

ENGINEERING PRACTICE

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SPECIAL FEATURES

Rock Bottom View: Rising from 2020's Ashes,
Ethylene Margins Offer Reason to Celebrate in 2021

Key Operations Checkpoints for the Smooth Operation
of Gas Dehydration Unit

Project Management in the Downstream Industry

Design of Compressor Non-Metallic Piston & Rider Rings

Molecular Investigation of a Condenser with Blocked Airflow

Key Thermo-Physical Properties of Light Crude Oils

Guidelines for Mist Elimination Equipment Selection,
Sizing, Safety & Troubleshooting

Megaproject OSBL Scope Development

Safety Connector: Coping with Work Related Stress
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Letter from the Editor

Days Go by Slow, Years Go by Fast



It seems that the days sometimes go by very slowly, but the years go by fast. Welcome to 2021; many people are happy to see 2020 gone. There were some challenges in 2020, but even with the challenges we should be thankful for the blessing that we have. I have been blessed far more than I can justify. For my age I am healthy and I have been given the opportunity to study and work. Many people would consider me lucky as I am a senior engineer working in a great profession.

But my path was not paved with luck. I worked and went to school for 11 years. Many years I worked the night shift, so I could attend some required day classes. If you will study and work people will one day will consider you lucky also.

Any easy way for you to continue to study as you are working is to gain knowledge and certification from the International Association of Certified Practicing Engineers (IACPE). This is a great program to gain practical knowledge of process, instrumentation, civil and mechanical equipment. We have programs for engineers, and non-engineers looking to increase their practical knowledge of processing equipment.

All the best,
Karl Kolmetz



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Rock Bottom View

Rising from 2020's Ashes, Ethylene Margins Offer Reason to Celebrate in 2021

Ronald J. Cormier, *Engineering Practice* Contributing Author



Few will disagree that 2020 was chock full of bad news for global public health, and accordingly, nearly all commodity value chains associated with living our modern lives. Hydrocarbon exploration and price fell to unprecedented negative value (thankfully a short-lived trading-related anomaly), and refining crack spreads fell precipitously as transport fuel demand collapsed. From crude to Jet A, commodity inventory rose and price eroded.

Moving a bit further downstream from the well-head and refining, basic petrochemicals at first followed, but now appear as a phoenix rising from the ashes. With the USGC's heavy reliance on NGL feeds, ethylene margins during late 4Q20 increased exponentially. Compared to April, December's ethylene price settlement of 37.5 cents per pound (USD) was up an amazing 4X. There are a whole range of factors responsible, including petchem outages due to an unprecedented number of Gulf hurricanes—in fact, so many that generous use of the Greek alphabet was required after expending NOAA's 2020 name list. Besides mother nature's wrath, new downstream derivative units coming online, robust exports from the Enterprise Morgan's Point dock, and well, good old strong demand for downstream products prevailed — everything from single-use food and safety packaging mandated by COVID, to construction materials (remote workers simultaneously could also better accomplish home improvement), were responsible.

Luckily, resumption of demand in the second half of the year turned out in stark contrast to signposts apparent at the depth of the pandemic-related meltdown. Most all durable goods from auto parts to appliances were shutting down. However, the crash was thankfully short-lived; petchems started turning around in May and along with ethylene prices, have been rebounding ever since.

Going forward, will appreciable olefins-based margins endure? Maybe it's worth an expanded look at the last five-year cycle to get an

idea. In 2016-17, ethylene was a comfortable 26-27 c/lb., and demand from downstream derivative plants was relatively balanced compared to olefins steam cracker output. Then in 2018, major players such as Dow Inc., CP Chem, ExxonMobil, Westlake-Lotte and Sasol added new olefins building-block capacity. While most of this output was in conjunction with new derivative consumption, these user plants came onstream later than the monomers. The result was soft ethylene pricing in the 17-19 c/lb. range, with hopeful expectations of increased demand from Enterprise Products' new export facility. 2020 opened with 60 days of similar trend, but Covid-affected economic meltdown set in by end 1Q20. Ethylene price fell and hit 8.5 c/lb. by mid-April. Shares in petchem companies fell by 50% with a dim outlook, until the sudden about-face offered improved demand.

Fingers crossed, the industry hangs hopes on step changes from remote-worker trends, single use polymers and medically-associated plastics devices and films driven by Covid (and vaccine distribution), plus increasing consumption from the refinery base looks to be better news for 2021. Winter is also historically positive for methane heating consumption and hence associated NGLs supply lengthens (barring liquids rejection, should gas price increase on some unplanned basis). Assuming current upturns in consumer demand hold, and ethane feeds prove plentiful, good times ought to be at hand for the 2021 petchem patch.

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Ronald J. Cormier is Owner and Managing Partner of Rock Bottom Enterprises, LLC. Independent commercial services consultancy/advisory, specializing in commercial business development, commodity product trading, and equipment repurposing for downstream refining, petrochemical, field liquids, and bulk liquid hydrocarbon logistics segments. Over 35 years of expertise and specialty with oils, fuels, olefins, aromatics, and their first derivatives.

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Key Operations Checkpoints for the Smooth Operation of Gas Dehydration Unit

Praveen Nagenderan C

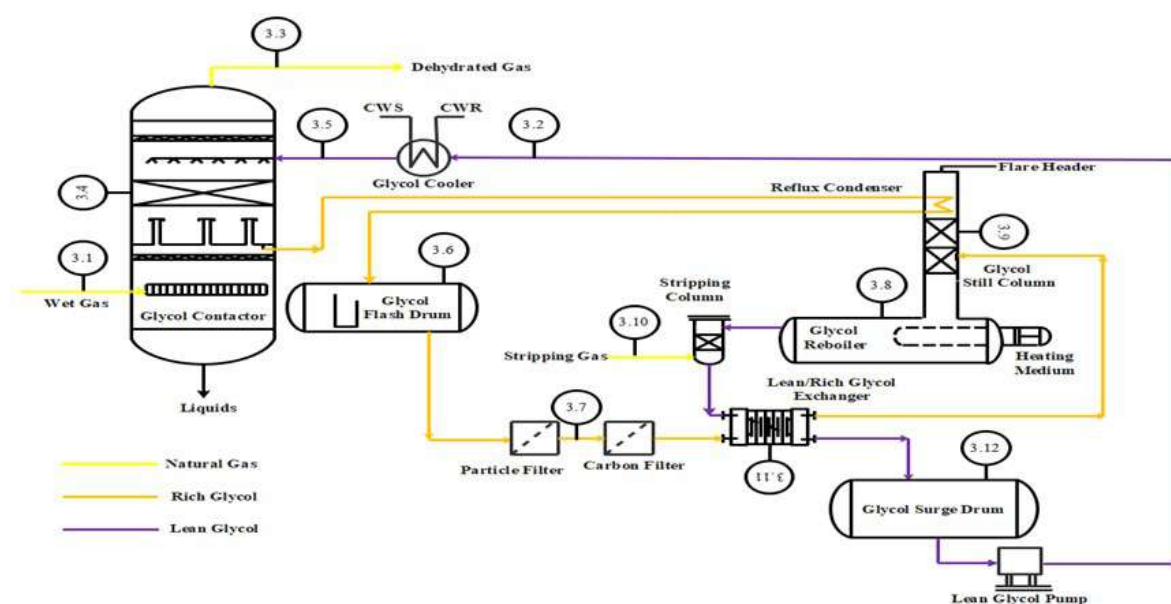
1.0 INTRODUCTION:

Natural gas when produced from the reservoir is saturated with water and most of the water has to be removed before it can be commercially marketed to meet the sales gas contract specifications. Other important reasons to remove the water from the natural gas are hydrate formation under certain conditions, corrosion especially in the presence of H_2S and CO_2 , slugging conditions (two-phase) & erosion, decrease in the heating value of the gas, and can cause freezing in cryogenic and refrigerated absorption plant. The amount of water that must be removed from the gas depends primarily on the lowest temperature to which the gas will be exposed in the pipeline or processing plant. The most commonly used process to dehydrate natural gas is the process that employs a liquid desiccant system that uses glycol to remove water from natural gas. Tri-Ethylene glycol is the most commonly used glycol in the industry.

2.0 PROCESS DESCRIPTION:

The process flow diagram of the Gas Dehydration unit employing TEG is shown below where the Wet gas enters into the Glycol Contactor

which is an absorber tower. Glycol Contactor normally builds with an internal scrubber where free water coming along with the natural gas is knocked off. Glycol Contactor employs either tray or packing where water is preferentially absorbed by the glycol when the natural gas and glycol comes in contact. The gas after gets into contact with glycol loses the water content and leaves the Glycol Contact or as dehydrated gas. The rich glycol from the Glycol Contactor goes to the glycol regeneration package. The rich glycol flows out of the Glycol Contactor and goes to the Glycol Reflux Condenser where it is heated with the condensing water vapor at the top of the Glycol Still Column. The rich glycol then flows to the Glycol Flash Drum where lighter and heavier hydrocarbons are removed. The glycol is then filtered through the Particle Filter and Activated Carbon Filter. The filtered glycol is then heated in Lean/Rich Glycol Exchanger before entering the Glycol Still Column by heat exchange with the hot lean glycol coming from the Glycol Stripping Column. The filtered glycol enters the Glycol Still Column and flows into the Glycol Reboiler space where the glycol is heated to remove water



Process Flow Diagram: Gas Dehydration Unit process employing TEG

vapor. The water vapor from the Glycol Reboiler rises through the Glycol Still Column where it is cooled and condensed in the Glycol Reflux Condenser where the condensed liquid acts as reflux. The water vapor is then discharged to the low-pressure flare header. The hot lean glycol flows into the Glycol Stripping Column where the stripping gas is used to improve the glycol concentration further. The hot lean glycol stream from the Glycol Stripping Column undergoes cooling in the Lean/Rich Glycol Exchanger before entering the Glycol Surge Drum. The lean glycol is pumped from the Glycol Surge Drum by the Lean Glycol Pump to the Glycol Cooler where lean glycol gets cooled by the cooling water. The cooled lean glycol goes to the Glycol Contactor for absorbing water from the natural gas.

3.0 KEY OPERATIONS CHECKPOINTS:

The key operations checkpoints in the operation of the Glycol Dehydration unit are as discussed below:

3.1 WET GAS TEMPERATURE:

Generally, Inlet gas temperature is to be maintained between 80°F and 100°F. A higher temperature indicates higher water content of the gas which thereby increases the amount of water to be removed from the gas. Glycol vaporization loss will increase at higher gas temperatures. Glycol will become very viscous at lower gas temperature. The gas which enters the Glycol Contactor is saturated with water therefore the inlet wet gas temperature is the inlet water dew point. Empirical correlations are used for the prediction of water content in the natural gas. McKetta and Wehe correlation is used for sweet gases where Campbell or Robinson and Maddox correlation is used for sour gases as H₂S and CO₂ increase the saturated water content. Water content increases with increasing temperature and decreasing pressure. Sales gas specification for water content in the colder areas is 4 lbs/MMSCF and for warmer areas, the specification limit is 7 lbs/MMSCF. As the sales gas generally has the specification limit set in mass per unit volume it is necessary to determine the dewpoint temperature in Contactor pressure.

3.2 GLYCOL CIRCULATION RATE:

The glycol circulation rate of the unit is the Lean Glycol Pump discharge flow rate which is one of the important parameters to be monitored for the smooth operation of the unit. Required dew point depression (The dew point depression is the difference between the water dewpoint of the wet gas entering the Glycol

Contactor and the water dew point of the dry gas leaving the Glycol Contactor) shall be achieved by circulating a certain amount of glycol. Generally, if the glycol concentration is not high, any higher circulation will not achieve the required dew point depression but lesser circulation will certainly increase the moisture content of the gas. The glycol circulation rate shall be optimized based on the unit inlet wet gas flow rate after necessary calculations based on API SPEC 12GDU or JM Campbell book series guidelines. General causes for the low glycol circulation rate to contactor are pump or motor failure, Glycol Surge Drum level low plugged lines, and vapor lock in pump or pipeline.

3.3 DEHYDRATED GAS MOISTURE CONTENT:

The Dehydrated gas moisture content is measured at the outlet of the Glycol Contactor by the moisture analyzer instrument mounted on the pipeline. Periodically the moisture analyzer shall be calibrated and also shall be cross-checked by the portable moisture analyzer. The moisture content at the Glycol Contactor outlet determines the overall unit performance. Critical priority alarm settings shall be configured in the HMI of the DCS/PLC system for effective monitoring by the operation team. General reasons for the high moisture content of the dehydrated gas are low lean glycol concentration, low glycol circulation rate concerning the gas flow rate of the unit, plugging of trays or packing which leads to inefficient contact of gas and glycol, and foaming conditions in the Glycol Contactor.

3.4 GLYCOL CONTACTOR PACKING DIFFERENTIAL PRESSURE:

Glycol Contactor packing or trays differential pressure above 1.0 Kg/cm² (g) indicates foaming. Reasons for foaming are high differential temperature between glycol and wet gas inlet temperature, high pH of glycol, presence of hydrocarbons in the glycol, and suspended solids. Foam test shall be performed in the field or in a laboratory where the foam height of 10-20 ml with break time of 5 seconds is considered to be normal. If the result indicates more height and break time then it indicates foaming. Anti-Foam agents shall be added at the suction of Lean Glycol Pump for the foaming control. Carbon filter to be kept in by-passed condition while anti-foam injection because the carbon sites will absorb the chemical and thereby makes injection less effective to the system and potential damage to the carbon sites.

3.5 DIFFERENTIAL TEMPERATURE – GLYCOL & WET GAS:

Lean glycol entering the Glycol Contactor shall be 7-5°C warmer than the wet gas inlet temperature of the Glycol Contactor. Generally, the required temperature control can be achieved by providing a by-pass line around the Glycol cooler in the glycol side flow path with a control valve. The differential temperature value is the calculated value configured in the HMI of the DCS/PLC system between the Glycol inlet temperature and Wet gas inlet temperature. The by-pass control valve present in the by-pass line shall modulate based on the configured calculated differential temperature (DT) value.

3.6 FLASH DRUM VENT PRESSURE CONTROL VALVE:

The main purpose of the Glycol Flash Drum is the removal of lighter and heavier hydrocarbons present in the glycol. The lighter hydrocarbons get removed by flashing the glycol in the Glycol Flash Drum. These gases are generally routed to the flare header or other hydrocarbon recovery system of the plant. Skimming operation to be performed periodically to remove the settled heavier hydrocarbons floating in the glycol inside the Glycol Flash Drum. The pressure of the Glycol Flash Drum determines the effective removal of the hydrocarbon gases. Better removal of hydrocarbon gases from the glycol can be achieved by lowering Glycol Flash Drum pressure but also the pressure maintained in the Flash Drum should be good enough to flow to the downstream equipment as well. An eye on the vent PCV manipulated output value (MV) gives a good indication of gases being removed from the glycol. A drastic increase or change in the manipulated output value of the vent pressure control valve (PCV) can indicate lighter hydrocarbons carry over along with the glycol which in turn can be used as a checkpoint to carry out necessary adjustments in the operations to avoid further carryover.

3.7 PARTICLE FILTER AND ACTIVATED CARBON FILTER DIFFERENTIAL PRESSURE:

Particle filter removes solid particles over 5 microns in size from the rich glycol stream which prevents the downstream equipment from fouling. If cartridge filter differential pressure doesn't change over 7 days or reads zero continuously then the filter element may be installed incorrectly or failed. Periodically the

verify that the gas has not broken into the pipeline or gas pocket conditions. Activated Carbon Filter absorbs heavy hydrocarbon to reduce the load on the Glycol Reboiler and potential foaming in the Glycol Contactor and Reboiler. Carbon filter change-out frequency shall be done every six months. Both, Particle and Carbon Filter elements shall be replaced with new elements if the differential pressure reading crosses 1.0 Kg/cm² (g). The performance of the Carbon Filter shall be evaluated by analyzing the hydrocarbon presence at the outlet of the filter. Carbon sites indicate saturation condition if the hydrocarbon presence is confirmed at the outlet of the filter.

3.8 REBOILER TEMPERATURE:

The purpose of the Glycol Reboiler is to provide heat to the glycol to boil the water vapor out of the glycol solution. Reboiler temperature directly determines the lean glycol concentration. Lower reboiler temperature will cause reduced glycol concentration which in turn will increase the moisture content of the dehydrated gas at the outlet of the Glycol Contactor. Reboiler operating temperatures are maintained between 190-195°C with stripping gas support to achieve a glycol concentration of 99.6 wt %. Maintaining Reboiler temperature above 205°C will cause thermal degradation of the glycol hence reboiler operating temperature shall be optimized based on the glycol concentration.

3.9 GLYCOL STILL COLUMN TEMPERATURE:

Glycol Still Column operating temperature to be maintained between 120 -130°C. Glycol Still Column temperature more than 135°C would indicate insufficient reflux and will result in the vaporization loss from Glycol Still Column. Glycol Still Column temperature below 110°C would indicate excessive reflux which in turn will increase the Glycol Reboiler duty and reduce the lean glycol concentration. Reflux condenser by-pass line shall be provided with a control valve to maintain the Glycol Still Column temperature to the desired limits. Additionally, the rich glycol pipeline from the outlet of Glycol Contactor, Reflux Condenser, and till to the inlet of the Glycol Flash Drum shall be insulated which can be helpful to keep the rich glycol temperature profile constant in the system thereby eradicating the ambient temperature changes effects on the rich glycol pipeline.

3.10 STRIPPING GAS FLOW RATE:

Stripping gas is a small stream of natural gas flowed into the hot glycol. Stripping gas will help to increase the glycol concentration to 99.6 wt %. Excessive stripping gas rates can lead to flooding in the reboiler and high level. The Stripping gas rate is usually set as a ratio of sm³/sm³ of glycol circulated. GPSA Handbook shall be referred for determining and optimization of stripping gas flow rate for the associated glycol concentration.

3.11 LEAN/RICH GLYCOL EXCHANGER TEMPERATURE & PRESSURE PROFILE:

Lean/Rich Glycol Exchanger temperature and pressure profile to be monitored and recorded on daily basis. Over a while, the temperature profile of the exchanger shall be assessed for the fouling of the exchanger. Also, a pressure survey shall be carried out periodically which shall indicate exchanger passing conditions i.e Rich glycol getting mixed into the Lean Glycol side which will reduce the glycol concentration of the lean glycol and also increase the lean glycol temperature which can also potentially increase the load on the Glycol cooler.

3.12 GLYCOL SURGE DRUM LEVEL AND TEMPERATURE:

Glycol Surge drum level reduction directly indicates the glycol loss from the system. Daily losses in the system can be calculated by performing volume calculation of the Glycol Surge Drum on daily basis. The difference in Glycol Surge Drum volume between yesterday and today will give the glycol loss quantity that happened in the system provided there is no hold-up in the other vessels. Generally, a typical glycol loss is 13 liters per MMSCM. Anything beyond the acceptable loss limits to be investigated accordingly. Lean Glycol Pump design temperature is based on the design temperature of Surge Drum. Lean/Rich exchanger fouling or passing will increase Surge Drum temperature close to the design temperature and can cause Lean Glycol Pump failure. Lean Glycol Pump suction temperature high trip is provided as a safety measure for the pumps. Glycol make-up to the surge drum is done directly into the Glycol Surge Drum.

4.0 ANALYTICAL CONTROL:

- Rich glycol and lean glycol samples are to be analyzed for pH and concentration on a daily basis.
- Fortnightly checks to be carried for the glycol samples for Iron, Hydrocarbons, Specific gravity, Chlorides, Solids, and Foam test.
- Once in a week take a sample from the Surge Drum bottom drain point and check for fine black particles in the glycol sample which indicates corrosion due to FeS or Fe₂O₃- and filter problems. Also, check for the oily layer floating on the glycol which indicates a heavier hydrocarbon presence.
- Specific gravity indicates the purity of glycol. High specific gravity indicates that glycol may be contaminated with solid particles and low specific gravity indicates more water content, high hydrocarbon content, and thermal degradation.
- Hydrocarbon content allowable limits in the glycol streams are <0.3 wt %.
- High suspended solids and residual solids indicate inadequate filtration. These solids generated can create sludge in the system, foaming, and emulsion. Allowable suspended solids limits in the glycol streams are < 20 ppm.
- Chlorides are tested as a measure of salt content. Allowable limits are <500 ppm.
- pH indicates the acidity or alkalinity of the glycol. pH to be maintained between 7 to 8.5. pH below 7 promotes corrosion and above 8.5 causes chances of foaming.
- MEA is the preferred chemical to boost the pH of the glycol and BORAX solution is used to reduce the pH of the glycol in case of alkalinity state. If MEA is added into the system then the Glycol Particle Filter differential pressure to be monitored closely as soluble iron precipitates out after addition of the chemical and gets filtered in the particle filter. If MEA is used then the Lean glycol pH raise will be relatively lower when compared to the rich glycol pH as the boiling point of MEA is 170°C. Here, some amount of MEA might have been lost along with the reboiler vapors

as Glycol Reboiler operating temperature is on the higher side. In that case, Glycol Reboiler temperature shall be brought down from 190-195°C to below 170°C for a shorter duration to avoid a negative impact on the moisture content of the dehydrated gas and maximize the MEA effect on the lean glycol circuit.

- Iron is the index of corrosion. Allowable Iron content is < 15 ppm. Corrosion rates of the system shall be monitored and recorded by the corrosion coupons placed on both the rich and lean glycol streams. Oxygen will promote oxidation and form corrosive organic acids hence oxygen ingress should be prevented in the system.

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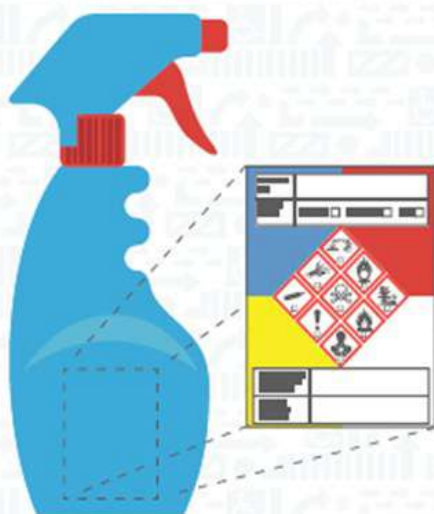
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Praveen Nagenderan C is a Chemical Engineer with experience in the field of Oil & Gas production & processing facilities and Refinery process units. Professional experience covers in Production operations, Facility surveillance, Technical safety, Technical Services, and Projects. Praveen has worked with major Oil & Gas companies in India namely Nayara Energy formerly known as Essar Oil Limited and Cairn Oil & Gas.



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Project Management in the Downstream Industry

Dr. Marcio Wagner da Silva, *Engineering Practice Contributing Author*

INTRODUCTION AND CONTEXT

The agility to implement new enterprises in crude oil refineries is fundamental to allow quickly adaptation of the refining hardware both to achieve better operational performance and safe conditions. In the last years, the project management in crude oil refineries became especially important to the competitiveness due to the tighter refining margins that leads to a necessity to a more quickly return over investment, creating great pressure over the project managers in crude oil refineries.

Taking into account the difficulties related to the execution phase in process plants which operates 24 hours seven days per week, the project management in crude oil refineries represents a special challenge. In this environment, one of the most important disciplines in the project management is related to the

Our experience shows that an adequate stakeholders management can ensure better integration, lower internal resistance, less conflicts, lower implementation terms, and shorter time to achieve the desired return over investment. The specialized literature presents some available tools to identify and management stakeholders, even in small projects focused in operational improvement in brownfield crude oil refineries.

THE TRADITIONAL TRADE OFF IN THE PROJECT MANAGEMENT AND THE EARNED VALUE STRATEGY

One of the most common challenge in the project management is the trade off between the called golden triangle of cost, quality and schedule as presented in Figure 1.

As presented in Figure 1, the success of any project is strict related to an adequate

The Golden Triangle of Project Management

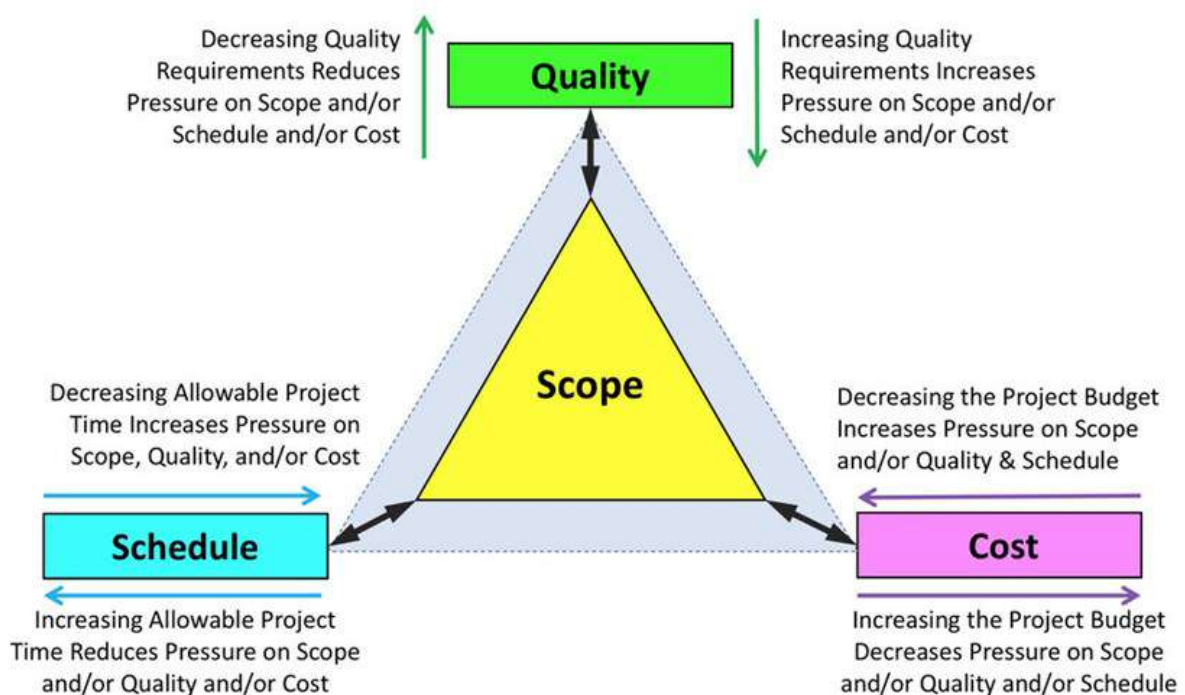


Figure 1 – Trade Off Between Schedule, Cost and Quality in Project Management (WARNER, M. 2018)

equilibrium between quality, cost, and schedule. In the downstream industry, as aforementioned, normally the projects present high return over investment and the pressure to quick implementation is increasingly high as well as the quality is a fundamental premise once failures can lead to great financial losses and, in extreme cases, process accidents.

This fact creates great pressure over the schedule, normally the project managers involved in downstream projects faces great challenges to meet the schedule, respecting the planned cost. Again, as presented in Figure 1, sometimes the trade off between cost, schedule, and quality can create pressure over the scope. It's common to hear in project implementation in crude oil refineries questions like "How is the minimum scope to ensure the start-up?", despite being a common situation it's important to taking into account that this can be a dangerous scenario, sometimes the minimum scope can compromise the quality and the planned return over the investment once the project can be ended with the "minimum" scope, specially in scenarios with great pressure over capital costs like the current situation due to the economic crisis provoked by the COVID-19 pandemic.

In order to minimize this, one of the most effective strategy in project management is apply the earned value strategy. The main focus of the earned value analysis is to measure the real value obtained with the capital spending, to understand the earned value management, it's necessary to define some basic concepts.

PV – Planned Value: The estimated cost

to the planned work;

EV – Earned Value: The estimated cost to the really done work;

AC – Actual Cost: The real cost of the done work

Suppose that a determined task has an estimated cost of US\$ 1.000,00 and was planned to finish today, despite this, the physical advance in the schedule to this task is only 90 %, in this case, the earned value with this task is only US\$ 900,00. Based in the earned value technique it's possible to control the cost of the project measuring the really added value of the completed tasks, defining some KPI (Key Performance Index) as follow:

CV (Cost Variance) = EV – AC: Negative values indicates that the project is spending capital without add value;

SV (Schedule Variance) = EV - PV: Positive values indicates advanced schedule while negative values indicates delay schedule, calling the project manager to define an action plan. Figure 2 present the concept of Earned value analysis in a graphic version.

Despite being an interesting and effective analysis, the earned value management present some weakness, the first concern is related with the quality. As presented above, the earned value technique does not provide measures to control the project quality, as aforementioned, especially in projects for the downstream industry this can be a dangerous limitation.

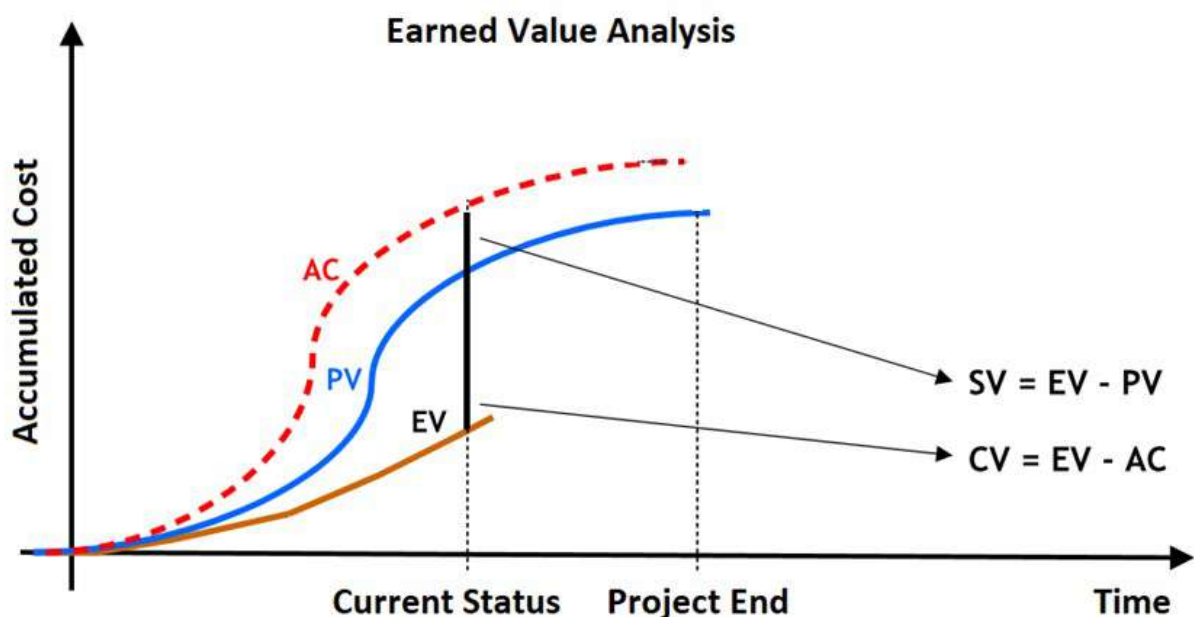


Figure 2 – Earned Value Analysis in Project Management

PECULIARITIES OF THE PROJECT MANAGEMENT IN THE DOWNSTREAM INDUSTRY

Despite being a global methodology, our experience shows that the project management in the downstream industry shows some peculiarities in relation to the other industries. The first peculiarity is related to the experience of the project manager, the most part of the project management schools indicates that the project manager does not need to be specialist in the project area, in our point of view this is a partial truth.

Normally, the projects in the downstream industry have a great technical charge and the minimum knowledge in the area from the project manager will help to discuss and deal with the specialists and stakeholders, mainly to manage expectation with the project deliverables and schedule. In our point of view, a minimum knowledge of the downstream business is fundamental to the success of the project manager once improve the empathy with the stakeholders, suppliers and technical team in order to allow a better negotiation performance.

Another peculiarity for the project management in the downstream industry is the relation with suppliers, normally just a limited number of suppliers meet the technical and quality requirements of the downstream industry. This fact impacts the risk management of the whole project as well as requires adequate planning to avoid trouble with suppliers limitation capacity, mainly in scenarios where the capital investment are attractive like high prices of crude oil barrel, in these cases, the schedule can be delayed due to shortage of materials, skilled labor, etc.

A deep concern with quality control can be quoted as another particularity of project management in the downstream industry. As aforementioned, quality issues can lead to poor performance of processing plants, compromising the return over investment and the competitiveness and, in extreme cases, can lead to serious process accidents.

In our point of view, the peculiarities quoted above requires a highlighted skill from the project manager, the stakeholder management.

THE STAKEHOLDERS MANAGEMENT – THE CONCEPT

The stakeholders management aims to integrate and manage the relationship between actors capable to influence, positively or negatively, the implementation of the project. In this

sense, an adequate stakeholders management is fundamental to allow the organization to achieve the desired and planned value with the project implementation.

According to the Project Management Institute (PMI), stakeholder is any person, group or organization capable to affect, be affected, and feel affected for a decision, activity, or result of a project.

The process of stakeholder management starts with the identification of the stakeholders of the project, followed by the classification of these stakeholders. One of the most famous models applied to classify the stakeholders is the Salience Model proposed by MITCHELL et. al. in 1997. In this model, the stakeholders are classified based on three characteristics:

- Power – Capacity to impose a will, desire, or point of view over the organization. The power can be coercive (force or threat), normative (regulation and media), or utilitarian (have information or resources);
- Legitimacy – General perception that an entity's actions are desirable or appropriate, according to the socially constructed context. Can be individual, organizational or social;
- Urgency - Immediate need for action that defines the speed of response organization in relation to stakeholder demands.

Based on these characteristics, the stakeholders can be classified in three different categories:

- Latent Stakeholder – Present only one of the characteristics and tends to receive low attention from the organization;
- Expectant Stakeholder – Present two of the attributes, raising their influence over the organization;
- Definitive Stakeholder – Present power, legitimacy, and urgency leading the organization to dedicate immediate attention to these stakeholders.

Despite this simple classification, the characteristics can overlap, as presented in Figure 3, leading the possibility to classify the stakeholders in eight distinct classes.

According to the Figure 1, the stakeholders can be described as below:

- Dormant Stakeholder - Group or individual that has the power to impose their desire on the organization, but has no legitimacy

or urgency. Tends to have little influence on the organization, but should be monitored for possibility of reaching a second attribute;

- Discretionary Stakeholder - Group or individual that has legitimacy, but it has no influence power and does not claim urgency;
- Demanding Stakeholder – Has only the urgency attribute. As don't have power and legitimacy, tends to not impose their will over the organization;
- Dominant Stakeholder – Present legitimacy and power and needs to receive great attention from the organization;
- Dangerous Stakeholder – Present power, and urgency. In this case, needs to be monitored once can be aggressive to the organization;
- Dependent Stakeholder – Present urgency and legitimacy but not influence power to impose their wish to the organization,

depending on other stakeholders to be considered;

- Definitive Stakeholder – Presents power, legitimacy and urgency. In this case, are the main stakeholders and needs to be prioritized by the organization;
- Non Stakeholder – In this category are classified the group or individuals that are not affect and are not affected by the organization.
- The Saliency Model is only one available to classify the stakeholders in the project management, there are some another alternatives like the model developed by MAINARDES et. al. in 2011.

STAKEHOLDERS MANAGEMENT IN CRUDE OIL REFINERIES

As aforementioned, the main difficult to implement operational improvements in the refining hardware is related to the implementation step once the process plant operates 24 hours per day, seven days per week.

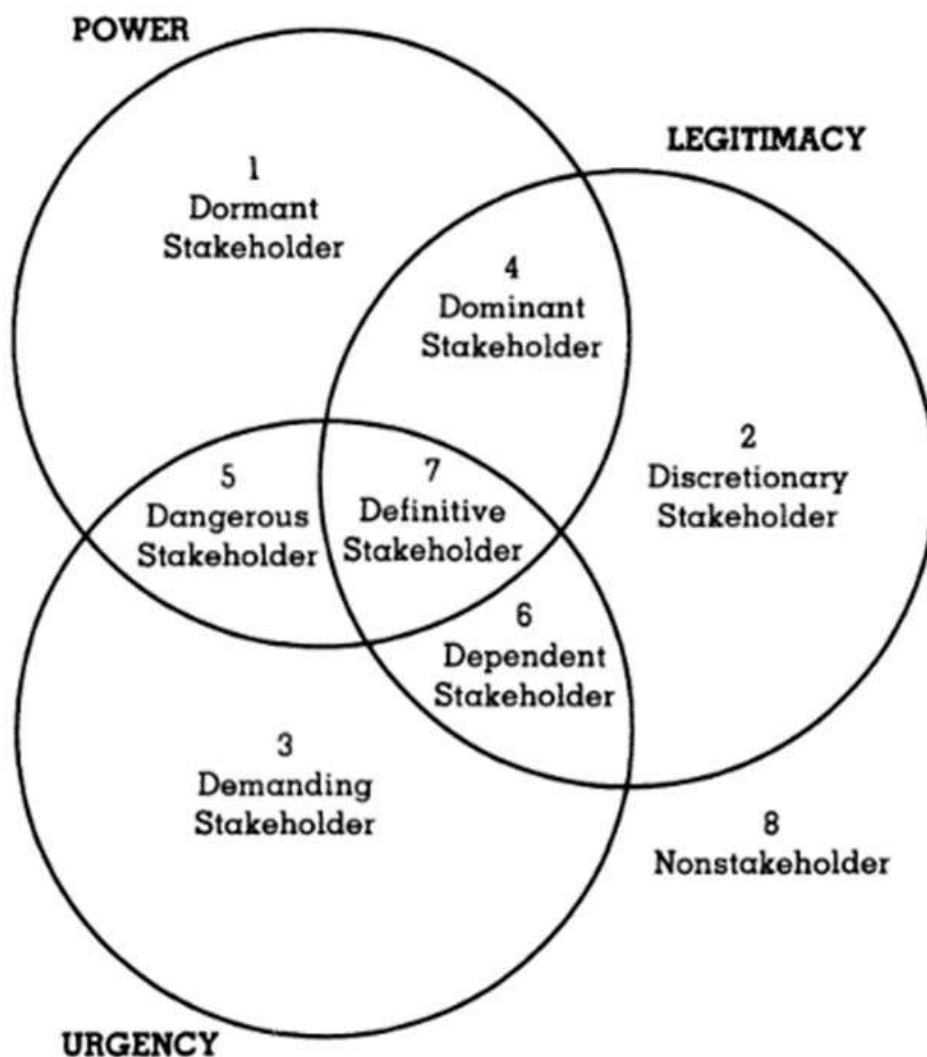


Figure 3 – Stakeholders Classification According to Saliency Model (MITCHELL et. al., 1997)

The design step needs to considerate this fact and an adequate communication plan needs to be executed, mainly to clarify to the operation team what is the main advantage of the project for the refinery, creating then an adequate engagement.

After the classification step applying the Saliency model, it's possible to define actions aiming to engage the stakeholders with focus to eliminate internal resistances. In the case of the requesting sector (normally the operation team) it must be understood that the central objective of the client will always be maintain a stable operation of the refinery's process units, so it is natural that there is resistance to the implementation of changes arising from investment projects. Aware of this fact, the project management team must act in order to make clear the objectives and benefits that will be achieved with the successful implementation of the projects, thus increasing the chances of success in engaging this stakeholder.

An adequate engagement strategy involves a satisfactory dissemination of information and the creation of a feeling of partnership between engineering management and its stakeholders. To this end, it is suggested to create meetings to monitor the physical progress of investment projects with the presence of these stakeholders so that they really feel part of the projects.

By our experience it's possible to achieve significant reduction in the implementation time applying adequate communication and stakeholders management in operation improvement projects in crude oil refineries, this can reduce the issues with contract management as well as accelerate the return over investment.

CONCLUSION

The downstream industry presents some peculiarities which requires special skills from the project managers and a previous knowledge of the downstream business can help the project managers to achieve the success.

The operational improvement actions are fundamental to keep the refining hardware up to date with the refinery necessity and an agile project implementation is a success factor in this sense. In crude oil refiners it's normal to face resistance to project implementation once the main objective is to keep the stable operation of the refining hardware, avoiding unplanned shutdowns or security issues, despite this scenario, an adequate stakeholders management and an effective communication plan can ensure shorter execution time as well as anticipate the planned return over investment.

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Design of Compressor Non-Metallic Piston & Rider Rings

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ABSTRACT:

The purpose of piston rings is to prevent the blow-by of gas from one end of the piston to the other. Rider rings or wear bands which support the weight of the piston plus half a rod, help guide the piston in the bore, and prevent rubbing of the piston on the cylinder wall. This paper presents the design of a non-metallic piston ring and rider rings for a reciprocating compressor. The values of metallic piston ring dimensions are tabulated in the standards ISO 6621...6626 (ISO 6621-4), DIN34110. Unfortunately, no such values or standards are available for non-metallic piston rings. In this paper, an attempt is made to arrive at some realistic assumptions & construct standard tables for non-metallic piston rings. The table values are calculated values based on reasonable assumptions.

INTRODUCTION

Reciprocating compressor pistons work against pressure and must have a sliding seal to allow the piston to compress the gas without leakage past the piston. The piston rings provide this sealing for maximum cylinder capacity, efficiency and assuring the flow of heat from the piston to the cylinder. The piston sealing elements are only subject to the dynamic pressure component varying between the suction and discharge pressure. The gas pressure pushing the piston ring outward

against the cylinder wall and side of ring results in sealing as shown in Fig 1.

Rider rings and piston rings are almost always of the same material. Rider rings must be designed so that they do not act as a piston ring. Otherwise, wear will occur too rapidly. Solid rider rings are not prone to outward expansion. Cut rider rings must be vented with holes or slots to bleed off pressure.

PISTON RINGS

The compressors Piston ring has a rectangular cross-section. Piston rings made of filled PTFE will have an end gap clearance of 0.020" to 0.024" per inch of piston diameter when fitted into the cylinder bore. Side clearance in the groove should be 0.010"-0.020" per inch of width. It should be remembered that Teflon expansion rates are approximately seven times those of cast iron. Values for oil-lubricated compressors with cast iron rings are 0.0035" per inch of diameter for the ring gap (P. Bloch).

RING CONTACT PRESSURES

1. Contact pressure from gas pressure [P_g] - The gas pressure (P_g) behind the first compression ring varies according to the cylinder pressure. The gas pressure behind the second compression ring is already significantly lower than the pressure behind the first compression ring. With a gas pressure acting on the piston ring, the contact pressure and thus the conformity is greatly increased. On the other hand, the gas pressures are of significance only for a small proportion of the engine cycle (Chittenden & Priest, 1993), page 272. Gas pressure augments both the radial and the axial contact in the piston ring groove. The action of the gas pressure increases the sealing capability of the piston ring. Axial contact can alternate between the top and bottom side of the groove owing to the interaction of gas, inertia and friction forces. The actual contact pressure is many times greater due to the gas pressure acting behind the ring. Mean radial gas pressure on the first ring is about 0.15 to 0.20 times the

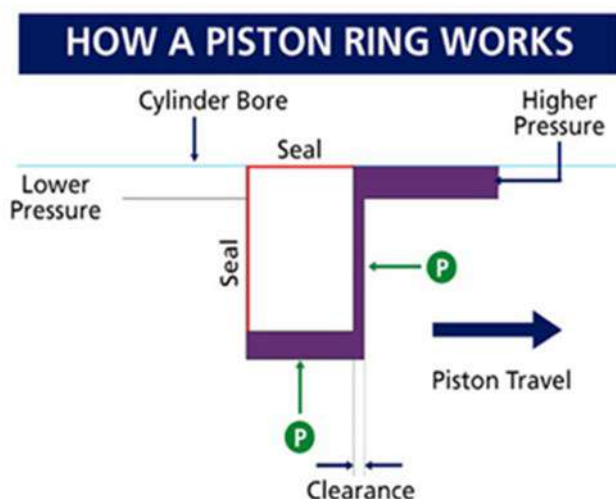


Figure 1. Piston Ring Working

differential pressure across the piston (EFRC). Teflon based Piston Rings for lubricated compressors are not recommended over 100 bar differential gas pressure across the piston.

2. Contact Pressure from Ring Compression [Pw] – One piece piston ring double acting is overturned per material tables to provide the pre-tension to maintain ring to cylinder wall contact (Pw). At atmospheric or vacuum suction, an expander may be required to provide additional loading of the ring against the cylinder wall. The angle cut of the joint standard is 45°. The Ring made from hard materials and diameter less than 350 mm are recommended to be two-piece rings. They do not exert any force or pressure on the cylinder wall when installed, because the turned OD is the same cylinder bore. The loading associated with the elastic spring force on rings is represented as equivalent pressure acting on the rear of the ring. It is typically 104 to 105 Pa, but this represents only one percent of the peak gas pressure (Dawson, 1993).

RING SIZING

The main structural dimensions of the piston rings can be adopted according to existing cylinder bore and available space. Therefore, the radial thickness and width of the ring should be sized as its material strength permits. Compressors OEMs (original equipment manufacturers) already designed non-metallic ring thickness (t) and width (H) with some significant differences between them. The maximum bending stress in piston ring is always 180 degree from the joint, the maximum tensile stress in the piston ring at working conditions or when the ring is closed in the cylinder, calculated by the curved beam bending stress equation,

$$St = \frac{3P_w D^2}{t^2} \frac{1}{1 + \frac{t}{D}} \quad (1)$$

Or by using

$$St = \frac{6 Ft (\frac{D}{t} - 1)}{h t} \quad (2)$$

P_w is the nominal contact or radial pressure of ring on the cylinder wall (mean pressure) that the ring exerts radially outwards against the cylinder wall. This is Piston Ring pre-tension force represented as an equivalent pressure and it is not gas pressure which is stated as,

$$P_w = \frac{2 Ft}{h \times D} \quad (3)$$

Ft is the force which when applied tangentially to the ends of the ring, is sufficient to compress the ring to the specified closed gap. The Tangential force of the piston ring in N, is calculated by.

$$Ft = \frac{0.0707 E g h}{(\frac{D}{t} - 1)^3} \quad (4)$$

Piston rings are subjected to the greatest stress during installation when the ring must be stretched over the piston to install it in the piston groove. Since the solution to the mathematically exact relationship would be too complicated, the installation stress is taken from Koopers Company and calculated as follows,

$$Si = \frac{0.424 E (8t - g)/t}{(\frac{D}{t} - 1)^2} \quad (5)$$

Where,

St = max. tensile stress in piston ring when it is closed in the cylinder [Mpa]

Pw = mean radial pressure on cylinder wall exerted by the ring [Mpa]

Ft = tangential force [N]

E = Young's modulus of elasticity in [Mpa]

g = Ring free gap less end clearance [mm],
g = πt

h = Axial Ring width [mm]

D = Nominal Ring diameter [mm]

t = Radial wall thickness opposite to joint [mm]

Si = ring installation stress [Mpa]

St = max. bending stress in piston ring [Mpa]

The installation stress (Si) should be less than the tensile strength of the ring material. If higher, the ring will break at the assembly. Then two piece rings or thinner rings should be used. The values of ring dimensions and specific tangential forces for various metallic piston rings are tabulated in the standards ISO 6621...6626 (ISO 6621-4), DIN34110.

Unfortunately, no such values or standards are available for non-metallic piston rings. So, the authors assume a modulus of elasticity [E] value of 1,300 Mpa (average of filled PTFE) and establish the below shown

standard table, taking the average of radial thickness and axial width values used by many OEMs and adding to the table, data such as Max. Bending stress, tangential force, radial wall pressure and installation stress.

standard table, taking the average of radial thickness and axial width values used by many OEMs and adding to the table, data such as Max. Bending stress, tangential force, radial wall pressure and installation stress.

Table 1. Specification of Compressor non-metallic Piston Ring Standard¹

D	t	h	Ft	g	P _w	St	Si
mm	mm	mm	N	mm	MPa	MPa	MPa
50	4	5	3,80	13	0,0304	13,19	20,25
100	8	7	10,64	25	0,0304	13,19	20,25
150	10	9	9,47	31	0,0140	8,88	13,66
200	13	10	12,62	41	0,0126	8,41	12,94
250	14	12	10,13	44	0,0068	6,12	9,42
300	16	12	9,92	50	0,0055	5,52	8,50
350	17	14	9,15	53	0,0037	4,53	6,98
400	17	14	6,01	53	0,0021	3,42	5,28
450	18	14	5,27	57	0,0017	3,01	4,65
500	18	15	4,06	57	0,0011	2,42	3,73
550	20	15	4,66	63	0,0011	2,47	3,81
600	20	15	3,55	63	0,0008	2,06	3,18
650	22	16	4,37	69	0,0008	2,13	3,29
700	22	16	3,47	69	0,0006	1,83	2,82
750	23	16	3,37	72	0,0006	1,74	2,68
800	23	17	2,93	72	0,0004	1,52	2,35
850	25	17	3,42	79	0,0005	1,59	2,46
900	25	17	2,86	79	0,0004	1,42	2,19
950	25	17	2,42	79	0,0003	1,27	1,96
1000	25	17	2,07	79	0,0002	1,14	1,76

¹This standard table prepared by Mehmet Samancioglu

For example, for the case of 197mm cylinder diameter (below drawing), D=197, t= 13, h=10,

From Eq.4, Ft = 14.14 N

From Eq.3, P_w = 0.0147 Mpa

From Eq.1 or Eq.2, St = 9.08 Mpa

From Eq.5, Si = 13.97Mpa

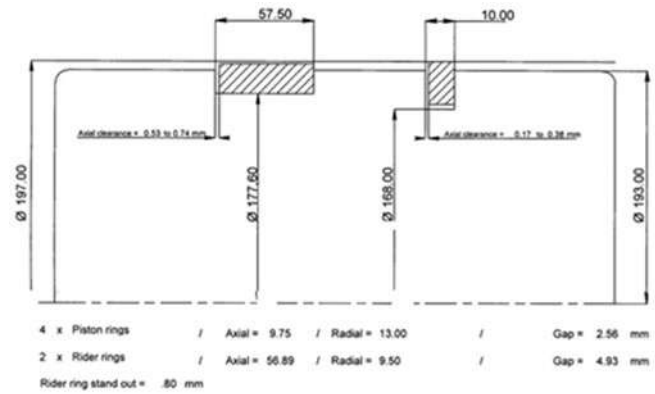


Figure 2. 197mm Cylinder Example

t = gives acceptable ring thickness values for non- metallic piston ring materials.

t = 0.04D to 0.045D, approximately for cast iron piston ring materials.

Axial width (h) of piston ring, h = 0.7t to t

The width of the ring should be as narrow as its strength permits. Below Graph indicates different Ring axial width for two known OEMs [Nuovo Pignone and Neuman Esser].

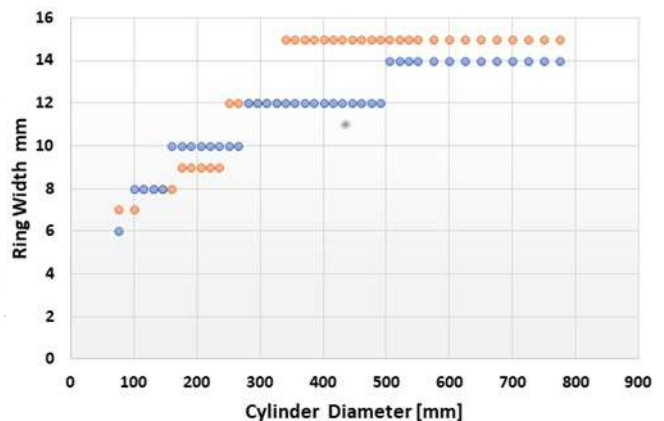


Figure 3. Ring axial width for various OEMs

NUMBER OF RINGS

The number of rings plays no principal role for the packing action except increase the frictional resistance of piston. Hence, a large ring breadth (width) will not be necessary. Therefore, the breadth of the ring should be as narrow as its strength permits. It may surely be said that when a piston ring has good quality for the packing action, its tightness for a high-pressure gas is attained well enough by the first one or two rings. The other rings serving are only for spare purposes. (Technical Memorandum, 1057, P.31-35). The number of rings has been misunderstood by many engineers where more rings are used than

required, i.e., more than double of suggested rings in the table. This only increases friction.

Table 2. NACA technical memorandum, No. 1057

56

NACA Technical Memorandum No. 1057

TABLE XXXV (fig. 61)

RELATION BETWEEN THE MAXIMUM PRESSURE AT THE END OF THE
COMPRESSION STROKE AND THE NUMBER OF RINGS

No. of rings	Maximum pressure (kg/cm ²)	rpm	Condition of oil	Remarks
0	8.9	134	none	Kind of rings is as P _{mn} = 0.8 to 0.9 kg/cm ²
1	27.2	131		
2	27.2	130		
4	27.3	126		
6	27.2	120		
0	10.2	137	poor	
1	28.8	134		
2	29.7	132		
4	29.9	131		
1	31.6	133	rich	
2	33.2	133		
4	33.4	132		

Table 3. Suggested minimum number of piston rings for non-lubricated compressors

Differential pressure [bar]	Minimum number of Rings
Up to 20	2
20 to 60	3
60 to 100	4
100 to 210	5
210 over	6

For better performance and low molecular weight gases an extra one ring can be added.

RIDER RINGS

Rider rings or wear bands which support the piston weight plus half the rod, help guide the piston in the bore, and prevent rubbing of the piston on the cylinder wall. The compressor Axial width of Rider Ring 'G' is calculated as below (API 618). For Horizontal type

$$G = \frac{M_{\text{piston}} + \frac{1}{2} M_{\text{rod}}}{0.866 \times P \times D} \quad (6)$$

For V-type

$$G = \frac{M_{\text{piston}} + \frac{1}{2} M_{\text{rod}}}{0.866 \times P \times D} \times 0.70 \quad (7)$$

Where,

G = Total width of Rider ring [mm]

D = Cylinder diameter [mm]

M = piston is piston weight as force [N]
(1kg=9.81N)

M rod is Rod weight as force [N]

P = Bearing load on Rider ring in N/mm²

For non-lubricated maximum P = 0.035 N/mm² = 5 psi (API 618 standard)

For lubricated maximum P = 0.07 N/mm² = 10 psi (API 618 standard)

Higher loading is possible (up to 0.6 N/mm²) depending on ring material and application. However the allowable Rider ring has a maximum width of 90mm. Above this value, multiple Rider is preferred.

RIDER RING DIMENSIONS

Table 4. Suggested Rider ring axial width for vertical compressors

Cylinder Diameter [mm]	Rider ring Width [mm]
Up to 70	12
Up to 130	16
Up to 260	20
Up to 510	25
Up to 1000	32

Table 5. Suggested Rider ring radial thickness

Cylinder Diameter [mm]	Rider Ring Thickness [mm]
100	7
200	9
300	10
400	11
500	12
600	13
700	14
1000	15

Table 6. Piston to liner diametrical clearances with Rider Band

Cylinder Diameter [mm]	Clearances [mm]
To 60	1
100	1.5
150	2.5
200	3
275	3.5
350	4
500	4.5
630	5
800	5.5
1000	6.5

CONCLUSIONS

The estimated table values are based on a reasonable assumption of P_w and St Values. The above clearances are based on an average of many OEMs data's and for compressor differential pressure up to 100 bar. It is particularly important to establish the recommended clearances given by the OEM for the various compressor components. Charts are generalized for installation, inspection of specific sizes which may vary due to pressure/ temp/ design parameters.

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Dr. Fikret Terzi has more than 30 years of teaching and professional experience in different Universities in Iraq, lecturing on Petroleum and Chemical engineering. He has held the position of Dean in Kirkuk Technical College, Iraq for 11 years. Further to his retirement from service in Iraq, he is currently the Assistant Professor in Cyprus International University, Lefkosa, North Cyprus, Turkish republic.



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Molecular Investigation of a Condenser with Blocked Airflow

Rueben Abraham

GOVERNING FACTORS

A common phenomenon that designers & technicians in the HVACR industry come across is the rise in condenser pressure due to restrictions in airflow. This article describes a thought experiment that analyzes the molecular mechanisms associated with this rise in pressure. Primarily, it is important to understand that the pressure inside the condenser is a function of several parameters that include, but are not limited to:

1. The capacity of the compressor i.e. the mass flow rate of refrigerant being pumped
2. The line size of the discharge tubing i.e. the inner volume of the condenser
3. Volume flow rate of the air through the condenser
4. Temperature difference between the air & the refrigerant in the condenser
5. Factors that affect condenser heat rejection, namely, area of heat exchange, fin shape, distance between fins, material properties of tubes & fins.
6. Size of the expansion device
7. Load on the evaporator
8. System gas charge quantity
9. Refrigerant properties

This article will focus on the effect of airflow on condenser pressure as its impact on other refrigerant parameters can be explained by with a similar methodology.

JOURNEY THROUGH THE CONDENSER

When the suction face area of an air-cooled condenser is blocked, either by an external covering or by debris trapped between its fins, the system begins to function at an elevated pressure relative to its designed point. This will have a consequence on the suction pressure, evaporating temperature [in case of a capillary], compressor current consumption, compressor head temperatures etc. eventually

causing an overall deviation of system performance from its intended range.

To understand the inner workings at a molecular level, we will need to cover the basics first. Refrigerant gas which is at a relatively higher temperature than the rest of the system, enters the condenser at a flow rate governed by the compressor's capacity. This refrigerant gas undergoes 3 major processes in its journey through the condenser

De-superheating: is process of removing sensible heat from a superheated gas until it has reached its point of saturation

Condensing: is the latent heat removal stage that causes a change in phase from a gas to a saturated liquid

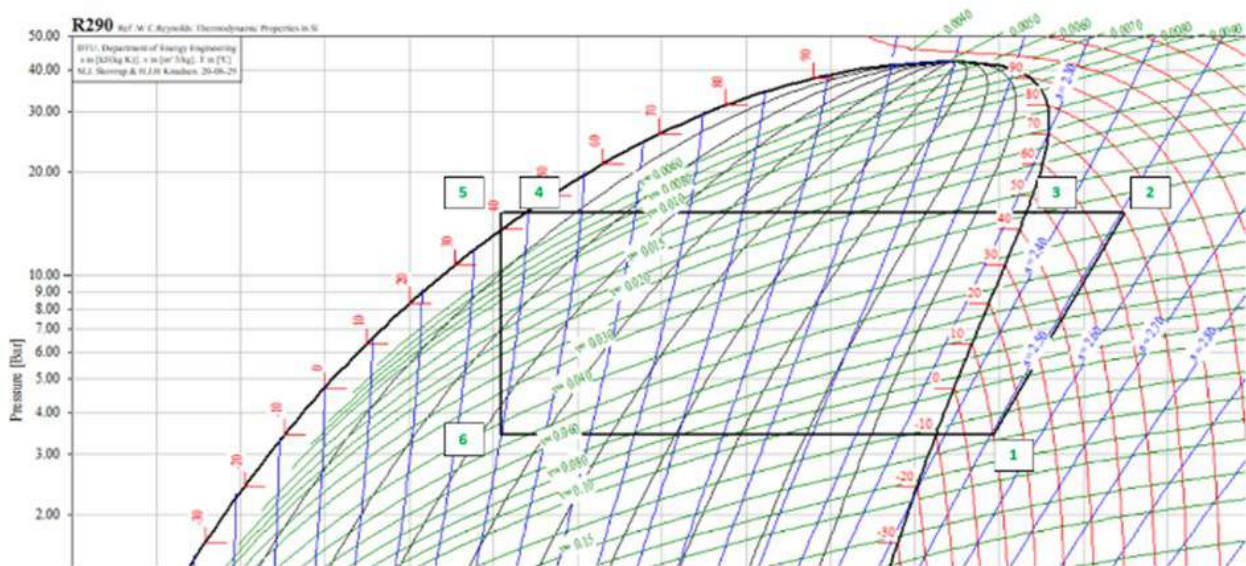
Sub-cooling: is the sensible heat removal process of a liquid below its temperature of saturation

REAL WORLD EXAMPLE

Let us consider a refrigeration system functioning at the following conditions to better understand the concept

- Condensing temperature of 45°C
- Evaporating temperature of -10°C
- Refrigerant capacity of 300 watts
- R290 as a refrigerant
- Superheat of 20°K
- Subcooling of 5°K
- Isentropic efficiency taken as 1 for simplicity

We can plot the P-H chart for this configuration using the coolpack software. See Graph 1



Graph 1: Temperature & Pressure plotted on a PH chart for R290

As the gaseous refrigerant enters the condenser [represented as point 2 on the P-H chart], it begins to lose its heat to the air being blown over it. It initially de-superheats from 2 - 3 and begins to change phase from points 3 - 4. The space occupied by the refrigerant during 3 - 4 is the main driving force for the pressure in the condenser. Since the refrigerant exists both as a gas & a liquid in the region between 3 & 4, the combined effect of gaseous & liquid specific volumes affect pressure directly. Gas molecules occupy more space than liquid molecules at the same condensing pressure. This can be visually represented by drawing two spheres of dimensions derived from the specific volume of the liquid & gas at the same condensing pressure. For simplicity, we imagine the molecules to be of a spherical shape. See Table 1 for property data.

Gas v/s Liquid Molecule Size Variation per Kilogram at 45°C Saturation

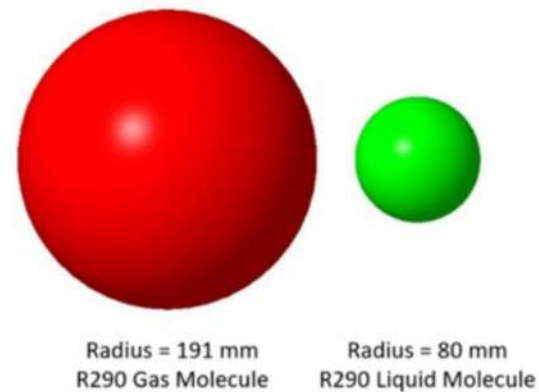


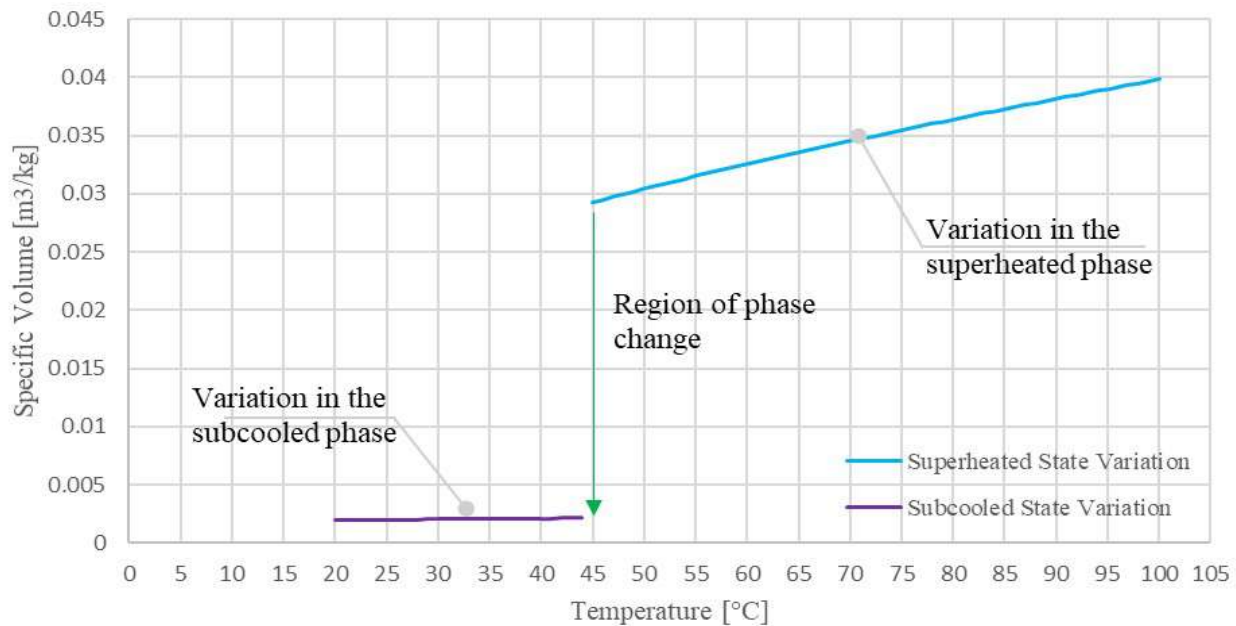
Fig 1: Size comparison between liquid & gas molecule of R290 at a condensing temperature of 45°C

Condensing Temperature	45	°C
Condensing Pressure	15.315	bar
Gas Specific Volume	0.0292	m ³ /kg
Liquid Specific Volume	0.002165	m ³ /kg
Radius of Sphere	$(3V/4\pi)^{1/3}$	
Radius of gas molecule	0.191028463	m
Radius of liquid molecule	0.080252105	m
Percentage Reduction in Size per Kilogram	58%	

Table 1: Properties derived for R290 at 45°C condensing temperature

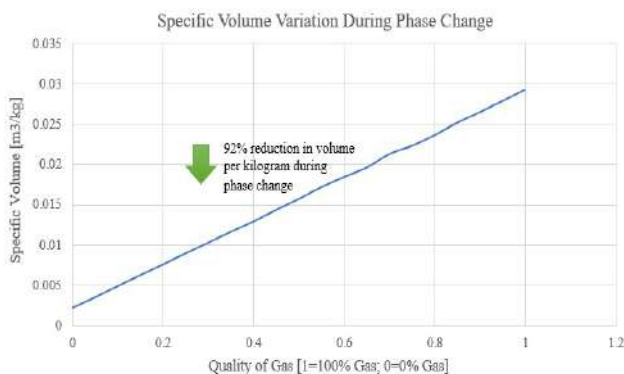
It is observed that the molecules undergo a 58% reduction in the radii & a 93% reduction in volume as the gas condenses to liquid.

Graph 2 shows the variation in specific volume of the molecules at the same condensing pressure of 15.34 bar. The slope is steep in the superheated phase & flat in the liquid phase. Also notice the sudden drop in specific volume at a constant temperature of 45°C. This is the region of phase change where a reduction in specific volume is nearly 93%. Therefore, we can infer that the quicker we are able to condense the superheated gas to liquid, more the space available to accommodate extra refrigerant & lower the pressure in the condenser. As the air flows through the condenser, it picks up heat from it & instigates condensation. The faster this airflow, the quicker the rate of condensation, thereby



Graph 2: Specific Volume Variation at 15.34 bar

keeping the pressure within limits. Graph 3 indicates the variation in specific volume of R290 at different qualities at 45°C.



Graph 3: The "Region of phase Change" indicated in Graph 2 at a condensing temperature of 45°C

GRAPHING OUR THOUGHTS

Let's take up a graphical exercise to drive the point home. Some assumptions for this analysis include

Red spheres represent gas molecules while the green spheres represent liquid

Dimensions of the molecules are scaled based on the data shown in Table 1. All molecules are assumed to be spherical.

The size variation of the gaseous molecules at different qualities is not modeled. Only the boundary specific volumes between the gas & liquid at the said condensing pressures.

Compressibility of the gaseous molecules is

not graphically represented in the analysis

The white spaces in between the molecules do not represent vacuum. All space would be filled with gas or liquid molecules

Figure 2, shows the condensation process taking place in the condenser. The larger (red) gaseous molecules undergo a reduction in volume as the condensation progresses. The condensation is instigated by the air flow across the tube & the

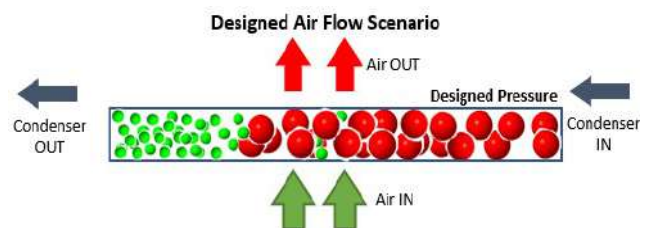


Figure 2: Designed airflow scenario

temperature difference between the air & the refrigerant.

Consider a 2nd scenario of increased airflow compared to scenario 1 [maintaining the temperature of incoming air constant]. The gaseous molecules would begin changing phase to liquid at a much faster rate. This higher rate of condensation means a quicker rate at which larger gas molecule converts to a smaller liquid molecule. This leads to a more space being available in the condenser for more molecules of refrigerant to be accommodated. This also means that the pressure in the line is lower than its designed case. See Figure 3

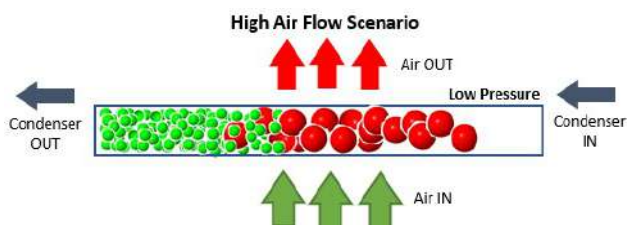


Figure 3: High airflow scenario

Consider the opposite case where the air flow across the condenser is reduced below its designed condition. The rate of condensation would reduce, causing a slower rate at which the gas molecules convert to liquid. This causes a buildup of gas molecules in the line as the rate at which the molecules enter the condenser is greater than the molecules condensing & leaving the condenser. This leads to build up of pressure in the line attributed to the continuous pumping of gas molecules into the condenser by the compressor.

PUTTING IT ALL TOGETHER

A side by side comparison of the 3-scenarios represented in the previous sections sheds light on the importance of airflow & the repercussions of a blocked condenser on pressure. The air flowing through the condenser picks up heat from the refrigerant & instigates the condensation process. The quantity of this airflow has a direct impact on the pressure built up in the discharge line. Greater the airflow, faster the rate of condensation & hence more space available for the more refrigerant gas to be accommodated in the condenser. Similarly, lower airflow would amount to a smaller rate of condensation thereby causing a buildup of gas molecules in the discharge line, hence raising the pressure.

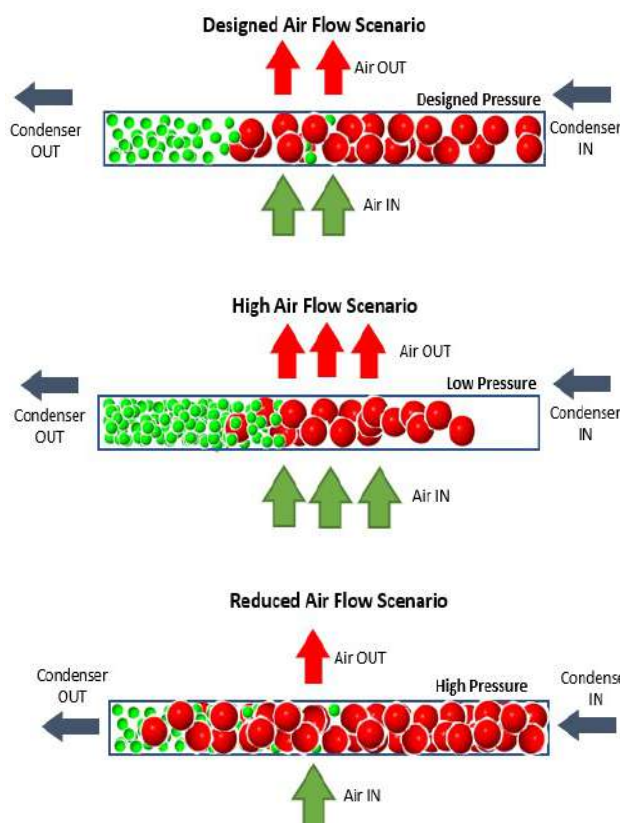


Figure 5: Side by Side Comparison of the 3 Scenarios

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ABOUT THE AUTHOR

Reuben Abraham has been at the helm of research, development & design of heating/cooling systems for over 7 years. From designing refrigeration plants, the size of football fields to systems that sit on a countertop, Reuben's experience stretches across industrial, commercial & domestic applications with projects executed for global markets. Although formally trained with a degree in Mechanical engineering, he leverages his curiosity for electronics & coding to develop innovative solutions to pertinent problems.



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Key Thermo-Physical Properties of Light Crude Oils

Jayanthi Vijay Sarathy, *Engineering Practice* Contributing Author

Process facilities are equipped with protection measures, such as pressure safety valves (PSV) & as a minimum, PSVs are sized for a fire case. To do so for a pressure vessel containing crude oil a key parameter is the Latent heat of Vaporization [Hv].

For pure components, the Joback's Method can be employed which uses basic structural information of the chemical molecule to estimate thermo-physical data. However it can be complex for equipment that contains crude oil because the plus fractions [C7+] can contain thousands of straight chain, cyclic & functional groups. Therefore by splitting and lumping the crude fractions, a smaller number of components are arrived at, to characterize and be able to apply Equation of State (EoS) correlations to estimate the fraction's thermo-physical properties.

To estimate properties such as MW, Specific gravity [g], Critical Pressure [Pc], Critical Temperature [Tc] and Latent heat of Vaporization [Hv], the following article provides few correlations applicable for light crudes with boiling points < 4550C based on D-86 Distillation curves.

GENERAL NOTES

1. Latent heat of Vaporization [Hv], can be estimated using critical properties of the plus fractions in the hydrocarbon mixtures.
2. Oil fractions tend to decompose at ~6500F (3440C) at 1 atm. As a result, it becomes necessary to lower the pressure to as low as 40mm Hg to obtain the True Boiling Point (TBP) distillation curves. ASTM methods can be used to convert the resulting boiling point curve into TBP curves using correlations from API Technical Data Book – Petroleum Refining.
3. The ASTM D-86 distillation of an oil fraction is conducted in laboratory room conditions at 1 atm and the D-86 distillation curve ends at ~6500F (3440C).

4. The ASTM D-1160 distillation of an oil fraction is conducted at much lower pressures, typically 10 mmHg for heavier oils with high boiling points to prevent decomposition of the oil sample. With this method, oil fractions can be distilled upto ~9500F to ~10000F (5100C to 5380C), reported on a 760mm Hg basis.
5. The boiling point of all compounds in a crude mixture can be represented by a single characteristic boiling point called Volume Average Boiling Point [VABP]. Since the individual mole fractions of the petroleum stream is not known, VABP is calculated from standard distillation data [ASTM D-86] followed by calculating the mean average boiling point [MeABP].
6. The Molecular weight [MW], Specific gravity [g] & boiling point [Tb] are taken as the key properties to define the makeup of a petroleum fraction. In this article, the Katz-Firoozabadi [1978], Riazi-Daubert [1980, 1987] & Ahmed [1985] correlations are shown to predict MW, specific gravity [g], Critical Pressure [Pc] & Critical Temperature [Tc]. To estimate Hv, Riedel correlation is employed to estimate the Latent Heat of Vaporization [Hv,NBP] at Normal Boiling Point [MeABP/NBP/Tb]. Watson relation is used to estimate HV,T at desired temperature.

SELECTED CORRELATIONS

The below table gives a summary of the two generalized correlations to estimate MW, Pc, Tc and Hv of the petroleum fraction.

Table 1. Generalized Correlations for P_c , T_c and MW**Katz-Firozabaadi Correlation [1978]**

$$MW \left[\frac{\text{kg}}{\text{kmol}} \right] = \left[\frac{6.97996 - \ln(1080 - T_b)}{0.01964} \right]^{3/2}$$

$$\gamma[-] = 1.07 - e^{[3.56073 - (2.93886 \times MW^{0.1})]}$$

$$P_c[\text{bara}] = e^{[6.34492 - (0.7239 \times MW^{0.299})]}$$

$$T_{br}[-] = 1.2 - e^{[-0.34742 - (0.02327 \times MW^{0.55})]}$$

$$T_c[^\circ\text{K}] = \frac{T_b}{T_{br}}$$

$$N_c[-] = \left[\frac{[6.9955 - \ln(1090 - T_b)]}{0.11193} \right]^{3/2}$$

$$T_b = ^\circ\text{K}$$

Riazi-Daubert Extended Correlation [1980]

$$MW \left[\frac{\text{kg}}{\text{kmol}} \right] = [42.965 \times T_b^{1.26007} \times \gamma^{4.98308}] \times e^{[(0.0002097 \times T_b) - (7.78712 \times \gamma) + (0.00208476 \times T_b \times \gamma)]}$$

$$T_b = ^\circ\text{K}; \gamma = \text{Unitless}$$

Riazi-Daubert Correlation [1987]

$$P_c[\text{psia}] = [45203 \times MW^{-0.8063} \times \gamma^{1.6015}] \times e^{[(-0.0018078 \times MW) + (-0.3084 \times \gamma)]}$$

$$T_c[^\circ\text{R}] = [544.4 \times MW^{0.2998} \times \gamma^{1.0555}] \times e^{[(-0.00013478 \times MW) + (-0.61641 \times \gamma)]}$$

The Latent Heat of Vaporization [H_v] is calculated as,

Table 2. Riedel Correlation and Watson Relation

Riedel Correlation

$$H_{v,NBP}[\text{kJ/mol}] = \frac{1.092 \times 8.3145 \times T_b \times [\ln P_c - 1.013]}{[0.93 - \frac{T_b}{T_c}] \times 1000}$$

$$P_c = \text{bara}; T_c = ^\circ\text{K}; T_b = ^\circ\text{K}$$

Watson Relation

$$H_v[\text{kJ/mol}] = H_{v,NBP} \times \left[\frac{T_c - T}{T_c - T_b} \right]^{0.38}$$

$$T = ^\circ\text{K}; T_c = ^\circ\text{K}; T_b = ^\circ\text{K}; H_v = \text{kJ/mol}$$

It is to be noted that, the Katz-Firozabadi [1978] correlation was originally based on Kreglewski and Zwolinski [1961] generalized expression which is of the form,

$$\theta = \theta_\infty - e^{[a - (b \times MW^c)]} \quad (1)$$

Where, q represents the properties such as T_b , g , P_c and T_{br} .

The value of the constants, a , b , c in the above expression is based on a tabulated set generated from the physical properties of 26 condensates and crude oil systems. The value of g based on MW in the Katz-Firozabadi correlation predicts within 0.4% for straight chain numbers [SCN] groups from C_6 to C_{50} . Similarly, the absolute average deviation (AAD%) of the Kreglewski and Zwolinski [1961] correlation gives an AAD% of 0.4%, 0.07%, 0.15% and 1% in the properties of T_b , g , T_{br} , P_c respectively between correlations and physical properties of the 26 condensates and crude oil systems.

VABP & MeABP CALCULATION

For petroleum fractions usually, there would be no information available about the weight, mole or volume fractions considering the large number of compounds present. In such cases, the ASTM based D-86 distillation data for light oils (API Gravity > 31°API and D-86 Temperatures < 455°C) can be used to estimate the Volume Average Boiling Point (VABP) and Mean Average Boiling Point (MeABP) which can be calculated as follows,

$$VABP[^\circ\text{C}] = \frac{T_{10\%} + T_{30\%} + T_{50\%} + T_{70\%} + T_{90\%}}{5} \quad (2)$$

It is to be noted that when the average boiling point (ABP) of a crude sample is estimated based on weight (W), moles (M) and volume (V) basis, there would exist a difference in each of these average boiling points. To relate the different types of ABPs, the VABP value is corrected with a slope line and correction factor line to find other ABPs. The Slope Line (S) is estimated as,

$$S[^\circ\text{C}/\% \text{ Recovered}] = \frac{T_{90\%} - T_{10\%}}{80} \quad (3)$$

With the S value, the correction factor, DT_{MeA} is estimated using the empirical expression,

$$\Delta T_{MeA} = -1.53181 - [0.0128 \times VABP^{0.6667}] + \frac{[3.646064 \times S^{0.3333}]}{1} \quad (4)$$

Where,

VABP = Volume Average Boiling Point [$^\circ\text{C}$]

With the correction factor, DT_{MeA} , the MeABP is estimated as,

$$MeABP[^\circ\text{C}] = VABP - \Delta T_{MeA} \quad (5)$$

To estimate the critical properties, MW and latent heat of vaporization [H_v], MeABP becomes the normal boiling point, T_b .

CASE STUDY

Light Crude Oil is present in a process vessel at 325°K [51.85°C]. To size a PSV for fire case, the latent heat of vaporization [H_v] value is required to be computed. The D-86 distillation curves are as follows,

Table 3. ASTM D86 Vol% vs Temperature

Vol% [ASTM D86]	D86 Temperature [°C]
0 [IBP]	155.1
10	179.1
30	222.4
50	260.3
70	289.0
90	315.7
100 [FBP]	352.9

With the available data, VABP is estimated as,

$$VABP[°C] = \frac{179.1+222.4+260.3+289+315.7}{5} \quad (6)$$

$$VABP[°C] = 253.3°C \quad (7)$$

The slope, S is estimated as,

$$S [°C/\% \text{ Recovered}] = \frac{315.7-179.1}{80} = 1.7075 \quad (8)$$

The correction factor DT_{MeA} becomes,

$$\Delta T_{MeA} = -1.53181 - [0.0128 \times 253.3^{0.6667}] + [3.646064 \times 1.7079^{0.333}] = 10.1°C \quad (9)$$

The MeABP is estimated as,

$$MeABP[°C] = T_b = 253 - 10.1 \cong 243°C \quad (10)$$

$$\text{Or, } T_b \cong 243°C \cong 516°K \cong 929°R \quad (11)$$

Applying the MeABP/ T_b value, the critical properties, g and MW is estimated as follows,

$$MW \left[\frac{kg}{kmol} \right] = \left[\frac{6.97996 - \ln(1080-516)}{0.01964} \right]^{3/2} = 188.4 \quad (12)$$

$$\gamma = 1.07 - e^{[3.56073 - (2.93886 \times 188.4^{0.1})]} = 0.8238 \quad (13)$$

$$API \text{ Gravity} = \frac{141.5}{0.8238} - 131.5 = 40.26°API \quad (14)$$

$$P_c = e^{[6.34492 - (0.7239 \times 188.4^{0.299})]} = 17.8 \text{ bara} \quad (15)$$

$$T_{br} = 1.2 - e^{[-0.34742 - (0.02327 \times 188.4^{0.55})]} = 0.733 \quad (16)$$

$$T_c = \frac{516}{0.7335} = 704°K \quad (17)$$

$$N_c = \left[\frac{[6.9955 - \ln(1090-516)]}{0.11193} \right]^{3/2} = 13.78 \quad (18)$$

Similarly applying Riazi-Daubert correlations from Table 1 with $g=0.8238$ and $T_b = 516°K$.

$$MW \left[\frac{kg}{kmol} \right] = 189.8 \quad (19)$$

$$P_c = 266 \text{ psia} = 18.3 \text{ bara} \quad (20)$$

$$T_c = 1,254°R = 697°K \quad (21)$$

The Latent Heat of Vaporization [$H_{v,NBP}$] based on Katz-Firoozabadi P_c , T_c , T_b data is,

$$H_{v,NBP} = \frac{9.079434 \times 516 \times [\ln 17.8 - 1.013]}{[0.93 - \frac{516}{704}] \times 1000} \cong 44.5 \frac{kJ}{mol} \quad (22)$$

At 325°K, $H_{v,T}$ is,

$$H_{v,T} = 44.49 \times \left[\frac{704-325}{704-516} \right]^{0.38} = 59.23 \frac{kJ}{mol} \quad (23)$$

Similarly, using Riazi-Daubert P_c , T_c , T_b data,

$$H_{v,NBP} = 46.96 \frac{kJ}{mol} \quad (24)$$

$$\text{At } 325°K, H_{v,T} = 61.8 \frac{kJ}{mol} \quad (25)$$

ADDITIONAL CORRELATION – AHMED [1985]

Based on Ahmed [1985] correlation of the Katz-Firoozabadi [1978], physical properties are tabulated with the number of carbon atoms in petroleum fractions using a regression model of the form,

$$\theta = a_1 + a_2 n + a_3 n^2 + a_4 n^3 + \frac{a_5}{n} \quad (26)$$

Where,

$q = T_c, P_c$

n = number of carbon atoms

a_1, a_2, a_3, a_4, a_5 = coefficients

Table 4. Ahmed [1985] Constants - γ and MW

Property	γ	MW
Coefficients	[-]	[kg/kmol]
a_1	0.86714949	-131.11375
a_2	0.00341434	24.96156
a_3	-0.00002840	-0.34079022
a_4	2.4943308×10^8	0.00249412
a_5	-1.16279840	468.32575

Table 5. Ahmed [1985] Constants - P_c and T_c

Property	P_c	T_c
Coefficients	[psia]	[°R]
a_1	275.56275	915.53747
a_2	-12.522269	41.421337
a_3	0.29926384	-0.7586859
a_4	-0.00284521	0.00586754
a_5	1711.7226	-1302.8779

Based on Ahmed [1985] correlation,

$$MW[\text{kg/kmol}] = 188.7 \quad (27)$$

$$P_c = 266 \text{ psia} = 19.1 \text{ bara} \quad (28)$$

$$T_c = 1,254^\circ\text{R} = 702^\circ\text{K} \quad (29)$$

$$H_{v,NBP} = 46.71 \frac{\text{kJ}}{\text{mol}} \quad (30)$$

$$\text{At } 325^\circ\text{K}, H_{v,T} = 61.15 \frac{\text{kJ}}{\text{mol}} \quad (31)$$

RESULTS

Table 6. Results Summary

Property	Katz-Firoozabadi	Riazi-Daubert	Ahmed [1985]
MW [kg/kmol]	188.4	189.8	188.7
γ [-]	0.8238	-	0.8245
P_c [bara]	17.8	18.3	19.1
T_c [°K]	704	697	702
H_v [kJ/mol]	44.49	46.96	46.71
$H_{v,T}$ [kJ/mol]	58.12	61.80	61.15

Taking an average of the estimates made, the critical properties, MW and H_v is estimated as,

Table 7. Average of Estimates

Property	Average Properties
MW [kg/kmol]	189.0
γ [-]	0.8242
P_c [bara]	18.4
T_c [°K]	701
$H_{v,NBP}$ [kJ/mol]	46.05
$H_{v,325^\circ\text{K}}$ [kJ/mol]	60.36

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Guidelines for Mist Elimination Equipment Selection, Sizing, Safety & Troubleshooting | Part 1

Karl Kolmetz, Utami Ledyana Daulay, Apriliana Dwijayanti

INTRODUCTION

Mist elimination, or the removal of entrained liquid droplets from a vapor stream is one of the most encountered processes equipment requirements regardless of unit operation. Mist elimination can be defined as the mechanical separation of liquids from gases. The equipment used for the removal of this entrainment is referred to as a mist eliminators.

A properly engineered mist eliminator may reduce liquid carryover by a factor of more than one hundred percent (100%) relative to a standard vanilla unit. Pressure drop head losses reduced by fifty percent (50%) or more and increase production capacity by factors of three to four hundred percent (400%).

In the chemical process industry, there are a number of processes where gases and liquids come into contact with each other and whenever this happens the gas will entrain a small amount of the liquid particles. This liquid phase which gets carried away with the gaseous phase may lead to a number of problems like loss of product quality, equipment damage for example as in a compressor, process inefficiency, and needs to be eliminated and / or reduced.

Proper mist elimination equipment selection can reduce the size of the separation vessel leading to a large cost saving in capital of a project. Proper selection of fouling resistant mist elimination equipment can increase run length significantly.

Unfortunately, mist eliminators are often considered commodity items and are specified without the proper attention to available technologies and design approaches. Many times, they are specified incorrectly leading to lower capacity, fouling, high pressure drop and failure.

One would think that the multiple failures would lead to better design practices. The challenge of mist elimination design is having

troubleshooting to build these best practices. There are very few groups that have the knowledge of all three – installation, unit operation and troubleshooting.

The one piece that most group lack is unit operation and being able to estimate the failure mechanisms. Ensure that your designer has knowledge in all three areas before designing mist elimination or in fact any process equipment.

DESIRED FEATURES IN A MIST ELIMINATOR

- Simple structure.
- Lightweight.
- High porosity.
- Low pressure drops.
- Large surface area.
- High mist separating efficiency.
- Easy to install, operate and maintain.
- Easily tailor made to suit most vessel shapes and sizes.
- Durable and long service life.
- Corrosion resistance

KLM Technology Group would be happy to assist in your needs for mist elimination. We are one of the few groups that have all three requirements to professionally design process equipment - installation, unit operation and troubleshooting. We can engineer, supply, or troubleshoot your application. Please contact us at info@klmtechgroup.com.

SELECTION OF EQUIPMENT

Mist eliminators find a wide variety of applications such as evaporators, three phase separators, knockout vessels, scrubbers, distillation columns and others. The choice of mist eliminator must be done on the basis of the application requirements. Products are available in a wide array of metals, plastics, and thermoplastics to suit a variety of applications.

1. Wire Mesh Pad Mist Eliminator: The mesh pad mist eliminator removes droplets by impingement on surface of a wire. The

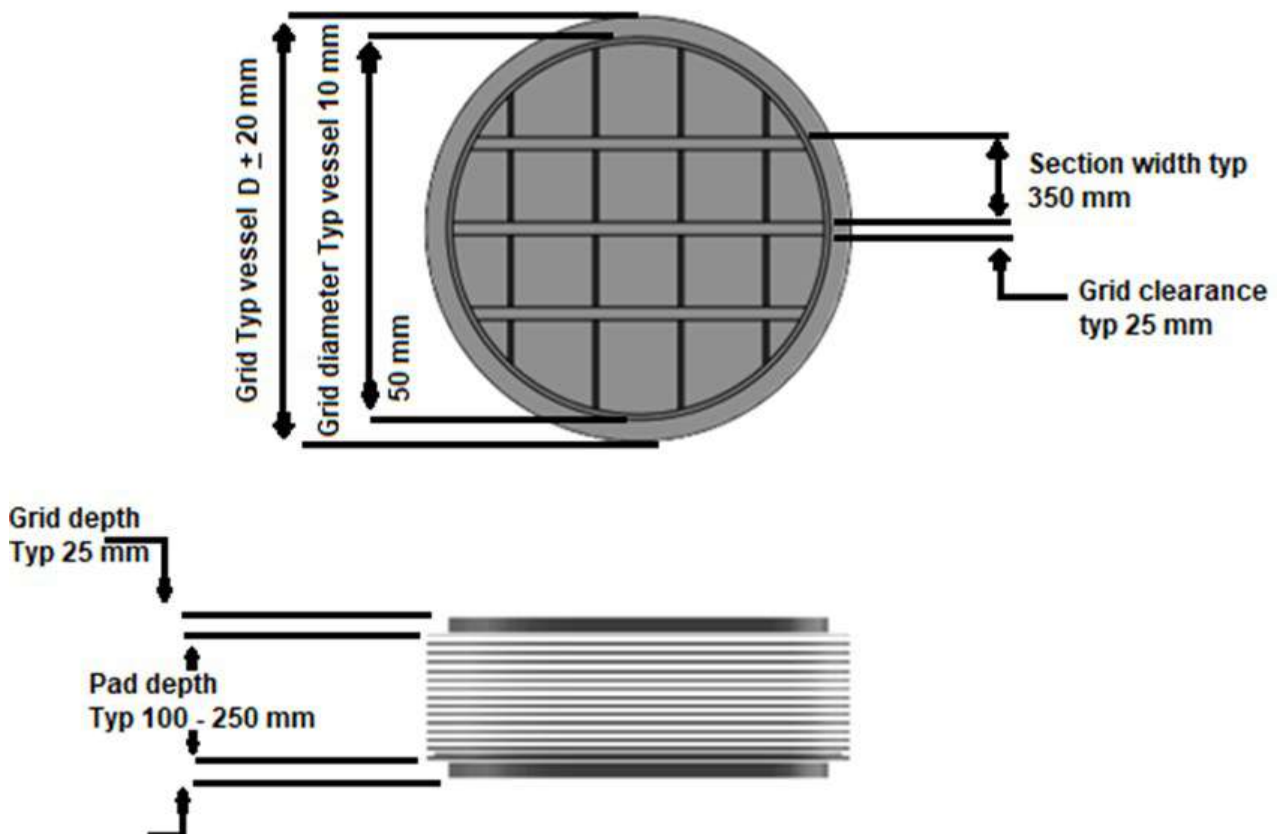
liquid collected on the filament is drained off under gravity. These mist eliminators provide may provide removal of droplets down to 3 to 5 microns.

2. Plain Vane Pack Mist Eliminator: The plain vane pack mist eliminator is a high efficiency mist eliminator commonly used for removing entrained liquids from vapor flowing vertically upwards. These mist eliminators use corrugated vanes as a mechanism for mist elimination.
3. Pocketed Vane Pack Mist Eliminator: The high capacity vane pack mist eliminators use a hooked vane mechanism for higher capacity mist elimination. They provide for efficient droplet removal and superior resistance to fouling for high rate horizontal vapor flow.
4. Mist Eliminators for high efficiency mist elimination: The high efficiency mesh pad mist eliminators remove droplets by impingement on the wire surface. The liquid collected on the filaments drains off under gravity. They provide removal of droplets down to about 3-5 microns. They provide a turndown range of vapor rate of around 3:1.

WIRE MESH DEMISTER PADS

The simplest and most commonly specified is the wire mesh mist eliminator, the wire mesh eliminator, in the most general sense, is a simple porous blanket of metal or plastic wire that retains liquid droplets entrained by the gas phase. The separation process in the wire mesh mist eliminator includes three steps:

1. The first, being 'inertia impaction' of the liquid droplets on the surface of wire. As the gas phase flows past the surface or around wires in the mesh pad the streamlines are deflected, but the kinetic energy of the liquid droplets associated with the gas stream may be too high to follow the streamline of the gas and they impinged on the wires.
2. The second stage in the separation process, is the coalescence of the droplets impinging on the surface of the wires.
3. In the third step, droplets detach from the pad. In the vertical flow installations, the captured liquid drains back in the form of large droplets that drip from the upstream face of the wire mesh pad. In the horizontal flow systems, collected liquid droplets drain down through the vertical axis of the mesh pad in a cross flow fashion.



Typically, maximum allowable velocity for a mist eliminator is limited by the ability of the collected liquid to drain from the unit. In vertical up flow mesh demister, when the gas velocity increases past design levels, liquid begins to accumulate in the bottom of the unit. The liquid buildup results in re-entrain of the liquid with the gas stream. This is because the inertia of the incoming gas prevents the liquid from draining out of the bottom of the unit. In horizontal units, the gas inertia pushes the captured liquid toward the downstream face and with the gas stream.

As a rule, smaller diameter wire targets collect smaller liquid droplets more efficiently. For example, a 10 mm wire removes smaller droplets than a 200 mm wire. However, a bed of 10 mm wires normally has the tendency to flood and re-entrain at much lower gas velocities than a bed of 200 mm wire. This is because the thinner wires provide dense packing that can trap the liquid by capillary action between the wires.

Interweaving of small diameter wires with larger diameter wire has been used often to tackle some of the most difficult mist removal problems. This design uses the metallic or plastic wires as a support structure to hold the wires apart. Special internal mesh geometry modifications are now available that allow these bi-component (that is, small fiber and large-diameter wire mesh) configurations to operate at velocities essentially the same as conventional mesh designs.

These ultra-high-efficiency designs can be substituted for conventional mesh and used, for example, in the dehydration towers of natural gas production plants, where even small losses of absorption chemicals, such as ethylene glycol, can be a significant operating expense.

Construction materials for the wires include metal, fiberglass, plastics, or polymers such as polypropylene or Teflon. Recently, three new alloys have been made available in wire form, which routinely provide three to five times the service lives of the traditional

materials. They can offer improved service depending on the temperature and acid concentration of the gas stream. The gas phase velocity should be limited to 4 ± 5 m/s to prevent any re-entrain of the water droplets captured in the wire mesh pad.

WIRE MESH DEMISTER PAD INSTALLATIONS IN COLUMNS/ VESSELS / TOWERS

Wire Mesh Demister Pads may be installed in columns, vessels or towers in various positions depending upon the shape, vapor inlet nozzle location, vapor outlet nozzle location, liquid outlet nozzle location and process applications.

WIRE MESH ELIMINATOR DESIGN SIZING

Wire Mesh Eliminator Demister Pads should be designed so that the face area provides a vapor rate of approximately 80% of maximum allowable re-entrainment velocity. For the purpose of estimation, suitable design velocities occur at a K-factor of 0.107 m/s for vertical flow or 0.150 m/s for horizontal gas flow (due to better drainage) where,

$$v_s = K \sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \quad \text{Eq 1}$$

Where,

V_s = Actual vapor velocity (m/s)

ρ_V = Vapor density

ρ_L = Liquid density

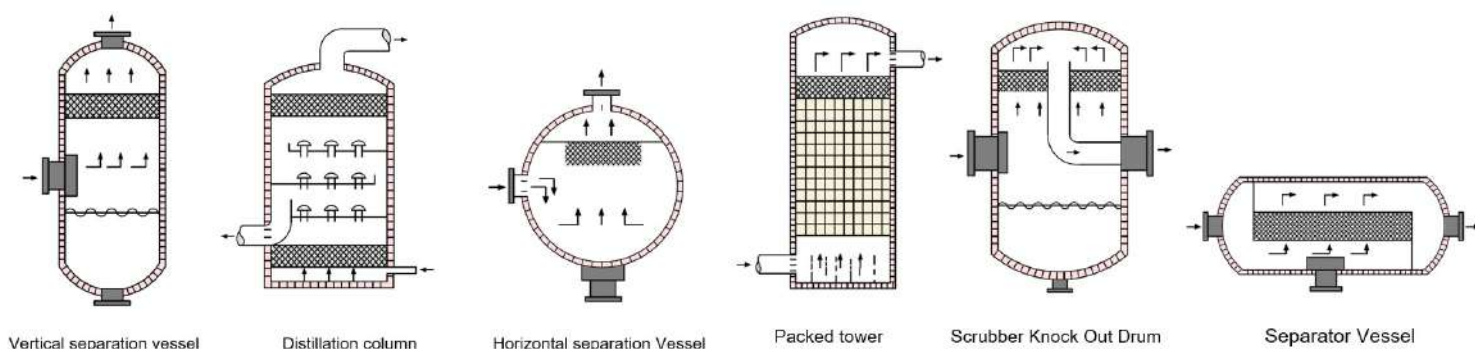
An approximate pressure drop can be estimated from the following formula

$$P \text{ (kPa)} = C(\rho_L - \rho_V) K^2 t \quad \text{Eq 2}$$

Where $C = 0.20$ for a typical mesh pad demister, and t is the pad thickness in meters.

Note that the dry pressure drop is half of the wet figure.

The method of droplet creation will often give a good indication about the difficulty of separation. Physical properties of each phase and other data need to be collected:



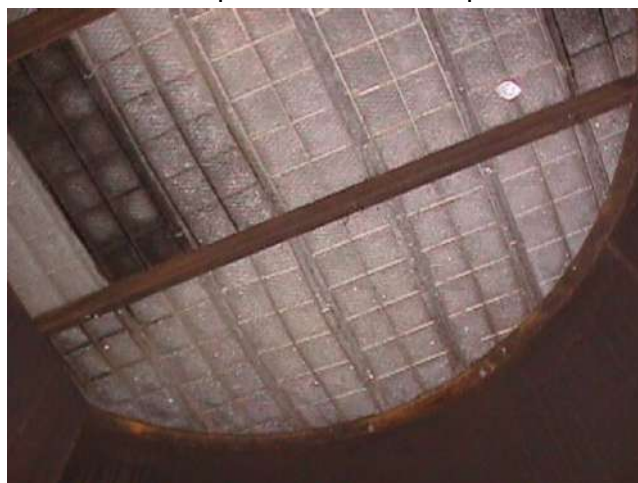
1. Density differences and viscosity determine how fast the droplets will disengage,
2. Flow rates will determine the ultimate size of the required separation equipment,
3. Desired separation performance must be defined,
4. Interfacial tension, which is a measure of the ease of droplet coalescing and how it is affected by pH and temperature, is extremely helpful when available,
5. presence of impurities and solids will often create a more difficult separation, since they can collect at the interface between the liquids, making coalescing difficult and also limiting equipment choices,
6. Relative solubility at operating temperature will help the designer understand whether the desired separation is being prevented by solubility limits.

WIRE MESH ELIMINATOR TROUBLESHOOTING

In fouling services wire mesh eliminator demister pads have a high failure rate. A typical fouling service would be an ethylene plant caustic tower. This is a picture of a fouled demister pad in an ethylene plant caustic tower. You can see the fouling that will lead to high pressure drop across the demister pad. If the pressure drop becomes high enough it will lift the demister pad leading to vapor bypassing.



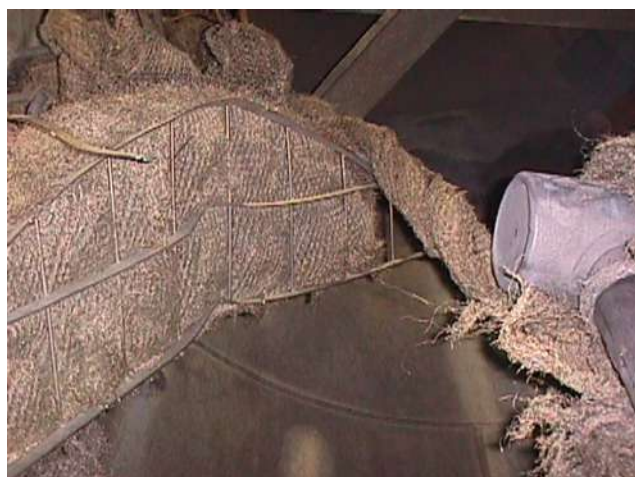
Here is a new demister pad that was had one panel not delivered. Notice the difference between the new panels and the old panel.



As the pressure drop increases the demister pad will lift leading to vapor bypassing the demister pad. Here is demister pad failure.



This picture is from an ethylene plant steam generator tower, they are used to recycle water. Any time you have steam generation you have the high probability of pressure surges, and you should design for this possibility. This demister pad is not fouled, so this probability was a pressure surge.



SAFETY

From a safety perspective after reviewing pictures like this failure, many people want to limit the possibility of a failed demister pad plugging a Pressure Relief Device. Newer designs in fouling service are placing the Pressure Relief Device below the demister pad,

CONCLUSIONS FOR PART 1

Mist elimination seem simple to design, and there are multiple groups providing mist elimination equipment leading to many failures. One would think that the multiple failures would lead to better design practices. The challenge of mist elimination design is having some experience in installation, operation and troubleshooting to build these best practices. There are very few groups that have the knowledge of all three – instillation, unit operation and troubleshooting. The one piece that most group lack is unit operation and being able to estimate the failure mechanisms. Ensure that your designer has knowledge in all three areas before designing mist elimination or any process equipment.

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Megaproject OSBL Scope Development

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Designing critical OSBL facilities for the Sadara Project presented the UPI team with some unique challenges, which required innovative solutions.

The Sadara Chemical Company is a joint venture between The Dow Chemical Company and Saudi Aramco. Sadara constructed at Al Jubail, KSA the world's largest petrochemical complex ever executed in a single phase. Total CAPEX for the Sadara project was approximately \$20 billion. Its 6-km² site features 26 integrated, world-scale manufacturing plants that produce a total of over 3 million metric tons of high value-added plastics and chemical products each year. (1)

The Sadara site includes a world-scale Mixed Feed Cracker (2), which went live in 2016 (7), and produces approximately 1.5 million tons per year of ethylene and approximately 400,000 tons per year of propylene (5, 8).

The design teams for the 26 process plants were located in contractor offices all over the world during the FEED and detailed design phases of the project (5, 8). The scope of the Sadara Utilities, Power, and Infrastructure (UPI) Project (3), which was developed in the US and UK, included:

- Steam Generation and Utilities
- Power Distribution
- Interconnecting Facilities
- Waste Treatment
- Interface Management

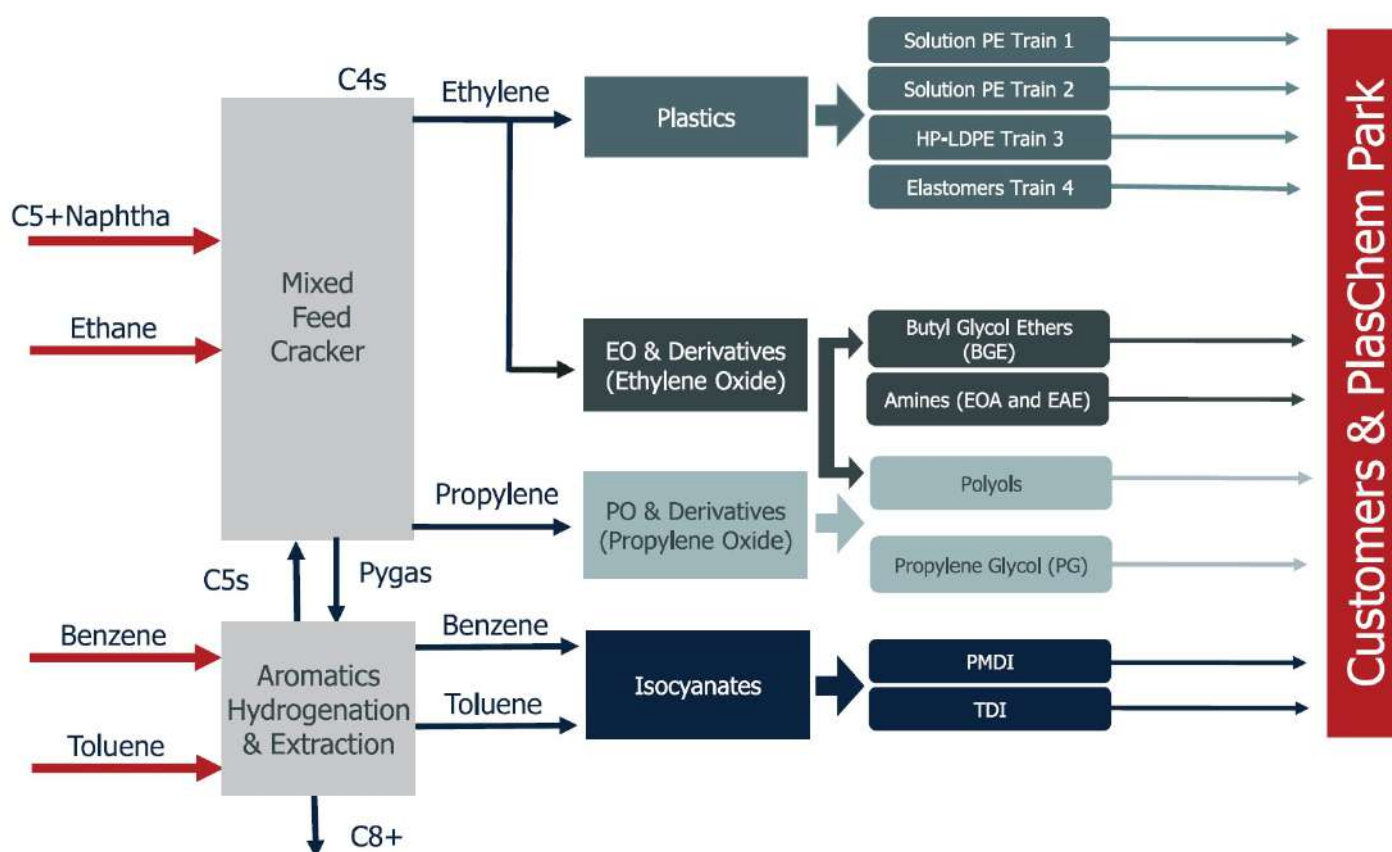


Figure 1- Sadara Configuration (2)

The Sadara Steam Generation plant featured six 80MW boilers, each fitted with advanced NOx and SOx emission control systems (6). The UPI Interconnecting Facilities scope included distribution of 6,000m³/hour of desalinated water produced by a third party for makeup to cooling towers located throughout the site (4). The Waste Treatment scope included two world-scale Thermal Treatment Units to process hazardous, toxic, and halogenated hydrocarbon wastes generated across the complex (7).

Designing critical OSBL facilities such as these supporting a megaproject like Sadara presented the UPI team with some unique challenges, which required innovative solutions.

Practically all of the UPI project facilities had to be mechanically complete and commissioned before any of the process plants could begin to start up. Yet the schedule for the Sadara project required the UPI team to finalize the design of their facilities before the design for many of the process plants had advanced far enough to allow their utility and waste treatment requirements to be firmly set. To overcome this schedule disconnect, as the UPI team collected utility and waste treatment demand data from the teams designing the individual process plants, they were asked to not only define the expected normal and peak stream flowrates, they were also asked to honestly assess how firm that data was. Based on this information, the UPI team assigned an “uncertainty factor” to each bit of design data, which reflected the extent to which the utility and waste treatment demands reported by the process plant design teams could grow as their designs progressed. Essentially a design margin, an uncertainty factor of 1.0 was assigned to data UPI received regarding any process plant whose design was finalized and thus considered firm. A higher uncertainty factor, up to 1.5, was assigned to design data UPI received regarding any process plant whose design was preliminary, and hence potentially subject to significant growth. Although subjective and imprecise, this approach nonetheless allowed the UPI team to assemble the design data for their facilities in a manner consistent with the overall Sadara project schedule.

The UPI team next had to aggregate the individual bits of uncertainty-adjusted utility and waste treatment demand data regarding the 26 individual process plants into design requirements for the overall Sadara site utility and waste treatment systems. UPI was



Figure 2 – Sadara Steam Boilers Under Construction (3)

charged with designing cost-efficient facilities that would support up to the peak flowrate for each utility stream going to or waste stream coming from each of the process plants, whether during startup, shutdown, or any other non-steady-state operating condition. And yet it would have been uneconomical for UPI to design their facilities to accommodate all the peak flowrates for any given utility supply or waste treatment system from all relevant plants occurring simultaneously. Thus, for the first pass, the UPI team adopted the philosophy of designing each utility and waste treatment system for the “sum of the normals plus the greatest single peak.” In other words, UPI started with the assumption that all peak utility demand or waste generation scenarios for the various process plants would occur independent of each other. Then UPI went back and, in collaboration with the design teams for the process plants, identified scenarios in which one or more of the utility or waste generation peak flows could occur simultaneously, and only designed for such scenarios by exception. Thus, the Sadara UPI team met its obligation to design cost-efficient facilities that would support the full range of expected operations for the process plants.



Figure 3 – Sadara Power and Piperack Interface (3)

Due to its massive scale, UPI’s interface management role presented the team another unique challenge. There were several hundred interface points between UPI’s facilities and those of the 26 individual process plants to be tracked and managed as the Sadara project progressed. These interface points included not just utility and waste streams, but also all raw material feedstocks and any process streams exchanged among

the process plants that passed through UPI's Interconnecting Facilities. At first, the only information that was known regarding each of these interface points was what might be found in a typical process simulator – normal and peak flowrate, composition, temperature, pressure. Then, as the design progressed, the interface data was expanded to include pipe size and flange rating, which had to match between the UPI and ISBL sides of each interface point. During detailed design, the interface data was further expanded to include the physical location in space for each interface point, which again had to match exactly – to the millimeter. During construction, the interface data was finalized by including the date when the section of pipe making up each half of each interface point was expected to be installed. None of the Sadara interface management work was azeotropic distillation. But just the sheer volume of data that had to be exchanged, checked, and repeatedly rechecked during each phase of the project with teams scattered all across the globe for the hundreds of individual points in UPI's interface management database made this critical aspect of UPI's scope a major undertaking.



Figure 4 – Sadara 2km Interconnecting Facilities Piperack (3)

Hydraulic hammer, or surge, is typically only considered in process plants for long liquid lines. But since UPI's Interconnecting Facilities spanned across Sadara's entire 3km x 2km site, every liquid line was a long line. UPI conducted over a hundred hydraulic hammer calculations and ten dynamic simulations, and then managed the resolution of all problems that these evaluations uncovered. Vapor waste streams presented the UPI team a different challenge. UPI conducted heat-loss calculations on each of the vapor waste streams between the sending process plants and the UPI waste treatment systems, and identified the insulation and/or heat tracing needed to keep each stream safely above its dew point throughout.



Figure 5 – Sadara 35m Wastewater Tank Construction (3)

In the end, the Sadara Project was a resounding success due in no small part to the contributions of the Utilities, Power, and Infrastructure Team that designed and installed critical OSBL facilities supporting the entire \$20 billion venture. The Sadara UPI team learned along the way how to overcome the unique process risks associated with such a megaproject, stitching together Sadara's 26 process plants so they could work together as parts of a unified whole.

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Quarterly Safety Connector



For Engineers; Because Safety Is Part Of The Process! By: Chris Palmisano, MESH, IFSAC January 2021

Coping with Work Related Stress in a Pandemic



Let's face it, 2020 has been a stressful year. Even if you are one of those people that loves their job, work related stress can occur, especially during this pandemic and the lockdown. But if work related stress becomes chronic, it can be harmful to your overall health and can even create an unsafe and or otherwise tense work environment.

Common Causes Of Work Related Stressors In 2020 Due To The Pandemic Can be Many:

- Excessive workloads due to furlough of staff
- Less opportunity for advancement
- Reduced business and income
- Lack of clarity for social distancing and sanitation
- Job security (Unclear future of your company)
- Coping with working at home

The effects of uncontrolled stress:

Work-related stress can persist and pile on. A stressful home or work environment can create a multitude of problems and even chronically affect your health, compounding the problem. People who have difficulty handling stress need to take a step back and look for ways to first identify stress, and then find ways to manage it.

Identifying & Managing Stressors:

- **Recognize:** First identify which situations create the most stress and then figure out how you are going to respond. Getting mad at everything is not the solution. Distraction is your best friend in times of stress. When things get stressful grab a healthy snack, go ride a bike or take a brisk walk. These are good ways to get the stress out of your mind. Look for patterns among your stressors, what causes you stress and your reactions to it.

- **Take the high road to distraction from stress:** Nurture healthy responses to fight stress. Smoking, caffeine, high calorie comfort foods and drinking alcohol may provide temporary relief but over time these distractions can cause you more harm than good, resulting in even more stress. The better choices to relieve stress on the high road are physical and mental activity, such as puzzles, exercise, games, hobbies, gardening and visiting family, as long as you are visiting safely. As a writer, one of the things that has helped me tremendously is writing. This lock-down may be the perfect time to start that book you always wanted to write.
- **Don't rule out professional help:** While many psychiatrist, therapists and counselors are not having one-on-one sessions with clients/patients at present, due to the pandemic, many offer telephonic and web based alternatives that can be very helpful in overcoming stressors.
- **Sleep is important:** Getting a good eight hours of sleep can also help in coping with stress. Minimizing the use of your phone and TV while in the bed room helps you sleep better. Getting a good night's sleep can, "believe it or not", also help in losing weight.
- **Cause of stress and how they deal with it is different for everyone:** One important thing to do is show empathy for others, because we all take on stress differently, including the way we react to it. The pandemic has put us all in altered situations. My job for example requires a lot of business travel, but the pandemic has me working from home due to company mandated travel restrictions. I'm sure if you asked my wife if she is happy with me being home every day, she would probably say, she'd be happier if I were back on the road. Also think about your co-workers and what challenges they might be facing. The old saying that you can catch more flies with sugar than vinegar holds true. Give others space and consideration in these times. Empathy is a treasured tool for preventing conflict with others.

One distraction I've personally taken on to reduce stress and conflict with my spouse is housekeeping. It all started out with small jobs like cleaning out closets and drawers, now it has morphed into a full scale daily routine for me. The result of my housekeeping efforts have really paid off, as my home looks magnificent. Another thing I've started doing is walking my dogs. This benefits the dogs as well as myself. Some people love to read. This is a great time to catch up on reading. These are all things that have helped me.

- **Working from home can be a doubled edged sword:** If you are in this situation due to the pandemic, establish boundaries between work-time and you-time. Just because you are home all the time, doesn't mean work should take up time that belongs to you. Set your work time and view it as having an end point in your day. That may mean making a rule not to check email and your phone past 5:00PM. People have different preferences when it comes to how much they merge work and self-time, so set boundaries and stick with them.
- **Plan for time to veg or relax.** Yoga and meditation can be really rewarding for some. The challenge is to purposefully set aside time to relax. The best time to implement relaxation is right after exercise or other physical activities.

In Conclusion: Know what stresses you and others, and don't let an urge for relief to take you down a dark path to chronic stress, depression or unhealthy habits. Keep a positive attitude, have consideration for others and have hope that we are going to get through this rough time. Hope will never let you down, giving up hope however will.*

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