PROCESS OPERABILITY
Why Operability?

Is design complete when we have a solution for the base case material and energy balances?

What could go wrong with a plant design that satisfied the M&E balances correctly for the base case?

It could be unsafe, unreliable, be unable to satisfy production quantity or quality changes – and many more deficiencies!

We have a base case design but is it operable? Will it function for years in many situations?

A concise definition of operability*

Process operability

Ensuring that the plant has the capacity and flexibility to achieve a range of operating conditions safely, reliably, profitably and with good dynamic performance and product quality.

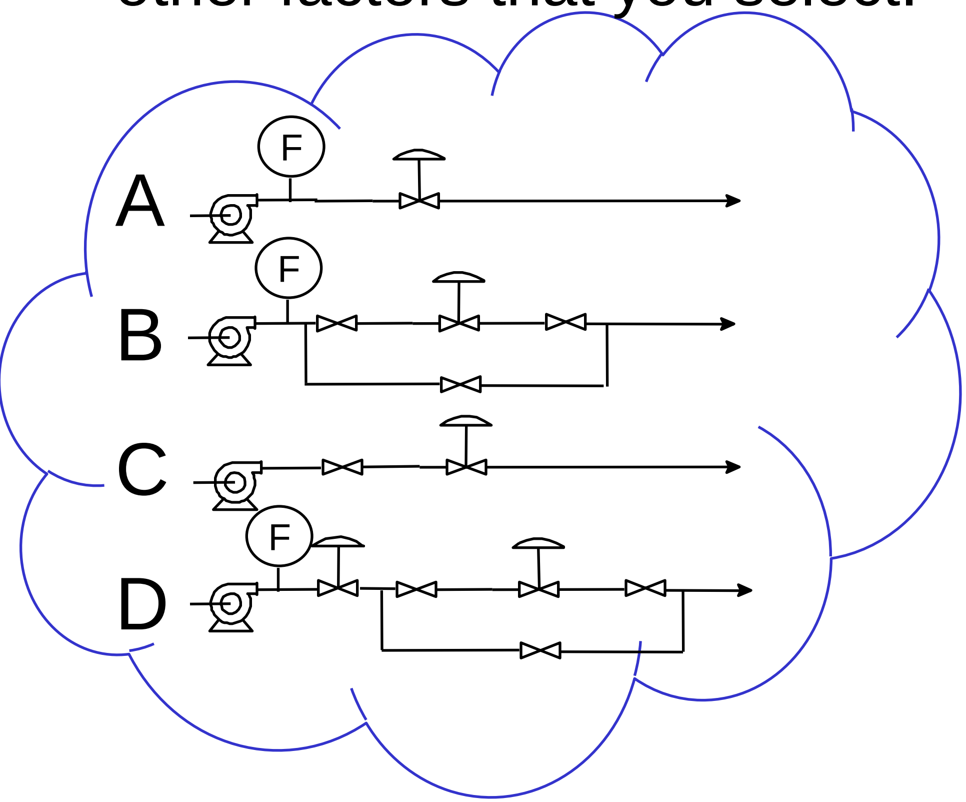
Some engineers prefer the term "Robust Design". The two terms have the same general meaning.

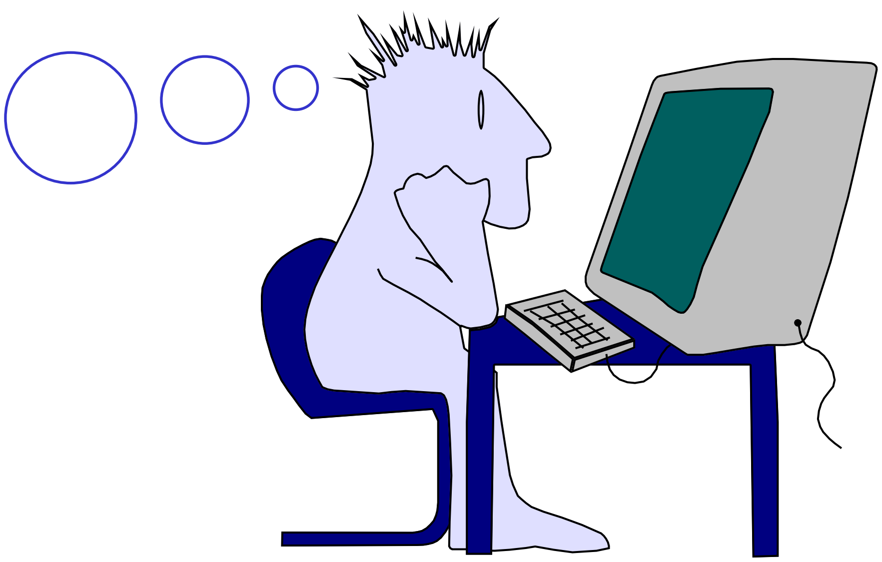
* Useful for concise description but not enough detail to guide engineering decisions.

Class workshop

We need to regulate the flow, but how complex should the equipment be?

Rank designs for simplicity, cost, reliability, flexibility and other factors that you select.





Process operability

Roadmap for this lesson

- What will we learn in this lesson?
  - review the basic Process Design Procedure
  - Locate Operability analysis in the design procedure
  - Identify Causes of Variability in process plants
  - Introduce the Eight Operability Topics
  - Present the Learning Goals for the operability topic

Used in all future problem solving

A process design procedure

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flow sheet
- Design equipment

Often performed for only 1 operating point, called the "**base case**"

Construct and start up

Operate the plant over a range of conditions, including many operating points and transitions between them

Inconsistency!

Operability prevents this inconsistency!

Operability: when do we introduce it in the design procedure?

Design Procedure

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flow sheet

  The flow sheet typically involves basic M&E balances, equilibrium and rate processes. It does not consider practical issues for achieving the operation.
- Design equipment

  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.

Operability: when do we introduce it in the design procedure?

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  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.

We must define the range of operations and goals to achieve before we begin the design!

Design limited to the "base case" is not likely to be satisfactory.

We have to know where we are going before we can design!

Design Procedure

- Set goals and design specifications
- Select process technology
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  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.

The design must define the range of operations to be achieved.

We can accept less than full production rate or top efficiency for extreme situations.

We must document specifications and range for operations and review with all stakeholders!

Operability: when do we introduce it in the design procedure?

Design Procedure

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flow sheet

  The flow sheet typically involves basic M&E balances, equilibrium and rate processes. It does not consider practical issues for achieving the operation.
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  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.

This might influence the range of operations!

For example, a fluidized bed reactor could have a smaller range of flow than a packed bed.

Operability: when do we introduce it in the design procedure?

Design Procedure

- Set goals and design specifications
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This might influence the range of operations!

For example, the addition of a recycle stream might allow a wider range.

Operability: when do we introduce it in the design procedure?

Design Procedure

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flow sheet

  The flow sheet typically involves basic M&E balances, equilibrium and rate processes. It does not consider practical issues for achieving the operation.
- Design equipment

  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.`

Some of the flow sheet variables, such a distillation feed location and reactor volume, influence the achievable range of operations.

Operability: when do we introduce it in the design procedure?

Design Procedure

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flow sheet

  The flow sheet typically involves basic M&E balances, equilibrium and rate processes. It does not consider practical issues for achieving the operation.
- Design equipment

  Equipment design achieves the base case flow sheet (plus other concerns). This sets the "capacity" of the plant.

Equipment design has a very strong influence on the range of plant operation.

Again, satisfying the "base case" is not sufficient.

A process design procedure with operability

- Set goals and design specifications
- Select process technology
- Define process structure (sequence)
- Simulate the flowsheet
- Design equipment

Operability analysis

Iterate as needed

Construct and start up

Operate the plant over a range of conditions, including many operating points and transitions between them

Process design with operability

The design procedure should ensure that the plant is operable, that it functions "well". This requires a specification that addresses a range of conditions.

What are causes of deviation from base case conditions?

1. Changes to operations introduced by plant personnel deliberately

- We need to match production rate to sales
- We often produce multiple products and some products are made at different qualities (grades)
- We often process various feed materials

Process design with operability

The design procedure should ensure that the plant is operable, that it functions "well". This requires a specification that addresses a range of conditions.

What are causes of deviation from base case conditions?

2. Disturbances - Many "external" variables change from their assumed base case values. We refer to these as disturbances - really normal variation in the plant.

Examples are feed composition, ambient temperature, cooling water temperature, catalyst deactivation, heat exchanger fouling, etc.

Process design with operability

The design procedure should ensure that the plant is operable, that it functions "well". This requires a specification that addresses a range of conditions.

What are causes of deviation from base case conditions?

3. Mismatch in design models – Our predictions are imperfect - not useless, just contain some errors.

Examples include equilibrium, rate processes, and efficiencies. We compensate for these errors through flexibility.

If we rely on *perfect* models, the plant will not likely operate as expected.

Process design with operability

The design procedure should ensure that the plant is operable, that it functions "well". This requires a specification that addresses a range of conditions.

What are causes of deviation from base case conditions?

4. Equipment malfunction – Plants operate for months (or years) without stopping, but process equipment sometimes requires immediate maintenance.

- control valves
- heat exchangers
- motors and pumps

We need to perform some maintenance without stopping the (entire) plant, and respond safely to all faults.

Process design with operability

The design procedure should ensure that the plant is operable, that it functions "well". This requires a specification that addresses a range of conditions.

What are causes of deviation from base case conditions?

5. Human error – People make many important decisions in the plant, and inevitably, errors occur.

A single human error should not

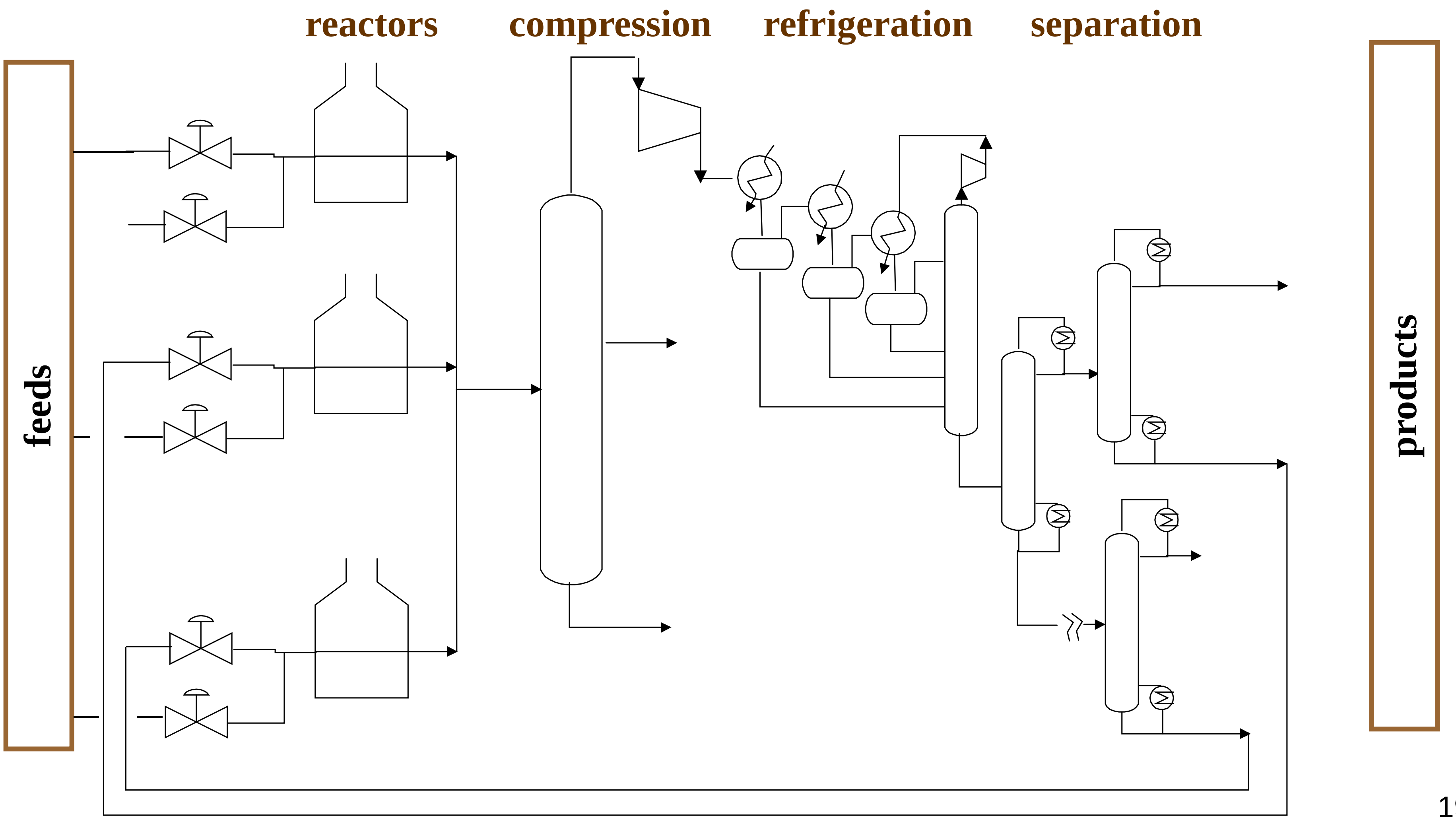
- cause an unsafe condition

- cause environmental damage

- remain undetected (to enable fast correction)

Operability Class Workshop

Identify key design specifications that could change and whose ranges and frequency must be defined in a Design Basis Memorandum.



Operability Class Workshop

Identify key design specifications that could change and whose ranges and frequency must be defined in a Design Basis Memorandum.

Identify a few sources of variability for each of the five categories

1. Changes by Plant Personnel (meet product demands, achieve high profit, etc.)		
2. Disturbances (undesired and uncontrollable variability)		
3. Model Mismatch (deviation of plant from design models)		
4. Equipment malfunction (partial or total loss of function)		
5. Human Error (inadvertent action)		

Causes of Variability

These are just some examples. There are many other correct answers.

1. Changes by Plant Personnel (meet product demands, achieve high profit, etc.)		
Feeds: Feed flow rate	Plant Operations: Reactor severity/conversion Reactor yields/selectivity Refrigeration temperatures Distillation pressures	Products: To storage or to pipeline
2. Disturbances (undesired and uncontrollable variability)		
Feeds: Compositions	Environment: Ambient temperature, e.g., • cooling water • need for steam tracing Disturbances, e.g., • rain storms	Utilities: Fuels Steam Recycles: Flow or composition
3. Model Mismatch (deviation of plant from design models)		
Reactors: Yields at specific operating conditions	Energy Units: Efficiency of furnaces Efficiencies of compressors	Separation: Condenser and reboiler duties for specific separation
4. Equipment malfunction (partial or total loss of function)		
Out of service: Failure (stoppage) of compressor	Leak: Heat exchanger leak	Loss of utility: Sufficient steam Compressed air
5. Human Error (inadvertent action)		
Improper operating condition: Too low a flow to furnace/reactor Too low a suction pressure to compressor	Rate of Change: Change conditions too quickly, e.g., feed flow rate	Incorrect variable: Manually close a valve that should remain open

PROCESS OPERABILITY

Ensuring that the plant has the capacity and flexibility to achieve a range of operating conditions safely, reliably, profitably and with good dynamic performance and product quality.

By learning about process operability, we will be able to design processes that respond well to variability, just the way a well-designed automobile responds well to curves, bumps, and demands to accelerate and brake quickly.

OK, so how will we organize the study of operability?

Key Operability issues

1. Operating window

2. Flexibility/ controllability

3. Reliability

4. Safety & equipment protection

5. Dynamic operation & product quality

6. Operation during transitions

7. Efficiency & profitability

8. Monitoring & diagnosis

OPERABILITY TOPICS WILL BE GROUPED INTO EIGHT CATEGORIES

These are the eight categories of operability topics that you will learn and apply to many process examples.

We will

- **Learn eight of the most common operability issues**
- **Understand typical designs through many class workshops**

To learn, we must see <u>many examples</u>!

OPERABILITY TOPICS WILL BE GROUPED INTO EIGHT CATEGORIES

The design procedure involves balancing many objectives, including the eight operability issues.

Sometimes, we call this multi-objective design or multi-disciplinary design.

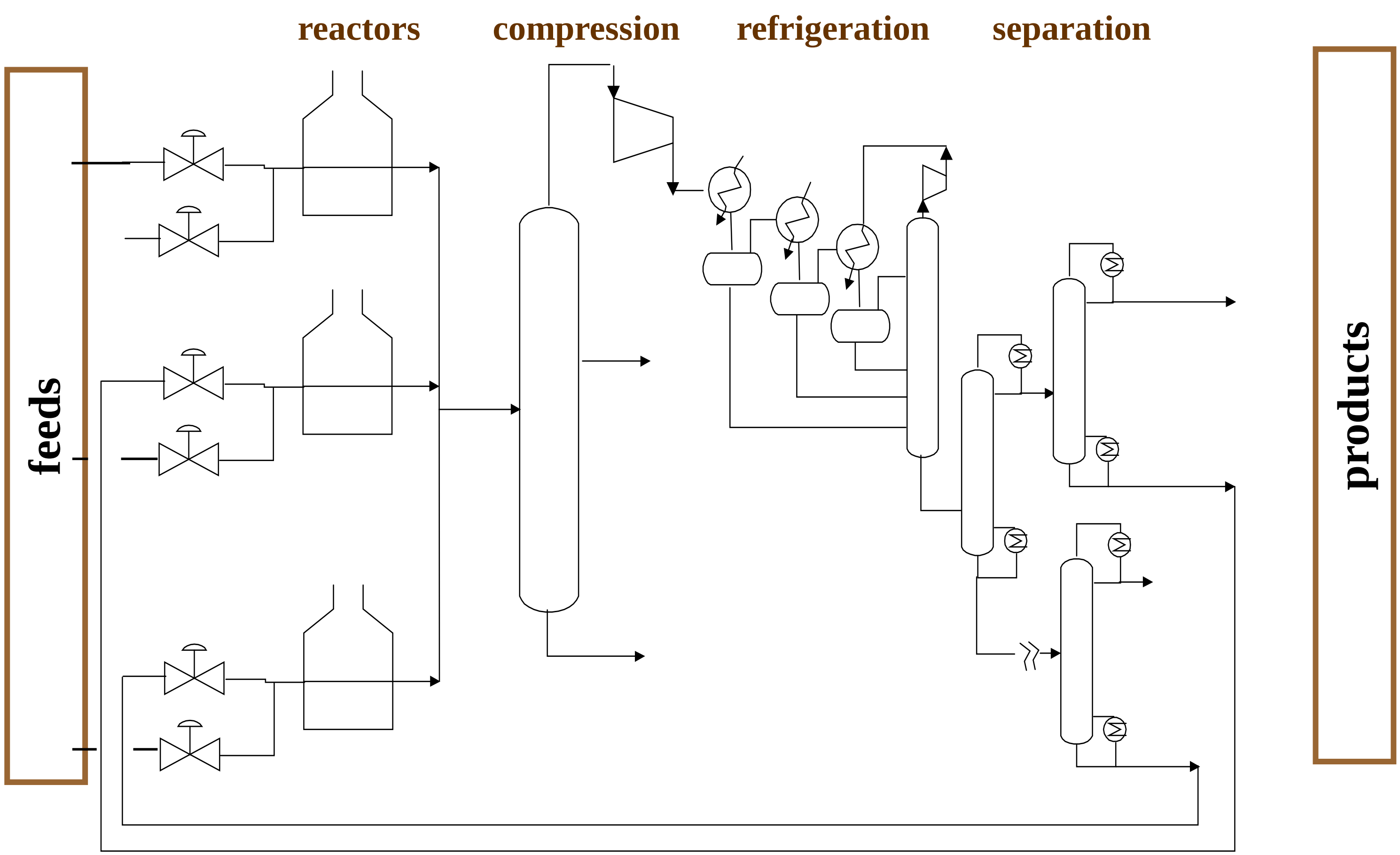
One way to combine disparate objectives is through economics, but objectives like safety and contracted product delivery and quality must be satisfied, regardless of cost. (If they cannot in a profitable manner, we do not proceed with the project.)

Key Operability issues

1. Operating window
2. Flexibility/ controllability
3. Reliability
4. Safety & equipment protection
5. Dynamic operation & product quality
6. Operation during transitions
7. Efficiency & profitability
8. Monitoring & diagnosis

Operability Class Workshop

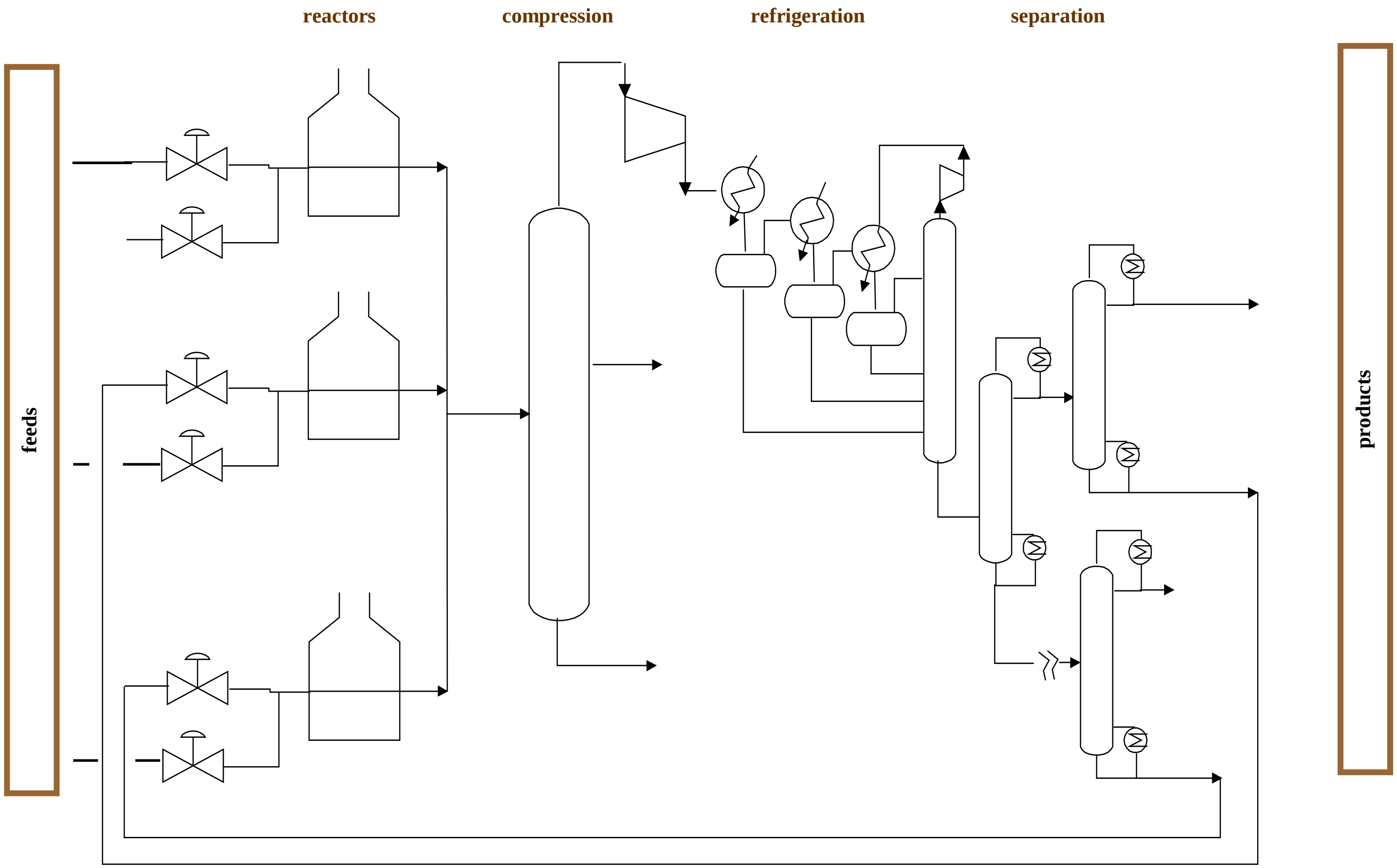
For the plant sketched below, identify one operability issue in each of the eight categories, and for each, propose a design to attenuate its effect.*



*** You have not been given much detail about the process or at this point, specific designs for operability. Therefore, don't expect to get a perfect answer now; just do the best you can with the knowledge that you have. You will learn about solutions in many lessons on operability.***

Workshop Solution – Operating Window

The production rate will be changed frequently (daily) to match sales demands. Therefore, the flow rates through the plant will vary and the equipment must be able to accommodate these changes.

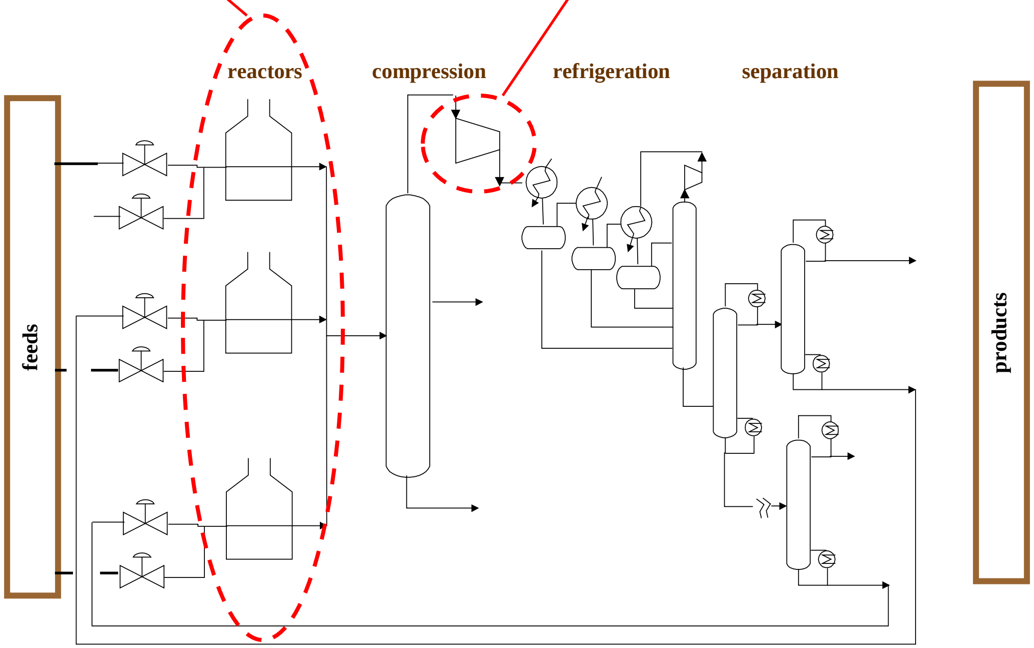


Workshop Solution – Operating Window

The production rate will be changed frequently (daily) to match sales demands. Therefore, the flow rates through the plant will vary and the equipment must be able to accommodate these changes.

a. The reactors process sufficient feed to produce the desired products. This rate can vary significantly.

b. The set of series compressors increase the pressure from slightly above atmospheric to about 30 atmospheres. The work required depends on the flow rate



Key Operability issues

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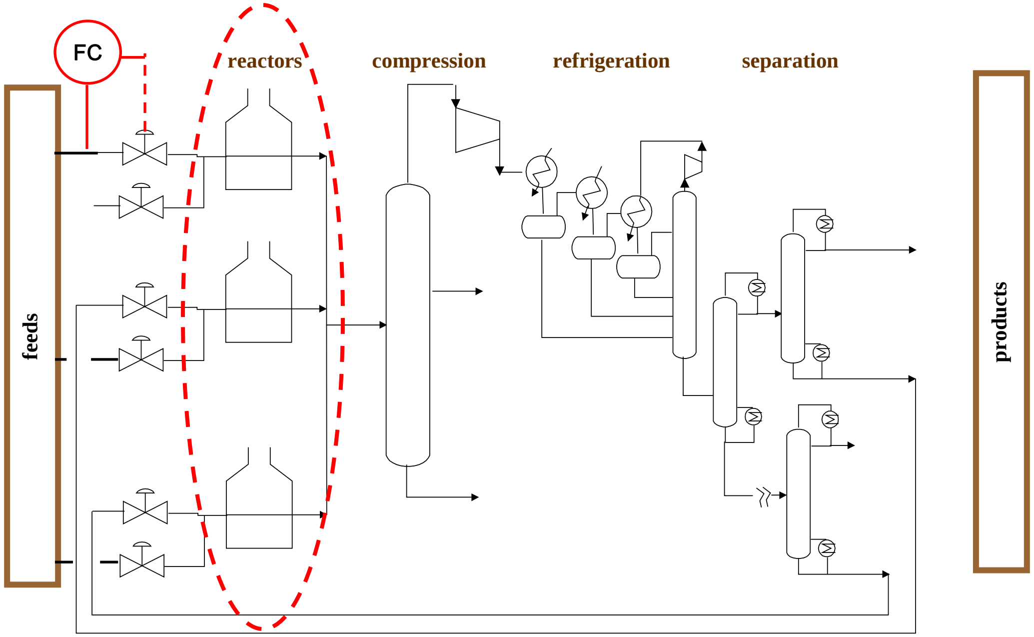
Workshop Solution – Operating Window

a. The reactors process sufficient feed to produce the desired products. This rate can vary significantly.

1. *A flow sensor and controller is required to maintain the feed rate at its desired value.*

2. *The allowable flow rate for a reactor is about 70%-110% of the base case design value. Therefore, multiple reactors are provided. To reduce the flow below 70% of design, one (or more) reactors can be shutdown.*

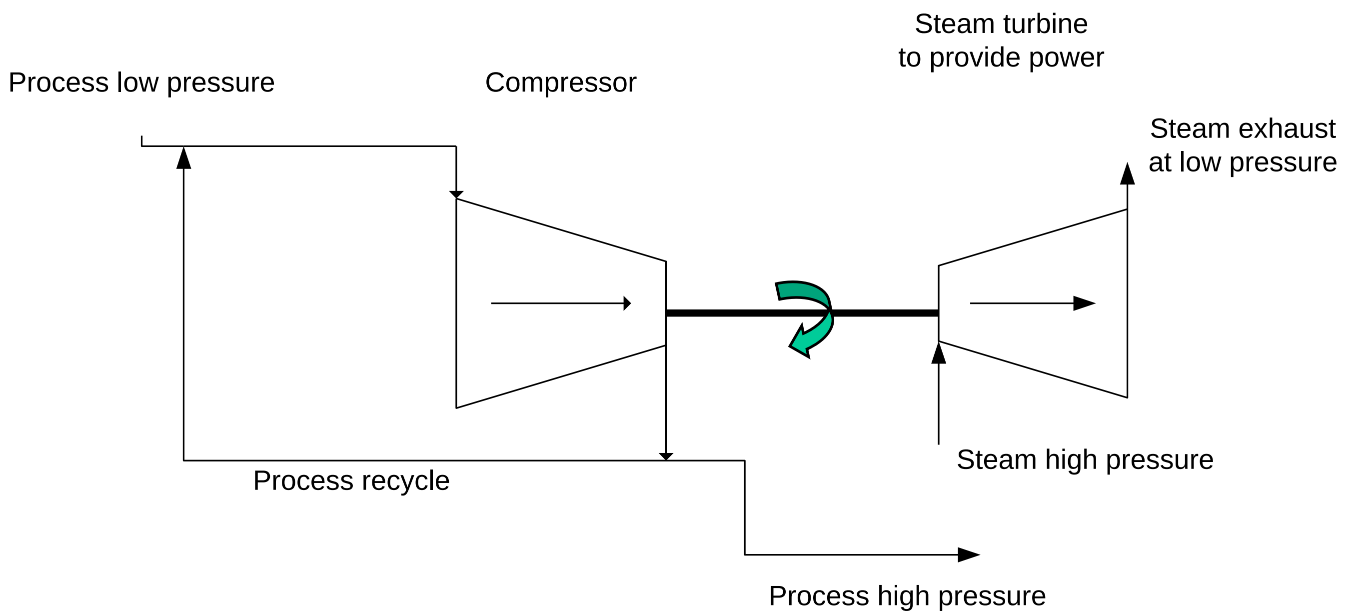


Workshop Solution – Operating Window

b. The set of series compressors increase the pressure from slightly above atmospheric to about 30 atmospheres. The work required depends on the flow rate

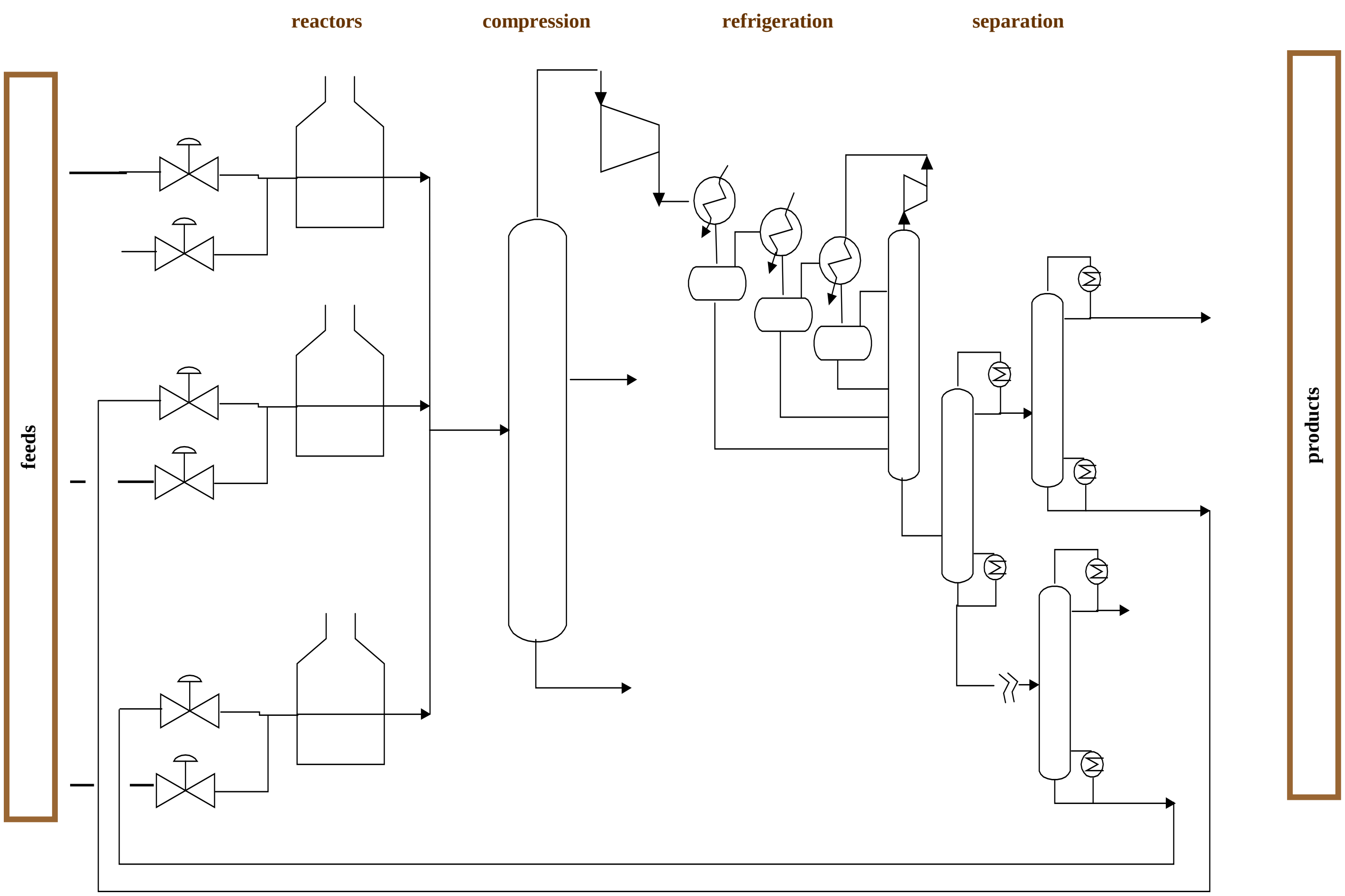
We provide the compressor with a source of power that has the required maximum capacity and can variable flow rate, including a much lower flow rate than the base case design. One way to achieve this is to provide a power source that is large enough and a recycle so that all gas passing through the compressor does not have to flow to the distillation section.

Here, the power source is a steam turbine, which is like a "reverse compressor". The turbine rotates and since is connected by a axle, the compressor is rotated. An electric motor could also be used.



Workshop Solution – Flexibility

We must provide equipment to ensure that the desired production rate can be achieved and to make the operation as easy as possible for the plant personnel.

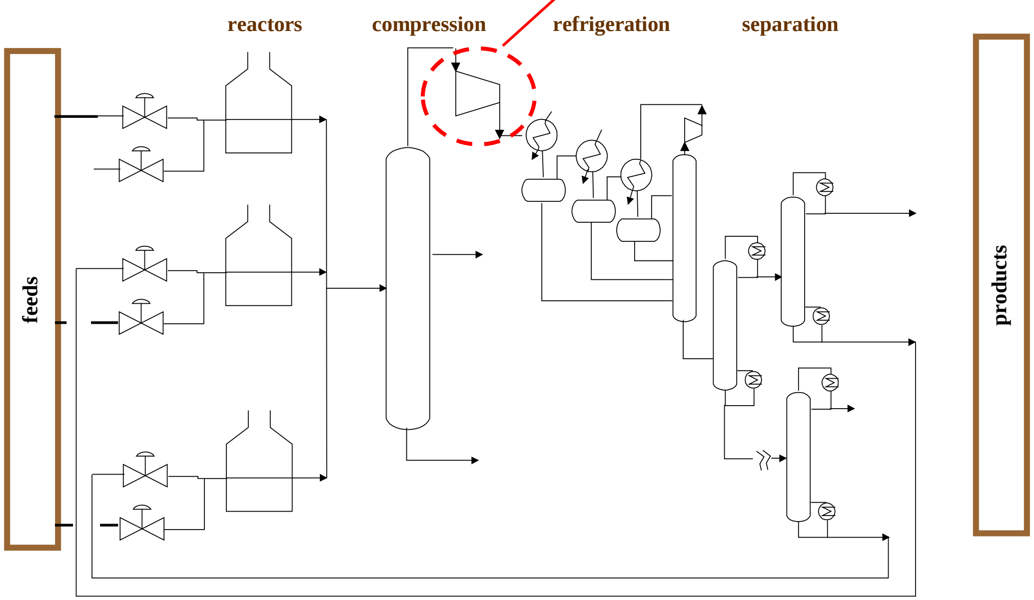


Workshop Solution – Flexibility

We must provide equipment to ensure that the desired production rate can be achieved and to make the operation as easy as possible for the plant personnel.

a. The required work must be provided and should be provided without frequent intervention by plant personnel.

b. The recycle flow should be used when needed. Note that centrifugal compressors have a minimum flow; if flows below this limit occur, the compressors experience "surge" or flow reversal and potentially severe damage.



Key Operability issues

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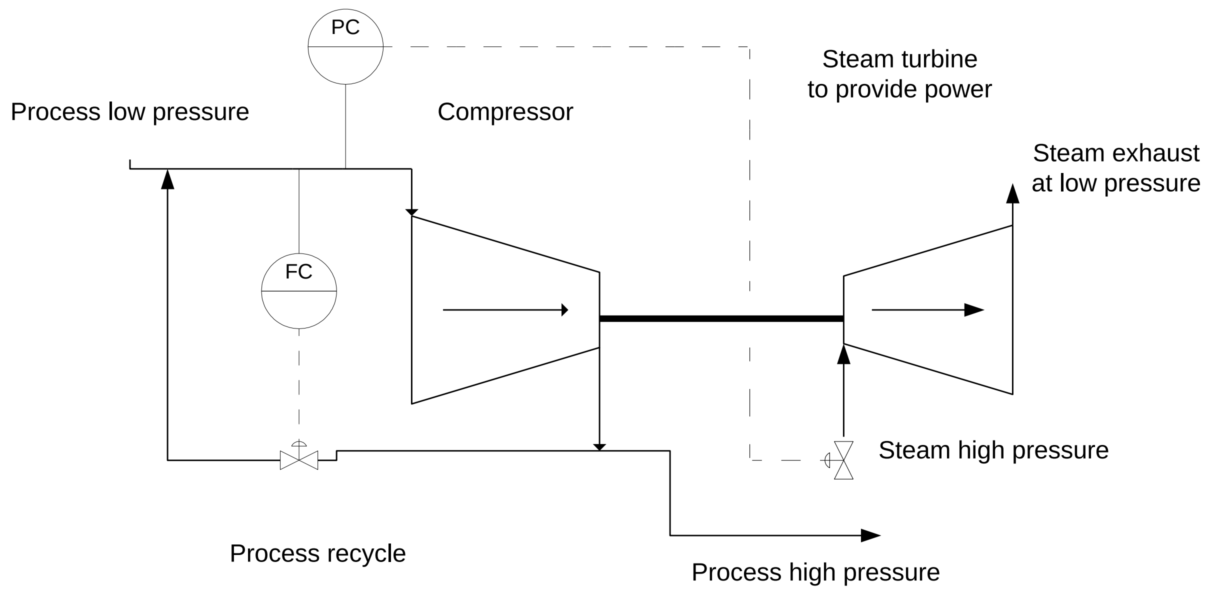
Workshop Solution – Flexibility

a. The required work must be provided and should be achieved without frequent intervention by plant personnel.

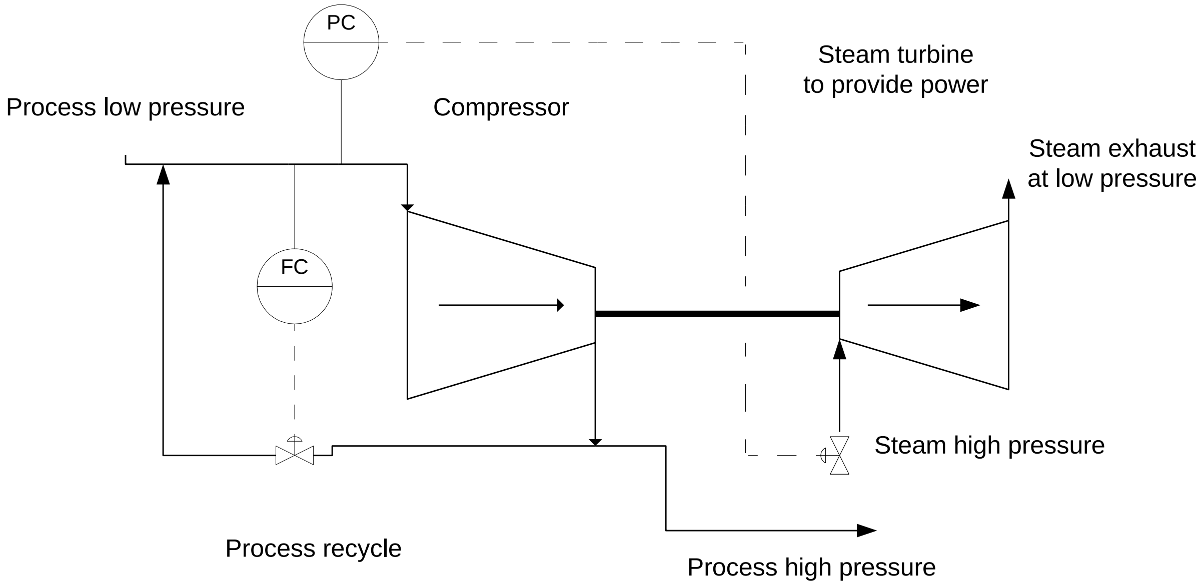
This is achieved by adjusting the steam flow to the turbine. The amount of steam is determined by a controller that maintains the compressor suction pressure at the desired value. For example, if the pressure increases, the flow through the compressor is too low, and the controller increases the flow rate of steam to the turbine.



Workshop Solution – Flexibility

b. The recycle flow should be used only when needed. Note that centrifugal compressors have a minimum flow; if flows below this limit occur, the compressors experience “surge” or flow reversal and potentially severe damage.

The flow rate through the compressor is measured. If this measured value is below the minimum, the controller adjusts the recycle valve to maintain the inlet flow rate at the minimum. Note, when the process flow rate without recycle is greater than the minimum, the controller closes the recycle valve, which is desired to prevent wasting energy.



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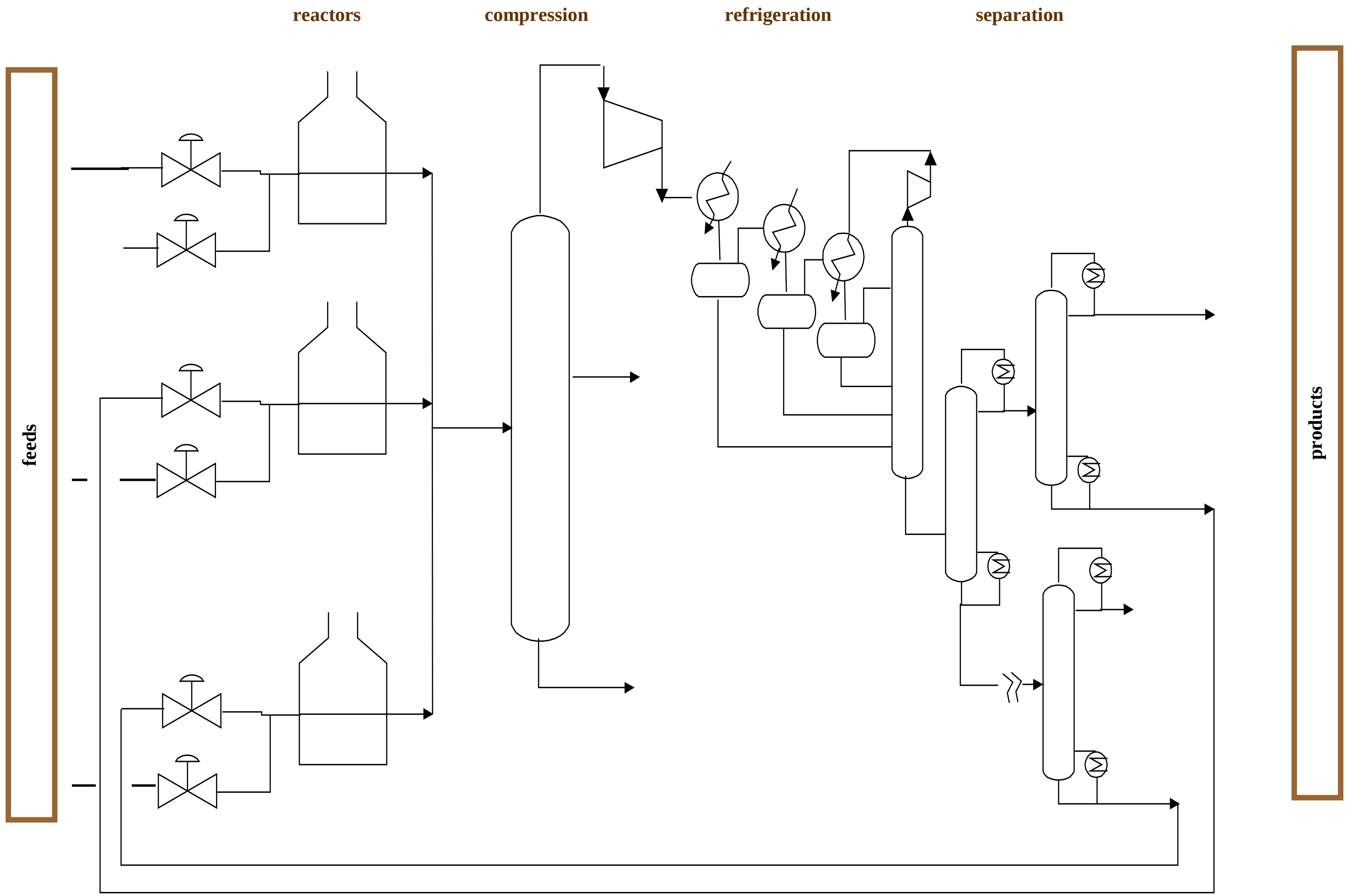
Operability Topics

Workshop Solution – Reliability

We must provide equipment to ensure that the desired production rate can be achieved and to make the operation as easy as possible for the plant personnel.

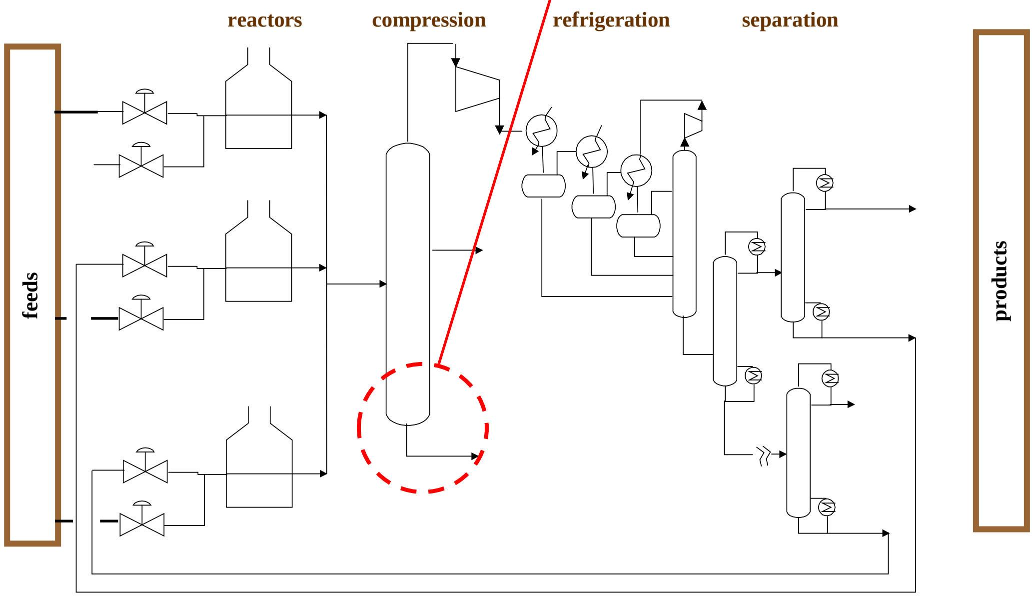


Workshop Solution – Reliability

We must provide equipment to ensure that the desired production rate can be achieved and to make the operation as easy as possible for the plant personnel.

Equipment malfunction should have the least effect on the overall plant behavior possible, without requiring very expensive additional equipment.

The liquid product from the bottom of the fractionator is pumped to storage, and pumps and drivers can fail to perform properly.



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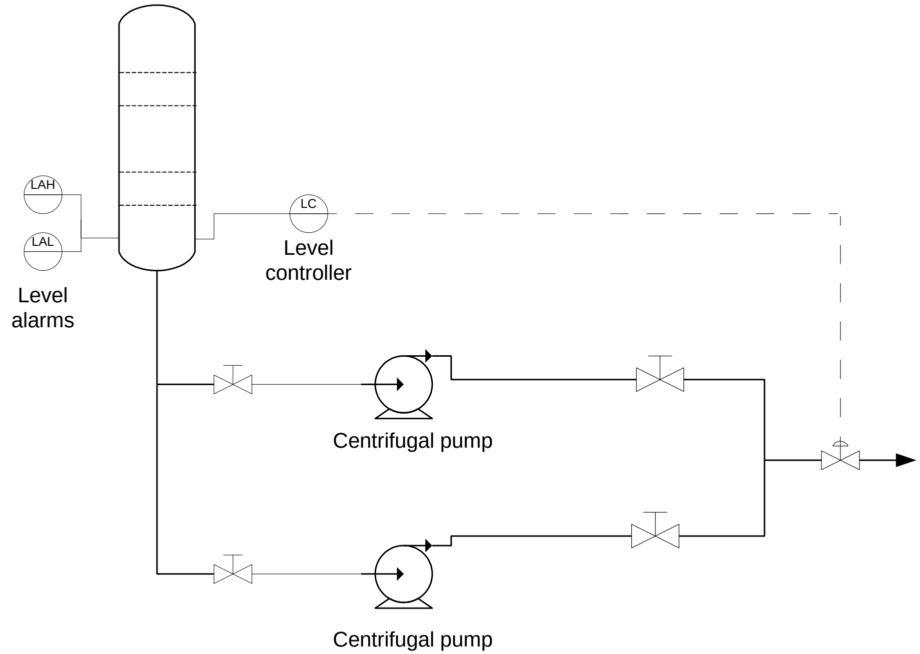
Workshop Solution – Reliability

Equipment malfunction should have the least effect on the overall plant behavior possible, without requiring very expensive additional equipment.

The design includes two pumps, with valves so that either can be in operation while the other is isolated from the process and under repair.

The level is measured and controlled to withdraw the correct amount of product. Level alarms are included to warn the operator of unusual situations.



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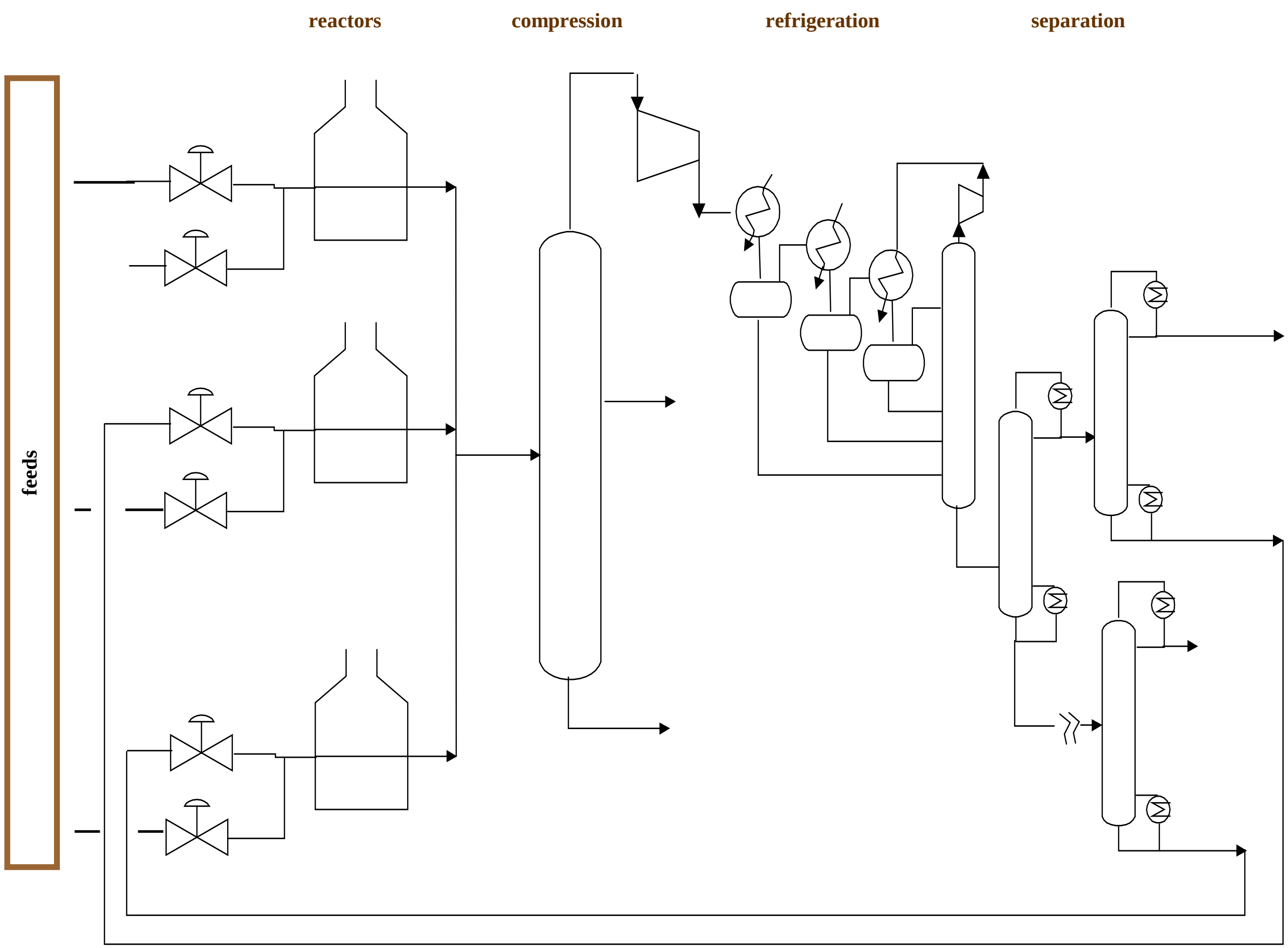
Operability Topics

Workshop Solution – Safety

Equipment is designed to operate within specific limits of pressure and temperature.



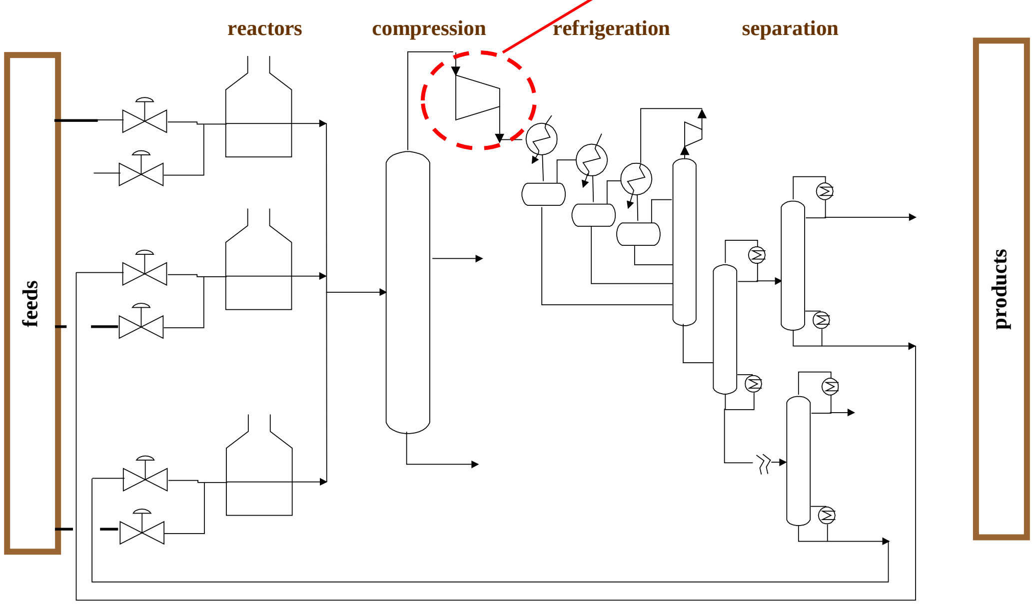
Workshop Solution – Safety

Equipment is designed to operate within specific limits of pressure and temperature.

The compressor suction pressure has upper and lower limits.

a. The upper limit is to protect the equipment from overpressure and failure, releasing hazardous gases to the environment.

b. The lower limit is to prevent the process pressure from being below atmospheric, which might lead to a leak introducing oxygen into the process hydrocarbon stream.



Workshop Solution – Safety

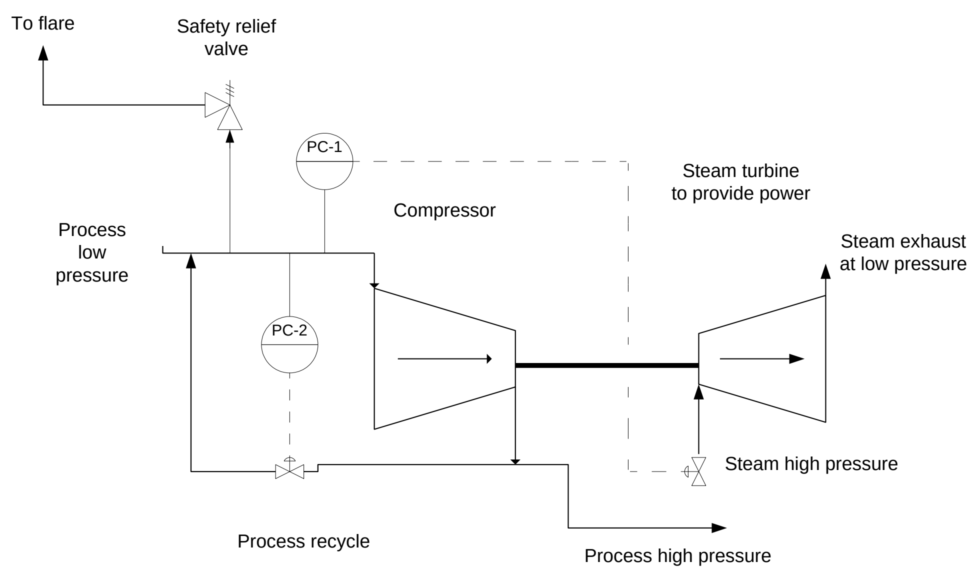
The compressor suction has upper and lower limits.

a. The upper limit is to protect the equipment from overpressure and failure, releasing hazardous gases to the environment.

A safety valve is located in the suction; it will open and provide a path to a safe location for storage or disposal.

b. The lower limit is to prevent the process pressure from being below atmospheric, which might lead to a leak introducing oxygen into the process hydrocarbon stream.

An additional pressure controller, PC-2, is added to open the recycle valve to prevent low pressures. (Note, that this must function in conjunction with the low flow recycle; the details are not shown here.)



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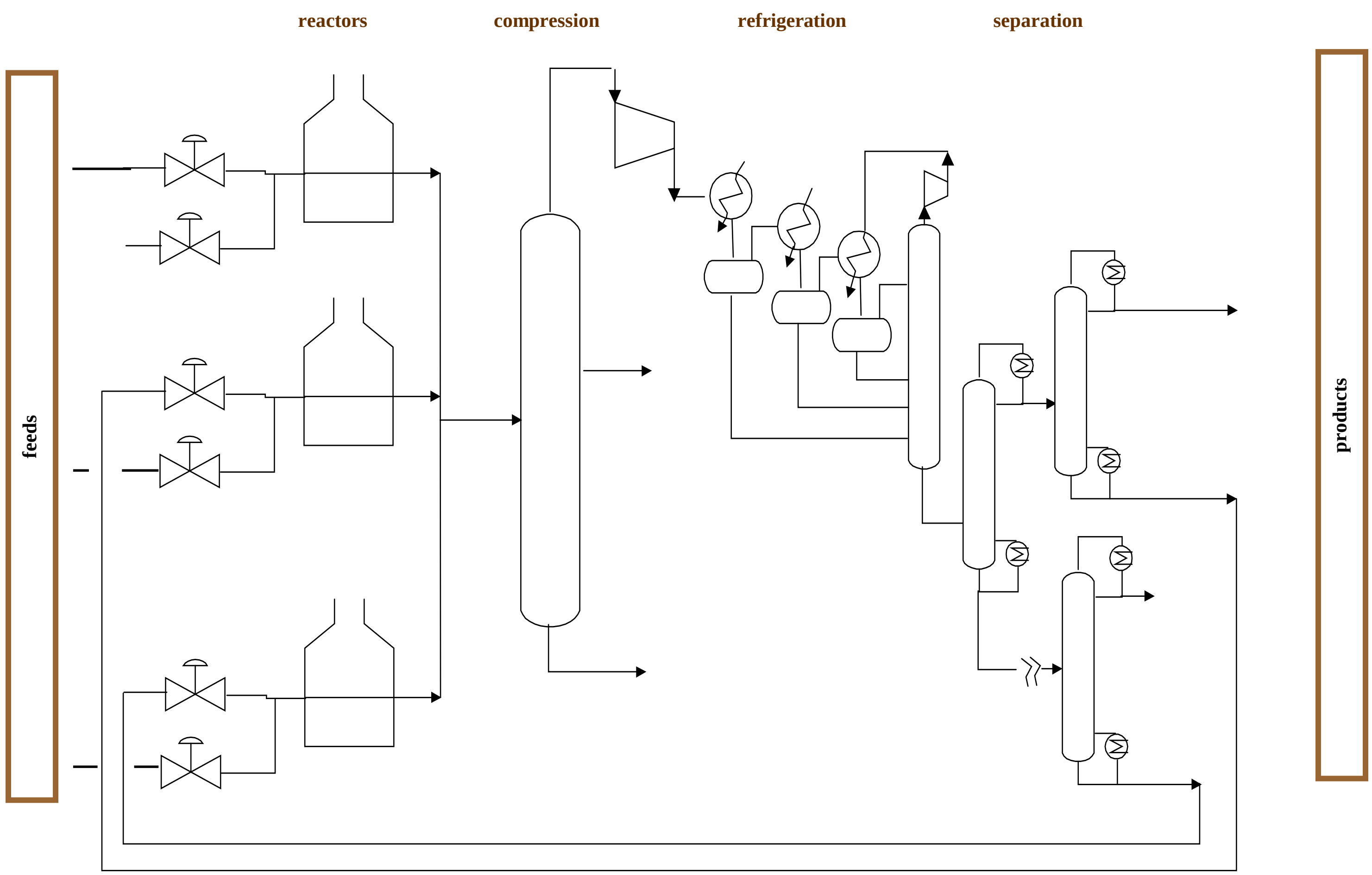
Workshop Solution – Product Quality

Operability Topics

The ethylene product is used on polyethylene reactors, which require very pure feed.



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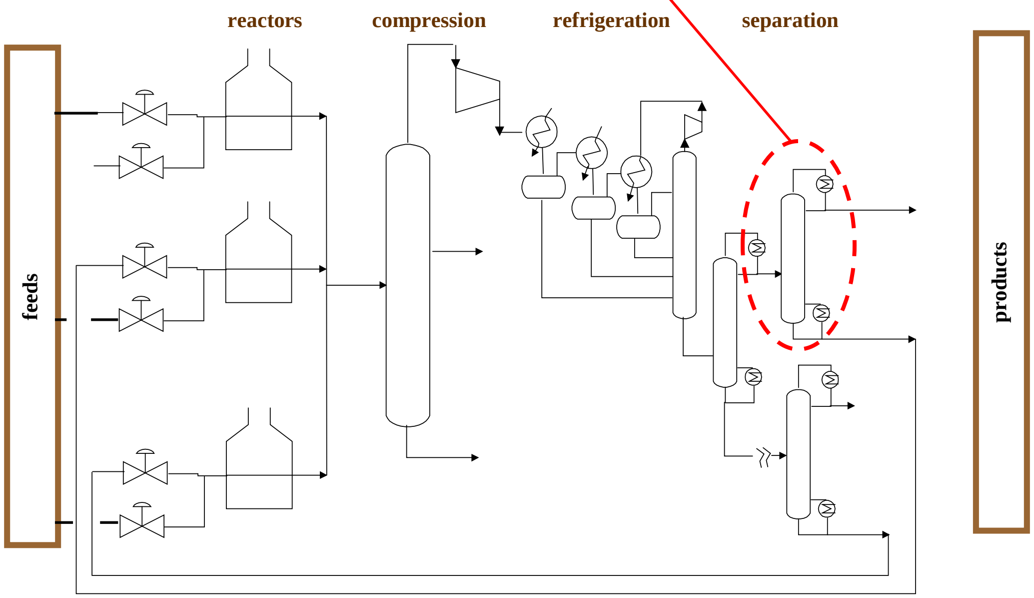
Workshop Solution – Product Quality

The ethylene product is used on polyethylene reactors, which require very pure feed.

The operation of a high purity distillation column is challenging. Simply setting the conditions (reflux, reboil, etc.) and expecting to achieve the desired purities is not an acceptable strategy.



Workshop Solution – Product Quality

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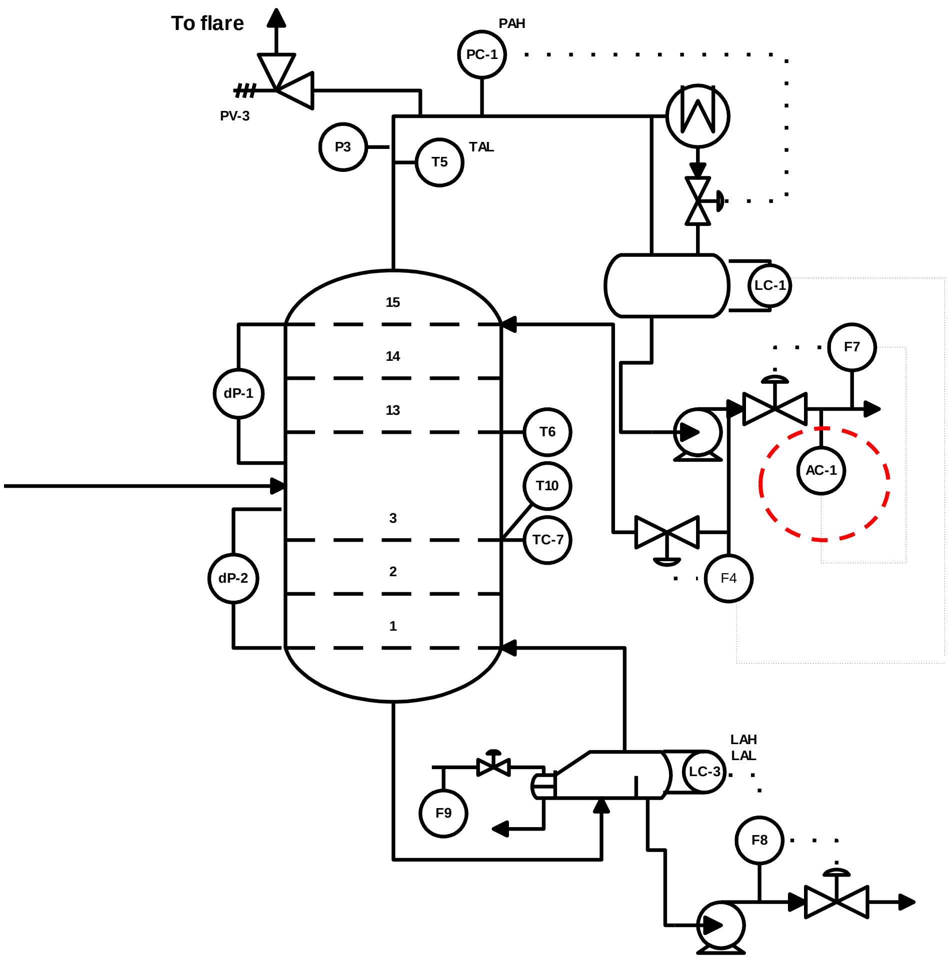

We install an on-stream analyzer to measure the concentration (ppm) of methane and ethane in the ethylene product.

The measured value of ethane is controlled by a feedback controller adjusting the distillate flow rate.

The methane cannot be influenced by this distillation unit. If methane is too high, the product must be sent to waste

Key Operability issues

1. Operating window

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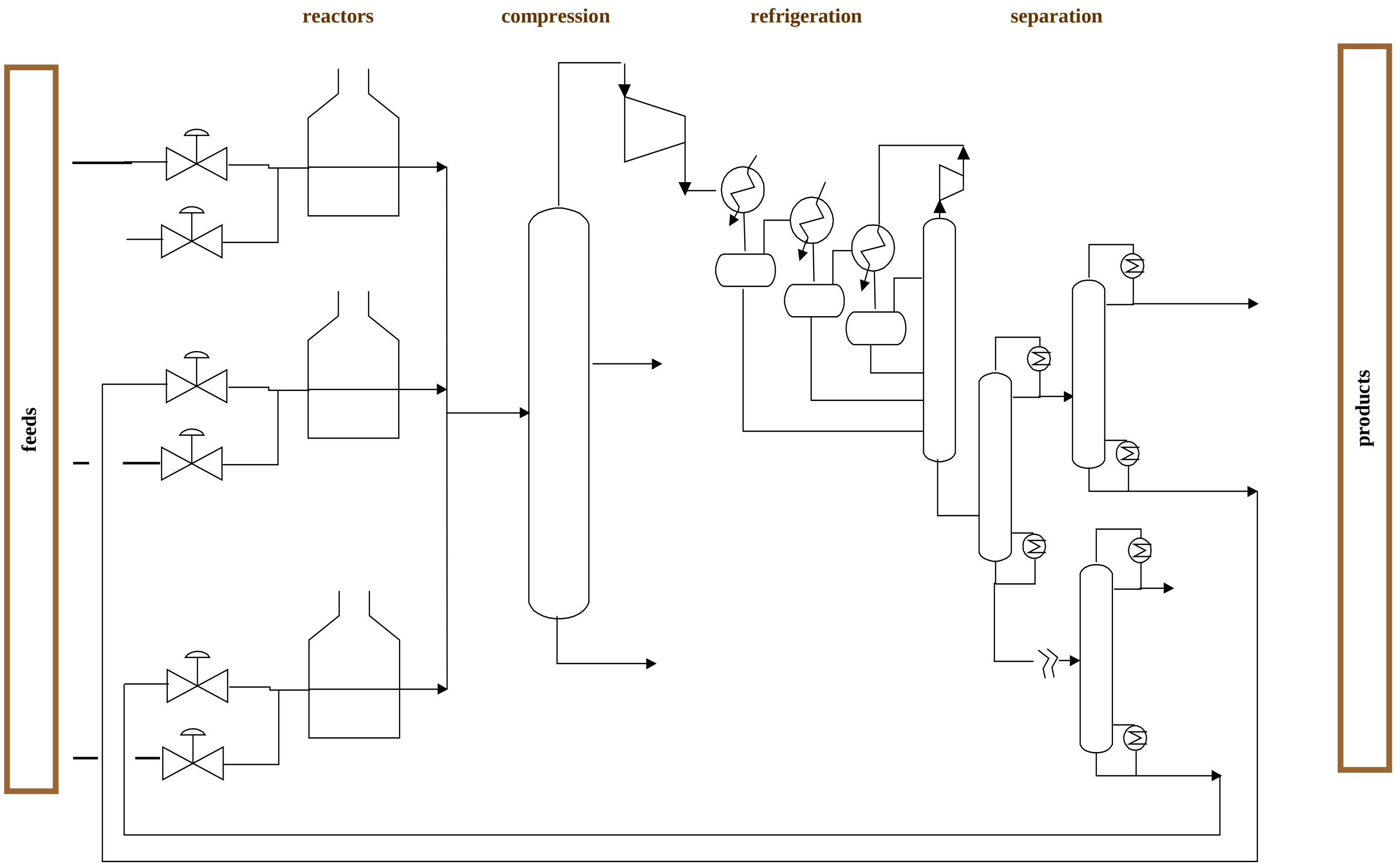
Workshop Solution – Operation During Transitions

Equipment must be taken out of service periodically for maintenance without stopping the entire plant..



[Key Operability issues]

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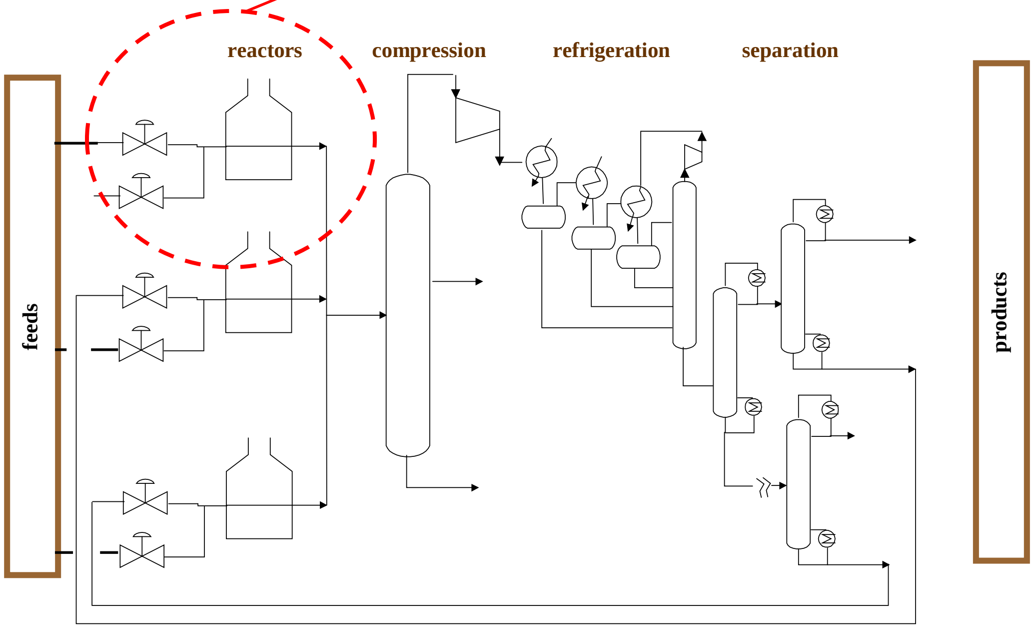
Workshop Solution – Operation During Transitions

Equipment must be taken out of service periodically for maintenance without stopping the entire plant..

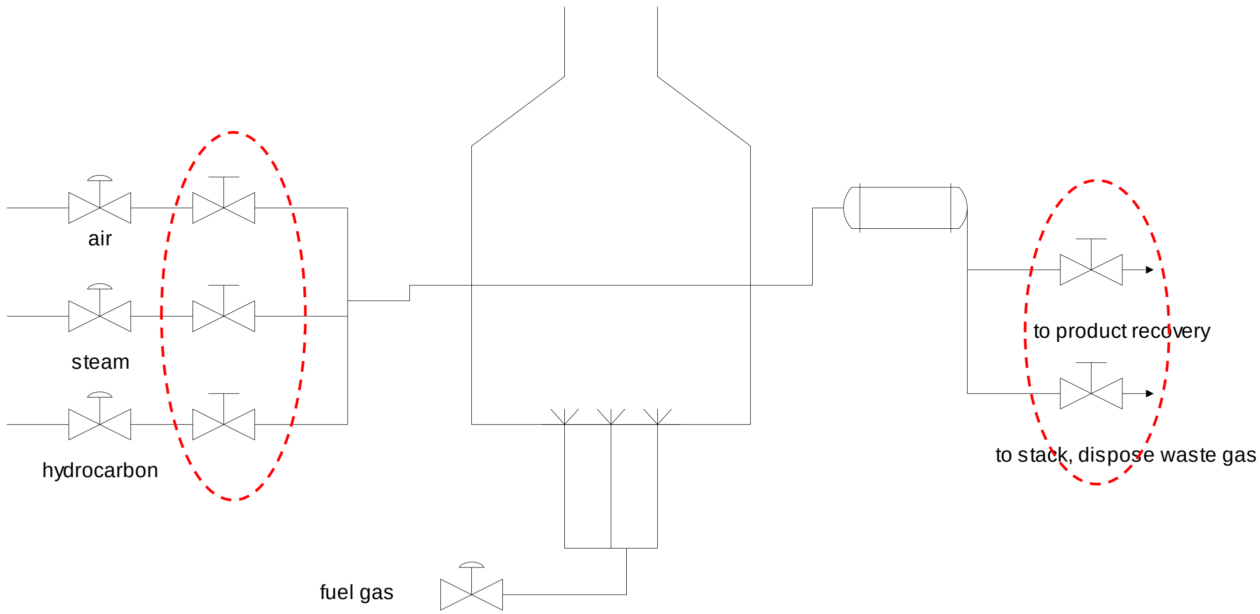
Each furnace/reactor has coke build up in the pipes (coils). When the coke thickness is too great, the reactor must be removed from production. Air and steam is used to react and remove the coke. During this time, the reactor effluent contains air and cannot be mixed with the hydrocarbons from the other reactors.



Workshop Solution – Operation During Transitions

Each furnace/reactor has coke build up in the pipes (coils). When the coke thickness is too great, the reactor must be removed from production. Air and steam is used to react and remove the coke. During this time, the reactor effluent contains air and cannot be mixed with the hydrocarbons from the other reactors.

Many isolation valves are required to change operation and keep streams separated. To ensure safety, these may be "double block and bleed" to provide greater assurance of isolation.



Very simplified drawing of the furnace/reactor

Key Operability issues

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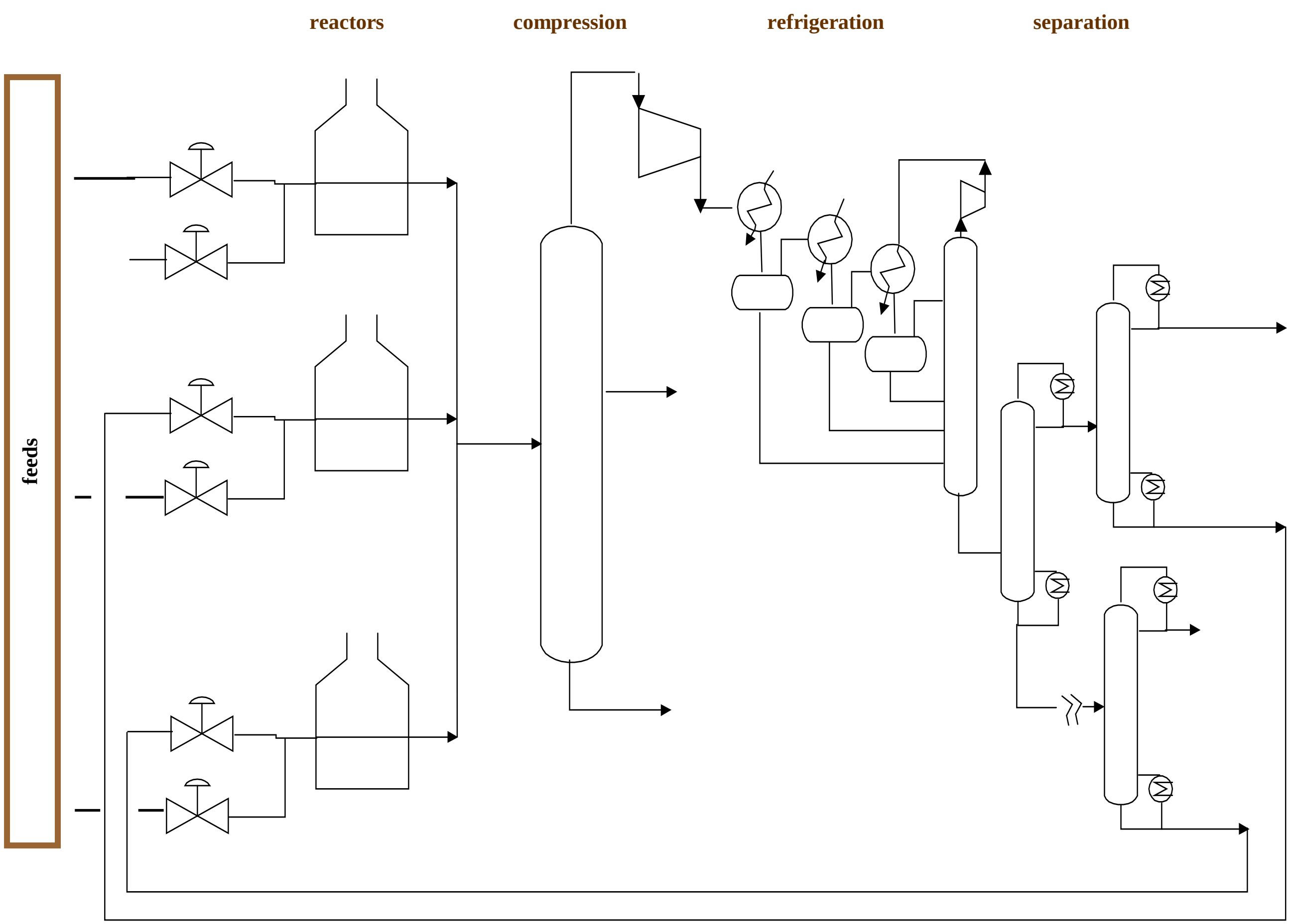
Workshop Solution – Efficiency and Profitability

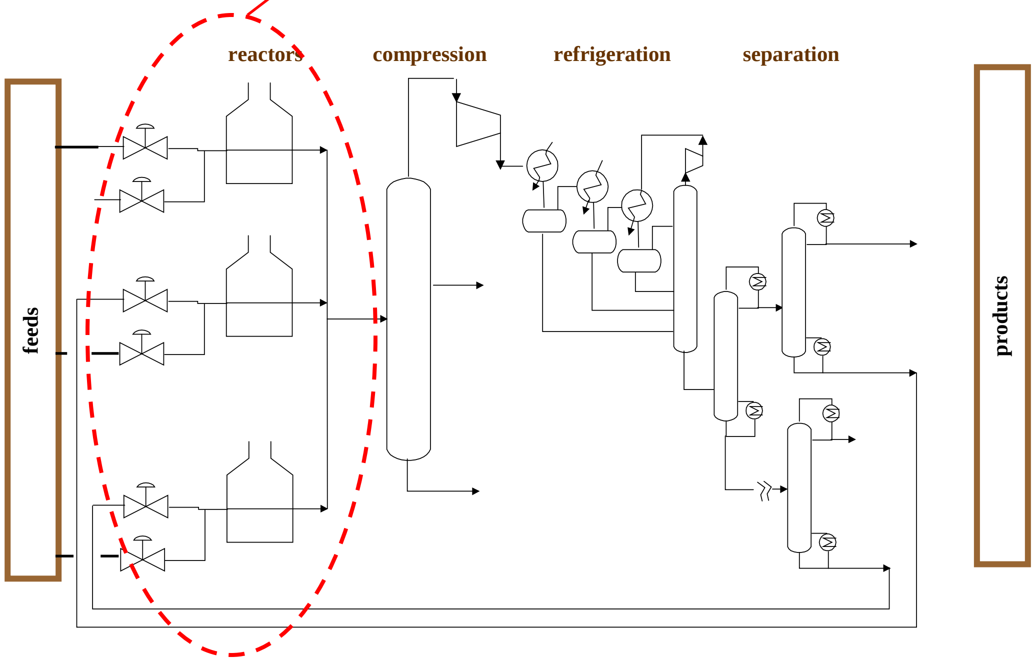
The heart of the plant is the reactors. We desire the best conversion and yields.



Workshop Solution – Efficiency and Profitability

The heart of the plant is the reactors. We desire the best conversion and yields.

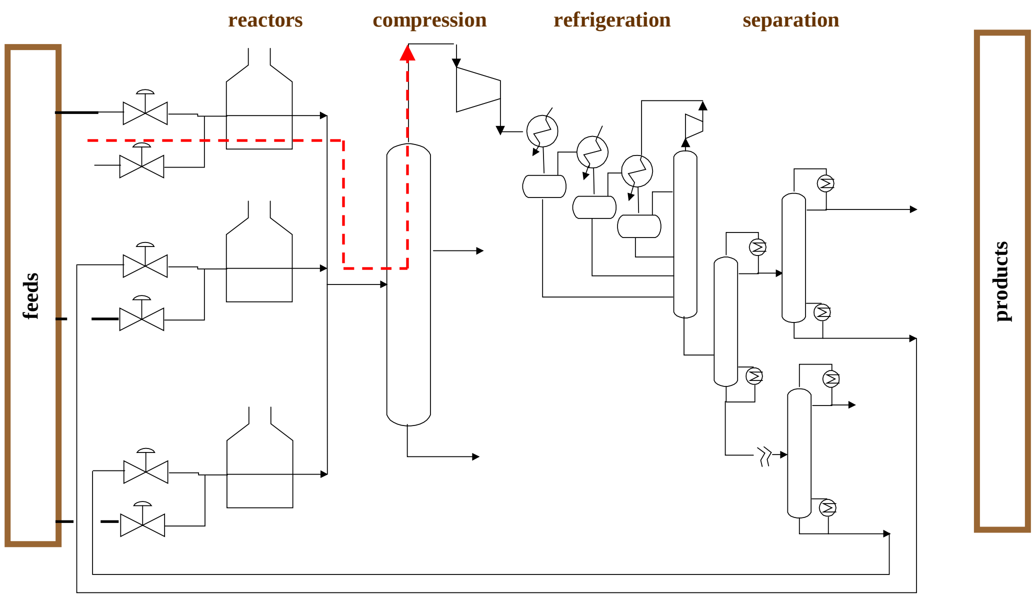
The temperature, pressure and dilution steam all have strong affects on the reactor performance.



Workshop Solution – Efficiency and Profitability

The temperature, pressure and dilution steam all have strong affects on the reactor performance.

To maintain the preferred low pressure, which improves ethylene yields, all equipment between the reactors and the suction to the compressor should be designed for low pressure drop.

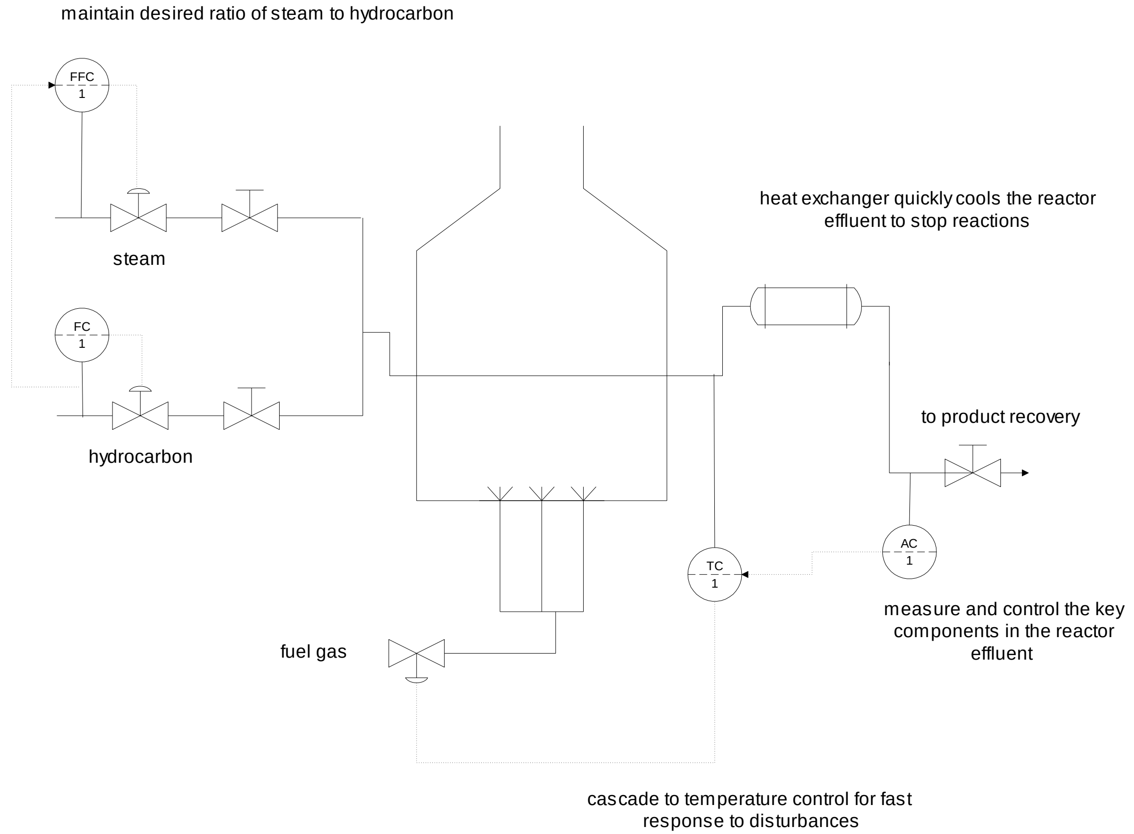


Workshop Solution – Efficiency and Profitability

The temperature, pressure and dilution steam all have strong affects on the reactor performance.

The ratio of steam to hydrocarbon is controlled.

The yields of key components can be measured periodically with an onstream analyzer using samples from the process. The yields can be controlled by adjusting the reactor outlet temperature.

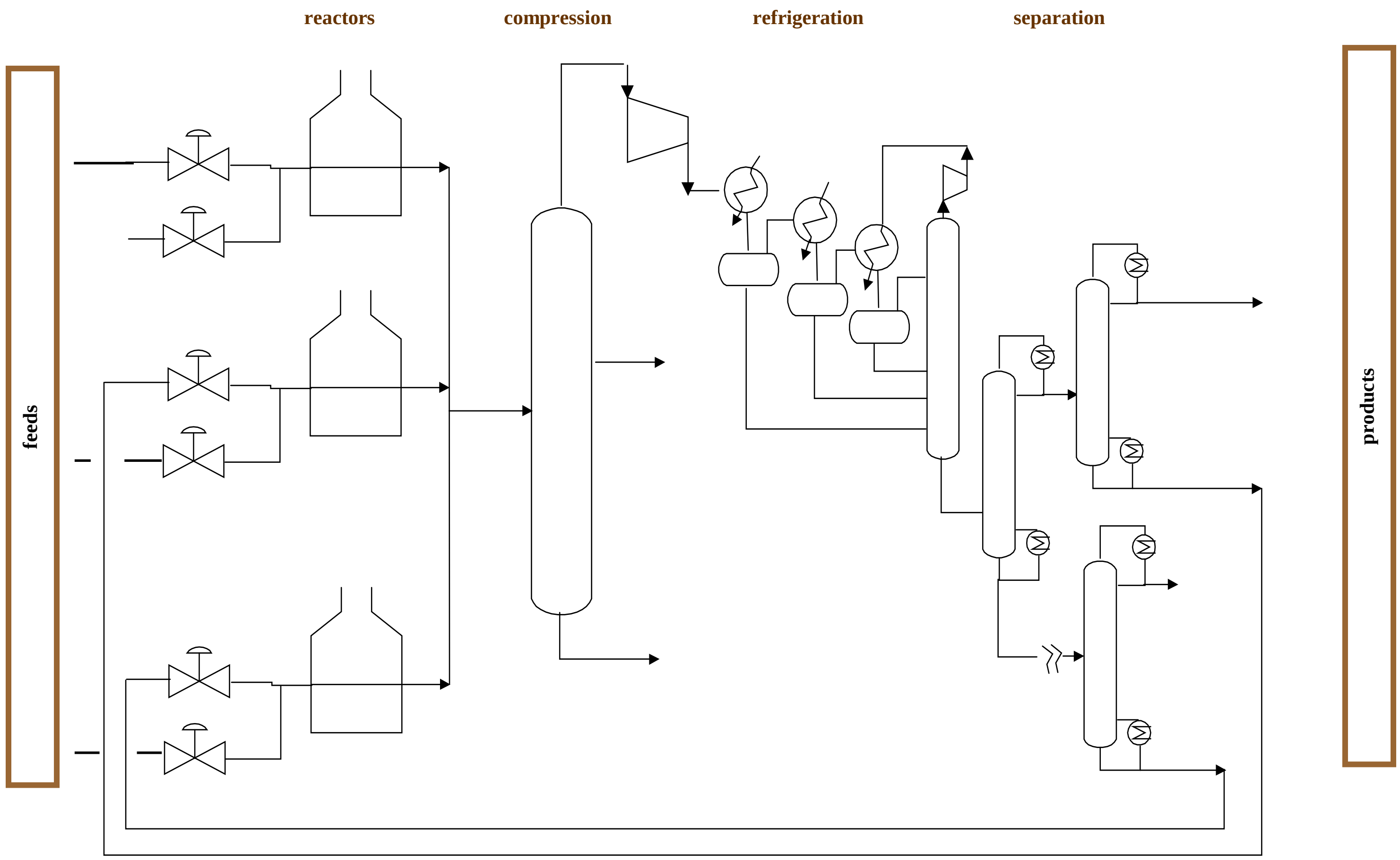


Key Operability issues

1. Operating window
2. Flexibility/ controllability
3. Reliability
4. Safety & equipment protection
5. Dynamic operation & product quality
6. Operation during transitions
7. Efficiency & profitability
8. Monitoring & diagnosis

Workshop Solution – Monitoring and Diagnosis

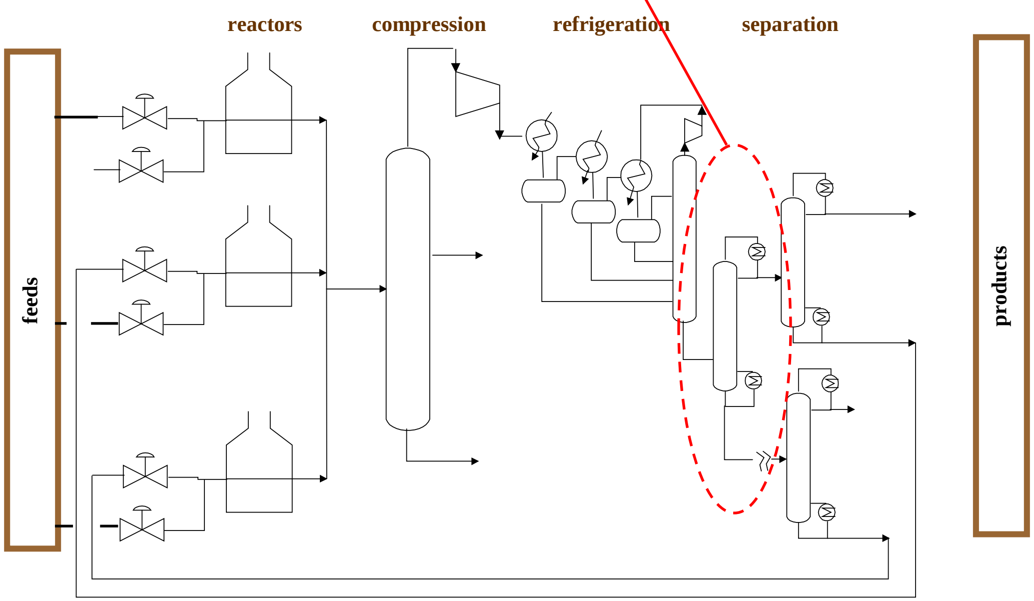
Plant personnel must continually monitor the plant operation and intervene when undesired events occur. Many extra sensors are required, and the people must have extensive training and experience.



Workshop Solution – Monitoring and Diagnosis

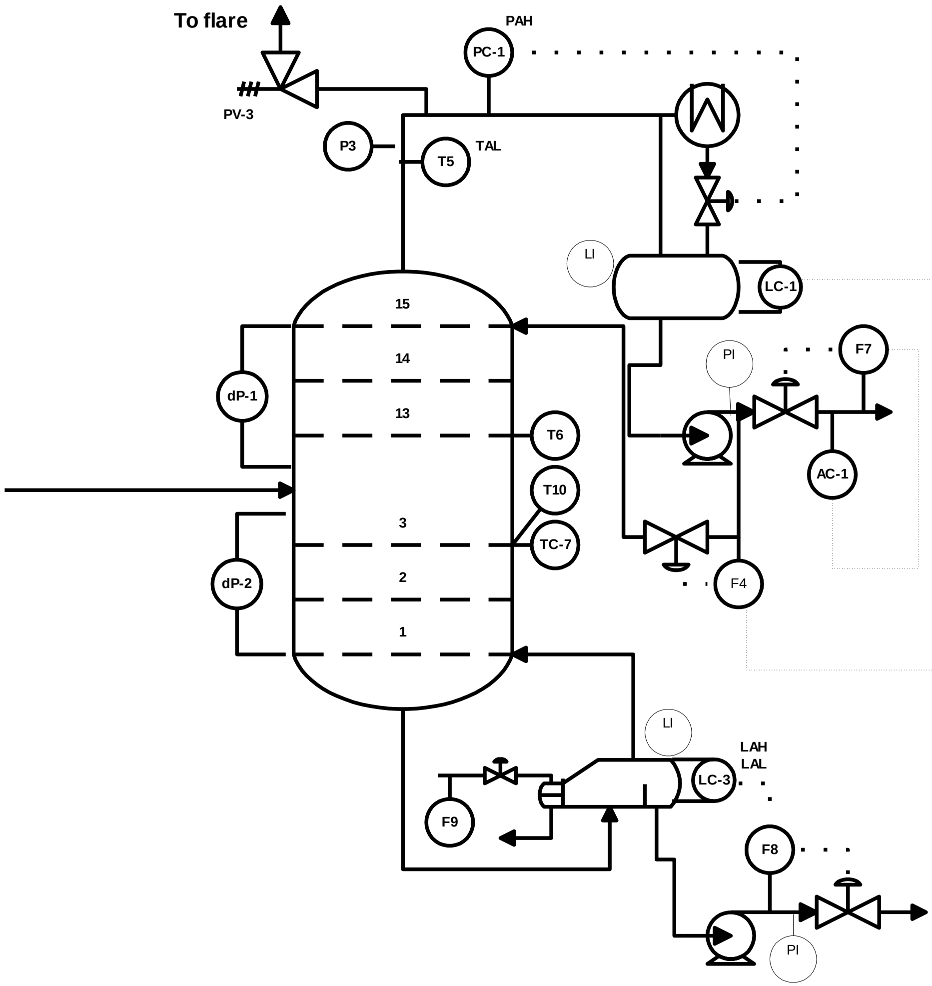
Plant personnel must continually monitor the plant operation and intervene when undesired events occur. Many extra sensors are required, and the people must have extensive training and experience.

Distillation towers, like all equipment, can exceed their operating window. Potential causes can be failures, such as tray corrosion or loss of cooling water, or human error, such as increasing the reboiler heating flow to too high a value.



Workshop Solution – Monitoring and Diagnosis

Distillation towers, like all equipment, can exceed their operating window.

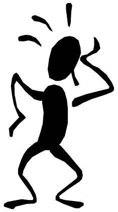


Many extra sensors not used for control!

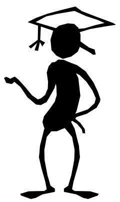
- *Tray temperatures*
- *Pressure drops across tray sections*
- *Redundant sensors for pressure and level*
- *Pressures around pumps*
- *.....*

How do we know which sensors to add? We must identify likely root causes and give the people the information needed to diagnose them.

Reflections on Operability Workshop

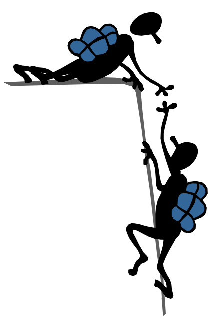


This looks very difficult. I would never have gotten those answers!



Don't worry, you were not expected to answer these questions perfectly. The purpose of this exercise is to introduce the topics, show the critical importance of operability, and demonstrate the types of learning that will be required in the remainder of this topic.

Without such examples, you would likely doubt the need to learn details about equipment performance. These examples motivate your learning.



We have a shared responsibility in the course. The instructor will provide fundamental information, methods of analysis, and compelling practical examples. The students will strive to learn and ask questions when topics are not clear.

OPERABILITY INVOLVES MANY ISSUES; What are the Learning Goals?

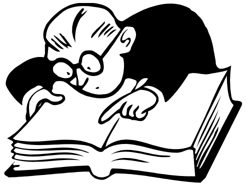
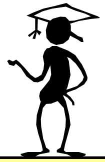


Table 1.3 Learning Objectives for Operability

Attitudes	Knowledge	Skills
• Process operating conditions and goals change frequently • Process behavior never matches theoretical predictions* • Operability is essential and cannot be “added on” after equipment design has been completed	• Defining sources of variability in plant operation • Standard designs to attenuate the effects on plant behavior of variability in eight major categories • Applying principles to develop non-standard designs in response to variability	• Problem solving process operations • Achieving a good solution to a problem with multiple criteria (e.g., economic and safety) • Managing a team project (e.g., HAZOP)

* Except fundamentals like material and energy balances



What else would you like to learn? Talk with your instructor.

OPERABILITY IS A CENTRAL DESIGN ISSUE
What will you be able to do?

- Identify the key operability issues in a process and design the process structure and equipment to achieve good process operability.
- You will be able to apply knowledge to many processes, not limited to class examples.
- You will be able integrate this analysis with sustainability, engineering economics, and so forth when selecting the best designs.
- You will be prepared for life-long learning

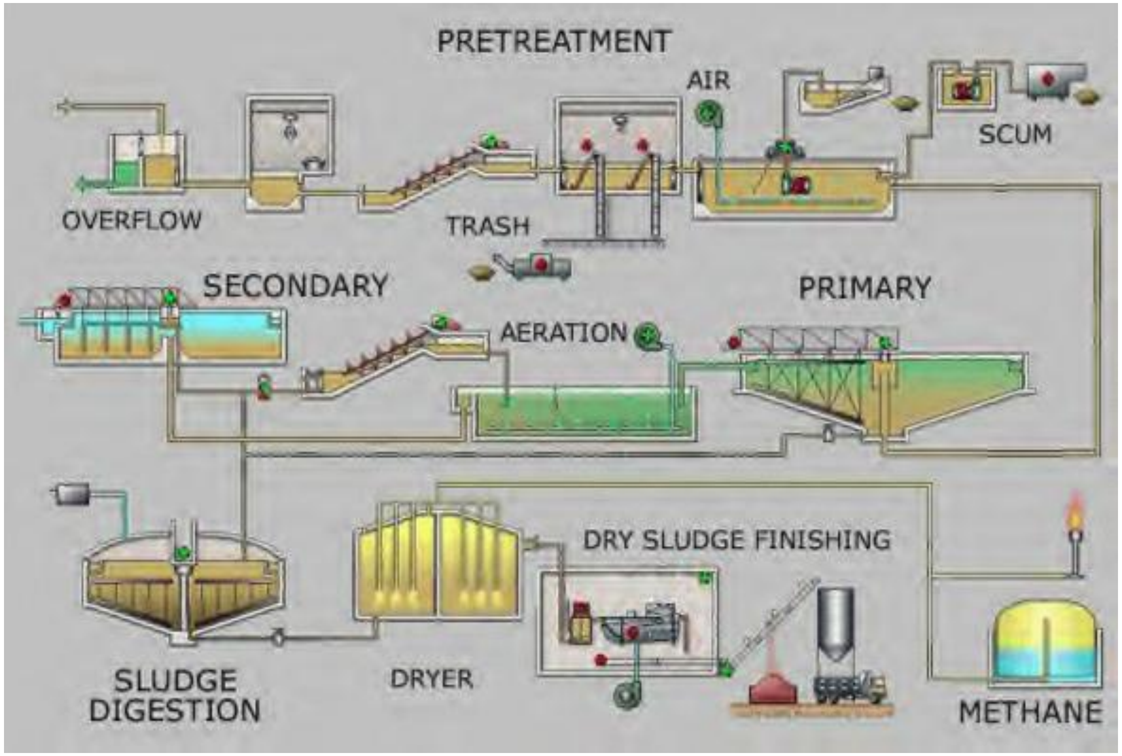
Let’s move on to detailed study of the first topic: Operating Window

PROCESS OPERABILITY
Why Operability?
Workshop #1- Waste Water Treatment Plant

Waste water treatment is essential for municipal sewage and industrial waste water. For a typical plant shown in the sketch,

a. Identify sources of variability in each of the five categories.

b. Identify an operability issue and propose a design to reduce the effect in each of the eight categories.



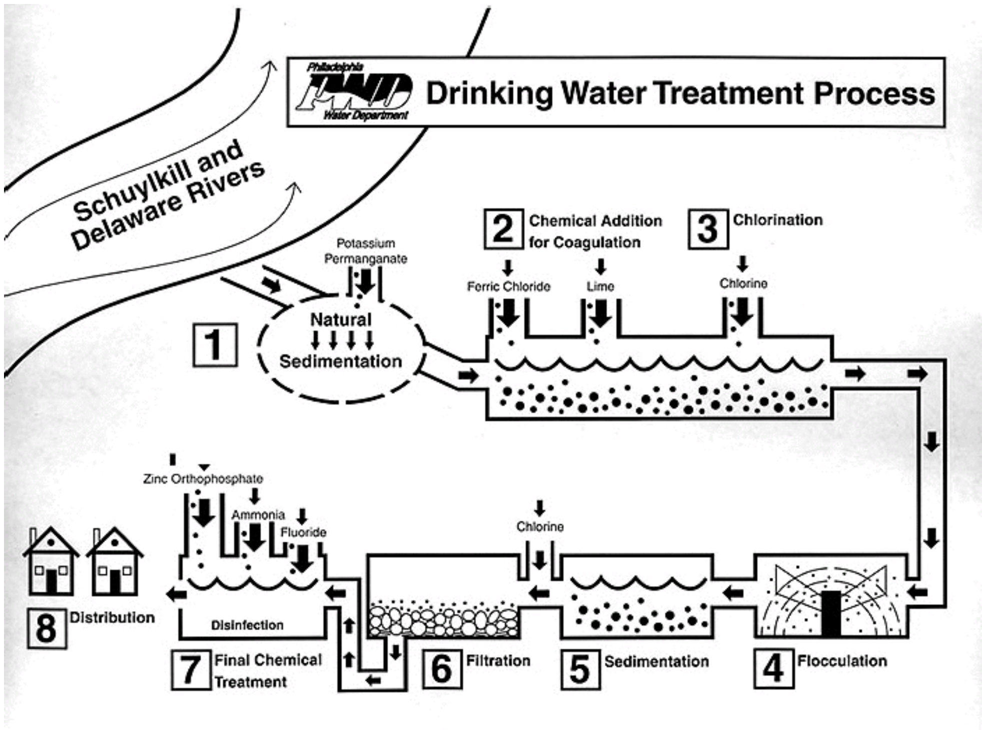
http://en.wikipedia.org/wiki/File:ESQUEMPEQUE-EN.jpg

PROCESS OPERABILITY
Why Operability?
Workshop #2- Drinking Water Treatment Plant

People need potable water for drinking and cooking. For a typical plant shown in the sketch,

a. Identify sources of variability in each of the five categories.

b. Identify an operability issue and propose a design to reduce the effect in each of the eight categories.



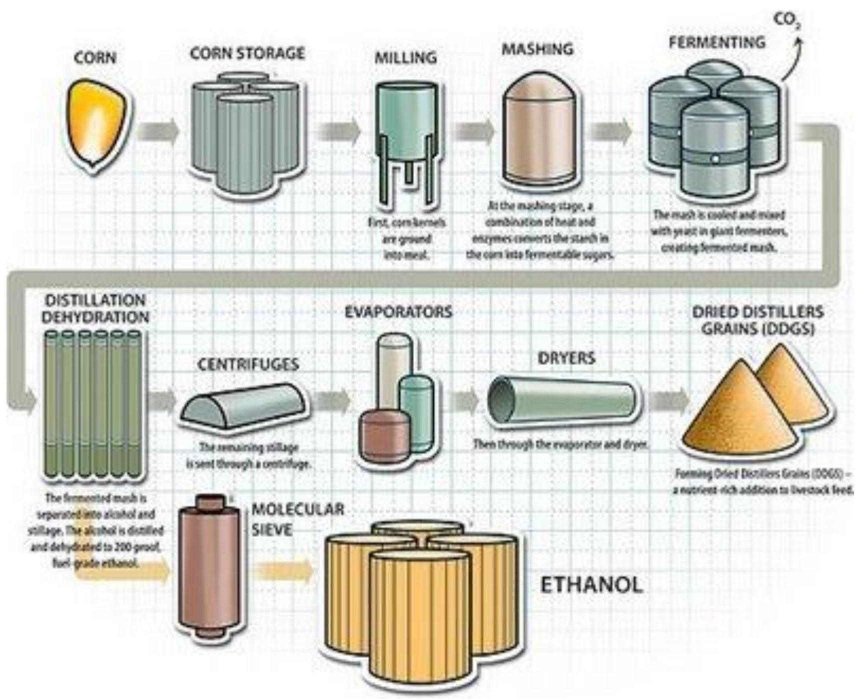
www.phillyh2o.org/backpages/MSB_Water.htm

PROCESS OPERABILITY
Why Operability?
Workshop #3- Ethanol from Corn Plant

Ethanol is an alternative fuel made from renewable materials. For a typical ethanol from corn plant shown in the sketch,

a. Identify sources of variability in each of the five categories.

b. Identify an operability issue and propose a design to reduce the effect in each of the eight categories.



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