4 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

| **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 |

Table 1 – Refining and Petrochemical Industry Characteristics

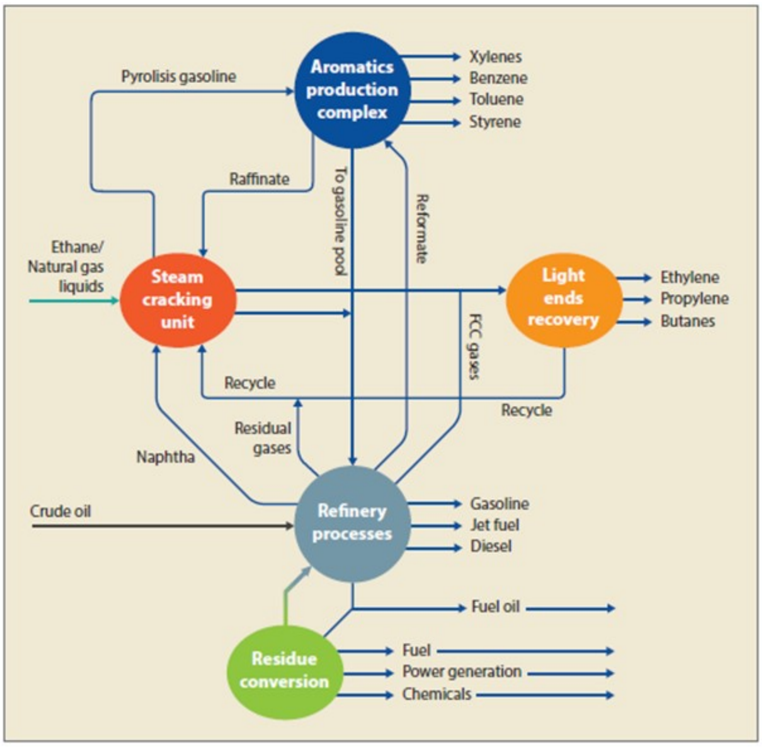


Figure 4 – Synergies between Refining and Petrochemical Processes

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 5.

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 petrochemicals like Ethylene, Propylene, and BTX.

## INTEGRATED REFINING SCHEMES – CLOSER INTEGRATION WITH PETROCHEMICAL ASSETS

Historically, the refining industry growth was sustained and focused by transportation fuels, this can explain the profile of the traditional refining schemes showed above. Nowadays, the downstream industry is facing with a trend of reduction in transportation fuels demand, followed by a growing demand by petrochemicals, this fact is the main driving force to promote the change of focus in downstream industry.

The growing market of petrochemicals have been led some refiners to look for a closer integration between refining and petrochemicals assets aiming to reach more adherence with the market demand, improve revenues, and reduce operation costs. To reach this goal, the refiners are implementing most integrated refining schemes as presented in Figure 6.

As presented in Figure 6, the integrated refining scheme rely on flexible refining technologies as catalytic reforming and fluid catalytic cracking (FCC) that are capable to reach the production of high-quality petrochemicals and transportation fuels, according to the market demand. Another significant characteristic of the integrated refining schemes is the strongly synergy between deep conversion technologies like hydrogracking and fluid catalytic cracking units and processing units capable to produce high added value petrochemicals like steam cracking and catalytic reforming units.

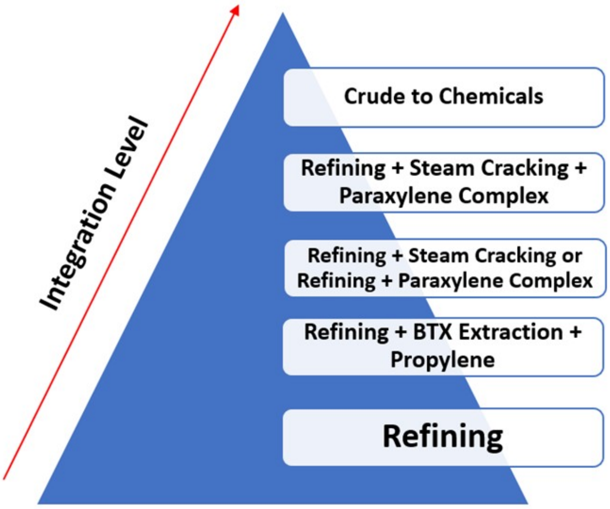


Figure 5 – Petrochemical Integration Levels (IHS Markit, 2018)

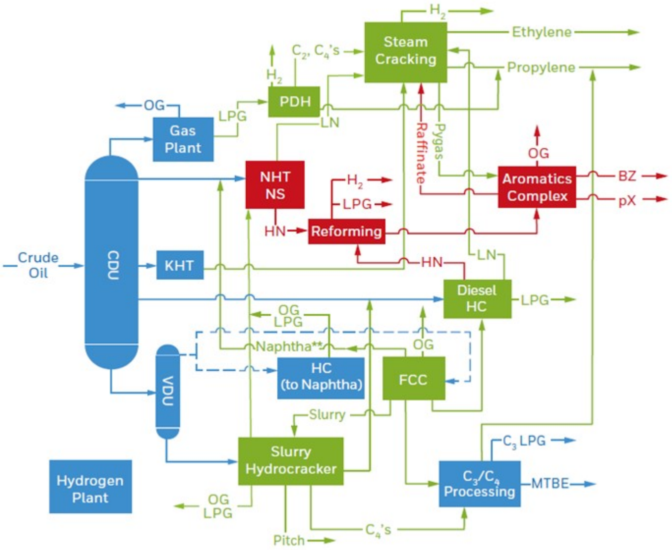


Figure 6 – Example of an Integrated Refining Focusing on Petrochemicals Scheme by UOP Company

A more integrated refining configuration allows the maximization of petrochemicals, raising the refining margins and ensures higher value addition to the processed crude oils. Another fundamental competitive advantage is the operational flexibility reached through the integrated refining configurations, allowing the processing of discounted and cheaper crude oils, raising even more the refining margins.

Sometimes the hydrocracking and FCC technologies are faced by competitors technologies in the refining hardware due to the similarities of feed streams that are processed in these units. In some refining schemes, the mild hydrocracking units can be applied as pretreatment step to FCC units, especially to bottom barrel streams with high metals content that are severe poison to FCC catalysts, furthermore the mild hydrocracking process can reduce the residual carbon to FCC feed, raising the performance of FCC unit and improving the yield of light products like naphtha, LPG, and olefins. Figure 6 presents an interesting example of synergy between FCC and hydrocracking units.

As presented in Figure 6, the integrated refining scheme rely on deep residue upgrading technologies as hydrocracking and fluid catalytic cracking (FCC) is capable to reach the production of high-quality petrochemicals, according to the market trends.

Considering the great flexibility of deep hydrocracking technologies that are capable to convert feed stream varying from gas oils to residue, an attractive alternative to improve the bottom barrel conversion capacity is to process in the hydrocracking units the uncracked residue in FCC unit aiming to improve the yield of high added value derivatives in the refining hardware, mainly middle distillates like diesel and kerosene.

Due to the higher profitability when compared with the traditional refining configurations, refiners and technologic licensors have been dedicated his efforts to developed technologies capable to add value to the crude oil through the production of chemicals of high added value and great interest by the society, these technologies are called Crude Oil to Chemicals (COC) technologies, further allow better refining margins the COC technologies ensures better compliance face the current trends in the downstream market. The Honeywell UOP Company presented the concept of Zero Fuels Refinery as described in Figure 7.

As presented in Figure 7, the production focus change to the maximum adding value to the crude oil through the production of high added value petrochemical intermediates or chemicals to general purpose leading to a minimum production of fuels. Big players as Saudi Aramco Company have been made great investments in COC technologies aiming to achieve even more integrated refineries and petrochemical plants, raising considerably his competitiveness in the downstream market. The major technology licensors as Axens, UOP, Chevrons Lummus Global, Shell, ExxonMobil, etc. has been applied resources to develop technologies capable to allow a closer integration in the downstream sector.

As aforementioned, face 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.

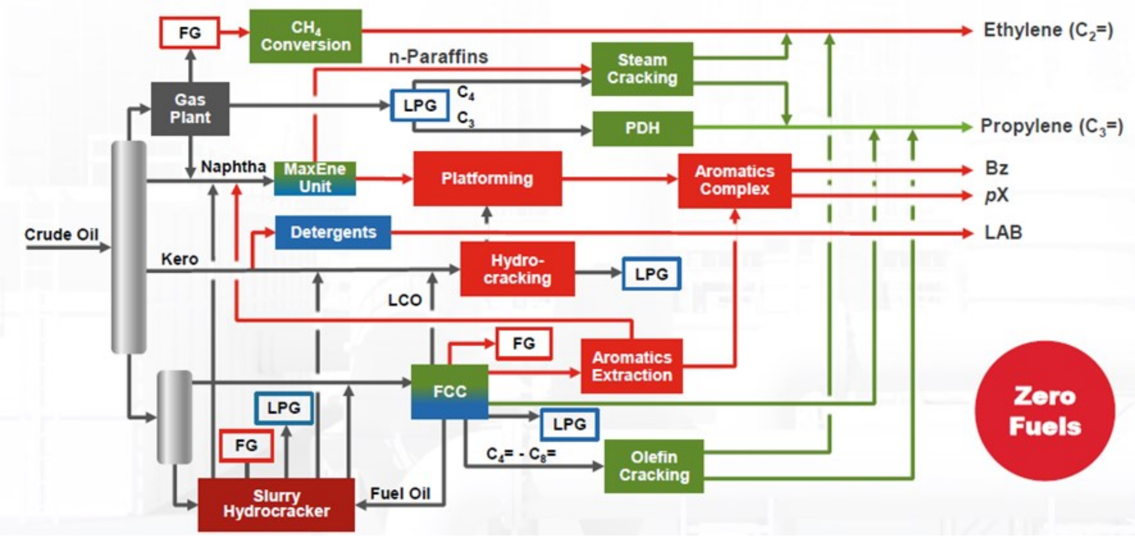


Figure 7 – Zero Fuels Refinery Concept by Honeywell UOP

Although the advantages presented by closer integration between refining and petrochemical assets, it's important to understand that the players of downstream industry are facing with a transitive period where, as presented in Figure 1, the transportation fuels are responsible by great part of the revenues. In this business scenario, it's necessary to define a transition strategy where the economic sustainability achieved by the status (transportation fuels) needs to be invested to build the future (maximize petrochemicals). Keep the eyes only in the future or only in the present can be a competitive mistake.

## CRUDE OIL TO CHEMICALS STRATEGY

Due to the increasing market and higher added value as well as the trend of reduction in transportation fuels demand, some refiners and technology developers has dedicated his efforts to develop crude to chemicals refining assets. One of the big players that have been invested in this alternative is the Saudi Aramco Company, the concept is based on the direct conversion of crude oil to petrochemical intermediates as presented in Figure 8.

The process presented in Figure 8 is based on the quality of the crude oil and deep conversion technologies like High Severity or petrochemical FCC units and deep hydrocraking technologies. The processed crude oil is light with low residual carbon that is a common characteristic in the Middle East crude oils, the processing scheme involves deep catalytic conversion process aiming to reach maximum conversion to light olefins. In this refining configuration, the petrochemical FCC units have a key role to ensure high added value to the processed crude oil.

As quoted above, some technology developers are dedicating his efforts to develop commercial crude to chemicals refineries. Figure 9 presents the concept of crude to chemicals refining scheme by Chevron Lummus Company.

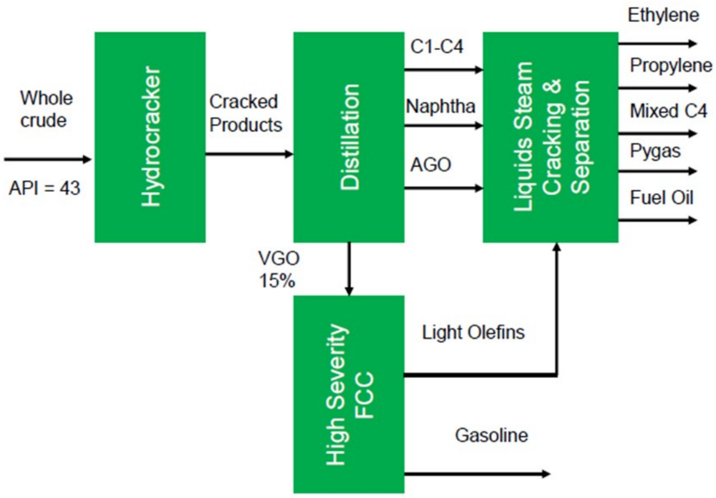


Figure 8 – Saudi Aramco Crude Oil to Chemicals Concept (IHS Markit, 2017)

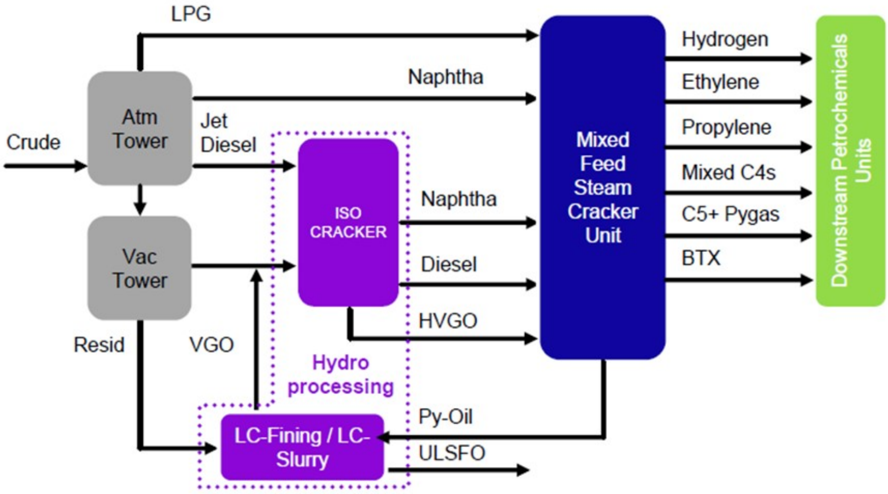


Figure 9 – Crude to Chemicals Concept by Chevron Lummus Company (Chevron Lummus Global Company, 2019)

Another great refining technology developers like UOP, Shell Global Solutions, ExxonMobil, Axens, and others are developing crude to chemicals technologies, reinforcing that this is a trend in the downstream market. Figure 10 presents a highly integrated refining configuration capable to convert crude oil to petrochemicals developed by UOP Company.

As aforementioned, big players as Saudi Aramco Company have been made great investments in COC technologies aiming to achieve even more integrated refineries and petrochemical plants, raising considerably his competitiveness in the downstream market. The major technology licensors as Axens, UOP, Lummus, Shell, ExxonMobil, etc. has been applied resources to develop technologies capable to allow a closer integration in the downstream sector aiming to allow refiners extract the maximum added value from the processed crude oil, an increasing necessity in a scenario where the refining margins are under pressure.

## AVAILABLE CRUDE TO CHEMICALS ROUTES

Nowadays, there are three technically available routes that are being considered to capital investments to crude to chemicals refining complexes. Figure 11 present the concepts based on the information o IHS Markit Company.

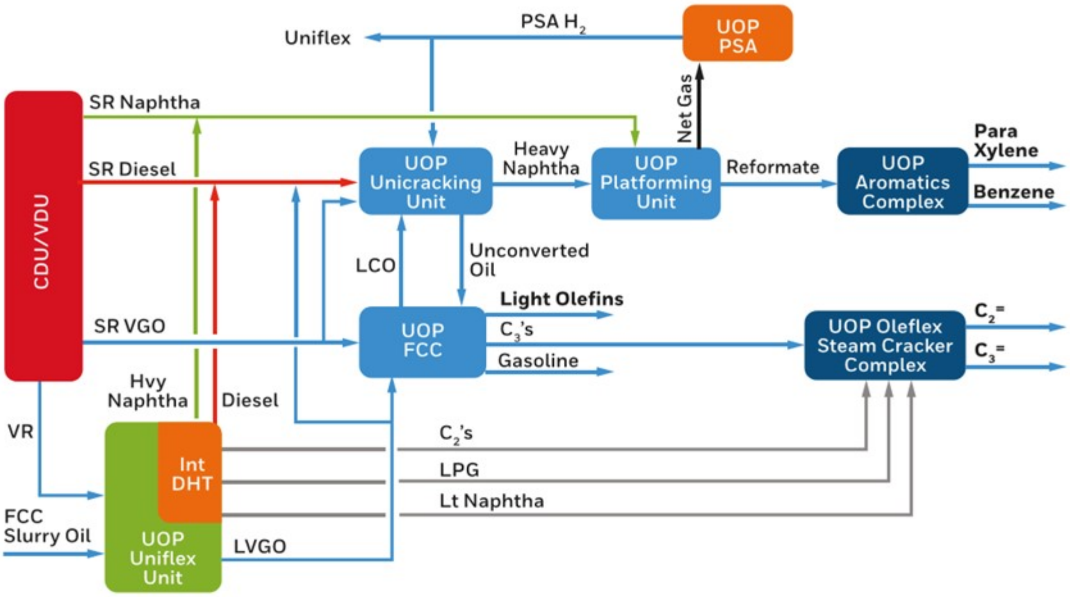


Figure 10 – Integrated Refining Configuration Based in Crude to Chemicals Concept by UOP Company.

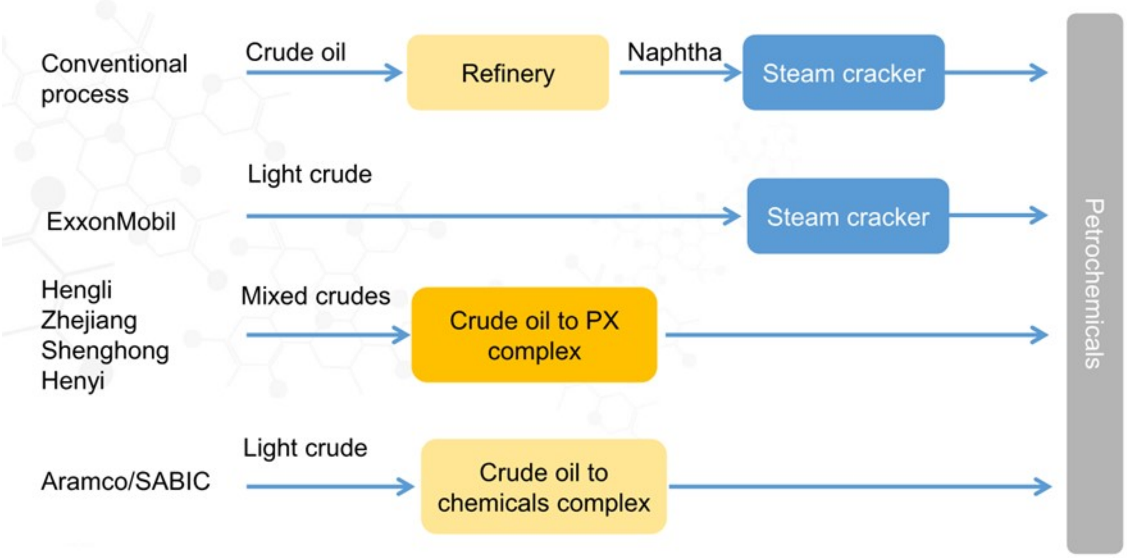


Figure 11 – Crude to Chemicals Concepts (IHS Markit, 2019)

The conventional routes consider the processing of crude oil in a conventional crude oil refinery, producing petrochemical intermediates like naphtha which is supplied to a petrochemical asset like a steam cracking unit. The ExxonMobil route is based on the direct feed of selected crude oils, normally light and low contaminants crudes, to petrochemical assets, while the Chinese enterprise Hengli Zhejiang Shenghong Henyi project consider the feed of mixed crude oil slate to a crude to PX (Para-Xylene) complex to ensure the domestic Chinese market that present high demand by light aromatics (BTX).

As aforementioned, the Aramco/Sabic concept is based on a high complexity refining hardware to convert selected crude oil (light) to maximize the yield of petrochemical intermediates, mainly light olefins.

Although the advantages presented by closer integration between refining and petrochemical assets, it's important to understand that the players of downstream industry are facing with a transitive period where, as presented in Figure 1, the transportation fuels are responsible by great part of the revenues. In this business scenario, it's necessary to define a transition strategy where the economic sustainability achieved by the status (transportation fuels) needs to be invested to build the future (maximize petrochemicals). Keep the eyes only in the future or only in the present can be a competitive mistake.

## 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 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 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. Another advantage is the reduction of risks of transportation fuels oversupply, facing the current scenario of demand reduction and restriction of fossil fuels. It's important to consider that integrated processes lead to higher operational complexity, however, given current and middle term scenarios to the refining industry, better integration between refining and petrochemical processes is fundamental to the economic sustainability of the downstream industry. The scenario faced by the players of the downstream industry requires even more competitive capacity to ensure higher value addition to the processed crude oils, mainly considering the current trend of reduction in transportation fuels demand followed by the growing market of petrochemicals that requires a higher conversion capacity in the refining hardware aiming to ensure higher yields of added value derivatives. In this scenario, high integrated refining configurations based on residue upgrading and flexible refining technologies can be economically attractive.

Despite the advantages it's important to take into account the high capital investment in petrochemical and integrated refining technologies and the time of these investments is a strategic decision to refiners aiming to be prepared to the future of the downstream market, although these risks, the petrochemical integration seems a significant driver to the future of the crude oil refining market and the FCC and steam cracking technologies can develop a highlighted role in this scenario.

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# The Heating Value Estimation for Natural Gas Applications

Jayanthi Vijay Sarathy

For natural gas custody transfer applications, the gross calorific or gross heating value is necessary for both the buyer and seller to estimate the sales price of natural gas. In case of fuel suppliers, heat content is expressed in terms of Higher Heating value (HHV) to estimate fuel charges in kWh. Whereas Lower Heating Value (LHV) is employed to estimate fuel requirements since the total energy input for a specific power output is already fixed. To understand how fuel heating values are affected, LHV and HHV is explained as,

1. The lower heating value (LHV) or net calorific value (NCV) of a fuel is defined as the amount of heat released by combusting a specified quantity at 25°C and returning the temperature of combustion products to 150°C, with the assumption that latent heat of vaporization of water in the reaction products is not recovered, i.e., when water in the combustion product, is in its vapour form, it is called LHV/NCV. LHV is a better indication of a fuel's useful heat since the combustion products are above the boiling point of water.
2. The higher heating value or gross calorific value (GCV) of a fuel is defined as the amount of heat released by combusting a specified quantity at 25°C and the products have returned to a temperature of 25°C, considering the latent heat of vaporization of water in the products. i.e., when water in the combustion product, is in its liquid form, it is called HHV/GCV.
3. Presence of water is detrimental to a fuel's heating value, since with high combustion temperatures, water turns into steam & eats away a portion of the energy released as latent heat of vaporization [DHV], i.e., HHV includes latent heat of vaporization of water.

## ESTIMATING FUEL CALORIFIC VALUES

The Gross calorific value (GCV) in mass terms can be computed as per ISO 6976:1995 at 1.01325 bara & 15 0C (referred to as Standard Conditions as per ISO 6976), as follows,

$$GCV_{mass} = \frac{\sum X_i \times GCV_{i[mol]}}{\sum X_i \times M_i} \qquad (1)$$

Where,

$X_i$ = Molar fraction of component 'i'

$GCV_{i[mol]}$ = Molar Gross calorific value of component 'i', [kJ/mol]

$M_i$ = Molecular mass of component 'i' [g/mol]

However, in this module, the standard temperature is taken as $25^0$C and the heating values are estimated based on a stoichiometric balance instead of ISO 6976:1995 method. Taking the following natural gas composition,

Table 1. Natural Gas Composition

| **Component** | **MW** | **Mol%** |
|---|---|---|
| **-** | **kg/kmol** | **%** |
| Methane [$CH_4$] | 16.043 | 85.0 |
| Ethane [$C_2H_6$] | 30.070 | 5.0 |
| Propane [$C_3H_8$] | 44.097 | 3.0 |
| n-Butane [n-$C_4H_{10}$] | 58.123 | 1.0 |
| i-Butane [i-$C_4H_{10}$] | 58.123 | 1.0 |
| n-Pentane [n-$C_5H_{12}$] | 72.15 | 0.5 |
| i-Pentane [i-$C_5H_{12}$] | 72.15 | 0.3 |
| Hydrogen [$H_2$] | 2.016 | 0.1 |
| Carbon monoxide [CO] | 28.011 | 0.1 |
| Carbon dioxide [$CO_2$] | 44.011 | 0.2 |
| Nitrogen [$N_2$] | 28.0135 | 3.8 |
| Mixture MW [kg/kmol] | | 19.385 |

To estimate the heat of reaction, the combustion of hydrocarbons follows the below stoichiometric balance as,

$$C_nH_{2n+2} + \left[\frac{3n+1}{2}\right]O_2 \rightarrow nCO_2 + [n+1]H_2O$$

To estimate the natural gas calorific value, the calculations require,

1. Natural gas Composition
2. Heat of formation [$DH^0_f$] at Ref. Conditions
3. Heat of Reaction per mole computed as,

$$\Delta H^0_{Rxn,25^\circ C} = \sum X_{i,P}\Delta H^0_{f,P} - \sum X_{i,R}\Delta H^0_{f,R} \qquad (1)$$

4. Based on per mole heat of reaction for each combustible species/component, the individual mole fraction of each component is multiplied with the respective heat of reaction and summed up to arrive at the Net Calorific Value (NCV) or Lower Heating Value (LHV). A negative sign in the LHV/ NCV value indicates, heat is released due to the combustion process.
5. To estimate the HHV, firstly, the hydrogen content in each component of the natural gas mixture (which forms water) is multiplied by its respective component's mole fraction, summed up, divided by 2 and multiplied with the heat of reaction from the conversion of $H_20(g) \rightarrow H_20(l)$, i.e., [$DH_{Rxn,25^0C} = DH^0_{f,H2O(l)} - DH^0_{f,H2O(g)}$]. Followed by, subtracting the above estimate from the modulus (positive) value of LHV/ NCV.

The standard heat of formation [$DH^0_f$] at $25^0C$ for the reactants and products are as follows, Table 2. Standard Heat of Formation [250C]

Performing a stoichiometric balance of the combustion reactions, Table 3. Combustion Reaction Set

Quoting a sample case for methane at $25^0C$,

$$\sum X_{i,R}\Delta H^0_{f,R} = [(1 \times -74.84) + (2 \times 0)] \qquad (2)$$

$$\sum X_{i,P}\Delta H^0_{f,P} = [(2 \times -241.83) + (1 \times -393.51)] \qquad (3)$$

$$\Delta H^0_{Rxn} = [-877.162] - [-74.84] = -802.32\,\frac{kJ}{mol} \qquad (4)$$

Table 2. Standard Heat of Formation [$25^0C$]

| **Component** | **$\Delta H^0_{f,25^0C}$** |
|---|---|
| **-** | **kJ/mol** |
| Methane [$CH_4$] | -74.84 |
| Ethane [$C_2H_6$] | -84.67 |
| Propane [$C_3H_8$] | -103.85 |
| n-Butane [n-$C_4H_{10}$] | -124.73 |
| i-Butane [i-$C_4H_{10}$] | -134.50 |
| n-Pentane [n-$C_5H_{12}$] | -146.40 |
| i-Pentane [i-$C_5H_{12}$] | -154.40 |
| Carbon monoxide [CO] | -110.52 |
| Hydrogen [$H_2$] | 0.00 |
| Oxygen [$O_2$] | 0.00 |
| Nitrogen [$N_2$] | 0.00 |
| Carbon dioxide [$CO_2$] | -393.51 |
| Water Vapour [$H_2O$ (g)] | -241.83 |
| Water [$H_2O$ (l)] | -285.84 |

Table 3. Combustion Reaction Set

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ | + | 2 | $O_2$ | → | 1 | $CO_2$ | + | 2 | $H_2O(g)$ |
| $C_2H_6$ | + | 3½ | $O_2$ | → | 2 | $CO_2$ | + | 3 | $H_2O(g)$ |
| $C_3H_8$ | + | 5 | $O_2$ | → | 3 | $CO_2$ | + | 4 | $H_2O(g)$ |
| $nC_4H_{10}$ | + | 6½ | $O_2$ | → | 4 | $CO_2$ | + | 5 | $H_2O(g)$ |
| $iC_4H_{10}$ | + | 6½ | $O_2$ | → | 4 | $CO_2$ | + | 5 | $H_2O(g)$ |
| $nC_5H_{12}$ | + | 8 | $O_2$ | → | 5 | $CO_2$ | + | 6 | $H_2O(g)$ |
| $iC_5H_{12}$ | + | 8 | $O_2$ | → | 5 | $CO_2$ | + | 6 | $H_2O(g)$ |
| $H_2$ | + | ½ | $O_2$ | → | | | | 1 | $H_2O(g)$ |
| CO | + | ½ | $O_2$ | → | 1 | $CO_2$ | | | |
| $H_2O(g)$ | | | | → | | | | 1 | $H_2O(l)$ |

For the case of $H_2$ at $25^0$C,

$$\sum X_{i,R} \Delta H^0_{f,R} = [(1 \times 0) + (0.5 \times 0)] \quad (5)$$

$$\sum X_{i,P} \Delta H^0_{f,P} = [1 \times -241.83] \quad (6)$$

$$\Delta H^0_{Rxn} = [-241.83 - 0] = -241.83 \frac{kJ}{mol} \quad (7)$$

For the case of $H_2O$(g) to $H_2O$(l) at $25^0$C,

$$\sum X_{i,R} \Delta H^0_{f,R} = -241.83 \quad (8)$$

$$\sum X_{i,P} \Delta H^0_{f,P} = -285.84 \quad (9)$$

$$\Delta H^0_{Rxn} = [-285.84 - (-241.83)] = -44.01 \frac{kJ}{mol} \quad (10)$$

Similarly, performing calculations for other components to yields,

Table 4. Heat of Reaction Summary

| **Component** | **$\Delta H^0_{Rxn,}$ $25^0$C [kJ/mol]** |
|---|---|
| $CH_4$ | -802.32 |
| $C_2H_6$ | -1,427.83 |
| $C_3H_8$ | -2,043.98 |
| $nC_4H_{10}$ | -2,658.44 |
| $iC_4H_{10}$ | -2,648.67 |
| $nC_5H_{12}$ | -3,272.11 |
| $iC_5H_{12}$ | -3,264.11 |
| $H_2$ | -241.83 |
| CO | -282.99 |
| $H_2O$(g) | -44.014 |

Therefore, the LHV/NCV is computed as, Table 5. LHV/NCV Estimation

Table 5. LHV/NCV Estimation

| **Component** | **$X_i \Delta H^0_R$** | |
|---|---|---|
| **-** | **[kJ/mol]** | |
| Methane [$CH_4$] | 0.85 × -802.32 | -681.974 |
| Ethane [$C_2H_6$] | 0.050 × -1,427.83 | -71.392 |
| Propane [$C_3H_8$] | 0.030 × -2,043.98 | -61.320 |
| n-Butane [n-$C_4H_{10}$] | 0.010 × -2,658.44 | -26.584 |
| i-Butane [i-$C_4H_{10}$] | 0.010 × -2,648.67 | -26.487 |
| n-Pentane [n-$C_5H_{12}$] | 0.005 × -3,272.11 | -16.361 |
| i-Pentane [i-$C_5H_{12}$] | 0.003 × -3,264.11 | -9.792 |
| Hydrogen [$H_2$] | 0.001 × -241.83 | -0.242 |
| Carbon monoxide | 0.001 × -282.99 | -0.283 |
| Carbon dioxide | 0.000 | 0.000 |
| Nitrogen [$N_2$] | 0.000 | 0.000 |
| ***Lower Heating Value (LHV)*** $= \sum X_i \Delta H^0_R$ | | **-894.43** |

The higher heating value (HHV) is computed by initially making a hydrogen balance as,

| **Component** | **Hydrogen Balance** | |
|---|---|---|
| Methane [$CH_4$] | 0.850 × 4 | 3.4 |
| Ethane [$C_2H_6$] | 0.050 × 6 | 0.3 |
| Propane [$C_3H_8$] | 0.030 × 8 | 0.24 |
| n-Butane [n-$C_4H_{10}$] | 0.010 × 10 | 0.1 |
| i-Butane [i-$C_4H_{10}$] | 0.010 × 10 | 0.1 |
| n-Pentane [n-$C_5H_{12}$] | 0.005 × 12 | 0.06 |
| i-Pentane [i-$C_5H_{12}$] | 0.003 × 12 | 0.036 |
| Hydrogen [$H_2$] | 0.0010 × 2 | 0.002 |
| **Total** | | **4.238** |

The HHV/GCV is now calculated as,

$$HHV = 894.43 - \left[\frac{4.238\times-44.014}{2}\right] = 987.70\,\frac{kJ}{mol} \tag{11}$$

Expressing in mass terms [kJ/kg], the heating values are as follows,

$$LHV/NCV = \frac{894.43\times1000}{19.385} = 46{,}140\ kJ/kg \tag{12}$$

$$HHV/GCV = \frac{987.7\times1000}{19.385} = 50{,}951 kJ/kg \tag{13}$$

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# Third Quarter 2022 Update for the Southeast Asia (SEA) O&G Industry

July 2022

## KEY DRIVING FACTORS

Blackrock reported 5 major megatrends that are shaping investors thinking

1. Climate change and resource scarcity – crop failure, flooding, habitat destruction and energy shortage
2. Demographics and social change – labour shortage, healthcare demand and changing consumer demand
3. Technological breakthrough – machines will learn faster than humans and personal data will be a valuable commodity
4. Rapid urbanization – space and accommodation will become more of an issue in cities as 2/3 of population will live in cities versus 30% in 1950.
5. Shifting economic power – China as new superpower by 2030 and Asia population growth

## HIGHLIGHTS

As governments reach 70% vaccination more inbound travelling was expected. However, Asia Pacific is highly dependent on India and China travellers who are still grappling with COVID management.

Most national oil companies recording record profit for 1st quarter of 2022 due to higher crude prices. This however was limited to their refining business while the petrochemical business has reduced margin.

Petronas' profit after tax increased to US$5.3 billion for the first quarter ended March 31, 2022 (Q1 FY2022) versus US$2.1 billion a year ago in tandem with higher revenue, following an upward trend in prices partially offset by higher product costs and taxation.

The Nation Thailand said PTT Exploration and Production and the other oil-related businesses would see increased profits in the second quarter due to higher demand resulting from an economic recovery following Thailand's reopening.

However, the outlook for PTT Group's petrochemical business would not be so bright due to higher costs incurred from increased oil prices, the senior analyst said.

Pertamina reported 2021 profit at US$2.0B which is double that of 2020 coming mainly from upstream due to rising Indonesia crude price while downstream under pressure due to higher cost of feedstock. Its production increased from 863K barrel of oil equivalent per day to 897K.

The other National Oil Companies like Petron also see its profit double for the 1st quarter.

Nghi Son Refinery and Petrochemical is the sole multi-investment site that has been challenged operationally where it rejected crude imports.

President-elect Ferdinand Marcos Jr. has vowed to introduce nuclear power to the Philippines to lower electricity bills, but analyst anticipate a bumpy road for the low-carbon energy source's revival following a 36-year hiatus.

In a recent question and answer, Petronas Chief Sustainability Officer Charlotte Wolff-Bye discusses the company's net-zero plans, renewables, hydrogen, carbon capture, and "carbon-neutral" LNG businesses.

Petronas has introduced Gentari Sdn. Bhd. to accelerate the adoption and commercialization of clean energy. The intention is to form an entity that will deliver a suite of clean solutions across the value chain.

HEAT TRANSFER TECHNOLOGY

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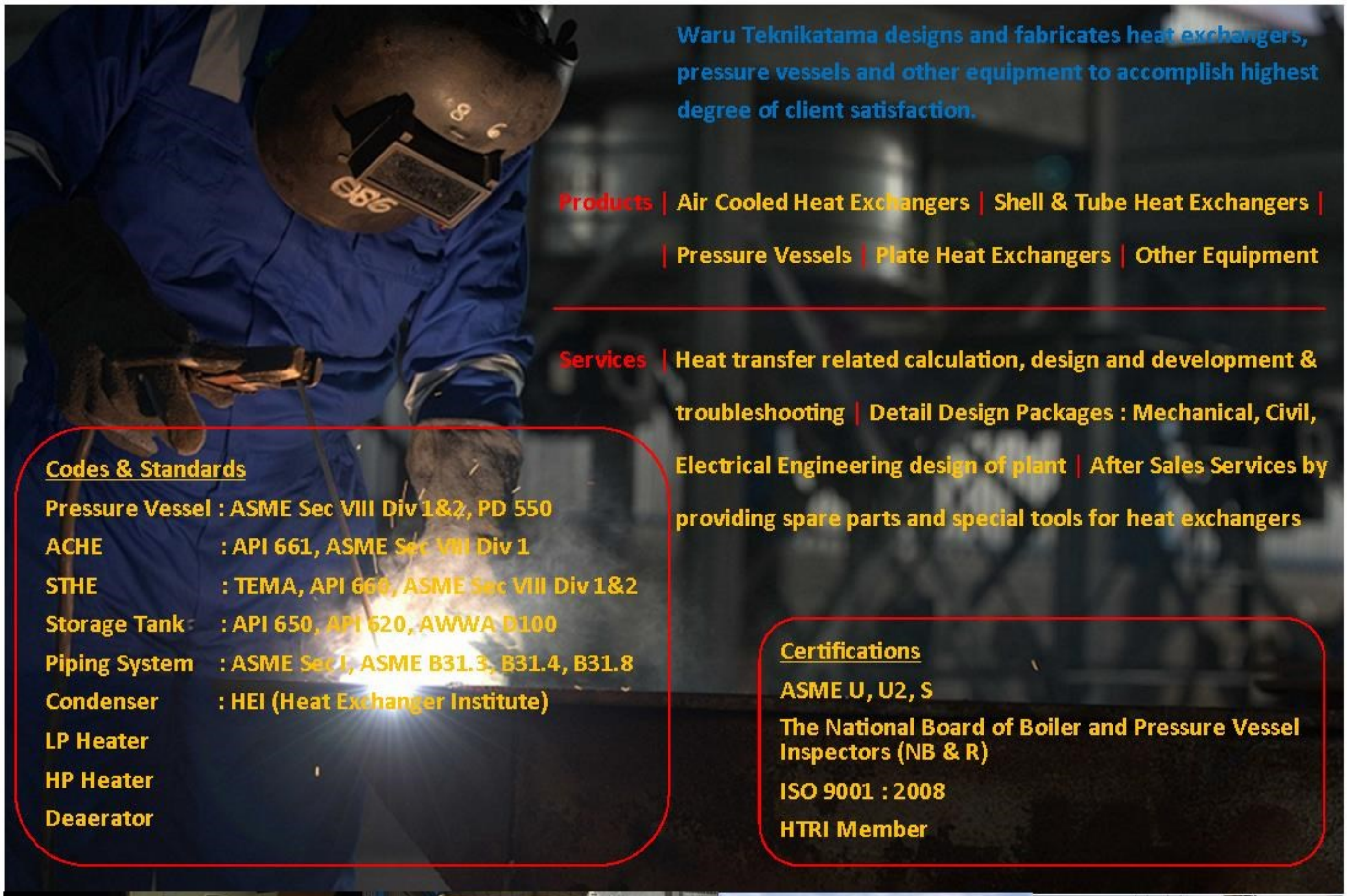

Waru Teknikatama designs and fabricates heat exchangers, pressure vessels and other equipment to accomplish highest degree of client satisfaction.

**Products** | Air Cooled Heat Exchangers | Shell & Tube Heat Exchangers | Pressure Vessels | Plate Heat Exchangers | Other Equipment

**Services** | Heat transfer related calculation, design and development & troubleshooting | Detail Design Packages : Mechanical, Civil, Electrical Engineering design of plant | After Sales Services by providing spare parts and special tools for heat exchangers

**Codes & Standards**

Pressure Vessel : ASME Sec VIII Div 1&2, PD 550
ACHE : API 661, ASME Sec VIII Div 1
STHE : TEMA, API 660, ASME Sec VIII Div 1&2
Storage Tank : API 650, API 620, AWWA D100
Piping System : ASME Sec I, ASME B31.3, B31.4, B31.8
Condenser : HEI (Heat Exchanger Institute)
LP Heater
HP Heater
Deaerator

**Certifications**

ASME U, U2, S
The National Board of Boiler and Pressure Vessel Inspectors (NB & R)
ISO 9001 : 2008
HTRI Member

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# Sustainable Air Fuel (SAF)

Hamid Reza Seyed Jafari, Seyed Mohammad Reza Seyed Jafari

## ABSTRACT

One of the most important and most widely used environmentally friendly renewable fuel is sustainable air fuel (SAF) in which will have a very positive effect on climate change mitigating and reducing global warming in airplanes energy consumptions in which producing of greenhouse gases in aviation industry.

## KEYWORDS

Sustainable Air Fuel (SAF), Climate Change, Renewable Resources Energy, Green House Gas (GHG), Global Warming, International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), Non-Renewable Resources Energy, Biofuel jet

## INTRODUCTION

The world is shifting to governments and business to reduce the human impact on climate change and global warming. While aviation's drive for fuel and operational efficiency has helped the industry limit its emissions, to go even further the aviation industry is embarking on a new journey. Sustainable aviation fuel is crucial to providing a cleaner source of fuel to power the world's fleet of aircraft and help the billions of people who travel by air each year to lower the impact of their journeys on our planet. Sustainable aviation is a multi-disciplinary field that seeks solutions to improve the environmental and societal impacts of air transportation. It aims to reduce aviation's contribution to climate change through new practices and radical innovation. These days, the world's leading companies design different technologies for Sustainable Aviation Fuels (SAF) as an alternative green air fuel to control climate change environmental impacts. SAF is a cleaner, direct replacement for fossil jet fuel and reduces greenhouse gas (GHG) emissions by up to 80% or more compared to fossil jet fuel. It is based on renewable hydrocarbon sources that are not fossil fuel based. This includes sources such as used cooking oil, municipal waste and forestry biomass, carbon capture CO2 and green Hydrogen etc. SAF is a biofuel used to power aircraft that has similar properties to conventional jet fuel but with a smaller carbon footprint. Depending on the feedstock and technologies used to produce it, SAF can reduce life cycle GHG emissions dramatically compared to conventional jet fuel. In what the airport called a "climate quantum leap," the sustainable fuel provider began delivering SAF to SFO via a pipeline. For example, American Airlines, Alaska Airlines, and JetBlue Airways… have signed on to use the fuel produced from waste and excess raw materials to partially power their flights from the airport.

### Why is sustainable aviation fuel important and why is it better for the environment?

Sustainable aviation fuel provides a cleaner alternative to fossil fuel, achieving up to an 80 percent reduction in greenhouse gas emissions over the fuel's lifecycle, compared to conventional fossil jet fuel but the process of its making may be very different. (1)

What are the most sustainable airlines?
Regarding to the latest news, now the 6 most sustainable airlines for flying green in the worldwide are following as (2):

1. KLM Royal Dutch Airlines.
2. Alaska Airlines.
3. Xiamen Airlines.
4. Cathay Pacific.
5. Delta Air Lines.
6. American Airlines.
7. …

### What is SAF?

Sustainable aviation fuel (SAF) is the title preferred by the aviation industry because the scope of the use of this term is broader than aviation biofuels. 'Biofuels' generally refers to fuels produced from biological resources (agriculture, animal, or biomass material). However, current technology allows fuel to be produced from other alternative sources, including non-biological resources; thus, the term is adjusted to highlight the sustainable nature of these fuels. SAF mix is made by blending conventional aviation turbine kerosene (known as: ATK which is fossil-based) with renewable hydrocarbon. They are certified as "Jet-A1" fuel and can be used without any technical modifications to aircraft. Other titles such as renewable aviation fuel, renewable jet fuel, alternative fuel, bio jet fuel, and sustainable alternative fuel have similar intended meaning.

Relative to fossil fuels, sustainably produced, unconventional, jet fuel results in a reduction in carbon dioxide (CO2) emissions across its life cycle. Carbon dioxide absorbed by plants during the growth of biomass is roughly equivalent to the amount of carbon dioxide produced when the fuel is burned in a combustion engine, which is simply returned to the atmosphere. This would allow the SAF to be approximately carbon-neutral over its life cycle. SAF is alternative, in this case non-conventional or advanced fuels, and includes any materials or substances that can be used as fuels, other than conventional, fossil-sources (such as oil, coal, and natural gas). It is also processed to jet fuel in an alternative manner. Feedstock for SAF are varied; ranging from cooking oil, plant oils, municipal waste, waste gases, and agricultural residues & biomasses.

There are two definitions of SAF issued by ICAO and IATA as follows:

1. ICAO : Sustainable aviation fuels (SAF) are renewable or waste-derived aviation fuels that meets sustainability criteria (reference: Annex 16 Volume IV). They are one element of the ICAO basket of measures to reduce aviation emissions, which also includes technology and standards, operational improvements, and the Carbon Offsetting and Reduction Scheme for International Aviation, CORSIA (3).
2. IATA : Sustainable aviation fuel (SAF) is the main term used by the aviation industry to describe a nonconventional (fossil derived) aviation fuel. SAF is the preferred IATA term for this type of fuel although when other terms such as sustainable alternative fuel, sustainable alternative jet fuel, renewable jet fuel or bio jet fuel are used, in general, the same intent is meant. (4)
3. The use of sustainable aviation fuel has been shown to provide significant reductions in overall CO2 lifecycle emissions compared to fossil fuels, up to 80% in some cases.

### Importance of Aviation

1. Aviation provides the only rapid worldwide transportation network, is indispensable for tourism and facilitates world trade. Air transport improves quality of life in countless ways.
2. Air transport moves roughly 3.8 billion passengers annually.
3. The air transport industry generates a total of 63 million jobs globally.
4. Air transport is responsible for transporting 35% of world trade by value.
5. 54% of international tourists travel to their destination by air.
6. Aviation's global economic impact is estimated at USD 2.7 trillion (including direct, indirect, and induced and tourism catalytic). If the aviation industry were a country, it would rank 21st in the world in terms of GDP.
7. Aviation is responsibly reducing its environmental impact through an ambitious, global set of goals: (www.enviro.aero)
8. The global aviation industry produces around 2% of all human-induced carbon dioxide (CO2) emissions. The International Panel on Climate Change (IPCC) forecasts that its share of global manmade CO2 emissions will increase to around 3% in 2050.
9. Despite growth in passenger numbers at an average of 5% each year, aviation has managed to decouple its emissions growth to around 3%. This is through massive investment in new technology and coordinated action to implement new operating procedures.
10. Aircraft entering today's fleet are over 80% more fuel-efficient than the first jet aircraft in the 1950s, consuming an average 3.5 litres per passenger per 100km. The Airbus A380 and the Boeing 787 – consuming less than 3 litres per 100 passenger kilometres – compare favourably with small family cars, with aircraft also having a higher average occupancy rate. (5)

### SAF chemical and physical characteristics

SAF mix chemical and physical characteristics are almost identical to those of conventional jet fuel, they can be safely mixed and blended with the latter to varying degrees, use the same supply infrastructure and do not require the adaptation of aircraft or engines. Fuels with these properties are called "drop-in fuels" (i.e., fuels that can be automatically incorporated into existing airport fuelling systems). Moreover, they also meet sustainability criteria such as lifecycle carbon emissions reduction.

Because of the very strict standards required in the aviation industry, SAF needs to be approved as safe and appropriate for commercial use. The aviation industry works closely with international fuel specification bodies to develop standards and certificates, such as ASTM International. To become approved for use, SAF must meet certain specifications from ASTM(Table -1) .Once it has demonstrated compliance with the requirements, it is blended with no more than 50% by volume (according to current standards) with conventional jet fuel and re-tested to show compliance. The reasons for the current blend limits are to ensure the appropriate level of safety and compatibility with the aircraft fuelling systems (mainly due to the level of aromatics which are necessary for the different systems). (5)

### SAF feedstock

Current technology allows sustainable aviation fuels to be produced from a wide range of feedstocks, including : (5)

1. Municipal solid waste (There is a lot of potential to use municipal solid waste as a sustainable feedstock, due to its vast supply. Rather than simply dumping municipal waste in a landfill site, where it will gradually emit CO2 and other gases into the atmosphere, it can be used to create jet fuel instead.)
2. Cellulosic waste (The excess wood, agricultural, and forestry residues. These residues can be processed into synthetic fuel via the Fischer-Tropsch process or converted into renewable isobutanol and, further, into jet fuel through the "alcohol-to-jet" (AtJ) process.)
3. Used cooking oil (This typically comes from plant or animal fat that has been used for cooking and is no longer usable for further cooking.)
4. Camelina (Primarily an energy crop, with high lipid oil content. The primary market for camelina oil is as a feedstock to produce renewable fuels.)
5. Jatropha (A plant that produces seeds containing inedible lipid oil that can be used to produce fuel. Each seed produces 30 to 40% of its mass in oil. Jatropha is toxic to both humans and animals and are, therefore, not a food source but excellent to produce jet fuel instead.)
5. Halophytes (Salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray where plants would not normally be able to grow.)
6. Algae (Potentially the most promising feedstock for producing large quantities of SAF. These microscopic plants can be grown in polluted or salt water, deserts, and other inhospitable places. They thrive off carbon dioxide, which makes them ideal for carbon sequestration, absorbing carbon dioxide, from sources like power plants. One of the biggest advantages of algae for oil production is the speed at which the feedstock can grow. It has been estimated that algae produce up to 15 times more oil per square kilometre than other biofuel crops. Another advantage of algae is that it can be grown on marginal lands that aren't used for growing food, such as on the edges of deserts. To date, we have not seen algae fulfil its early promise due to challenges surrounding commercialisation. However, continued research and development may result in wider application of this feedstock in the future.)
7. Non-biological alternative fuels (It includes 'power-toliquid', which typically involves creating jet fuel through a process involving electric energy, water and CO2. This fuel can be sustainable if the inputs are recovered as by-products of manufacturing otherwise taking place and/or if renewable electric energy is used in its production. For example, using the waste gases produced as a by-product in steel manufacturing to produce sustainable aviation fuel is showing great promise. While direct power-to-liquid options are based on technically proven steps, the process is currently prohibitively expensive and needs further development. Other, more advanced, technologies are in early stages of development, such as solar jet fuel (or sun-to-liquid), which uses highly concentrated sunlight to break up water and CO2 molecules.)

### Commercialized SAF

Now that SAF mix has been approved as suitable for use on commercial flights (and that thousands of commercial flights have now been operated using the fuel), economically competitive feedstock supply is a challenge to sustain production. The worldwide aviation industry consumes about 278 billion litres of jet fuel annually. IATA analysis suggests that a viable market for SAF can be maintained when as little as 1% of world jet fuel supply is substituted by SAF (or, put another way, 10% of the world's aircraft fleet is running on a blend of 10% SAF and 90% Jet A-1). Substantial progress has been seen within the period of 2013-2016 where several off-take agreements have been made between suppliers and airlines. (5)

**Different technologies of SAF production**

While blend limits exist today for technical and safety reasons of air fuels, this is not seen as an impediment to SAF development. SAF production is in the early stages of development and is not likely to be limited by the technical blend limitations for some years. The continued testing and development of new processes and technologies with different feedstock will yield useful data to support revision of the specification to allow more flexibility in the supply chain, as well as potential benefits in terms of fuel price stability and availability of SAF and thousands of commercial flights have now been operated globally using SAF now.

There are currently a few approved SAF production pathways, and each represents different processes and different feedstock. Each of these pathways has its benefits, such as the availability of feedstock, cost of the feedstock, carbon reduction or cost of processing.

**Actual a few events and evidence about SAF culture in recently years:**

At present, various countries that have planned access to using sustainable air fuel (SAF) as follows:

A. Austria: OMV and Associate Energy group are working together to distribute regional sustainable aviation fuel (SAF) produced by OMV company in Austria. (Source: https://lnkd.in/ejYpc8RV, May 4, 2022).
B. USA: Air Products is teaming up to build a new $ 2 billion major expansion project at World Energy LLC sustainable air fuel (SAF) production and distribution hub in California.(Source:https://lnkd.in/eg_QfsjN, April 29, 2022)
C. USA and Finland: Aemetis Company has announced that an offtake agreement has been signed with oneworld Alliance airline member Finnair for 17.5 million gallons of blended sustainable aviation fuel (SAF). (Source: https:// lnkd.in/d-qBgpAP , March 28 2022)
D. South Korea: Korean Air will use sustainable aviation fuel (SAF) on its route between Paris and Seoul. (Source: https:// lnkd.in/d9CCFKpb,March 10, 2022)
E. Canada: Canadian aviation industry leaders have launched the Canadian council for sustainable aviation fuels / Conseil Canadian des carburants d´aviation durables (C-SAF) to accelerate the deployment of sustainable aviation fuels (SAF) in the country. (https://lnkd.in/dyUwwWsx , February 25 ,2022)
F. Malaysia and Finland: Malaysian airline has operated its first flight using sustainable aviation fuel (SAF) in partnership Petronas and Neste in 2022.
G. USA:ExxonMobile has reached an agreement with sustainable aviation fuel (SAF) producer Neste in 2022 to commercially distribute Neste MY sustainable aviation fuel (SAF) at France´s largest airports.
H. Sweden:Swedish Biofuels AB and COWI have partnered up to supply the Swedish market with 400,000 tonnes of sustainable aviation fuel (SAF).( https://lnkd.in/eGNJdUsX , May 5 ,2022)
I. Singapore:Singapore is expected to have the world´s largest sustainable aviation fuel (SAF) production capacity when Finnish producer Neste´s facility in Tuas is early next year 2023.( https://lnkd.in/esUjUns ,April 22,2022)
J. USA:The sustainabel biofuel technology company Velocys has welcomed president USA´s commitment to incentivise the production of sustainable aviation fuel (SAF). ( https://lnkd.in/eqjga8hJ ,April 25 ,2022)
K. The Netherlands:Ryanair-Europe´s Favourite Airline announced a partnership with Neste to power a third of its flights at Amesterdam airport Royal Schiphol Group with a 40% sustainable aviation fuel (SAF) blend.( https://lnkd.in/eTpqnk2d ,April 22,2022)
L. UK: Johnson Matthey Company in England has unveiled new technology that will help enable the conversion of captured CO2 and green hydrogen (H2) into sustainable aviation fuel (SAF).

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Beginner's Guide to Sustainable Aviation Fuel Edition 3, ATAG, November 2017

## Authors

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# Update for the American Oil & Gas Industry

July 2022

**KEY DRIVING FACTORS**

- Countries including the U.S. and England have reported the highest inflation in decades. Energy, food costs, and materials for home construction lead the way. President Biden plans to reduce the cost of gasoline and diesel by releasing more Crude Oil from the Strategic Petroleum Reserve.

- Many companies in the US have increased their stock dividends. CF Industries declared a % 33 increase in its dividend. Pioneer Natural Resources is another example. Pioneer has increased its dividend over the last six years. It's important that the income tax consequences of all dividends be handled properly.

**HIGHLIGHTS**

Targa completes purchase of Southcross Energy Operating in South Texas. https://www.targaresources.com

Clean energy start-up reveals plan for $800MM renewable fuels facility in Port Allen, LA - Arbor Renewable Gas LLC, a Houston-based company formed in 2019 that produces renewable gasoline and green hydrogen from wood waste and forest residue, is evaluating West Baton Rouge Parish for a planned $800 million manufacturing and distribution facility employing carbon capture and sequestration emissions-reduction technology.

Venture Global LNG is announcing a final investment decision (FID) and successful closing of the $13.2 billion project financing for the initial phase (an upsized 13.33 MTPA) of the Plaquemine LNG facility and the associated Gator Express pipeline.

(From Reuters) - More than 5 million barrels of oil that were part of an historic U.S. emergency oil reserves release aimed at lowering domestic fuel prices were exported to Europe and Asia last month, according to data and sources, even as U.S. gasoline and diesel prices touched record highs.

# Rock Bottom View:
# Ten Energy Predictions for 2035

Ronald J. Cormier, *Engineering Practice* Contributing Author

Hello again from this old ranch house, amidst swelting summer heat in Texas. As I write this article, it is more than 109F/42.8C outside. Air conditioners in this part of Texas are whirring away and have been for over 90 days now. Local historical data shows this one is about the warmest central Texas summer temperatures on record (along with 2011); already over 35 days of 100+F/38+C highs.

It is obvious that our climate is structurally changing vs. the past. Additionally, this part of Texas rarely experienced prolonged humidity 25 years ago, yet many times, especially as the daily dew point closes in on lower temperatures at night (and that is only down to 90F/32C or so, overnight), humidity is also an unpleasant effect. The low temperature of the day is often still well above a comfortable thermostat setting indoors, much less actually achieving anything more than standard - 20F/7C HVAC refrigeration cycle correction, toward daily highs. Pray that the AC doesn't malfunction in between!!

Sultry weather and "Snowmageddon" winter freeze events (2021) are no longer outliers. Besides our future inability to inhabit certain parts of the planet due to rising temperatures, we must also combat rising sea levels.

Toward that end, the "Tipping Point Twenties" are going to change much faster than we can imagine. Nowhere more so, than in our own energy industry.

Here are our top 10 predictions, based on actual fundamentals and occurrences currently underway…

1. Fossil fuels will be banned.

Recently in the UK, *The Guardian* became the first major news organization to ban all advertising from fossil fuel extraction companies, in spite of the massive hit this will cause to its income. Fossil fuels are rapidly going to be seen as a dirty habit we need to kick, like cigarette smoking. Indeed, Boris Johnson brought forward the ban on diesel and petrol cars to 2035. We think it will be much sooner than this. The consumer pressure against Big Oil is reaching a tipping point. Governments and companies will follow suit.

2. "Clean oil" will fail.

The idea of clean oil is the last hurrah for fossil fuels. Norwegian oil giant Equinor recently announced it was investing billions in making their company go zero carbon by 2050. The elephant in the room is that they will be making only the extraction of oil emissions-free, not the use of it. Mark van Baal, the head of Dutch investor group *Follow This* put it beautifully. "An oil company with targets for its own emissions, and not for its products, is like a cigarette producer that promises all employees will quit smoking, while increasing cigarette production." It's significant that investor sentiment is skeptical. Money talks. Investment anticipates and follows trends, then propels them to the mainstream. Which leads us to…

3. Big Oil will divert its resources into renewables.

Sorry for the smoking analogy again, but what are the tobacco companies doing now? Massively investing in vaping because smoking is a dying habit. OK, the "benefits" of vaping are debatable, but the moral of the story isn't. As the pressure against fossil fuels becomes unbearable, global super-rich companies won't just sit on their hands and go "the game's up". They are energy experts and very long on cash. They will pour it into what the public and governments want – clean energy in the form of solar, wind, hydro, geothermal etc. They've dabbled for years, but now it's really picking up pace. Take a look at this recent Bloomberg article *Shell Leads Big Oil in the Race to Invest in Clean Energy.* Once this takes hold, the transformation will be rapid. The villain becomes the hero in the push to save the planet – (while making trillions in the process, of course)? It's not as far-fetched as you think. Because if these companies don't change, they'll be joining the dinosaurs that they've been digging up for so long!

4. Crash in car ownership/rise of solar-charged EV.
Imagine texting for a driverless car that turns up in minutes and will take you anywhere you want to go. It's quiet so you can work or play while you travel, and it's so much better now there's less traffic on the road. Accidents are almost a distant memory, and it costs a fraction of owning and operating your own car. Sounds like a pipe dream, but solar-charged autonomous driver electric vehicles are being produced now.

Tesla also has fully autonomous capability and with wireless charging now as efficient as plugging in; you don't need a human to start the car charging. In fact, solar charging on the car's roof/upper surfaces is very real technology. We predict a massive rise in shared ownership of electric driverless vehicles, which will trigger a big decline (at least 50%) of private cars by 2035. By 2045 they'll be almost eliminated. It is a real probability that young children today may not ever have to learn to drive.

5. Thorium reactors resurrected/Nuclear fusion still "just around the corner". Uhhh…maybe.

This one's a coin flip. Since the 1950s, the prospect of nuclear fusion has been heralded as the answer to the world's energy problems. Unlike its counterpart nuclear fission, fusion promises clean, endless, no waste, no carbon, no possibility of a meltdown energy that could, in theory, end the world's energy crisis. There's only one problem, it's incredibly hard to achieve. So far, all attempts have resulted in much more energy consumed, vs. energy produced. However, great progress has been made, and there are a number of government initiatives and private companies that say the first nuclear fusion reactors will be going live in the mid-2030s. If true, it will greatly help to cut CO2e. Renewable energy supporters are right to point out that by then it may all be too late. Besides we already have a nuclear fusion reactor that could provide all the energy we need. It's called the sun.

(Increased private and public investment in Thorium reactors, first proposed in the 1960s but then abandoned, is worth keeping an eye on, too. Thorium promises much cleaner nuclear fission, safer energy than conventional reactors and the possibility of much smaller, localized power plants.)

6. Geothermal enters the mix.
The amount of heat within 10,000 meters of Earth's surface contains 50,000 times more energy than all the oil and natural gas resources in the world. Geothermal energy, capturing the heat from the magma, via hot air or steam, below the earth's crust, has actually been around since the first power plant in Italy in 1911. Dow Chemical promoted a thermal power JV with Magma Power in southern California back in the '80s. In recent years, geothermal has seen significant growth (around 6%) in 2018 and looks set to leap forward as the technology advances. Many countries around the world are investing hugely in geothermal, as it produces 99% less CO2e than fossil fuels.

7. Fracking abandoned. Gas declines.

Investment in fracking is set to fall 14% in 2022-2023 (dependent on real time shortfalls without alternative). We predict the UK's current fracking moratorium will become permanent. In France, fracking technology was deemed illegal in industrial and academic institutions. There's little public support currently, and this is only going to fall further as renewables keep growing. Natural gas, an energy mainstay over the past century, is likely also on the way out. In the UK, from 2025, gas heating will be banned from all new homes. Stoves and ranges are currently exempt, but we suspect they will follow suit by 2030-2035.

8. Will domestic wind be a thing?

An interesting prospect as we know that wind & solar make a perfect match in terms of delivering energy consistently when they're used together. When it's windy, it's more likely to be cloudy; when it's sunny, it's less likely to be windy. IF a small effective wind generator could be attached to properties with solar, combined with storage (think Tesla home battery systems), this combination would give the perfect solution to enable off-grid living.

9. With 100%+ solar (and maybe wind) energy independent households, electricity grids go ultra-local, solar becomes compulsory on all new builds and green tariffs disappear.

We've already reached 90% independence from the utility companies using optimal solar panels, batteries, inverters, and immersion diverters. Battery storage prices are also predicted to plummet. Already this has spurred the growth of local smart grids where small residential and business areas export their excess solar energy to each other locally. This is 50% more efficient than the mainly one-way supply via the national grid and it's likely only going to rise in popularity. As this grows, it's only a matter of time before solar panels on every new build becomes law. It's shockingly short-sighted that this hasn't already happened. But it will. sooner rather than later.

Green tariffs will no longer be needed, because households will be able to provide all the energy they need. No further incentive necessary!

10. Threat of "energy wars" will accelerate international investment in renewables.

There's a theme here. We believe that the pressure towards adopting green energy is mounting rapidly. Governments and business react to pressure when it becomes unbearable. It's in their interest. So far, we've talked about pressure from the public. But what might tip it is the fear of energy blackmail on an international scale. Gas supply via pipelines from Russia into Europe has constantly been under threat over the last decade, with Ukraine in particular bearing the brunt recently. The possibility that the Nord 1and/or 2 pipelines shut are critically real at this writing. Nations don't need to give into blackmail if they are energy self-sufficient. Arguably, this could lead nations to defensively push toward maximum extraction of their own gas, oil and coal. It's anybody's guess this winter when most of Europe may well find itself critically short of Btus for heating. We predict a majority of nations will look to the rapid advances in green and nuclear energy as the answer.

In Conclusion.....

So, to sum up, some of these trends may not exactly be the "rays of sunshine" our current modern lifestyle demands. None of this expected change will be easy by any means. On the other hand, our industry will and must change in many ways completely foreign to past techniques and technologies historically studied in degree programs. Armed with such classic theory, we utilized this expertise to commercialize progress during our careers over the last seventy-five years. Ironically, it is this very critical need to perfect and ensure mankind's future existence, that will be required of upcoming STEM graduates.

Until September, we leave you with these thoughts to ponder. Stay cool in the meantime.

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# Use of Process Simulation for Distillation Design

Timothy M. Zygula, Pamela C. Dautenhahn

## ABSTRACT

The focus of this publication will be to demonstrate how to use a process simulation package to successfully design a distillation column. The authors will present two tests cases: a methanol and water system and a benzene, toluene, and cumene system These systems will be used to demonstrate the steps to obtain a good design using a process simulation package. First, equilibrium data results from the simulation will be compared to the literature data. The equilibrium data will be compared to results obtained from three commercial process simulation packages. Once the equilibrium data from the simulations have been determined to be reasonable, a step-by-step procedure will be provided demonstrating how to make sure your simulation results provide a successful design. These steps will be based on steps using graphical analysis techniques to evaluate simulation results. Finally, the authors will provide guidelines to select the correct mass transfer internals for the above-mentioned design cases.

## INTRODUCTION

In recent years the use of commercial process simulation packages for distillation column design has increased dramatically. Process simulation packages have made performing design calculations for distillation column significantly easier. Conversely the job of evaluating a simulation design to see if it is an optimum design or to see if the design simply will work falls to the engineer. The most difficult part of using a commercial process simulation package is determining if the design you get is a good design. Once a converged design is obtained there is no guarantee that the design is optimized or that the design is viable. Only using the proper techniques to evaluate a simulation design can the viability of a design be determined.

There are many factors to consider when designing a distillation column using a commercial process simulation package. The first concern is the thermodynamic package used in the design. Is the equation used correct for your system? Will the package used model your system accurately. The next concern is the design calculations for the internal vapor liquid traffic. Is the design optimal to minimize the tower diameter? Can the reboiler and condenser duties be lowered? These type of parameters will have a big impact on the final phase of the design. Therefore, it is important to make sure the design is optimized. An optimized design will have a big impact on the sizing of the column, design of the internals, and overall cost of the project.

The focus of this publication will be to present some guidelines to follow when using a commercial process simulation to design distillation equipment. The authors will present two design cases using three different process simulation packages for comparison purposes. The systems used in the design cases are as follows:

1. Methanol/Water
2. Benzene/Toluene/Cumene

These cases will be used to demonstrate the required steps needed to obtain a good design using a process simulation package. First, equilibrium data results from the simulation will be compared to the literature data on these systems. Once the equilibrium data from the simulation have been determined to be reasonable, a step-by-step procedure will be provided demonstrating how to make sure your simulation results provide a successful design. A graphical design technique will be used to evaluate simulation results. An optimal design for each system will be presented. Finally, the authors will provide some guidelines in selecting mass transfer internals for the above-mentioned design cases.

## SIMULATION MODEL

When a distillation column is being designed it is necessary to understand the separation to be made. Research is important, the more information you can obtain on the system the easier it is going to be to build your design model. The first step is to set the values for a complete set of independent variables. The feed variables need to be fixed (temperature, pressure, composition, and flow). This is extremely important because in order to have a good operating model the feed variables need to remain constant. With the feed variables set it is necessary to pick near-optimum values for the reflux ratio, column pressure, and the product purity. From this set of independent variables, it is possible to determine the number of theoretical stages needed to achieve the desired separation. The parameters previously stated need to be determined before a simulation model can be built.

### Column Pressure

Choosing the operating pressure of the column is not as easy as it sounds. There are many factors to be considered when selecting an operating pressure. Often the type of separation being performed determines the operating pressure. Some of the factors that need to be considered when selecting an operating pressure are:

1. At higher operating pressures the relative volatility of the system is lower which increases the separation difficulty. As a direct result of increased separation difficulty the reflux requirements for the column would increase. The column would also require more stages and increased duties for the reboiler and condenser to perform the separation.

2. At higher operating pressures the temperature in the bottom of the column increases. This increases the amount of chemical degradation, polymerization and fouling that occurs.

3. At higher operating pressures the reboiler temperature rises, thereby requiring a more expensive heating medium. If the same heating medium is used a reboiler with a larger heat transfer area would be required.

4. Increasing the operating pressure would increase the vapor density and therefore, the vapor handling capacity. This would lead to a reduction in the diameter of the column, which would reduce the capital equipment costs.

5. At higher operating pressures the distillate boiling point increases which allows the use of a cheaper cooling medium in the condenser. If the same cooling medium is used a condenser with a smaller heat transfer area would be required.

These are some of the factors to consider when setting the column pressure. The process of obtaining the most optimum operating pressure is lengthy. All factors must be considered, and the economics of each case compared (1).

### Minimum Stages/Minimum Reflux

Before a simulation model can be constructed it is important to determine the minimum amount of theoretical stages required for a particular separation. It is also necessary to determine the minimum reflux required. There are several short-cut methods that can be used to determine these two parameters. These methods are listed in most distillation design books. These parameters can also be obtained by using your simulation runs with specified conditions. Once a rigorous computer simulation is constructed it will be possible to determine the optimum number of stages and optimum reflux ratio (1).

### Physical Properties

Physical properties are critical to the success of a simulation model. Physical properties are also very important to the accuracy of the model. Sometimes poor physical property data may even prevent your simulation model from converging. The most typical problem is missing parameters in the thermodynamic package used. This is not unusual in most commercial simulation packages. Physical property parameters for most compounds are not known for every thermodynamic model at every pressure and temperature range. Many times, this fact is overlooked when a design model is constructed. Simulation models are constructed and executed with thermodynamic parameters missing. The model may appear to be correct but is completely wrong because of the missing thermodynamic data. Then there is the problem that all the thermodynamic data are present, but the data are not accurate. This problem is even worse than the problem of missing data. The problem with incorrect thermodynamic data is that the results from a simulation model will appear to be correct but the results are totally wrong due to incorrect data. Most simulation packages won’t alert the users that there is a problem. It is the job of the user to determine if the results from a simulation models are accurate (2).

The best way to confirm if your thermodynamic data are correct is to see if you can find any laboratory data or data from literature on your system. This may not always be practical because good thermodynamic test data are hard to find. Sometimes that data may have to be generated in a pilot plant before any design work begins. Research the system being modelled. Published thermodynamic data on the system being modelled may exist. If data are obtained, the data must cover the same temperature and pressure range that you are designing. Next, run a simulation with the same system and see if you can match the data.

### Simulation Accuracy

In order to determine the accuracy of a simulation it is always desirable to construct a McCable-Thiele diagram from the data generated from the simulation. The data from the simulation can be easily transferred to a software package where the graph can be constructed. This graph is used more as a tool to identify possible problems that won't be discovered until the column fails. The following is a list of the areas where a McCable-Thiele diagram can be used as a powerful analysis tool (1).

1. Pinched regions - Pinching is readily seen on an x-y diagram.
2. Mislocated feed points - The feed point should be where the q-line intersects the equilibrium curve. This is generally the rule in binary distillation. However, it is not always true in multicomponent distillation. A key ratio plot is often developed in the design phase. This type of plot is far superior to an x-y diagram for identifying mislocated feeds, especially with large multicomponent systems.
3. Determining if the column is being over refluxed or reboiled - This can be recognized by too wide of a gap between the component balance line and the equilibrium curve throughout the column.
4. Identify cases where feed or intermediate heat exchangers are needed.

### Test Cases

The results from two test cases will be examined. The first case is a methanol/water system and the second test case is benzene/toluene/cumene. Thermodynamic data on these systems were compared with results from three process simulation packages. This paper will examine the results from the three simulation packages by comparing the similarities and differences with respect to the design of distillation towers for these two cases.

The first system studied was the methanol/water system. The feed was a bubble point liquid of a 50-50 mixture of methanol and water at atmospheric pressure. Since there was literature equilibrium data presented at constant pressure, the simulations were run at constant pressure for a more accurate comparison of the equilibrium data. The products desired contained 99 percent methanol in the distillate and 99 percent water in the bottoms. This allowed the development of a good equilibrium curve. Several thermodynamic methods were chosen for use in the simulation packages. These methods included ideal, Soave-Redlich Kwong (SRK), Non-Random – Two-Liquid (NTRL), Van Laar, and others. The results from these methods were compared to values presented in the literature. One set of literature data was obtained from Chu (3) and the other set was from Perry's Chemical Engineering Handbook (4).

Figures 1A, 1B, 1C and 2 show the comparison of the results from the process simulators with the data obtained from the literature. The comparison shows that the NRTL predicts the best results. The curves in Figure 1A and 1B have very similar trends with respect to the simulator results and are very close to the literature curve. However, simulator C (Figure 1C) provides an opposite trend, i.e., it is above the literature curve at low methanol concentrations and below the literature curve at high methanol concentrations. In addition, the results from simulator C do not match the literature data as well as simulators A and B.

The SRK prediction (Figure 2) is close but not as accurate as the NRTL method. Figure 2 also shows the deviation among the different simulation packages. As one can see from the diagram, the different simulation packages predict the actual values fairly well, but deviate from each other considerably. One simulation package predicts an equilibrium curve consistently above the real equilibrium curve and the other two predict curves above at low concentrations of methanol and below at higher concentrations.

The Van Laar and ideal methods gave similar results (not shown) but deviate from the literature results. These curves were well below the literature curve from 0 to .45-mole fraction of methanol and then high from 0.45 to 1.

One would expect the NRTL method to be appropriate since both compounds are polar. Since the results from the NRTL method matched the real data reasonably well, this method was used for the future studies of the methanol and water system.

Test case two is benzene/toluene/cumene. The feed for this system was a bubble point liquid of 25 mole percent benzene, 35-mole percent toluene, and 40-mole percent cumene at atmospheric pressure. For the study of this ternary system, toluene was chosen as the light key and cumene as the heavy key. The desired specifications for this system were 95 percent recovery of toluene in the distillate and 96 percent recovery of cumene in the bottoms. Since the system should be reasonably ideal, ideal and SRK were selected for the thermodynamic methods in the simulation packages. The results from these methods were compared to the values given for this system in Wankat (5) using relative volatilities, which are 2.25 for benzene toluene and 0.21 for cumene/toluene. It is unknown whether the values given in Wankat were based on real data or calculated; however, no other data was found in the literature. Table 1 provides the comparison of relative volatilities.

Table 1. Relative Volatility Comparison for Benzene/Toluene/Cumene

| | Simulator A | Simulator B | Simulator C |
|---|---|---|---|
| Ideal | | | |
| $\alpha_{benz/tol}$ | 2.25 | 2.27 | N/A |
| $\alpha_{cum/tol}$ | 0.31 | 0.31 | N/A |
| SRK | | | |
| $\alpha_{benz/tol}$ | 2.18 | 2.27 | 2.20 |
| $\alpha_{cum/tol}$ | 0.33 | 0.34 | 0.31 |

Both the ideal and SRK methods gave similar results; however, the ideal method gave better slightly results compared to literature. For the relative volatility for benzene/toluene the ideal method agreed very well with the value in Wankat; however, the relative volatility for cumene/toluene deviated significantly (0.31 vs 0.21). The SRK values for the relativity volatilities deviated slightly more than ideal from the values in Wankat. Further research of the literature is needed to determine if the equilibrium data are accurate; however, for the purpose of illustrating the steps in the design the ideal method was chosen.

Since this is a ternary system, a pseudo light key was used to develop a graphical representation of the system. Benzene and toluene represented the pseudo-light key. Figure 3 provides the equilibrium comparison for ideal and SRK with the different simulation packages. The ideal results for the different packages matched very well and the SRK results deviated a little but were similar. Overall, the results from ideal and SRK are similar. The ideal method was chosen for use in the further studies because it was slightly closer to the data provided in Wankat, as discussed above.

Once the thermodynamic method was selected, simulation runs were performed to determine the optimum feed stage, minimum reflux ratio, and minimum number of stages. These can be obtained by following Kister's (1) procedure, which will be given below. A McCabe -Thiele diagram can verify the optimum feed stage obtained from following Kister's graphical technique. In addition, the McCabe-Thiele diagram can be used for the methanol –water system, a binary system, to determine the minimum reflux ratio and minimum number of stages. For the minimum reflux ratio and minimum number of stages using the McCabe-Thiele Method, the actual equilibrium data along with basic graphical techniques for binary distillation were used rather than the simulation data to create the operating lines and stage results.

## Optimization of Feed Stage

To determine the optimum feed stage, simulation runs were performed at several different feed positions. In the simulation runs, the material balance, reflux ratio, and total number of stages were kept constant. Then two main plots were created. One plot was the McCabe-Thiele diagram and the other was a concentration versus feed stage diagram. The McCabe-Thiele diagram was plotted using the mole fraction data calculated for each stage by the simulation. The equilibrium data and the operating lines were determined from these data. The McCabe-Thiele diagram shows how an optimum feed stage versus a non-optimum feed stage looks when using the simulation data. For the methanol-water system, Figures 4 and 5 show McCabe-Thiele diagrams with a mislocated feed at stage 5 and 9 from the top, respectively. Figure 6 provides the diagram showing an optimum feed at stage 7 from the top. One can see how on the optimum stage diagram produces reasonably straight operating lines without any strange curve when the top and bottom operating lines meet; yet the non-optimum stage has more curvature where the operating lines meet. This is also observed in the benzene/toluene/cumene system as shown in Figures 7, 8, and 9. Figures 7 and 8 show non-optimum feed stages (3 and 7 from the top) and Figure 9 shows the optimum feed stage (5 from the top) for this system. These diagrams show similar results as the binary system diagrams with one more distinction. In ternary and higher component systems, the curvature in the operating lines will also sometimes cause curvature in the equilibrium curve. This results from the discontinuity at the feed stage and the development of the equilibrium curves and operating lines from the same data.

In the second type plot, the key component concentration in the product streams are plotted against the feed stage numbers. The minimum in the curve will represent the optimum feed stage. One can generally assume the ratio of optimum feed stage to total number of stages is independent of the number of stages. (1) In both case systems, the total number of stages is kept constant at 10. Also, if the distillate rate is increased, it is expected to move the feed stage up the column. Figure 10 shows the methanol-water system and Figure 11 shows the benzene/toluene/cumene system for determination of the optimum feed stage. Figure 10 shows the optimum feed stage to be around the 7th or 8th stage from the top of the column for the given methanol/water system. This result agrees with the McCabe-Thiele diagram result showing an optimum feed stage at 7 from the top. It also agrees with the binary graphical solution of the McCabe-Thiele diagram using real data, which is shown in Figure 12. If the distillate rate increases the feed stage number will move up in the column. If the distillate rate is increased by two percent the feed stage moves up to the 5th stage form the top. If the distillate rate is increased by five percent, then the feed stage moves up to around the 3rd or 4th stage from the top. Figure 11 shows the optimum feed stage to be around stage 5 from the top for the benzene/toluene/cumene system. This result agrees with the pseudo-McCabe-Thiele diagram result for the benzene/toluene/cumene system. These results show how graphical techniques with specific simulations can predict the optimum feed stage.

### Minimum Reflux Ratio and Minimum Number of Stages by use of Simulation

To determine the minimum reflux ratio and the minimum number of stages, one develops a reflux-stage plot and extrapolates from it. To develop this plot, simulation runs are performed at different number of stages while keeping the material balance, product compositions, and the ratio of the feed stage to the number of stages constant. The reflux ratio is allowed to vary. Then a plot of the number of stages versus reflux or reflux ratio is plotted. The curve is extrapolated asymptotically to an infinite number of stages to obtain the minimum reflux ratio and asymptotically to an infinite reflux ratio to obtain the minimum number of stages. (1) Figure 13 is a demonstration of this graph for the methanol-water system and Figure 14 provides this diagram for the benzene/toluene/cumene system. Figure 13 shows that for a ratio of feed stage to total number of stages equal to 0.7 while maintaining the distillate rate and product compositions the minimum reflux ratio is approaching 0.775 and the minimum number of stages is 7 or 8. The simulation would not run with 7 stages. These results for methanol and water are confirmed by Figure 12 in which a minimum reflux ratio was determined to be 0.768 and the minimum number of stages was determined to be 8. In Figure 14 with the feed stage to total number of stages equal to 0.5, it is shown that the minimum reflux ratio is 0.489 and the minimum number of stages is 6 or 7. The simulation would not run with 6 stages. This graphical technique is a very easy one to do and ensures that the design is not approaching the minimum limits.

### Column Sizing

Once the internal liquid and vapor traffic is obtained from the simulation model. The diameter of the column must be obtained. Most simulation packages have tower-sizing routine. These routines are fairly easy to use and yield quick results. However, these results should be verified by calculation.

Column sizing is done on a trial-and-error basis. The first step is to set your design limits. The design limits are as follows:

1. Maximum Design rates – Vapor/Liquid Traffic is needed at Maximum Operating rates.
2. Design rates - Vapor/Liquid Traffic is needed at Design Operating Conditions.
3. Minimum Design rates - Vapor/Liquid Traffic is needed at Minimum Operating rates.

Sizing calculations need to be performed in areas of the column where the vapor/liquid traffic is expected to be highest and lowest for each section. For example,

1. The top tray and bottom tray in the column.
2. The feed tray.
3. Any product draw-off tray or heat addition/removal tray.
4. Trays where the vapor liquid loading peaks.

For the case studies this publication will be examining the authors will be looking at the top tray in the column, the bottom tray in the column, and the feed tray including the trays above and below the feed when sizing the column.

There are also shortcut methods to sizing a column, which involve using a flooding correlation. These methods minimize the amount of trial-and-error calculations. Using the method as outlined by Kister (1) the first step is to determine the C-Factor at the most heavily loaded point in the column. Using an entrainment flooding correlation like the Kister and Haas correlation the C-Factor at flood can be calculated.

1. $C_{SB} = 0.144\,[d^2_H\,\sigma/\rho_L]^{0.125}\,[\rho_G/\rho_L]^{0.1}\,[S/h_{ct}]^{0.5}$ – Kister and Haas (1)

Next the vapor velocity at flood based on net column area minus the tray downcomer area needs to be calculated. This calculation is done for the top and bottom section of the column (1).

2. $u_N = C_{SB}\,[(\rho_L - \rho_V)/\rho_V]^{(1/2)}$ – Flooding Vapor Velocity, ft/s

Next, the bubbling area required for the top and bottom sections of the column need to be calculated using equation 3. In new designs columns should be design for 80% flood (1).

3. $A_N = CFS/[(SF)(0.8)u_N]$

Bubbling Area Required (Column Cross Sectional Area less downcomer top area, ft2)

Next, the downcomer top area needs to be calculated using equation 4. This calculation is done for the top and bottom section of the column (1).

4. $AD = GPM/VD_{dsg}$

Downcomer Area.

Once this has been completed the tower cross sectional area can be calculated using equation 5. The tower diameter can be calculated from the tower area. (1).

5. $A_T = A_N + A_D$ – Tower Cross Sectional Area, $ft^2$

The following are the definitions of the parameters used in the above equations.

$C_{SB}$ – C-Factor at flood, ft/s
$d_H$ – Hole Diameter, in
S – Tray Spacing, in
$h_{ct}$ - Clear liquid height at the transition from the froth to spray regime, in of Liq.
$\rho_G$, $\rho_L$ – Vapor and Liquid Density, $lb/ft^3$
$\sigma$ - Surface Tension, Dyne/cm
SF – Derating Factor or Foaming Factor
GPM – Tray Liquid Loading, GPM
$VD_{dsg}$ – Downcomer, $GPM/ft^2$
$A_N$ – Tray Bubbling Area, $ft^2$
$A_D$ – Downcomer Top Area, $ft^2$
$A_T$ – Total Tower Cross Sectional Area, $ft^2$

## Column Internals Design

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 the modelling and careful design work will mean nothing if the wrong type of column internals are chosen. There are basically two different kinds of internals that can be used packing or trays.

## Packed Towers

In recent years tower packings have become very popular especially in vacuum distillation applications. Structure packing has become the packing of choice these days. Structure packing is competitively priced these days and has proven to be very successful in many applications. However, there are a few things to remember when trying to decide if structured packing is correct for your application. The vapor and liquid loadings of the towers are important when considering structured packing. Generally, structure packing performs well at low liquid and vapor loadings. At high flow parameters the capacity and efficiency of structured packings can be significantly reduced. Structured packing is generally, most efficient in low-pressure distillation applications.

Some other items to consider when trying to decide to use packing in a tower.

1. Is your application a fouling service? Usually, structured packing does not perform well in heavy fouling applications.
2. Is your service highly corrosive? Structure packing has a low resistance to corrosion.
3. Is pressure drop a major consideration? Structured packing is a low- pressure drop device that provides high efficiency. This is why structured packing is extremely

successful in low-pressure distillation applications.

4. Does the system your modelling have foaming tendencies? Structured packing performs extremely well in foaming applications (6).

The most important part of a packed tower design is the distributors. Packed towers are more sensitive to liquid and vapor maldistribution than trayed towers. Therefore, it is critical that vapor and liquid enter packing evenly distributed. The performance of the packing depends heavily on the initial vapor and liquid distribution entering the packing. Poor vapor and liquid distribution to a packed bed can result in a loss of efficiency (7).

### Tray Towers

Trays are the most commonly selected type of tower internal. Just like packed towers, tower vapor and liquid loadings are an important consideration for trayed towers. Generally, trays perform well at high liquid and vapor loadings. At low flow parameters the capacity and efficiency of trays can be reduced.

Some other items to consider when trying to decide to use trays in a tower.

1. Is your application a fouling service? Usually, trays have downcomer capacity problems in heavy foaming services.
2. Is your service highly corrosive? Trays have a high resistance to corrosion.
3. Trays have higher pressure drop than structured packing or random packing.
4. Entrainment is an issue with trays. Trays usually have more entertainment than packings. Excessive entrainment can lead to efficiency loss.
5. Excessive vapor and liquid maldistribution can lead to a loss of efficiency in a tray tower.

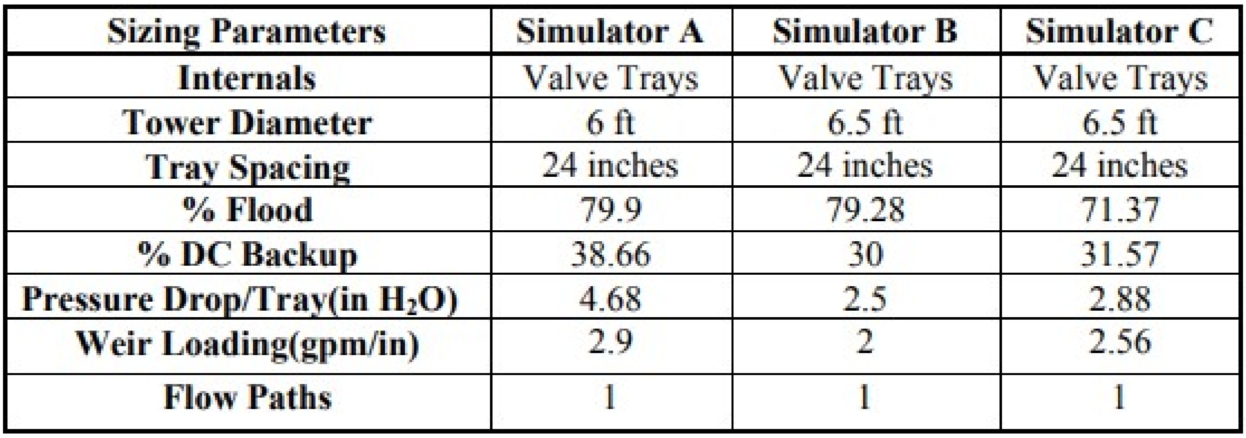
When comparing trays to packing it is always a good idea to get as much information as possible about the internals being considered. The tray vendors are a good source of information. There are many publications on the subject of distillation for example “Distillation Design” by Henry Kister (1). Talk with others in the industry to see what has been done before. Do as much research as possible before any decisions are made.

### Test Cases

Once the simulation runs for the test cases were completed and the accuracy of the models were confirmed, each process simulation package was used to size the diameter of the column and design valve trays for the column. The default design factors were used as the basis of the tray design. The only design parameter specified was the flood factor. A flood factor of 0.8 was used in each simulation design case.

The results from the process simulators for the methanol/water case are given in Table 2. Examining the results from the process simulation packages there is a large amount of variation in the results. Each package predicted about the same diameter column. The column diameter calculated by process simulator A was a ½ of a foot smaller that what process simulator B and C calculated. This may indicate a different sizing criteria from the other two simulation packages. The percent flood numbers for simulation packages A and B were very close. However, simulation package C reported a much lower percent flood number. The pressure drop per tray calculated by process simulator A is almost double of that calculated by process simulators B and C.

The results from the process simulator runs for the benzene/toluene/cumene case are in Table 3. Examining the results from the process simulation packages there is a large amount of variation in the results. Each package predicted the same column diameter. However, the percent flood number for simulation packages A, B, and C showed



| Sizing Parameters | Simulator A | Simulator B | Simulator C |
|---|---|---|---|
| Internals | Valve Trays | Valve Trays | Valve Trays |
| Tower Diameter | 6 ft | 6.5 ft | 6.5 ft |
| Tray Spacing | 24 inches | 24 inches | 24 inches |
| % Flood | 79.9 | 79.28 | 71.37 |
| % DC Backup | 38.66 | 30 | 31.57 |
| Pressure Drop/Tray(in $H_2O$) | 4.68 | 2.5 | 2.88 |
| Weir Loading(gpm/in) | 2.9 | 2 | 2.56 |
| Flow Paths | 1 | 1 | 1 |

Table 2 Methanol-Water Test Case Column Internals Sizing Comparison

extensive variation. These results are suspect considering that each simulation package calculated the same column diameter. Diameter and tray spacing are the two key elements in determining the capacity of a column. Since the column diameter and tray spacing are the same for all three cases there must a differences in the calculation method or the geometric layout of the trays. With each simulator producing widely different results it is hard to be sure which is correct without performing external calculations to verify the results.

There was also a wide variation in the pressure drop calculated by each process simulation package. The wide variation in calculated weir loadings may indicate the method used to perform the tray calculations varies from simulation package to simulation package. This is consistent with the wide variation seen in the percent flood numbers.

The results also show a big difference in the % downcomer backup between simulators A and B and simulator C. Again, this may indicate drastically different calculation methods from one simulator to another.

When using a process simulator to size a new column and design internals for that column all designs should be verified by external calculations. Most process simulators only do hydraulic calculations for internals

There can be big differences in tray and packing hydraulic calculations from simulation package to simulation package. This point was evident in the results for the three test cases presented. Many times different sizing calculation methods are used. This may even include the use of different hydraulic correlations. These differences could result in improperly sized columns and poor column internal designs.

Estimating the efficiency of packing and trays is extremely difficult. Packing and tray efficiency varies from system to system. Without the proper information regarding efficiency could result in a tower that is either oversized or undersized for the application. Failure to properly size the column or the internals that go in the column could result in a tower that does not perform as expected.

The best way to verify the design is to perform hand calculations based on recognized methods for column sizing. The tray vendors are a good resource to verify that the tray design is a good design. Most tray vendors have efficiency information on trays and packing in a wide variety of services. The tray vendors may even be able to recommend ways to optimize the design or suggest a different way to design the internals for the column.

## Conclusions

1. Thermodynamic packages can vary from simulation package to simulation package. Whenever possible verify the accuracy of the thermodynamic data being used in your model.
2. Always verify any simulation design by using graphical analysis techniques.
3. There can be big differences in tray and packing hydraulic calculations from simulation package to simulation package. Verify your design by using hand calculations based on recognized methods for column and tray sizing.

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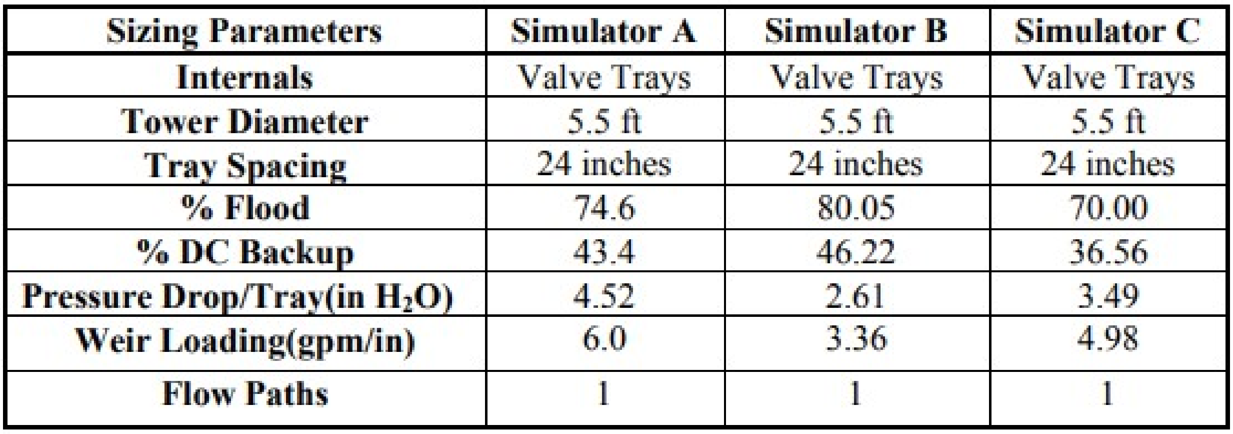

| Sizing Parameters | Simulator A | Simulator B | Simulator C |
|---|---|---|---|
| Internals | Valve Trays | Valve Trays | Valve Trays |
| Tower Diameter | 5.5 ft | 5.5 ft | 5.5 ft |
| Tray Spacing | 24 inches | 24 inches | 24 inches |
| % Flood | 74.6 | 80.05 | 70.00 |
| % DC Backup | 43.4 | 46.22 | 36.56 |
| Pressure Drop/Tray(in $H_2O$) | 4.52 | 2.61 | 3.49 |
| Weir Loading(gpm/in) | 6.0 | 3.36 | 4.98 |
| Flow Paths | 1 | 1 | 1 |

Table 3 Benzene-Toluene-Cumene Test Case Column Internals Sizing Comparison

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Wankat, Phillip C., Separations in Chemical Engineering-Equilibrium Staged Separations, Prentice Hall PTR,
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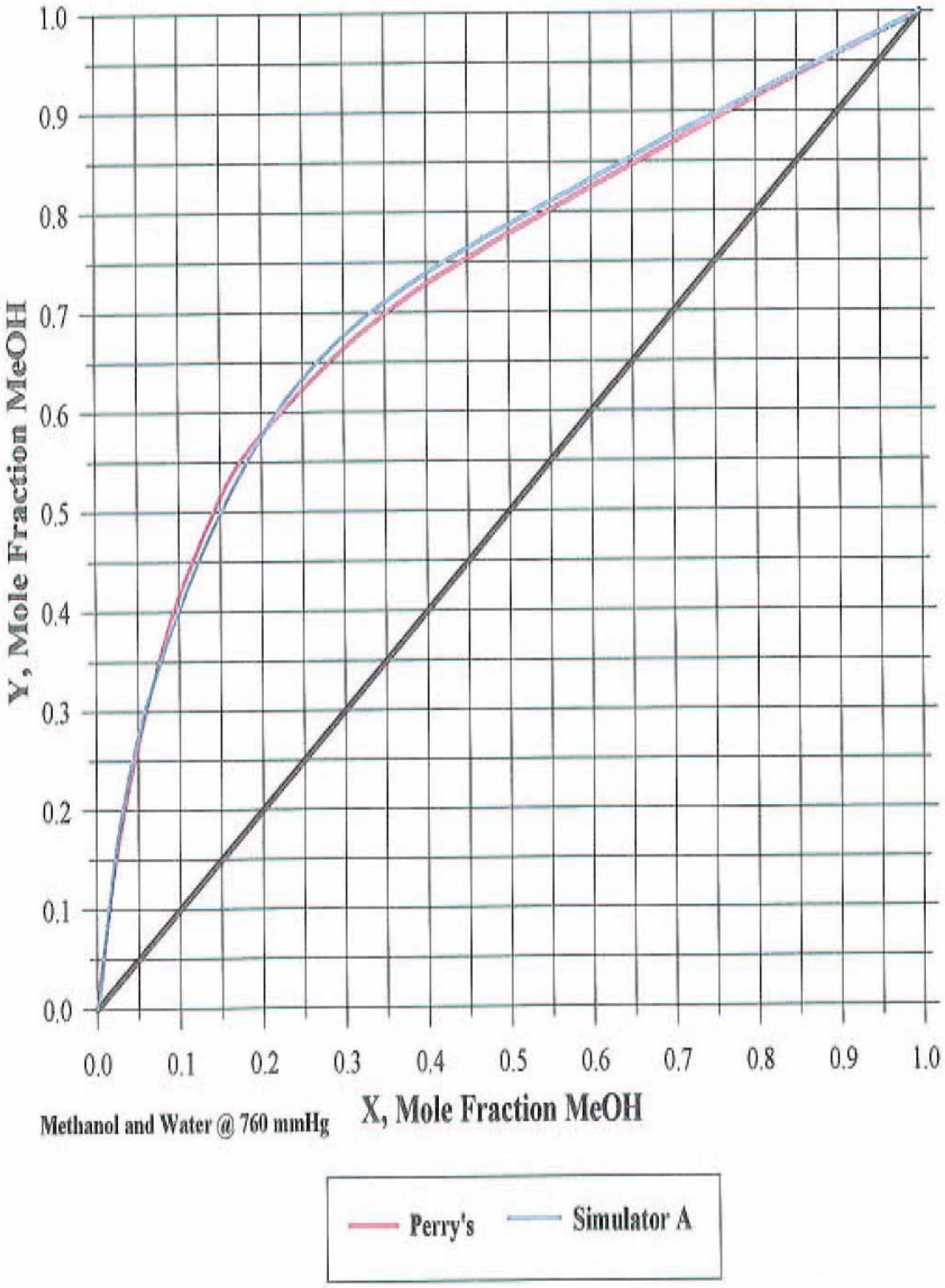
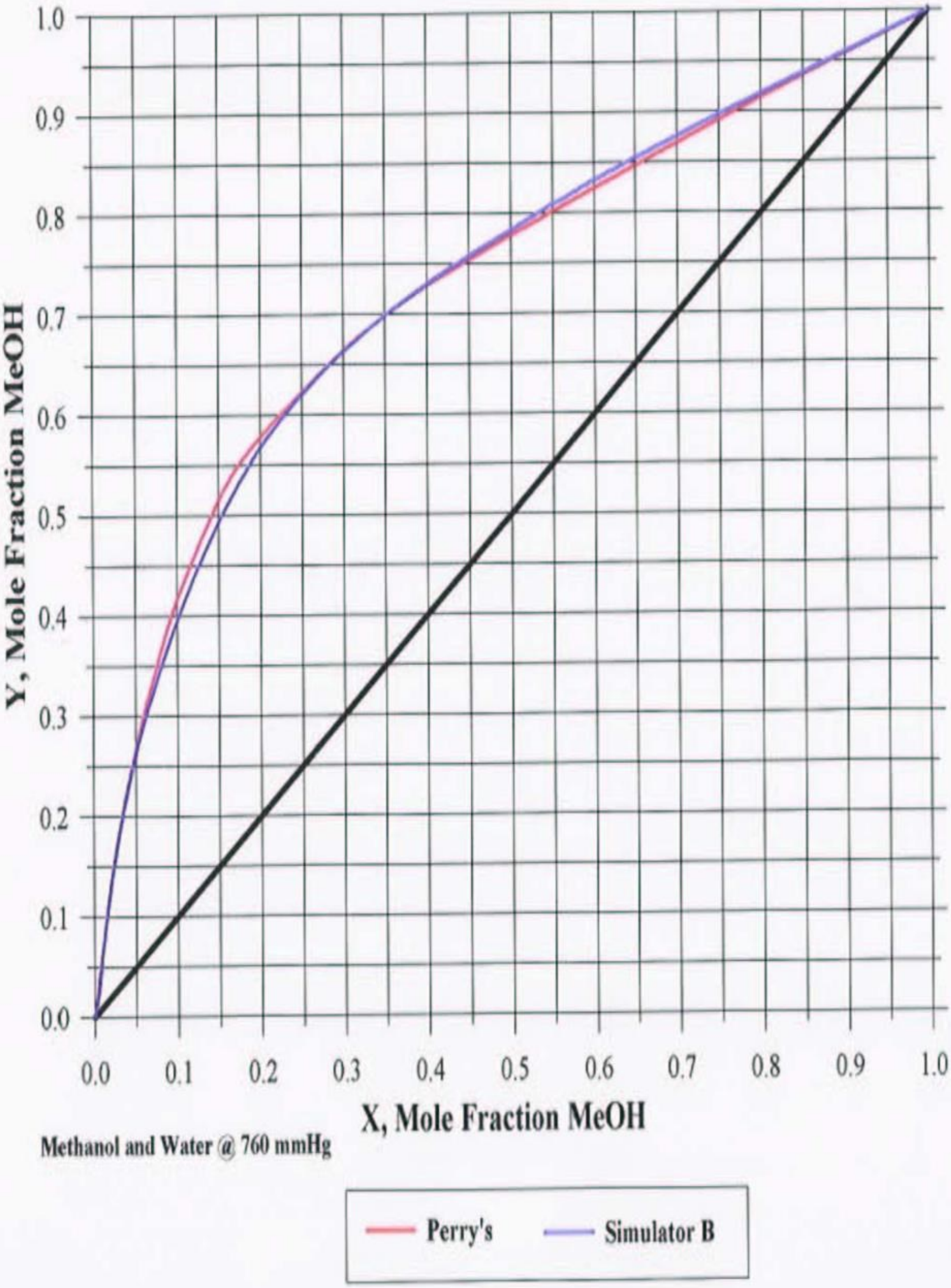
FIGURE 1A

Methanol and Water Equilibrium Data with NRTL



## FIGURE 1B

## Methanol and Water Equilibrium Data with NRTL



## FIGURE 1C

## Methanol and Water Equilibrium Data with NRTL

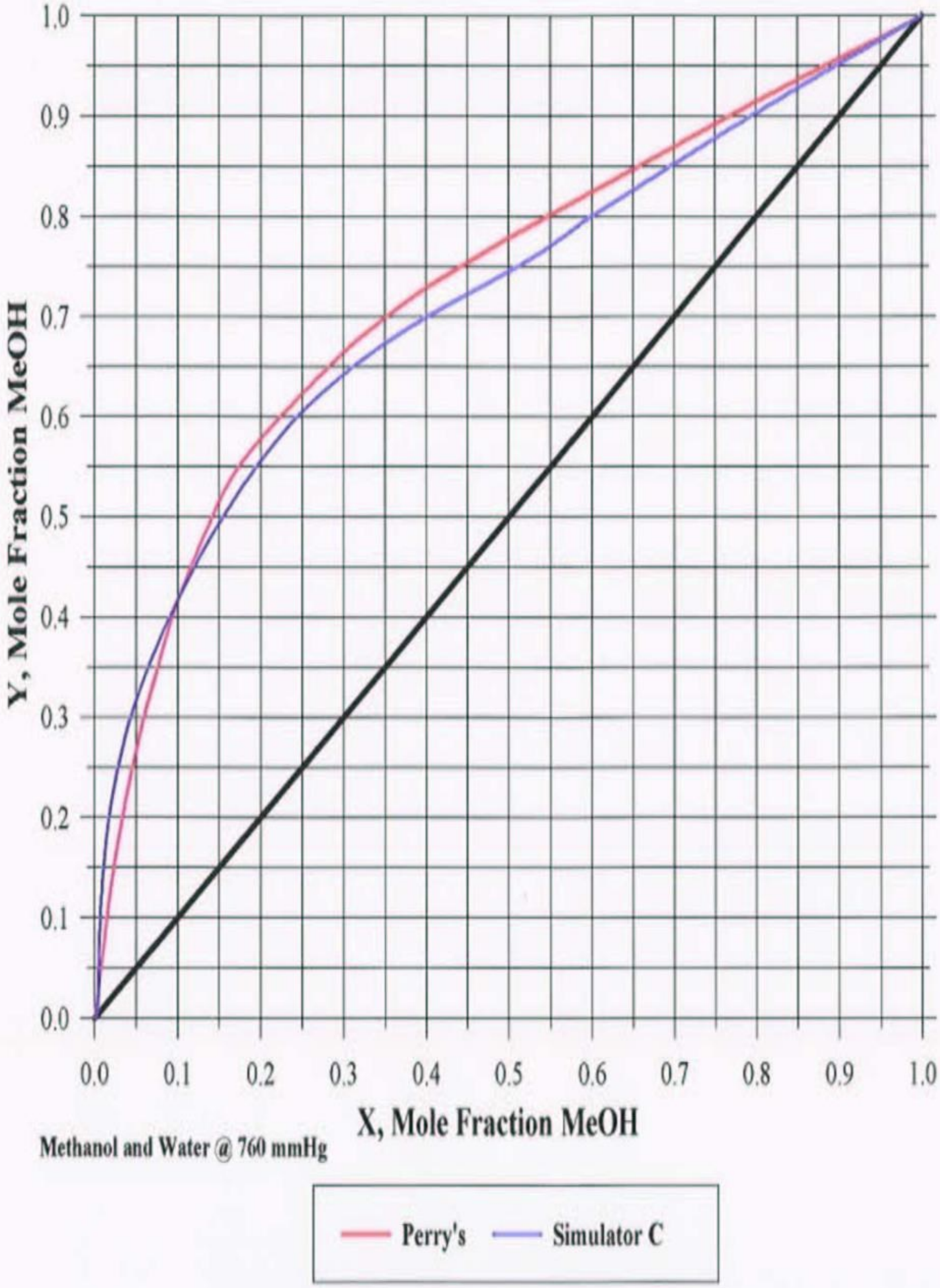


FIGURE 2

Methanol and Water Equilibrium Data with SRK

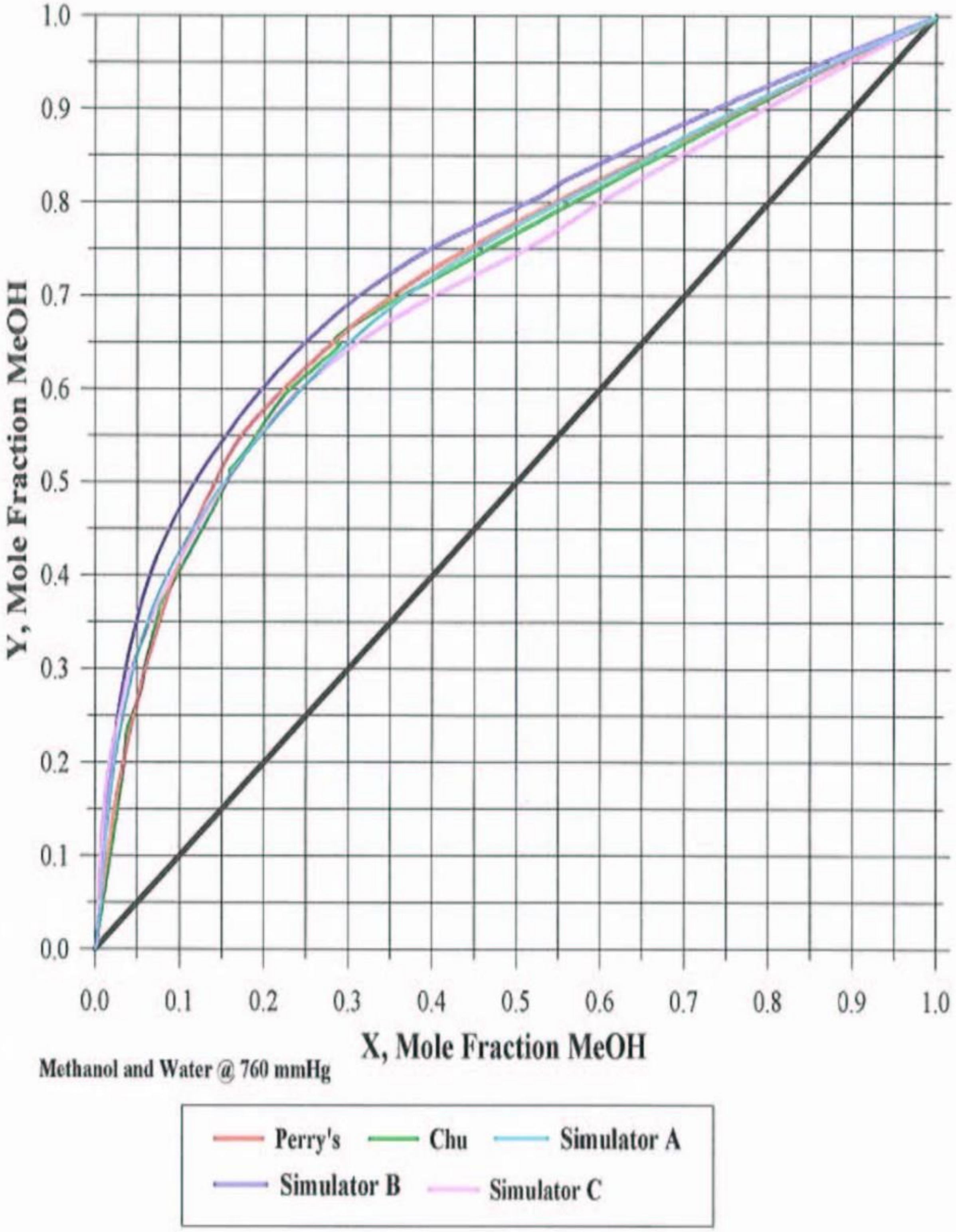
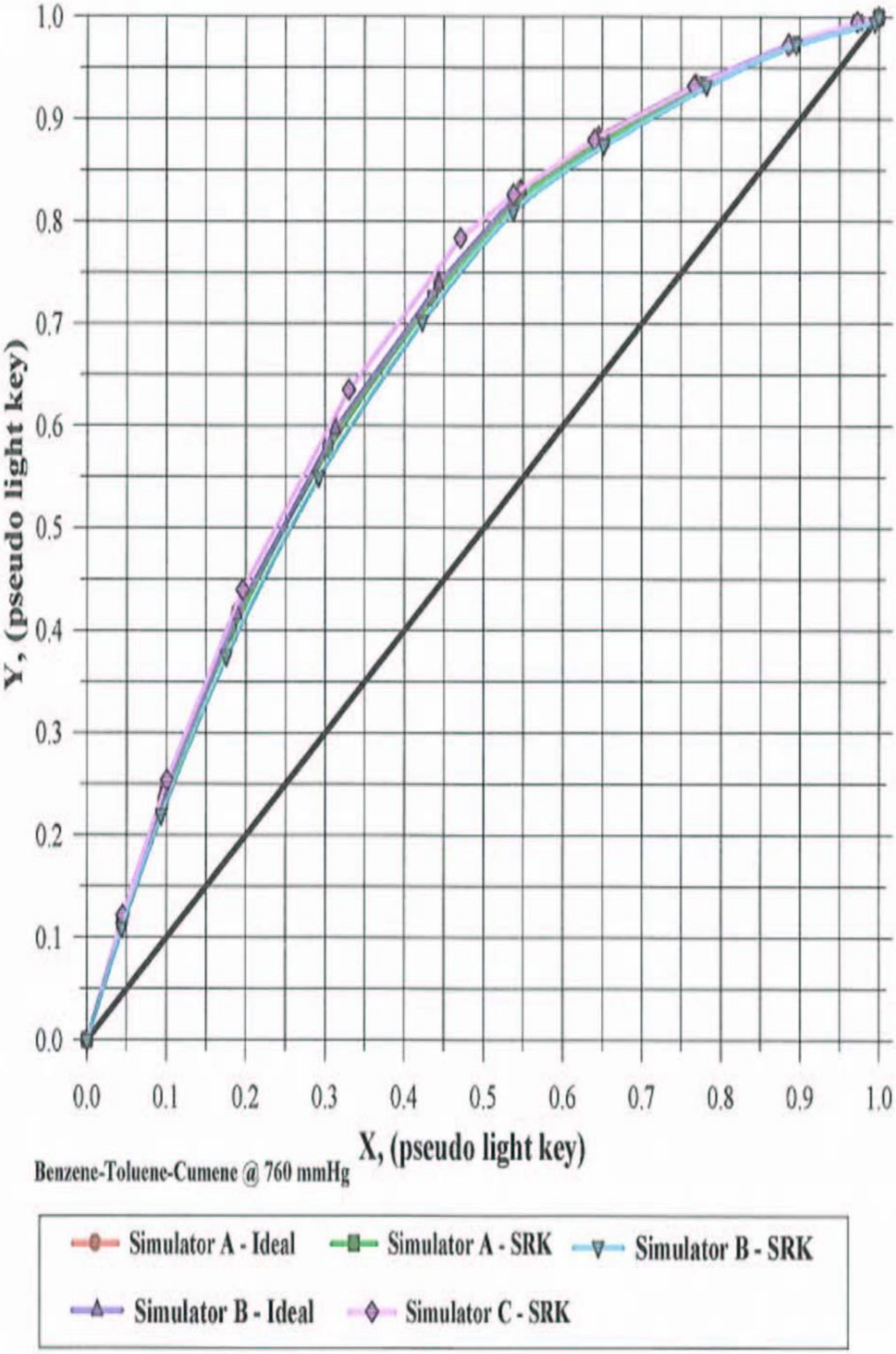


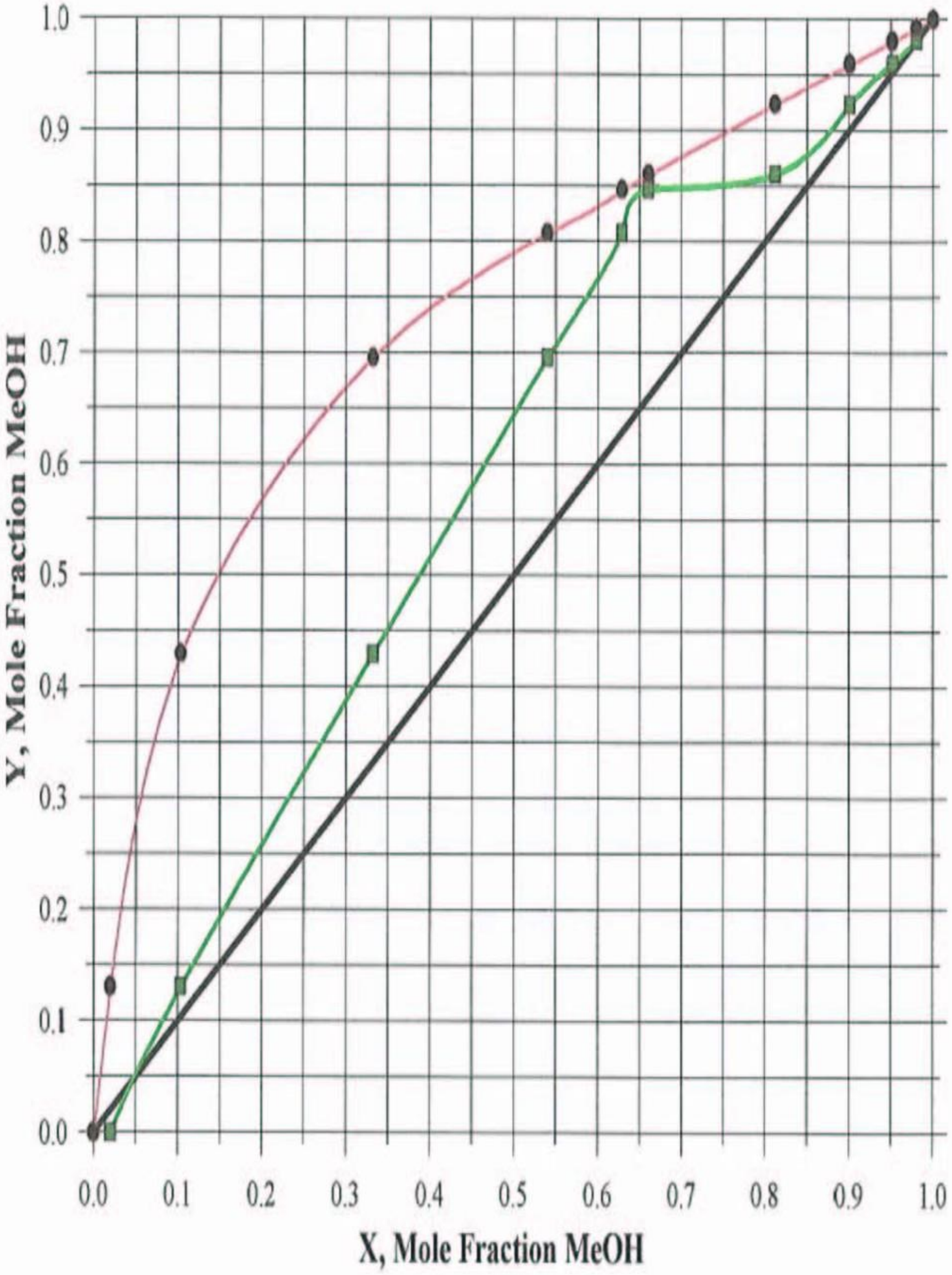
FIGURE 3

Benzene-Toluene-Cumene Equilibrium Data



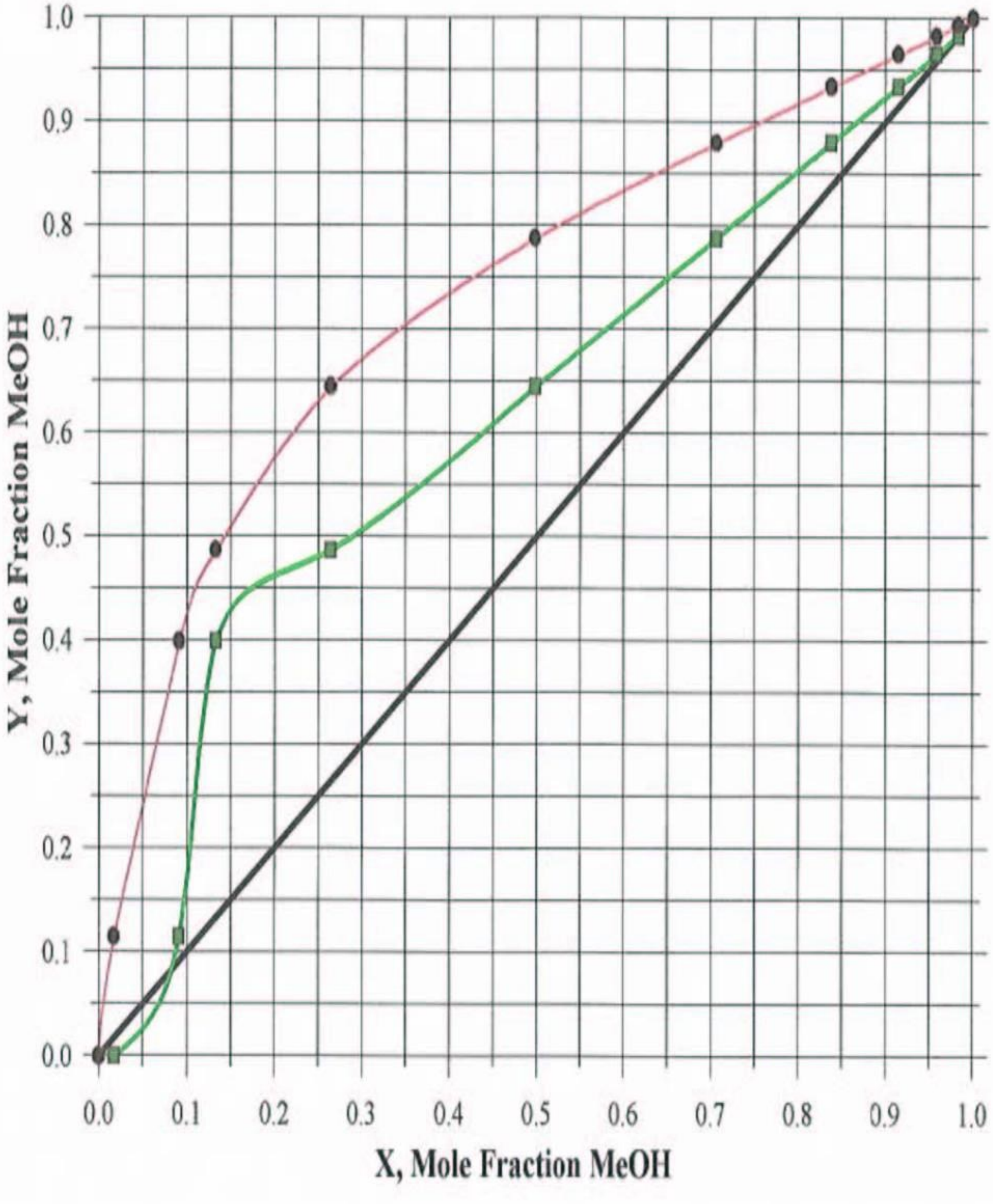
## FIGURE 4

## Methanol-Water Simulation at Feed Stage 5



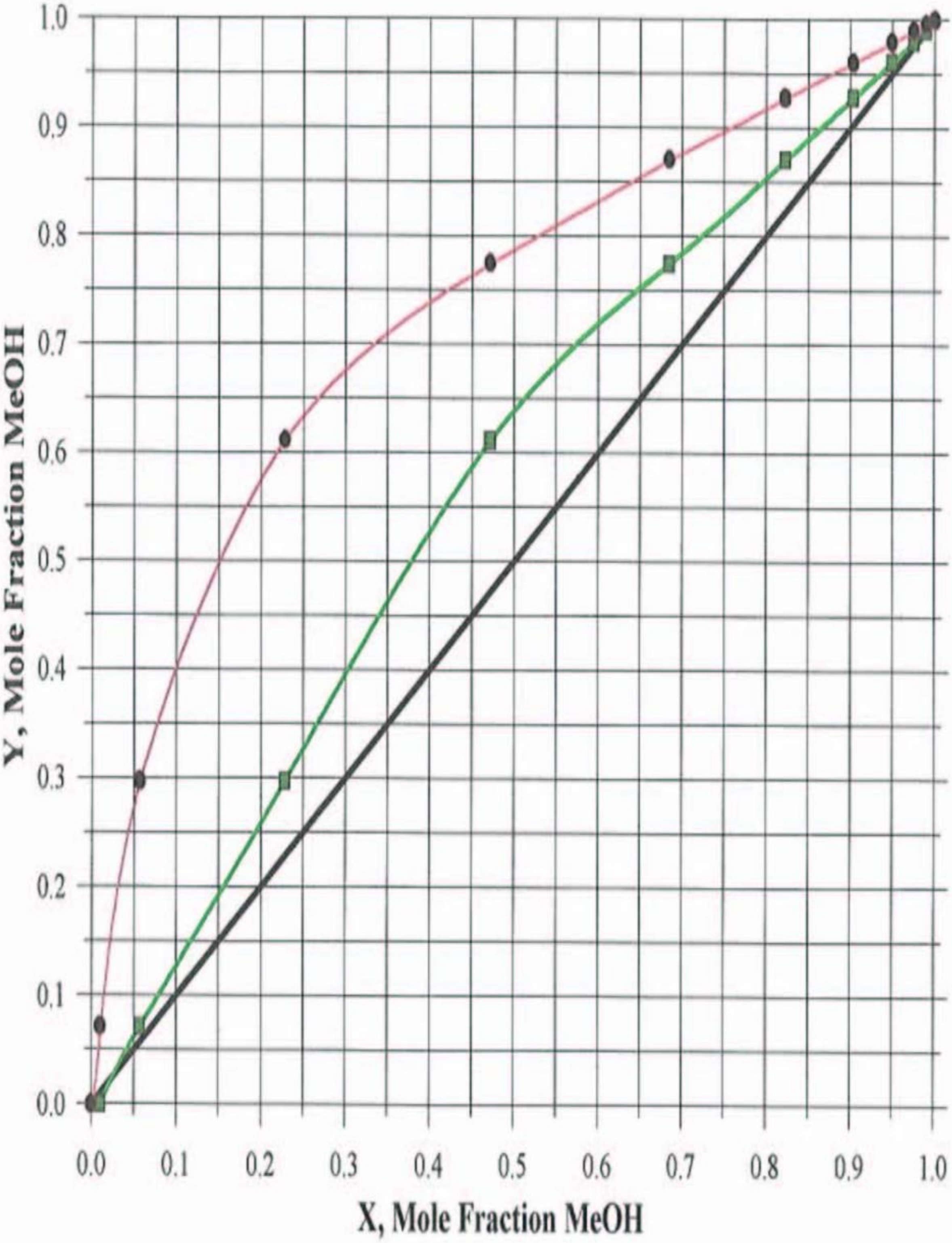
## FIGURE 5

## Methanol-Water Simulation at Feed Stage 9



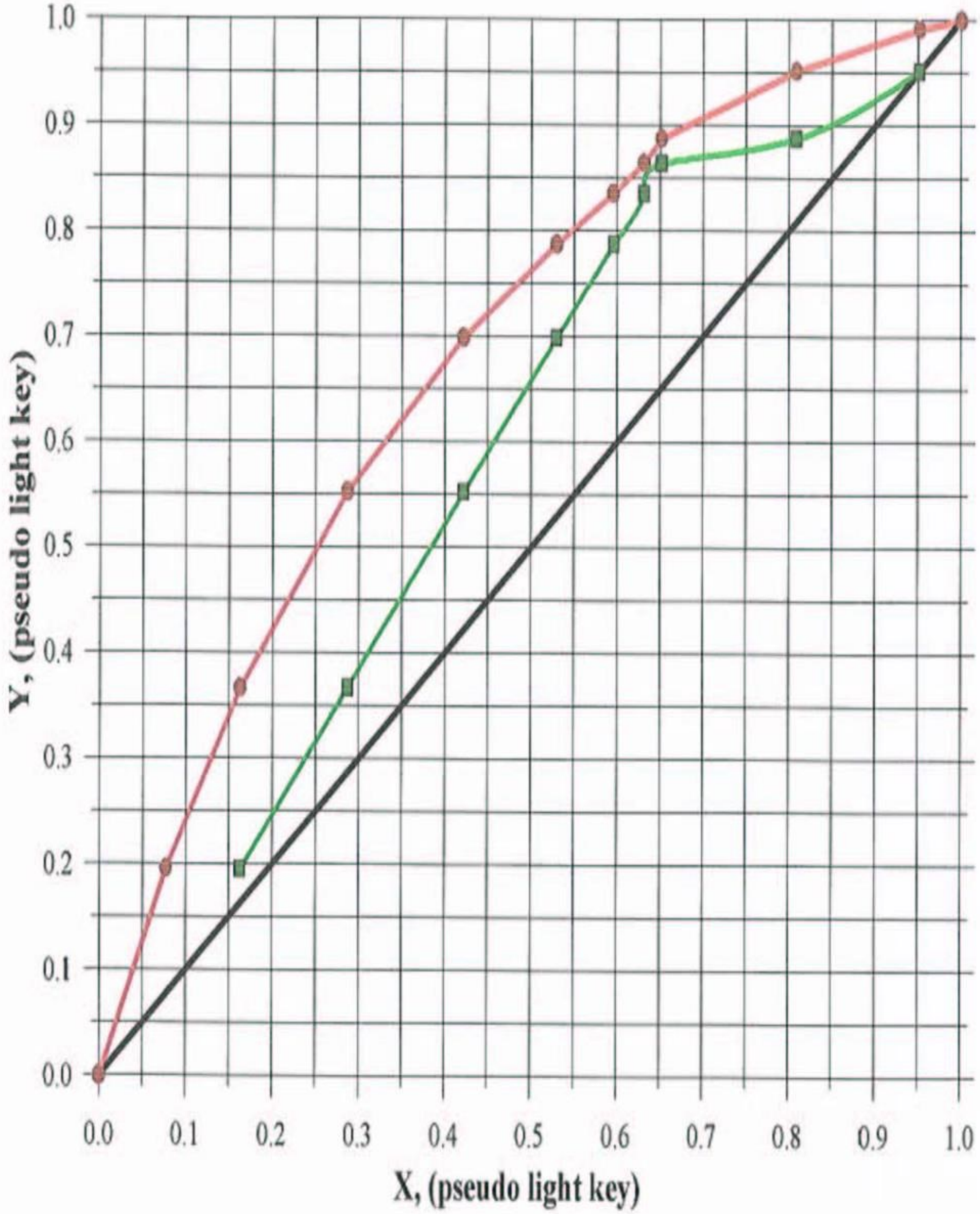
# FIGURE 6

## Methanol-Water Simulation at Feed Stage 7



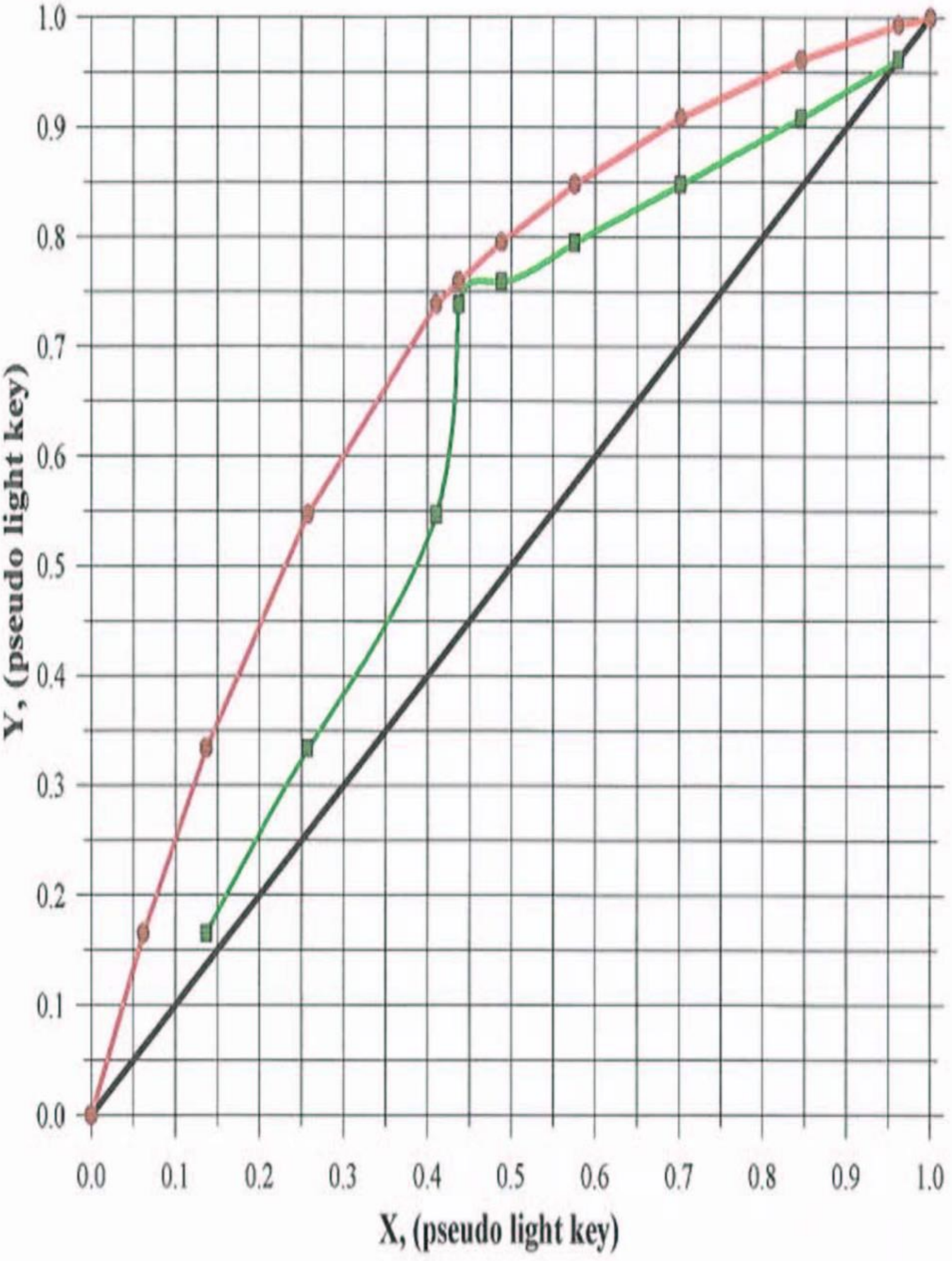
# FIGURE 7

## Benzene-Toluene-Cumene at Feed Stage 3



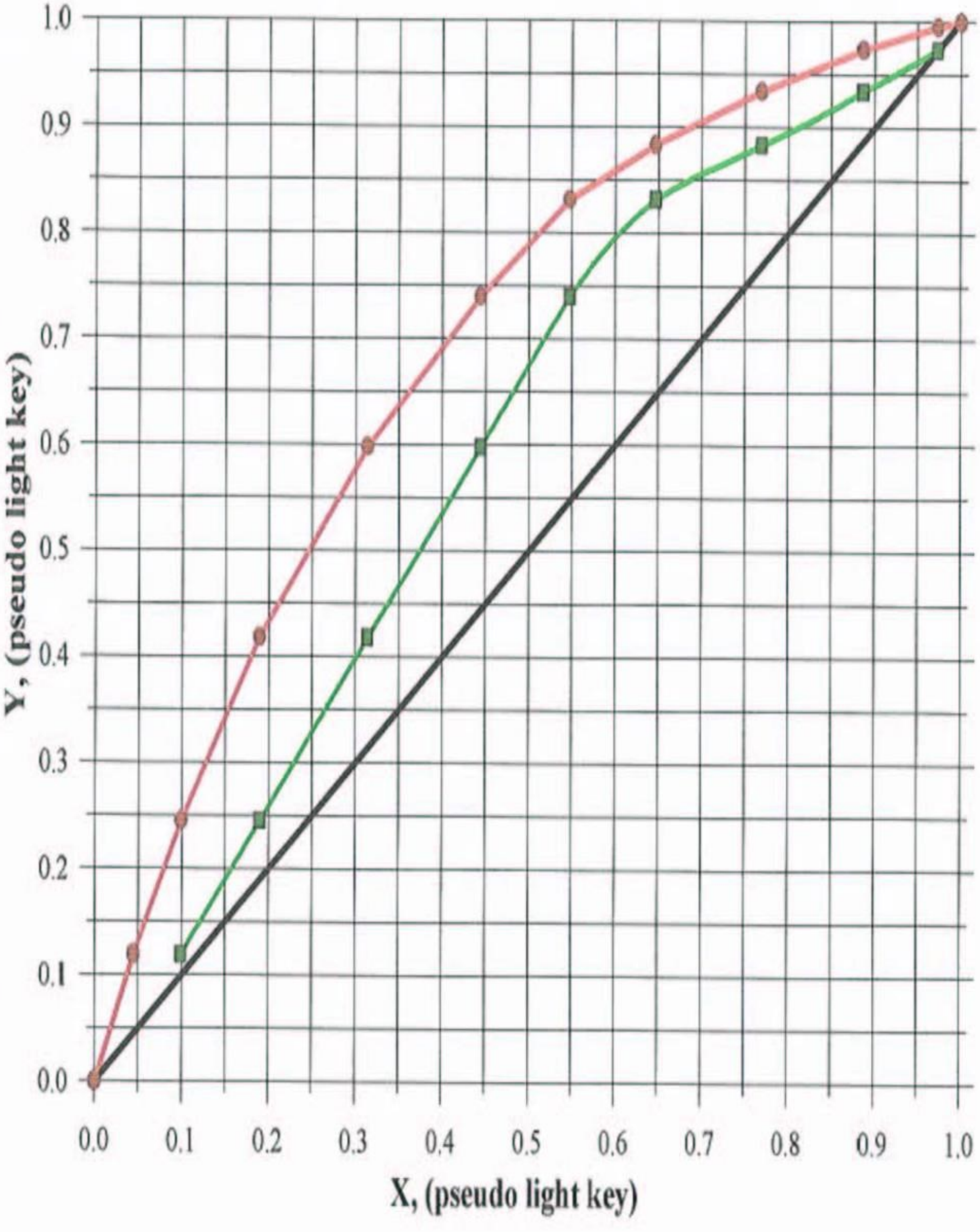
# FIGURE 8

## Benzene-Toluene-Cumene at Feed Stage 7



# FIGURE 9

## Benzene-Toluene-Cumene at Feed Stage 5



## FIGURE 10

## Methanol-Water Simulation Determination of Optimum Feed Stage

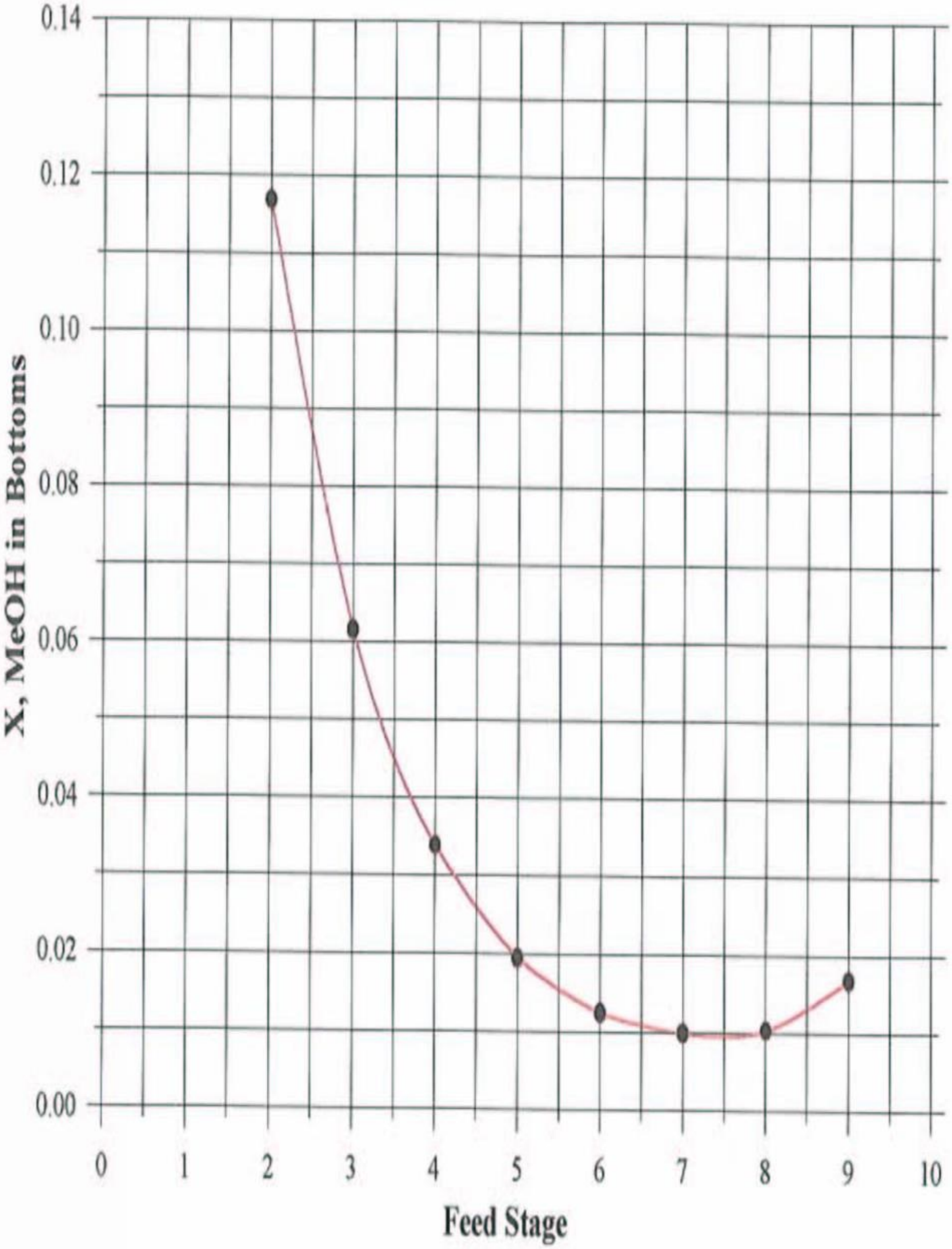
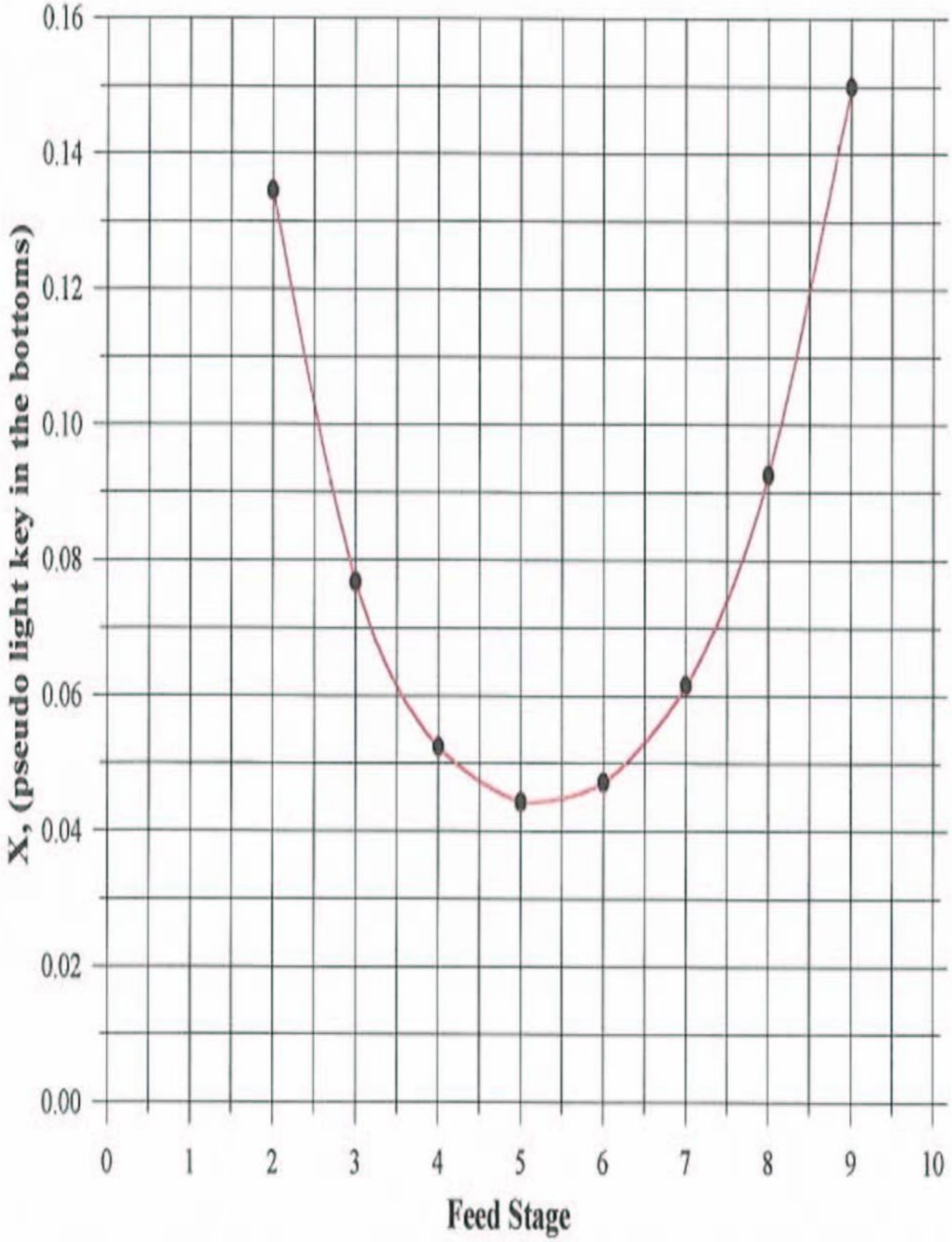
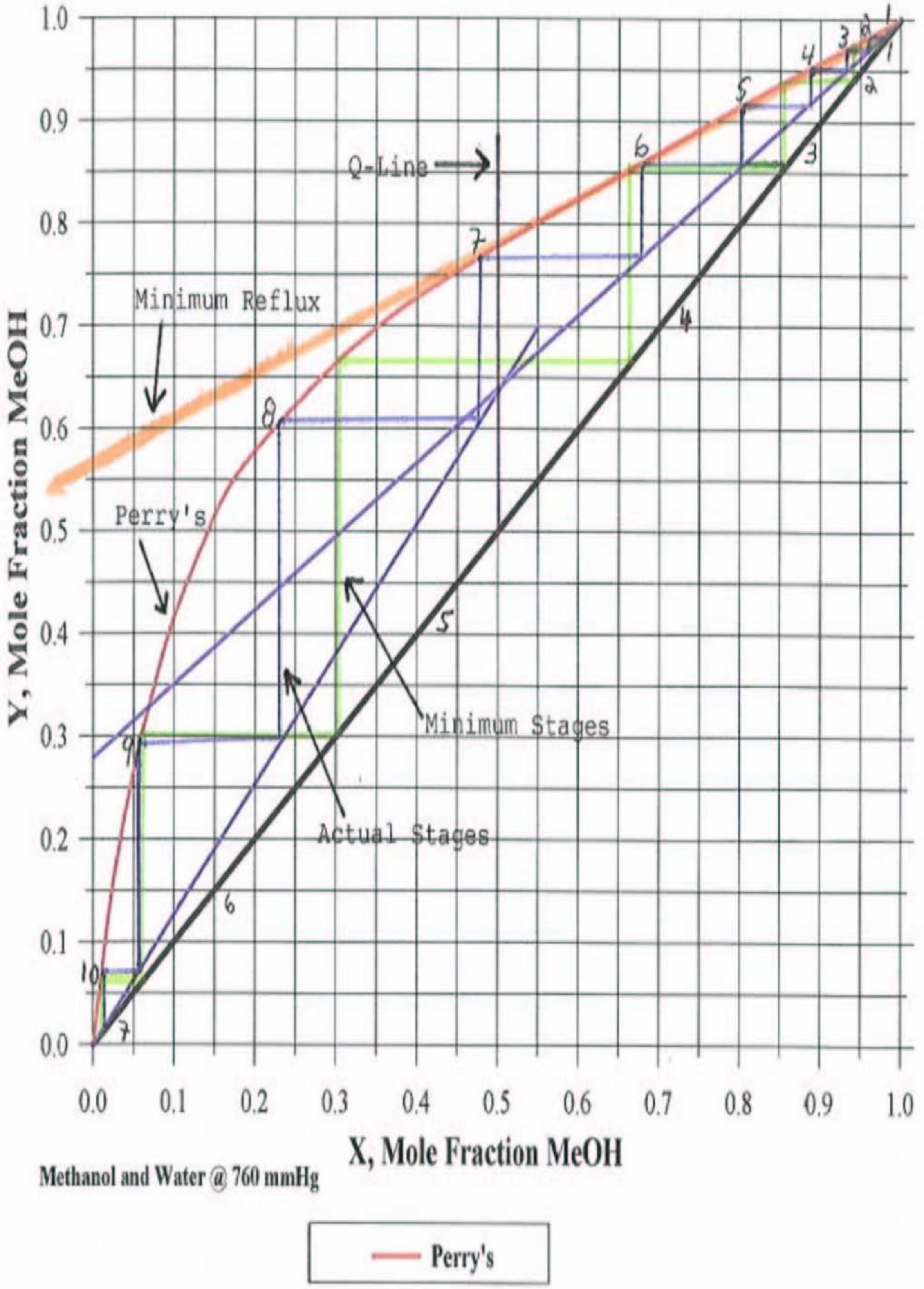


FIGURE 11, Benzene-Toluene-Cumene
Determination of Optimum Feed Stage



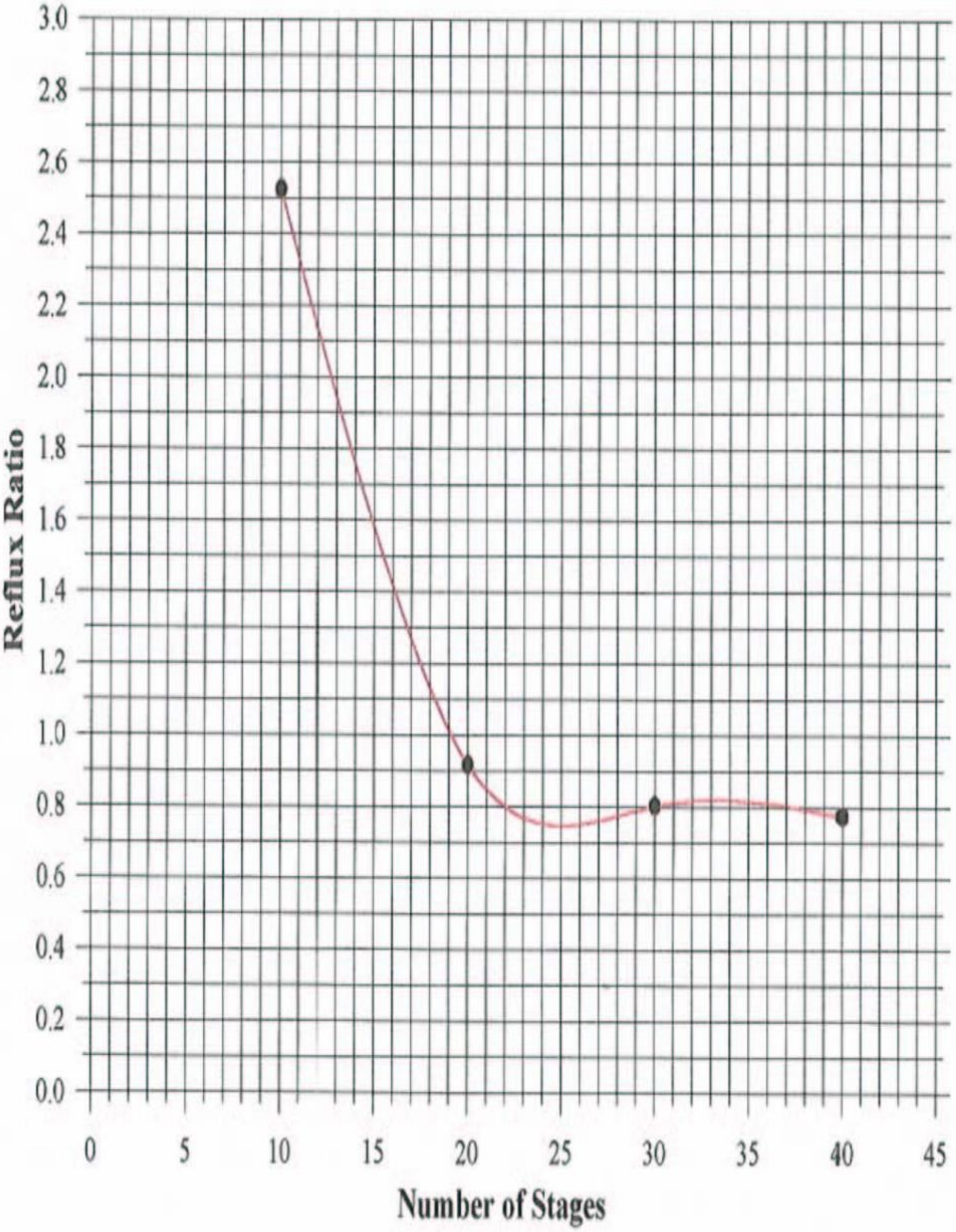
# FIGURE 12

## Methanol and Water at 760 mmHg



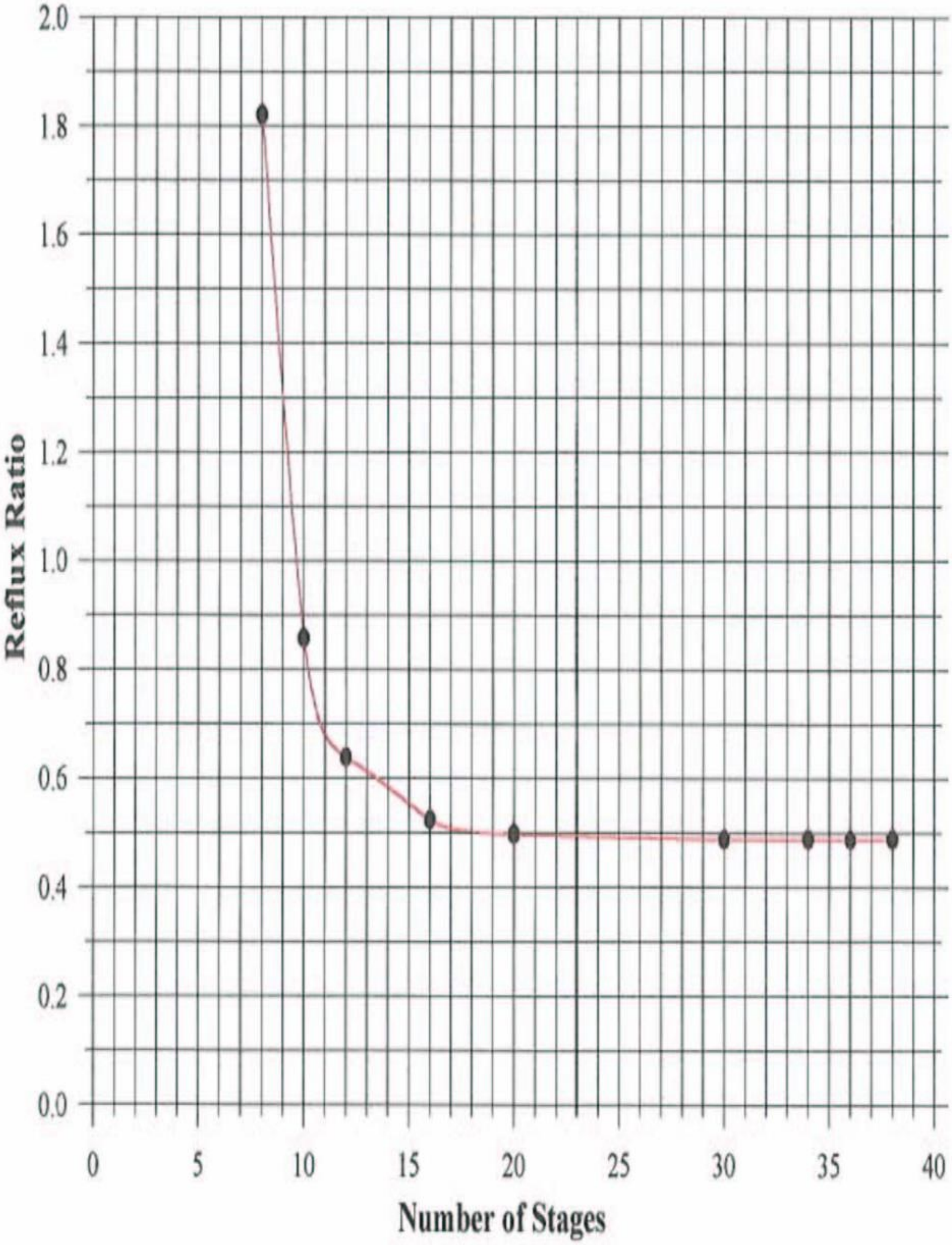
## FIGURE 13, Methanol-Water

## Determination of Minimum Reflux Ratio and Minimum Number of Stages



# FIGURE 14, Benzene-Toluene-Cumene

## Determination of Minimum Reflux Ratio and Minimum Number of Stages



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# Design Guidelines for Safety in Piping Networks

Karl Kolmetz, Stephen J.Wallace, Mee Shee Tiong

## INTRODUCTION

When compared to other equipment in a hydrocarbon processing plant, the piping network is designed to the most stringent standards. Mechanical Engineering codes require a 400% safety factor in the design of these systems. The piping system is normally considered the safest part of the plant. However, even with this level of safety, reviews of catastrophic accidents show that piping system failures represent that largest percentage of equipment failures (1).

Since these systems are responsible for many catastrophic accidents, operations, design, and maintenance personnel should understand the potential safety concerns. The best tool that we have to prevent future accidents is to review past incidents and incorporate lessons learned into future design and operation of piping systems.

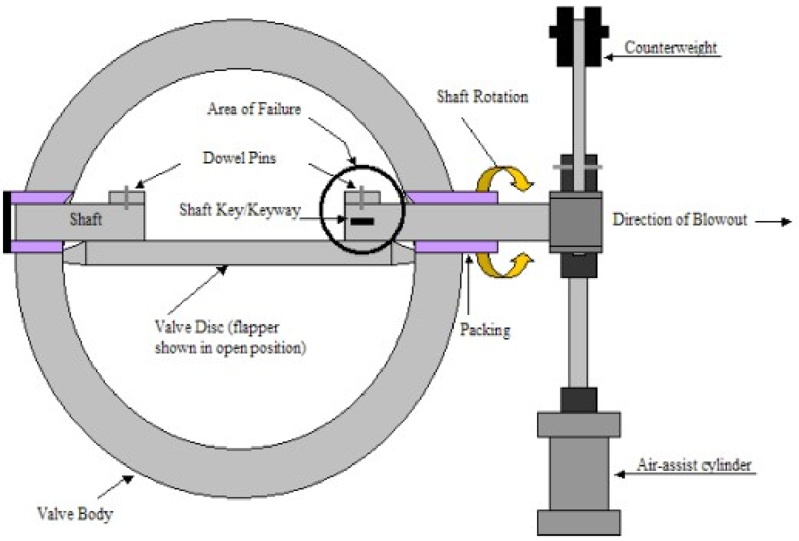
This paper will discuss various case studies that will help to illustrate the consequences of inappropriate design, operation, and maintenance of piping systems. The case studies include 1) Check valve failures; 2) Small bore piping in compressor discharge piping, 3) Low temperature embitterment, and 4) Hot tapping safety issues and hot tap shavings concerns.

## CHECK VALVE FAILURES

Check valves are important safety devices in piping. Check valves have been utilized in the process industry for many years to keep material from flowing the wrong way and causing operational or safety concerns. One common mistake is installing the check valve backwards and blocking the process flow. There is normally an arrow on the check valve designating the proper flow direction, indicating the proper installation position. There have been cases where the manufacturer showed the arrow incorrectly, which greatly hindered troubleshooting.

Case 1 - In December 1991, a chemical plant in Saudi Arabia (2) experienced a release of propane gas due to a check valve shaft blowout. The incident followed a process upset in the facility's ethylene plant, where the inadvertent shutdown of a cracked gas compressor resulted in downstream flow instabilities and initiated a 13 hour period of surging in the unit's propane refrigeration compressor.

Simplified cross-sectional view of check valve (flow direction is into page)



during this period, the check valves installed in the propane refrigeration compression system slammed closed repeatedly. The shaft of the compressor's third stage discharge valve eventually separated from its disk and was partially ejected from the valve. The shaft was not fully ejected because its path was blocked by an adjacent steam line inches away from the valve, keeping about 70 mm of the shaft's length within the valve body.

gas began to leak out of the valve around the gap between the shaft and its stuffing box until operators discovered the leak and shut down the compressor. Operators also discovered that the valve's drive shaft counterweights had broken off of the drive shaft and had been propelled approximately 16 meters (45 feet) from the valve.

The facility was fortunate that an adjacent steam line kept the shaft from being fully ejected from the valve, thus limiting the leak rate and preventing an accident of potentially greater severity. It was also fortunate that no one was struck by the counterweights when they were propelled from the valve.

A subsequent investigation and analysis of the check valve's internal components revealed that the dowel pin, which secured the drive shaft to the valve flapper, had sheared, and the shaft key had fallen out of its key-way. The investigation report also revealed that facility maintenance records indicated a long history of problems with the check valves installed there. The valves were installed in 1982, and due to continuing valve malfunctions, underwent repair or modification in 1984, 1986, 1987, 1989, and 1990. These repairs and modifications included replacement of damaged counterweight arms, replacement of seals and gaskets, replacement of dowel pins and internal keys, and installation of external shaft "keepers".

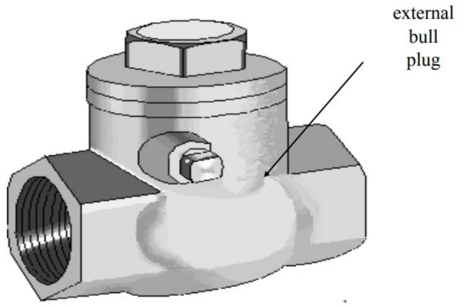
Case 2 – An incident with a similar failure mechanism occurred in an Ethylene Plant in Texas in June 1997 (2). The check valve was on the process gas compressor discharge line, which had high flow, high pressure and high temperature, along with compressor vibration; however, the investigation team found no evidence that these temperature and pressure limits were exceeded at any time prior to or during the accident. The check valve was installed on the fifth stage of the compressor and had an internal diameter of 36 inches and weighed 3.2 tons. The valve had a design limit pressure of 480 psig, and a design limit temperature of 115 degrees F. The drive shaft penetrates the pressure boundary through a stuffing box. The exterior portion of the drive shaft is connected to the pneumatic piston and counterweight, and the interior portion of the shaft is coupled directly to the valve disk using a cylindrical hardened steel dowel pin and a steel rectangular bar key. This arrangement provides a counter weight to partially balance the weight of the valve disk, and provides the pneumatic power assist to maintain the valve closed as described above.

This check valve was the same design as the previous check valve and had the same failure mechanism. The pneumatic assist assembly became unattached from the check valve, leading to loss of hydrocarbon containment and a major unit fire. The unit was down for several weeks for repair.

This fire resulted in minor process operator injuries, public road closures, and property damage both within the olefin unit and to off site business. The EPA and OSHA undertook an investigation of this accident because of its severity, its effects on the public, and "the desire to identify those root causes and contributing factors of the event that may have broad applicability to industry, and the potential to develop recommendations and lessons learned to prevent future accidents of this type".

Case 3 - An Ethylene Plant in Louisiana had a near miss from a check valve failure in 1999. The check valve had an external bull plug, which allowed the check valve swing pin to be installed. The bull plug slowly rotated out over time leading to loss of hydrocarbon containment on a medium pressure ethane feed line. The line was isolated, copious amounts of water were applied to the leak, and fortunately the vapor did not find a source of ignition.

This check valve was far away from a source of vibration such as a compressor. The root cause of the incident is was not totally identified but one theory is that normal piping vibration caused the bull plug to rotate. The



Ethylene plant reviewed all check valves in hydrocarbon service and installed an anti rotation locking device to prevent the bull plugs from rotating and causing a loss of hydrocarbon containment.

## SMALL BORE PIPING IN COMPRESSOR DISCHARGE PIPING

Since 1997, sixteen incidents attributed to vibration fatigue failure of piping within compressor stations and pump stations were reported to the Canadian National Energy Board (3). The fractures associated with these incidents typically initiated near welded junctions where small diameter pipe (NPS 2 or smaller) was tied into a larger pipe. The typical location where this occurred is on the discharge piping immediately downstream of a compressor/ pump unit. The consequences of these failures include facilities shutdown, worker injuries, loss of product and site contamination.

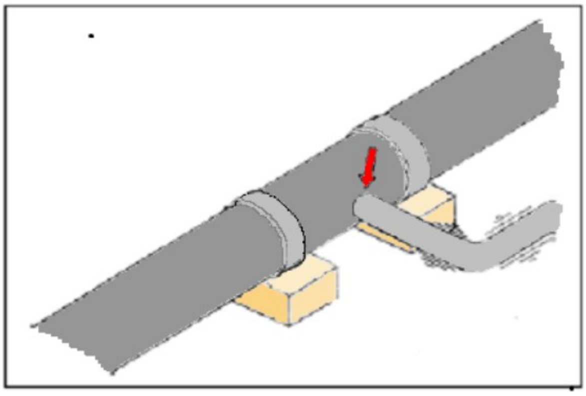
Although vibration fatigue has been deemed to be the immediate cause of all these failures, poor design and lack of effective piping support is considered the basic cause of the incidents. Designs included poor support for the smaller ipe components, sizing (length, diameter and thickness) of the piping itself, and lack of consideration for additional stresses on the pipe-to-pipe junction in situations where a valve or regulator was installed at the remote end of the small diameter pipe. This resulted in bending stresses at the junction being increased to the point of failure.

Vibration levels imparted to the piping adjacent to compressor/pump units should be monitored and managed. Piping configurations potentially at risk such as the one described above should be investigated and modified to manage any vibration, which may impact the pipe and associated junctions.

Case 4 - An Ethylene Plant in Malaysia had a major near miss from small bore piping on the discharge of a propylene refrigeration compressor in 2002. The compressor discharge piping had very high vibrations from unit commissioning. The original diagnosis of the high vibrations was the piping network, and several solutions were implement on the piping network without success. The root cause of the high vibrations was eventually found to be the compressor rotor.

One guideline is to restrict the small-bore piping to a safe distance from the discharge of the compressor to limit piping fatigue failure. A three quarter inch stub and valve on the fourth stage of the propylene compressor at 15 bar gauge (160 psig) discharge pressure experienced the high vibration from the compressor and failed, leaving an open ¾ inch line. The resulting massive loss of containment went unnoticed because the propylene vapor was at a high temperature 70 C (155 degrees F) and did not cause a vapor cloud.

The compressor was shut down and even with the massive loss of containment, greater than 10 tons of propylene in the battery limits of a functioning ethylene plant, the vapor cloud did not find a source of ignition.



## PIPING LOW TEMPERATURE EMBRITTLEMENT

Piping low temperature embrittlement is the loss of ductility, toughness, and impact strength that occurs in some metals at low temperatures. Normal carbon steel piping is rated for -20 F (–29 degrees C) at atmospheric pressure. This is also about the vaporization temperature of liquid Propane and Propylene (-49 F). In units with propane and lighter components, there is the possibility to exceed the low temperature limit of normal carbon steel.

Carbon steel piping is typically used in services with temperatures above -10 to –20 degrees F. At temperatures below -10 to -20 degrees F. normal carbon steel loses ductility and strength and the metal becomes brittle and can be susceptible to brittle fracture. Impact testing can certify the use of carbon steel piping in services as cold as -49 degrees F, and is named “killed” carbon steel.

John A. Reid (4) put together list of ethylene plant hydrocarbon incidents. He noted four incidents where low temperature embrittlement cause line failures. Cases he noted included:

1. 1965 Explosion and Fire Due to Cold Brittle Flare Line Fracture at PCI Olefin Unit in Lake Charles, La.
2. 1966 Flare System Explosion - Monsanto's Chocolate Bayou Olefin Unit

3. 1975 DePropanizer - Explosion in a Naphtha Cracking Unit – Dutch State Mines – 14 fatalities
4. 1989 Cold Brittle Line Fracture Results in Gas Leak, Explosion and Fire at Quantum's Morris Illinois Ethane/Propane Cracker – two fatalities

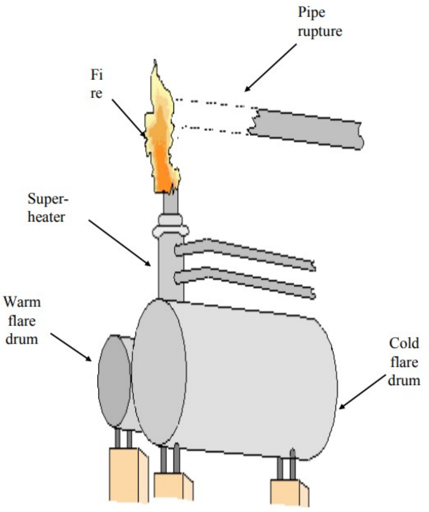
Case 5 - An incident occurred in January 2002 at an Ethylene plant in Louisiana. The Ethylene Plant published the incident in the AIChE Ethylene Producers Conference in 2004 (5) and in a conference in Asia in 2002 (6) to increase safety awareness in the process industry.

The plant was Olefins Ethane Cracker with a flow scheme of the DeMethanizer first and a back end acetylene converter. An off-spec event on 1/4/02 at the acetylene converter led to flaring of ethylene product via the unit cold flare drum. Through a sequence of events, the cold flare drum overhead line fell to below its minimum design metallurgy temperature. On 1/5/02, the cold temperatures led to brittle fracture of the cold flare drum overhead line, loss of hydrocarbon containment, and ultimately an explosion and fire.

The cold flare drum contents are vaporized and superheated with a closed loop propanol system. Heat is supplied to the propanol system with 70-pound steam, which is about 270 F. The vaporizer and super heater heats the cold flare drum material from cryogenic temperatures to above the minimum design metal temperature of the cold flare drum carbon steel overhead piping.

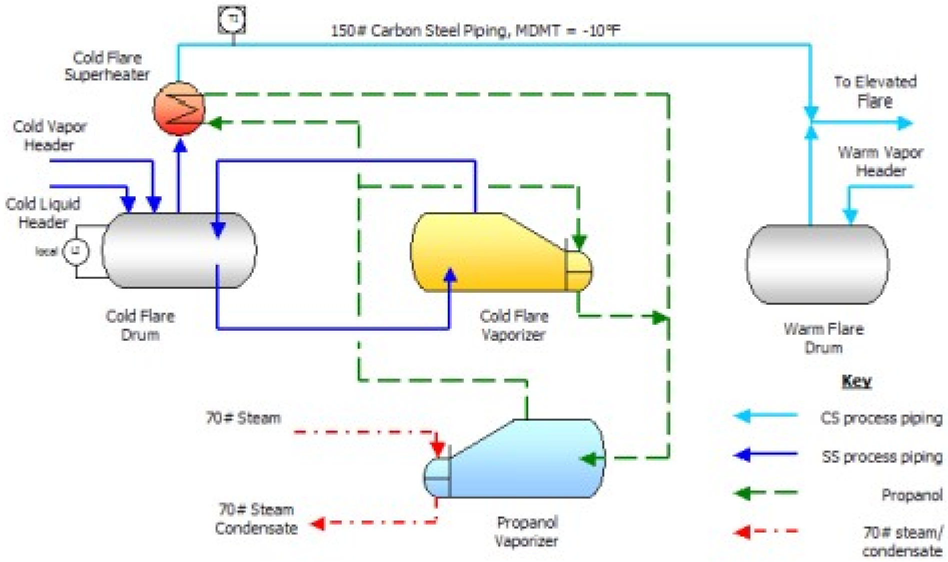
The event sequence was the ethylene product went off specification on acetylene and initiating flaring of liquid ethylene product began. The acetylene converter outlet analyzer was in error, which allowed the ethylene splitter inventory to be contaminated with acetylene prior to corrective action being taken. A portion of the off spec liquid ethylene product was consumed by internal customers, with the balance being flared via the cold flare drum. Malfunction of the cold flare drum vaporizer and super heater allowed the cold flare drum overhead line temperature to fall sharply.

A low temperature alarm sounded as the overhead flare line temperature fell to 0 F, and the thermocouple went bad at a value of -13 F. With the cold flare drum overhead line running below its minimum design temperature of -10 F, the pipe ruptured, resulting in loss of hydrocarbon containment. The hydrocarbon released found an ignition source, resulting in an explosion and fire.



The root causes of the incident included the vaporizer and super heater exchanger fouling, which had reduced heat transfer capacity of the cold flare system. Once flaring began, the cold flare drum overhead line experienced

**Flare Drum System Overview Original System**



low temperature resulting in the brittle fracture of cold flare drum overhead piping due to operation below the minimum design temperature of the carbon steel line.

The final stress that ultimately caused the brittle fracture of the piping has not been identified, but could have been any number of internal or external stresses. 1) External stress - Hard rain that came at the time of event, 2) Internal stress - Contraction of the cold flare line due to temperature gradient.

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## HOT TAPPING SAFELY AND PROCESS CONCERNS

Hot Tapping is used in plant maintenance activities to obtain access to a pressurized line or vessel. Hot tapping involves welding on a piece of equipment, typically a spool piece to which a valve is then connected. The types of equipment include pipelines, vessels or tanks that contain steam, natural gas or flammable liquids under pressure, in order to install additional connections to reroute or to block the flow in a line. It is commonly used to replace or add sections of pipeline without the interruption of service for air, gas, water, steam and petrochemical distribution systems. The hot tap process is utilized to install a new working valve or to control the de-pressuring of the equipment.

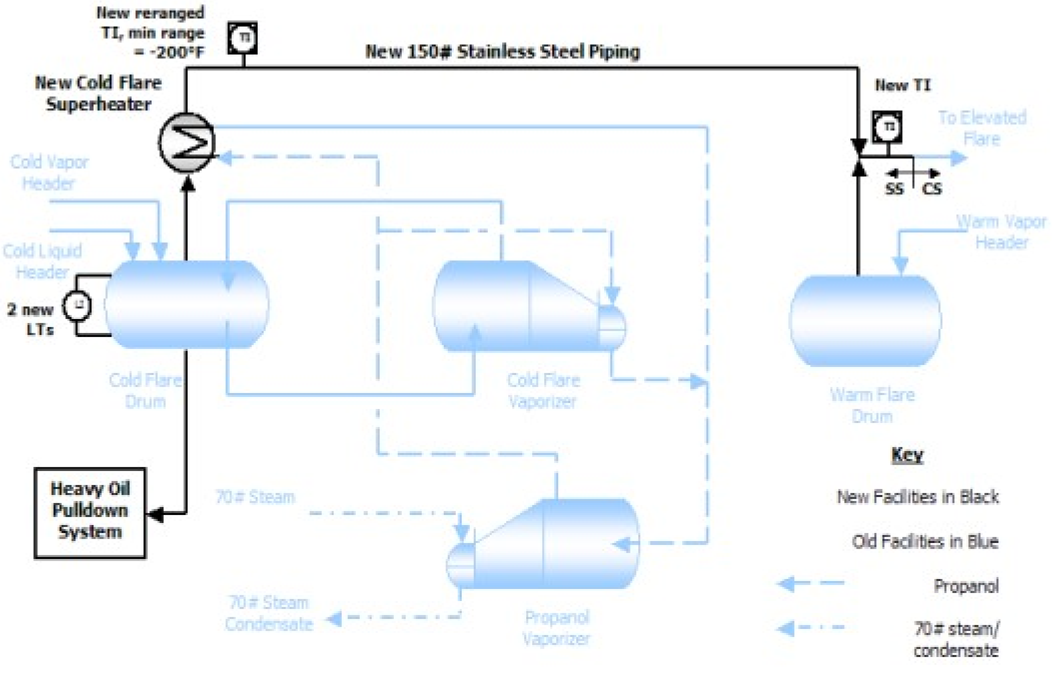
During the hot tap process a drill bit assembly is connected to the new spool piece and a new working valve. The new valve is attached to the line and the drill assembly is installed and the hole drilled. The bit is retracted past the valve, which can then be closed. A flow or line can then be fitted into the valve. The American Petroleum Institute has guidelines for precautions to take during hot taps.

One of the main concerns of hot tapping is the metal shavings, which are produced by either drilling or cutting. Some of the metal shavings will enter into the process and could be carried downstream and cause problems by entering pumps or strainers. Therefore, careful planning must be made to determine if the metal shavings will cause a problem down stream.

During the initial planning of the hot tap one aspect to look at would be to tap from the bottom, which would give you the best chance of retaining most of the metal shavings. However, there is also a concern about shavings entering the seat of the valve. The rule of thumb would be never tap at 5 o'clock or 7 o'clock as shavings could get into the seat and keep the valve from closing.

Case 6 - An olefins producer in Louisiana had two ethylene plants that shared a single flare area. The two steam lines to the flares were at one point only 100 feet apart. Whenever a unit upset occurs, steam is utilized in the flare tip to mix the hydrocarbons with air for complete combustion. This mixing reduces the flare smoking and environmental damage from carbon monoxide.

Flare Drum System Modifications



At times during unit upsets there can be a shortage of steam. This shortage can lead to additional flaring at the very time you need steam to reduce the smoking flare. Therefore, to address this scenario, the ethylene producer decided to connect the two flare steam lines together. When one unit was having operational problems, the adjacent unit could provide steam to the flare and potentially have the first unit recover faster while reducing overall flaring, with the additional economic benefit of being able to produce on specification product faster. The two adjacent steam lines were hot tapped and a line installed to connect the two new hot tap valves.

At the next unit upset the line was utilized to reduce the overall flaring and optimize unit production. Unfortunately, some metal shavings were left in the steam lines. These metal shavings were carried to the flare steam ring and blocked a portion of the steam ring above the steam line connection to the steam ring.

The steam ring no longer had uniform steam distribution as a portion of the ring was blocked by the hot tap metal shavings. This was not fully known until the next major unit outage when the flare tip was upgraded to reduce the smoking. Due to the mal-distribution of the steam the flare now smoked constantly, even at low flaring scenarios. The producer was then fined for the continuously smoking flare.

## GUIDELINES

These six case studies provide many incites into piping safety concerns. Petroleum plant personnel should review these case studies and consider implementing the guidelines where applicable for increased safety.

1. Check Valve Installations: Review large and small check valve installations for potential release scenarios. For large high-pressure check valves review the internals and the sited case study failure mechanism. Install anti rotation devices on external bull plugs.
2. Small Bore Piping on Compressor Discharge Piping: Review and reduce small-bore piping on compressor discharge piping. One guideline is to restrict the small-bore piping to a safe distance from the discharge of the compressor to limit piping fatigue failure. Vibration levels imparted to the piping adjacent to compressor / pump units should be monitored and managed. Piping configurations potentially at risk should be investigated and modified to manage any vibration, which may impact the pipe and associated junctions.

3. Low Temperature Embrittlement Concerns: Understand piping low temperature embrittlement concerns and potential release scenarios. There have been multiple piping failures and hydrocarbon releases from piping low temperature embrittlement. Review the process temperatures and the piping metallurgies where the temperatures are below –49 F, which is approximately liquid propane / propylene.

4. Safety Perform Hot Taps: When making a hot tap, certain steps should be followed prior to starting the actual tap. The following steps consist of basic procedures used in completing the hot top installation;

A) Perform a site visit, to determine if the job safety analysis information meets the proper criteria for that particular hot tapping operation.
B) Recognize and identify the hazards of the equipment, then outline steps to mitigate those hazards into a job safety sheet.
C) Review the job and file a basic safety plan.
D) The proposed hot tap area should be marked on the piping network.
E) Minimize the piping network pressure to the practical operations limit.
F) A plan for isolating the piping network should be prepared for an emergency.

## CONCLUSIONS

Piping network safety is a concern for all hydrocarbon producers even though piping may be the considered the safest part of the plant. The authors goals and hopes are that these case studies and guidelines provide additional safety incite into piping design, operation and prevention of future incidents.

ENGINEERING PRACTICE

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# Building Palm Oil Operational Excellence

16 Nov 2022
Kuala Lumpur
Malaysia

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- Palm Oil Distillation Troubleshooting - Karl Kolmetz KLM Technology Group
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