Challenge of Process Development in Decarbonization Era

TNCHE ASIA 2023 CONFERENCE

Phenomena

Smog

Forest Fire

Flood

Clean Water Scarcity

Acid Rain

By Gerd Altmann

https://unicbeirut.org/UN-Guterres-Covid19-water-and-sanitation

By Pok Rie

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Activities Harmful to Environment

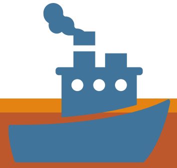
CO, CO_2 Emission

GHG Emission: CO_2, CH_4, NO_x, HCFC, HFC

Ground-Level Ozone (NOx + VOC + Sunlight $\xrightarrow{\text{Stagnant Air}}$ Ozone)

Ground-Level Ozone, along with particulate matter, is responsible for smog.

SO_x is dangerous to ecosystem and can cause acid rain. It is a by-product from heavy fuel oil combustion used in ships.



How Process Scale-up has influence on Carbon Footprint of a product

Process selection can have effects on the process performance long after design engineers are gone. Making correct selection foreseeing what's coming ahead is crucial. Obvious example is R22 refrigerant has been obsoleted and illegal to be produced and imported into Thailand starting 2030.

Start by drawing a high level process map, so to make sure you don't forget anything. There should be two separate maps,

1. Production Process
2. Design Process

This high level process map should be revisited along the duration of your scale-up project.

How Process Scale-up has influence on Carbon Footprint of a product

Inherently Safe Process Design:

1. Helps reduce inventory which may require more energy to maintain proper storage.
2. Helps select less harmful chemicals to be used.
3. Helps reduce energy by operating at less energy-consuming conditions.
4. Helps simplify, thus increase efficiency

Raw Material Handling: Reduce handling process, Recyclable Waste Raw Material, Reuse as applicable. **Think Zero Discharge.**

Raw Material Selection: Select

1. environment-friendly raw material,
2. local raw material to reduce transportation from overseas,
3. sustainable raw material.

Equipment Material Selection: Steels are recyclable. Most steels are from recycled materials. Stainless steel carbon footprint is approximately 0.39 ton of CO_2/ton of stainless steel

How Process Scale-up has influence on Carbon Footprint of a product

The Production Process itself (Scale, Type, etc.): Energy consumption, Efficiency, GHG Emission, SOx Emission.

Product Packaging: Efficiency, Low Emission, and Recyclable / Reusable packaging

By-Product Processing: Efficiency, Low Emission, and Recyclable / Reusable packaging

By-Product Usage and Value Add

Utility Chemical (Thermal Oil, Peroxide, Catalyst) Disposal: Safe to use and to store, Easy to store, Long shelf life, recyclable or has values, minimizable inventory (local supply)

Logistics (Plant Location): Optimized location considering source of material and energy

High Level Process Maps

Design Process

Supplier	Input	Process	Deliverables	Customers
1) R&D 2) Market Development Group	1) Process Design information 2) Product Information (Voice of Customers)	1) Develop (Draft) process design package for commercial scale 2) Develop process safety design package 3) Consider long-term continuous operation 4) Environment, laws and regulations 5) Consider long-term storage and storage during emergency of product, chemicals, and raw material 6) Minimizing inventory 7) Develop process design package for pilot scale foreseeing troubles in commercial scale and come up with plans to simulate condition and test it out 8) Design review with customers 9) Process Hazard Analysis 10) Design review for process efficiency 11) Carbon Footprint check	1) Process Design Package for pilot scale 2) Pilot trial plan and data collection plan	1) Pilot Plant Operators 2) R&D 3) Market Development Group

The first version of the design may not be perfect.

High Level Process Maps

Production Process

Supplier	Input	Process	Deliverables	Customers
1) Raw Material Suppliers	1) Raw Material	1) Raw Material handling and storage	1) Product in proper packaging	1) Product Customers
2) Chemical Suppliers	2) Chemicals	2) Mixing / Reaction	2) By-Product in proper packaging	2) By-Product Customers
3) Utility Suppliers	3) Utility	3) Product Transfer and Storage	3) Clean Air	3) Waste Customers
		4) By-Product treatment and storage (Find values of your by-product)	4) Clean Water	4) Surrounding communities
		5) Vent Gas treatment	5) Waste Product	
		6) Waste product handling	6) Waste Chemical	
			7) Waste Raw Material	

Some of the Necessary Activities in Development Phase

Process Hazard Identification in Lab Scale and Pilot Scale

Chemical Interaction Hazards Identification

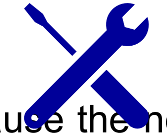
Chemical and Material Interaction Hazards Identification: Focus on main material of equipment, seals and anything in contact with process fluid, and possible accidental leakage which may cause domino effects.

Process Hazard Analysis: Continuous Process VS Batch Process VS Assembly Line or Labor Intensive Process and Maintenance Activities. In batch processes, pressure and temperature fluctuations can cause fatigue stress on equipment.

By-Product Application Exploration and Value Add

Things to Keep in Mind

Design for Ease of Assembly and Installation: Something that’s difficult to transport or install can more easily be damaged itself and can cause damages to adjacent components. Special tools and care have to be addressed.



Design for Maintenance: Think about how difficult it may cause the next technicians to work on your plant. Special tools may be required.

Design for Environment: Climate Change, Ground Level Ozone, and Water and Air Pollution.

Design for Cost Efficiency

Maintenance Training

Operation Training

From Lab Bench to Commercial Scale and to Pilot

- Visualize and Draft Commercial Scale including by-product handling unit.

- Pre-design commercial scale including waste and by-product operation for feasibility study and so the pilot scale would give you very good information for designing and commissioning the commercial scale plant

- Concepts of scaling-up of batch and continuous process: Heat and Mass Transfer, Residence Time, Transient and Steady State, FIFO, etc.

- Design robustness sometimes not covered in HAZOP review, but can be covered in FMEA or What-If Analysis.

From Lab Bench to Commercial Scale and to Pilot

- Foreseeing up-to-date technology

- Design for process safety

- Design for decarbonization.

- To increase the chance of business success in this fast-paced dynamic time and possibly more new business opportunities during carbon-emission-conscious era, design methodology to cover these perspectives has to be developed.

Translating customers requirement into specification and controllable parameters of production process

- You have 2 customers, internal customers and external customers. Therefore, voice of customers comes from both groups.

- Internal customers are production group, QA group, sales group, maintenance group, and people who make decisions or influence the decision making. Imagine yourself being charged money for difficulties arisen.

- External customers are customers of the product that your plant produces, end users, and customers who buy your competitors' product.

- Product Hazard Analysis: Analyze how customers will use, handle, and store your product

From Voice of Customers to Plant Design Parameters

- Voice of Customers is translated to Critical to Quality Specification. A systematic approach to translate customers' requirement to specification and consequently parameters to be controlled is Quality Function Deployment (QFD).

- This specification is then translated to parameters to be controlled. The plant is then designed according to parameters to be controlled.

- Parameters to be controlled cover raw material specification, operating procedures, storage, transportation, and how customers use and handle your product. This assessment is not covered in HAZOP directly. A good tool to use is FMEA.

- Sometimes VOC is not clear or not the first hand data. It may have been translated before reaching you.

From Voice of Customers to Plant Design Parameters

- ✓ You should know customers' process and how they detect failures or how each of your specifications affect their process and product. Sometimes customers just want to negotiate.

- ✓ Customers may say "I want the same product as your competitor." What does "same" mean? Translate it into measurable quantities.

- ✓ Now you know quality control is one of your priorities. It may not be your direct responsibilities, but it's something you need to consider. Completely all brand new technologies take on all the responsibilities.

- ✓ Good process and quality control reduces loss, consequently carbon footprint.

QFD – Quality Function Deployment

Quality Planning Table

Customer Needs	Importance (1-5)	Current (1-5)	Competitor A (1-5)	Competitor B (1-5)	Plan (1-5)	Improvement	Absolute	Customer Needs Weight
						0	0.0	0
						0	0.0	0
						0	0.0	0
						0	0.0	0
						0	0.0	0

Improvement is Plan / Current (Big or Small Change)

Absolute is Improvement x Importance.

Customers' Needs Weight is % Absolute of each Customers' Need per Total Absolute.

Then take each Customers' Needs breakdown to production parameters to be controlled. Each customers' need may require several controlled parameters. Each controlled parameters may cover several customers' needs.

Study chemicals to be used as raw material or utilities early in the lab and pilot scale phases.

Study how they interact with each other and other chemicals or other adjacent equipment in case of possible leakages. Example: Hot thermal fluid leaks and splashes onto very hot surface can cause fire.

Study how they interact with equipment or instrument material of construction, including seals and flexible hoses.

Doing this helps you familiarize with your chemicals and challenge you to find alternative materials. The more knowledge on your products, by-products, and chemicals you have, the easier it will be to design and the more likely your project will be successful.

Engage with process area owner, so they are too familiar with the process. This will in turn help you succeed in your project.

Process Hazard Analysis Batch vs Continuous

Parameters	More	Less	None	Reverse	As well as	Part of	Other than
Flow	High flow	Low flow	No flow	Reverse flow	Contamination	Deviate concentration	Wrong material
Pressure	High pressure	Low pressure	Vacuum				
Temperature	High temp	Low temp					
Level	High level	Low level	No level				
Time	Too long / too late	Too short / too soon					Wrong time
Reaction	Fast reaction / runaway	Slow reaction	No reaction	Reverse reaction	Incomplete reaction	Side Reaction	Wrong reaction
Mixing	Excess mixing	Poor mixing	No mixing		Foaming		
Draining / Venting	Too long	Too short	None		Deviating pressure		
Sequence	Step too late	Step too early	No sequence	Step backward	Extra action	Left out	Wrong action
Inertising	High pressure	Low pressure	None		Contamination		Wrong material
Vibrations	Too low	Too high	None				Wrong frequency

Think about abnormality, like leakage, machine malfunctions during commissioning, start-up, shut down, utility loss, and isolation. These may be consequences from assembly and installation.

Consider each step separately. The assessment can be applied to handling and transportation and storage.

Preliminary Process Hazard Analysis

Identify main potential hazards at early design stage. In a more detail design stage, HAZOP study will be conducted.

Identify potential hazards of each step in the process map, identify causes, and then design safeguards.

Inherently safe process design may be recognized at this stage.

Guidewords:

1. Hazardous substances: flammability, toxicity, reactivity, corrosivity / incompatibility, and contamination (chemical-chemical interaction)
2. Process Upsets
3. Environment
4. Equipment or Instrument Malfunction,
5. Integrity Failures (from process, material, or structures) like worn seals, structure failure, plugged vent pipe, broken belt, etc.
6. Utility Failures
7. Human Error
8. Analysis / Measurements Error
9. External Effects
10. Natural Hazards: Heavy Rain, snowfalls, Storms, Earthquake, etc.

Process Hazard Analysis of Assembly Line Type Process

What-If Analysis may be easier to apply.

Consider design robustness. Imagine you design a car. Then imagine what careless things people do to their cars on purpose or unintentionally with knowledge or lack of knowledge.

Consider safe system during normal operation, loss of utility, possible system alterations without consulting with designers, and maintenance.

Design layout considering proper access and ergonomics.

Apply digital: Rely less on human. This can be done if customers requirements are clearly translated into quantitative specifications.

Reduce labor intensity whenever possible. This sometimes requires some small invention.

Heat Transfer

Vessel Thickness: When design pressure or temperature is high, vessel wall has to be thick to withstand the stress from the exerted pressure. While minimizing this thickness, it may be unavoidable to use such thickness. When this happens, the heat transfer area, fluid velocity, or temperature difference may have to compensate for the inefficiency caused by vessel thickness. Below is equation for shell thickness calculation under internal pressure.

$$t = \frac{PR}{SE - 0.6P}$$

Allowable Stress for SS304, 316 is 138 Mpa. As temperature increases upto 156 degC, strength decreases.

For jacketed vessel, design engineers have to look up allowable pressure on the applicable chart or use software to calculate.

You should preliminarily calculate the vessel wall thickness to have a sense of time it would take to transfer heat between product and heat transfer fluid or heater. Other forces applied, like agitator or screw loads or bending moments that happens on horizontal reactors, will result in additional thickness.

Heat Transfer

Heat Transfer Area: Calculate heat transfer area per volume in the scale-up process. Vessel wall thickness may have to be taken into account.

When vessels operate in cooling and heating mode alternatingly, transient state to be calculated accordingly.

Sometimes coating to prevent rust or corrosion can reduce heat transfer ability. Current development of these materials has been made to improve heat transfer performance.

Dead Zone Consideration

- Performing CFD can help eliminate a lot of dead zones and achieve good heat and mass distribution.

- Small components in pipelines are often overlooked.

- Minor internal parts (supports, instruments, nozzles) in reactors may sometimes not be incorporated in the CFD model

- Change in properties of viscosities during reaction or after reaction. Consider both transient and steady state.

- This is why having visualization of commercial scale equipment is very important.

Long-Term Process Performance

- Accumulative heat
- Accumulative material in vessels or pipelines. If this accumulative material is still active, further reaction may occur.
- Equipment and Instrument Reliability and Suitability to process fluid
- Operator Activities: Consistency of operators' performance
- Maintenance Activities
- Expected Preventive Maintenance Frequency
- Periodic Cleaning
- Equipment Robustness to normal use and cleaning
- PLC and DCS Reliability
- While it is difficult to imagine how product or by-product may accumulate in reactor or piping systems over time, it should be observed in lab scale and prepare for cleaning in larger scale pilot. This accumulation may or may not occur in the commercial scale. Thoroughly assess the accumulation in pilot scale to predict what would happen in the commercial scale.

Carbon Emission

Carbon Emission is classified into 3 scopes

Scope 1: Direct Emission

Scope 2: Indirect Emission from purchased energy

Scope 3: Production of purchased material, discarded materials, transportation, and waste disposals

Vent Gas Treatment

- Flare
- Off-gas Recovery
- Activated Carbon
- Wet Scrubber
- Thermal Oxidizer
- Bio Scrubber

Selection of which system to use depends on vent gas components, concentration, available and required utilities, and feasibility. Some systems may generate by-product or liquid or solid waste.

Think about energy consumed and generated by the vent gas treatment system. Can such energy can be converted into useful energy?

Inherently Safer Process Design

- Safer utility and raw material chemicals used
- Lower process and transport temperature and pressure
- Reduce inventories: short transfer pipelines, continuous process equipment (as opposed to batch-wise)
- Less concentrated hazardous chemicals like acid and base
- Consider on-site and off-site.
- Build production team capabilities.
- Simplify production procedures and eliminate possibilities for human error.

Manpower Planning

How much background knowledge does your operator need to have? Each process varies in troubleshooting ability requirement.

Processes that could yield several different results when something is changed require personnel with more engineering and science background.

Qualification of personnel determines operating cost. This means the simpler the process design, the lower the operating cost.

Think about cost from quality control, e.g. sample collection, sample measurement, lab technicians, and equipment maintenance cost.

Packaging

- Recyclability
- Ease of filling and closing
- Ease of transportation
- Ease of storage
- Ease of usage: Easier to open and empty
- Robustness and Appropriate Durability
- Shelf Life
- Warning Labels

Positive Things you can do if all else are unavoidable

- Process Design is a rolling process. Follow up with your customers and continue to improve.
- Preserve water and use it efficiently.
- Think of waste handling projects
- Think of clean water projects
- Support clean energy projects
- Plant trees.
- Implant these concepts in younger generation.
- Taking initiatives too late or too soon could cause financial problems.