Process operability: Reliability

In this Lesson, we will learn

- The importance of reliability
- Key terms and definitions

  - Reliability, Failure Rate, Availability
- Process design to remove/replace equipment

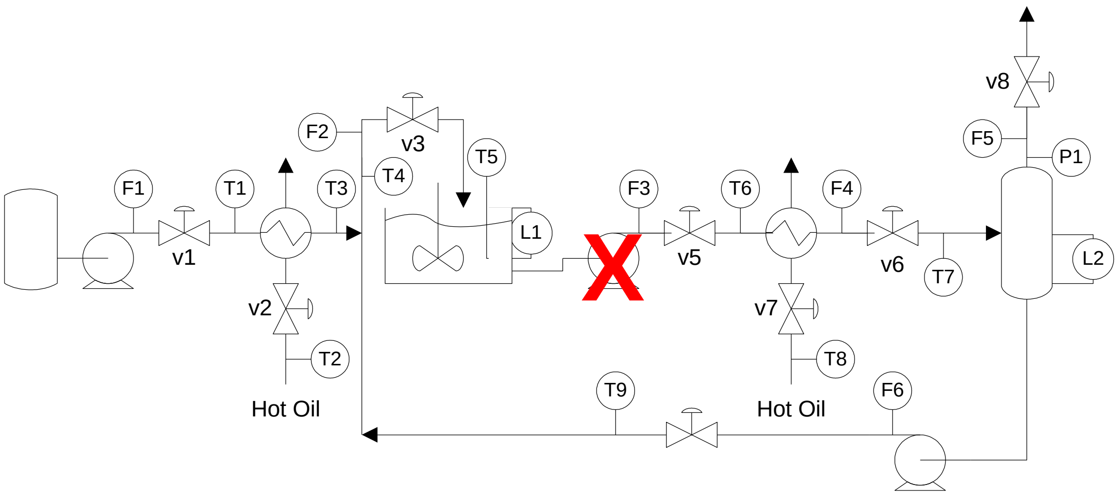
  - Pump, valve, heat exchangers
- Process structures to increase reliability

  - Calculate system reliability
  - Pump, Boiler, Fuel system
- Inventory location for reliability

  - Tankage

Reliability

Stopping the production of a plant can be very costly*



- Lost sales
- Storage, disposal or reprocessing of material in plant
- Heating/cooling process
- Repair or replacement of equipment
- Shutdown of integrated units
- Possible damage to equipment

* Safety is addressed in a topic 4.

Reliability

Reliability: The ***probability*** of a device successfully performing ***its function*** for a period of time under ***specified conditions***.

- **"*Its function*" clearly depends on the needs of the specific system**
- **"*Specified conditions*" define what is occurring in the system and how the device is maintained.**
- **"*Probability*" can be determined; the outcome of one instance of the device's action cannot be determined.**

$$\boxed{R(t) = 1 - \frac{n_{failed}(t)}{n}}$$

(Value between 0 and 1)

n = number of outcomes

Reliability

Other terms that are useful in discussing reliability are:

- Probability of failure, F(t): F(t) + R(t) = 1
- Failure rate, λ(t): The number of failures per unit of time at a specific lifetime divided by the number of items at that time.

$$\lambda(t) = \frac{1}{n - n_f(t)} \frac{dn_f(t)}{dt}$$

$$\lambda(t) = -\frac{1}{R(t)} \frac{dR(t)}{dt}$$

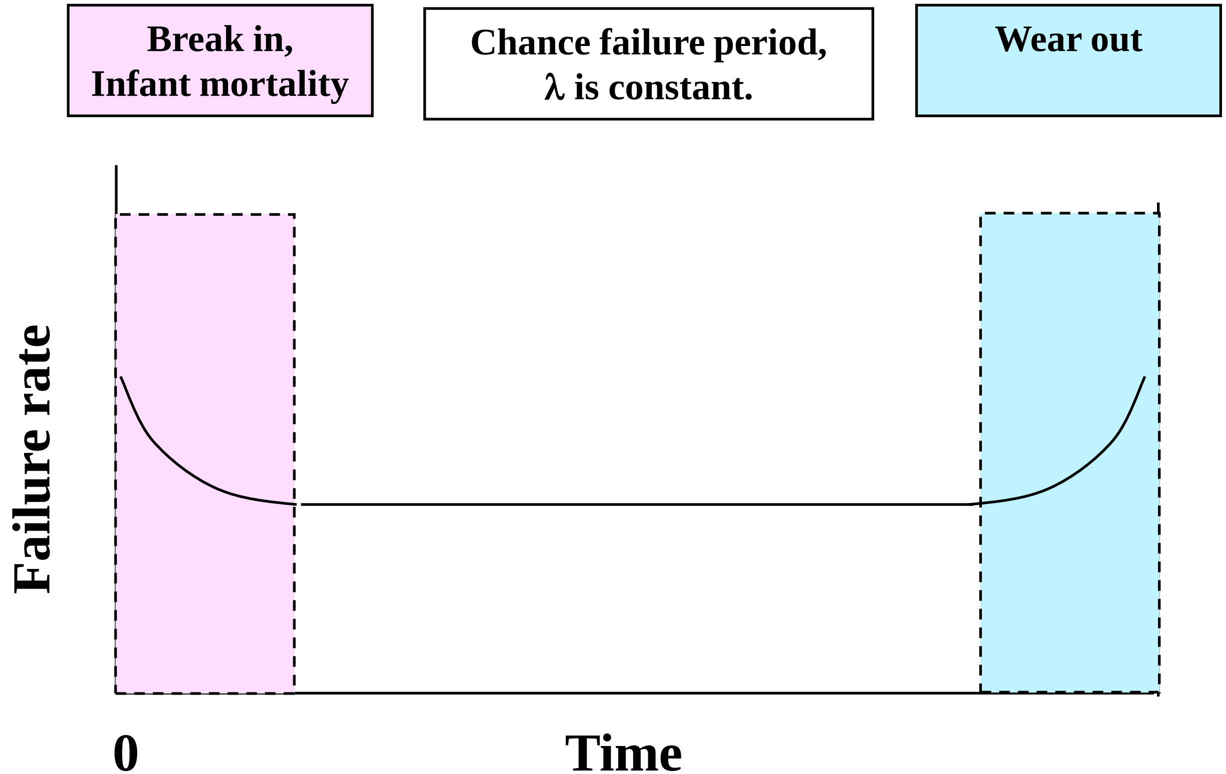
(Typical units: failures /10^6 h)

Key Operability issues

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

Reliability

Failure rate: The number of failures per unit time at a specific lifetime divided by the number of items at that time. A typical "bathtub curve" is shown below.



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Terminology

Reliability

Data from Wells (1980) gives a good visual display of relative reliabilities of categories of process equipment.

Wells, G., *Safety in Process Plant Design*, John Wiley & Sons, New York, 1980.

Figure 3.2 Typical failure rates (mainly mean values) for a range of equipment
[1] Not rechargeable batteries
[2] Values are pipelengths of 1 m; useful rule 10^{-4}/100 pipe diameters
[3] Reciprocating prime movers, low values
[4] Not HIPS (see Stewart, 1974)
[5] Most measurements — not pressure gauge
[6] Include off-specification readings
[7] Does not include some items specially made with high reliability for nuclear use
Recommended sources: Farmer (1971); Green *et al.* (1965/66); USAEC (1975); Lees (1976)

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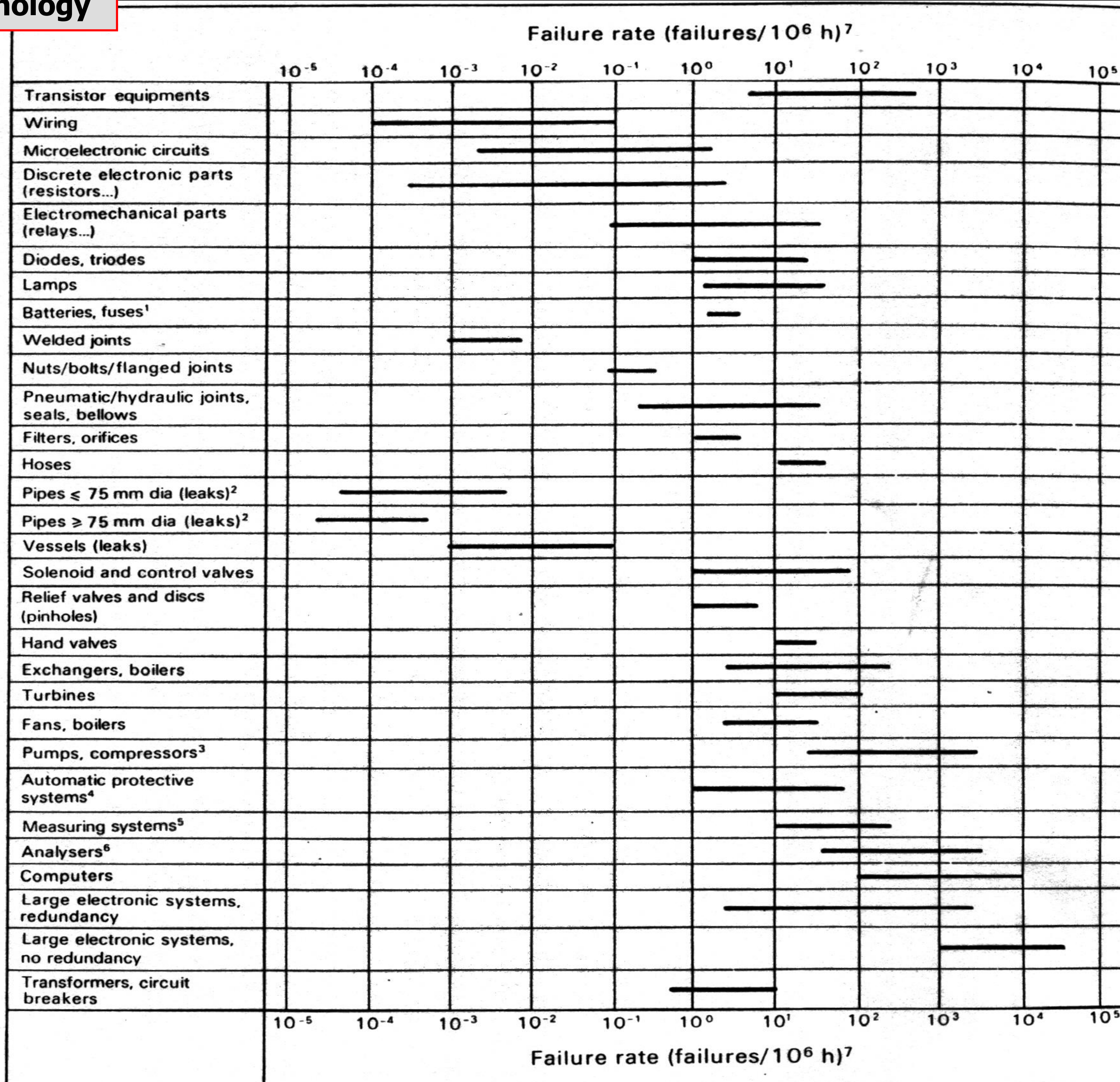
Terminology



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Sample from CCPS Data Base

Guidelines for Process Equipment Reliability Data, CCPS (AIChE)

DATA ON SELECTED PROCESS SYSTEMS AND EQUIPMENT

Taxonomy No.	3.3.2	Equipment Description	ROTATING EQUIPMENT - COMPRESSORS
Operating Mode		Process Severity	UNKNOWN

Population	Samples	Aggregated time in service (10^6 hrs) Calendar time	Operating time	No. of Demands	

Failure mode	Failures (per 10^6 hrs) Lower	Mean	Upper	Failures (per 10^3 demands) Lower	Mean	Upper
CATASTROPHIC a. Fails While Running b. Rupture c. Spurious Start/Command Fault d. Fails to Start on Demand e. Fails to Stop on Demand DEGRADED a. External Leakage	3.09	1430.0	5650.0			

Equipment Boundary

Key Operability issues

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Terminology

Reliability

Other terms that are useful in discussing reliability are:

- **Mean time to failure (MTTF)**: The ***average*** time between a device being placed in operation and it's first failure.
- **Mean time between failures (MTBF)**: Can include repairable systems, with time to repair and wait included.

When the failure rate is constant

$$R(t) = \exp\left\{-\int_0^t \lambda(t')dt'\right\} = \exp(-\lambda t)$$

$$MTTF = \frac{1}{\lambda} \quad (years/failure)$$

R(t) = reliability

λ = failure rate

Reliability

Other terms that are useful in discussing reliability are:

- **Availability: The ratio of the time a plant is producing product to the total time.**

MTTF = mean time to failure

MTTR = mean time to repair

MTOW = mean time of waiting (for spare parts, etc.)

Availability = MTTF/(MTTF+MTTR+MTOW)

Reliability

Generally, we are interested in availability, but we also need to keep an eye on MTTF

Why? Is everything OK when Availability = 99.9%?

If MTTR (repair) and MTOW (waiting) are very low, we could have a very high Availability with many failures.

An example would be lots of computer failures with a fast reboot after each one. If the control computer keeps failing, that is not good!

Reliability

Other terms that are useful in discussing reliability are:

- **Availability**: The ratio of the time a plant is producing product to the total time.

Availability = MTTF/(MTTF+MTTR+MTOW)

For a continuous process, we aim for a very high availability, for example, operating 361 days and having a turnaround (maintenance) once per year.

With all of the individual elements that could fail, how can we achieve this?

Reliability

AVAILABILITY: We want 100%. We'll never get it! What can we do to increase the reliably?

Some actions improve the reliability of each device.

- **Match equipment to process conditions and requirements (slurries, clean-in-place, etc.)**
- **Operate after "break in" and before "worn out"**
- **Perform preventative maintenance**
- **Use high quality components (resistance to corrosion, compatible with process conditions, well manufactured, etc.)**
- **Repair quickly by highly trained personnel using spare parts stores**

Besides the component reliabilities, what else affects plant reliability?

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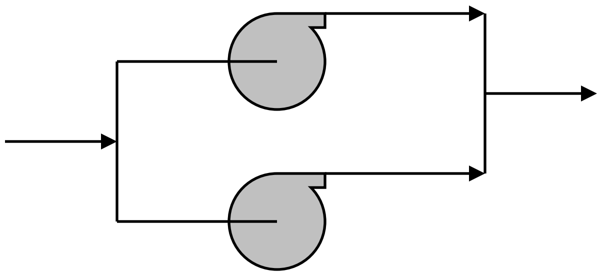
Remove/replace equipment

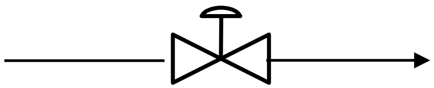
Reliability

How can we replace or remove equipment without stopping plant production?

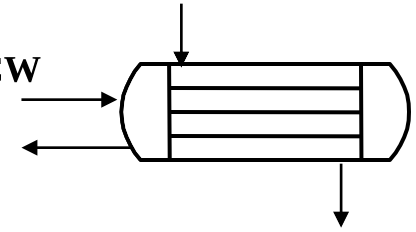
Only one pump needed; we want to switch between the two



The valve is leaking; therefore, we need to replace it



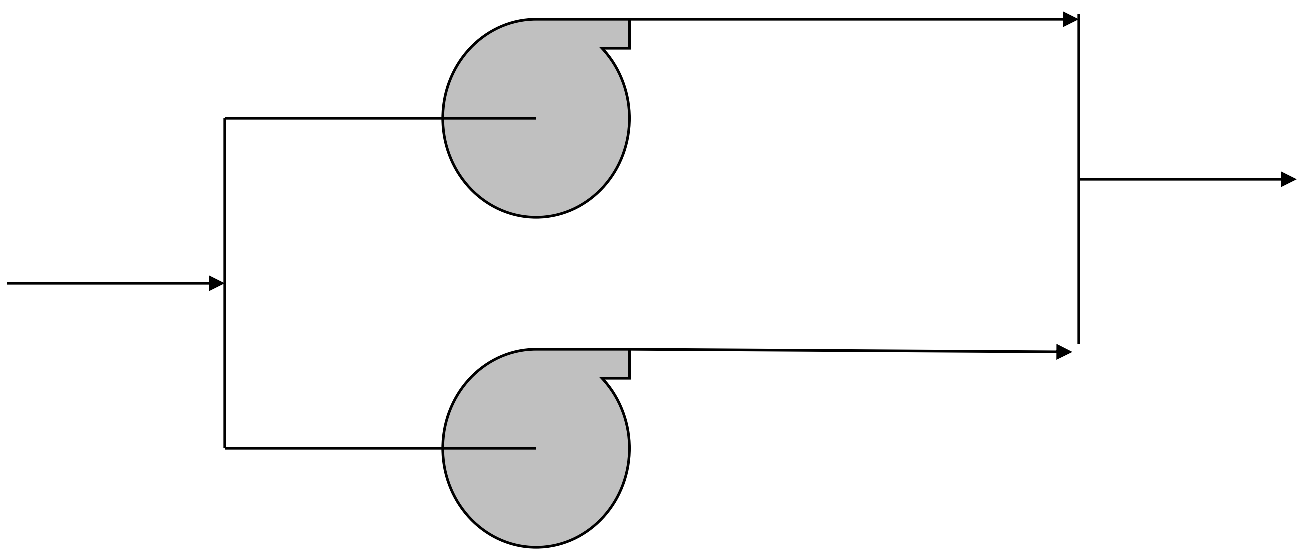
The heat exchanger is fouled; we need to take it out of service for mechanical cleaning



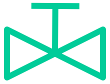
Reliability

How can we replace or remove equipment without stopping plant production?

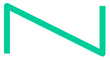
Only one pump needed, want to switch between the two



Hint: add some of these



Manual (hand) valve

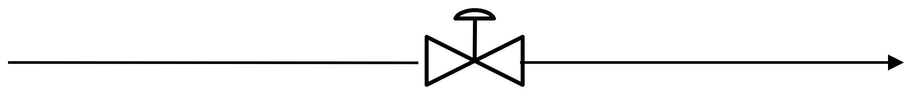


Check (one-way) valve

Reliability

How can we replace or remove equipment without stopping plant production?

The valve is leaking, we need to replace it



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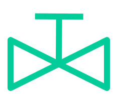

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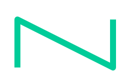

Check (one-way) valve

Remove/replace equipment

Reliability

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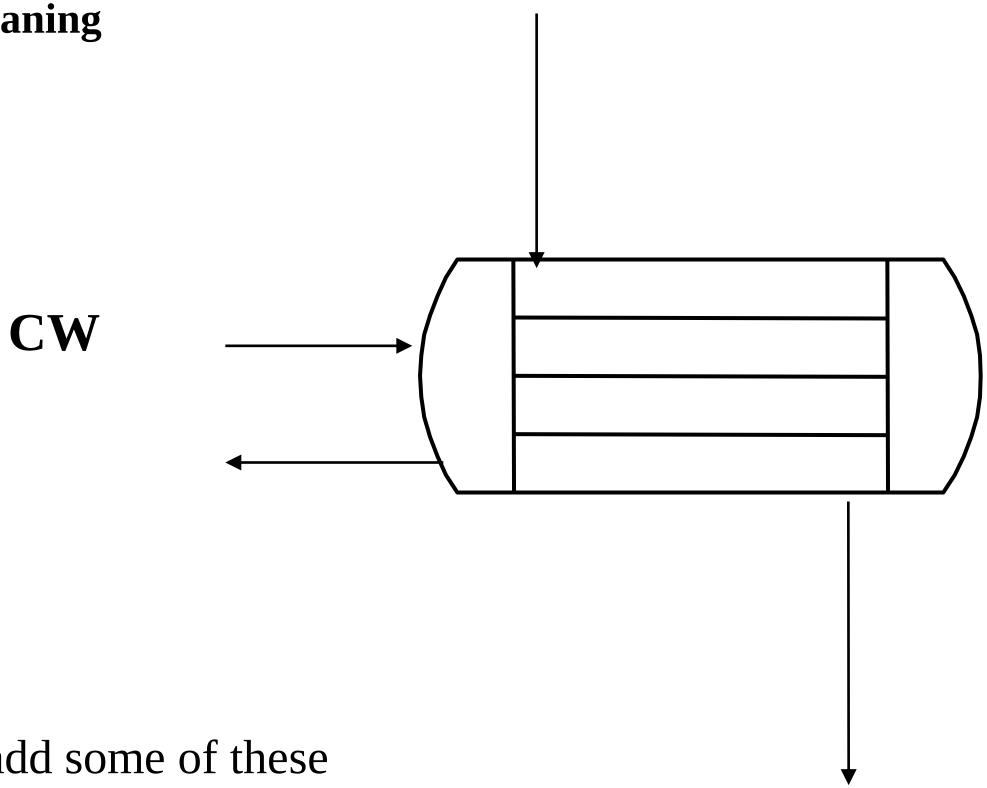
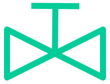
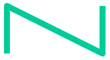
The heat exchanger is fouled, we need to take it out of service for mechanical cleaning



Hint: add some of these



Manual (hand) valve



Check (one-way) valve

Key Operability issues

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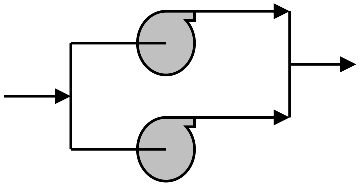
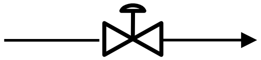
Remove/replace equipment

Reliability

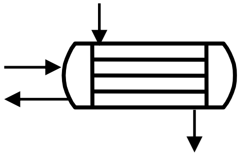
Lesson Learned

Some equipment is not essential for acceptable plant operation, at least for a short time, and other equipment has a spare in a parallel configuration.





This equipment can be taken out of service for repair, if the design provides components for required reliability.



Result – many more valves and more parallel equipment than you might initially expect.

Key Operability issues

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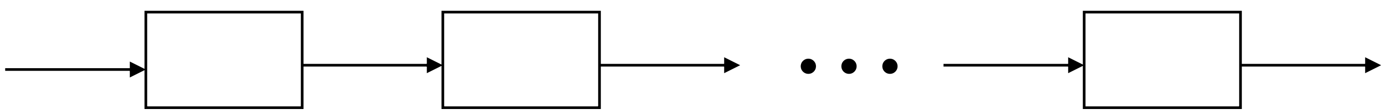
Process structures

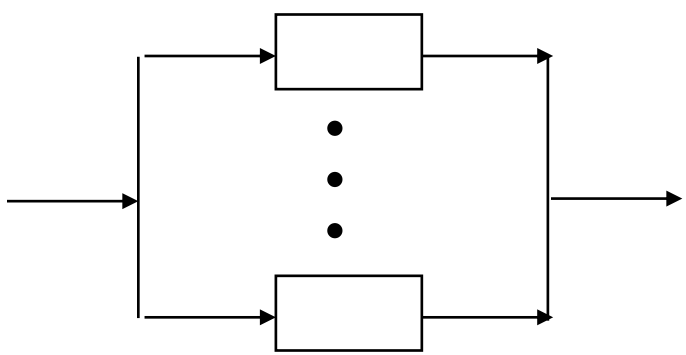
Reliability

Structure: A plant consists of many components connected in complex structures. These structures influence the reliability of the overall system.

Series



Parallel

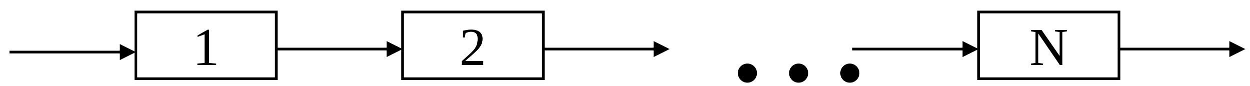


If we know the reliability of each component, can we determine the reliability of the system?

Reliability

Structure: Simple ***series*** structure.

System functions only when all components function.



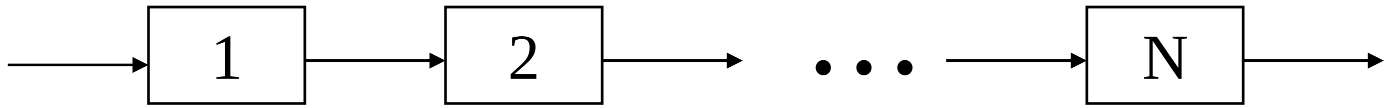
If each reliability is independent (e.g., no common failure causes), what is the reliability of a series structure which requires all to function?

$$R_{Series} = R_1 R_2 \bullet\bullet\bullet R_N = \underset{i=1}{\overset{N}{\pi}} R_i$$

What are “common-cause” failures?

Reliability

Structure: Simple ***series*** structure.

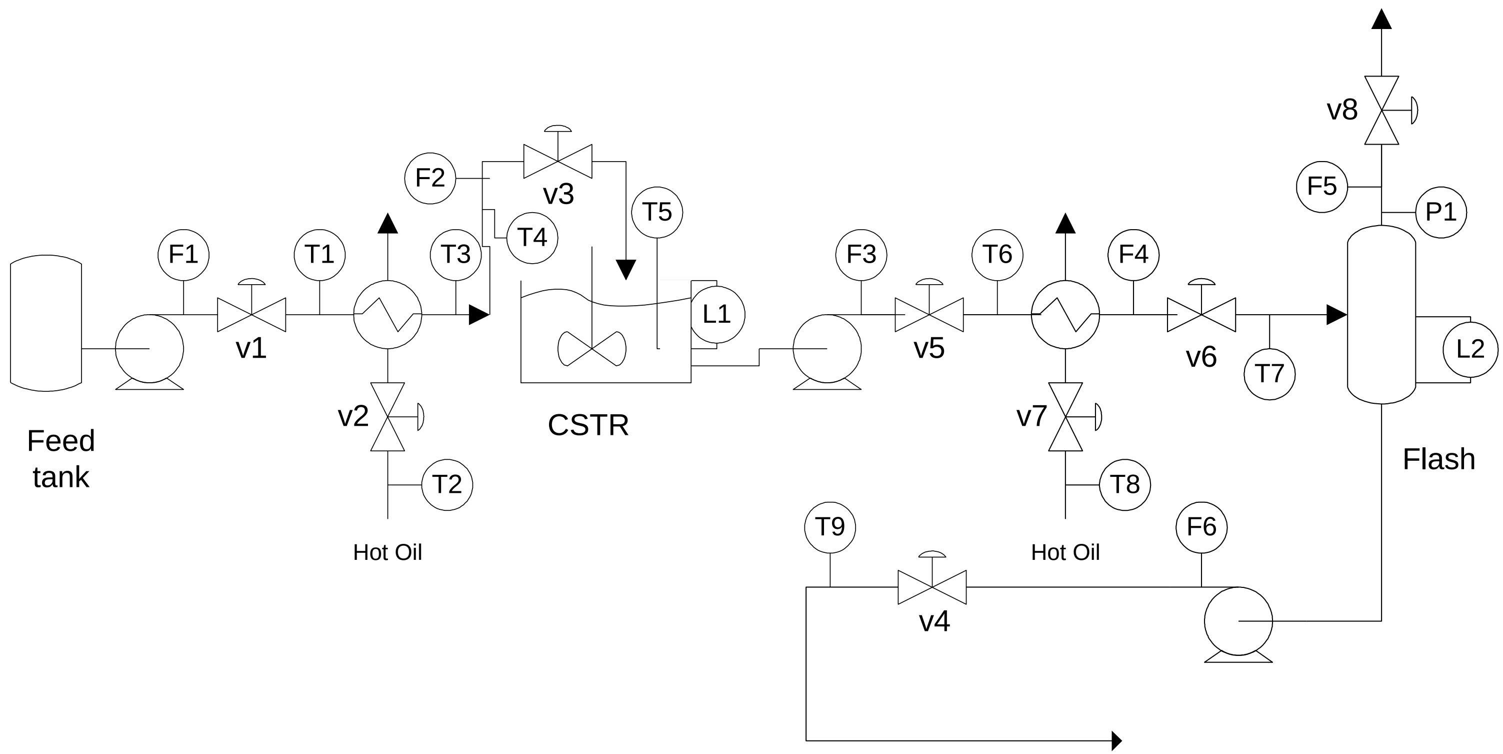


$$R_{Series} = R_1 R_2 \bullet\bullet\bullet R_N = \underset{i=1}{\overset{N}{\pi}} R_i$$

Class Workshop: Give some examples of series equipment in process plants.

Reliability

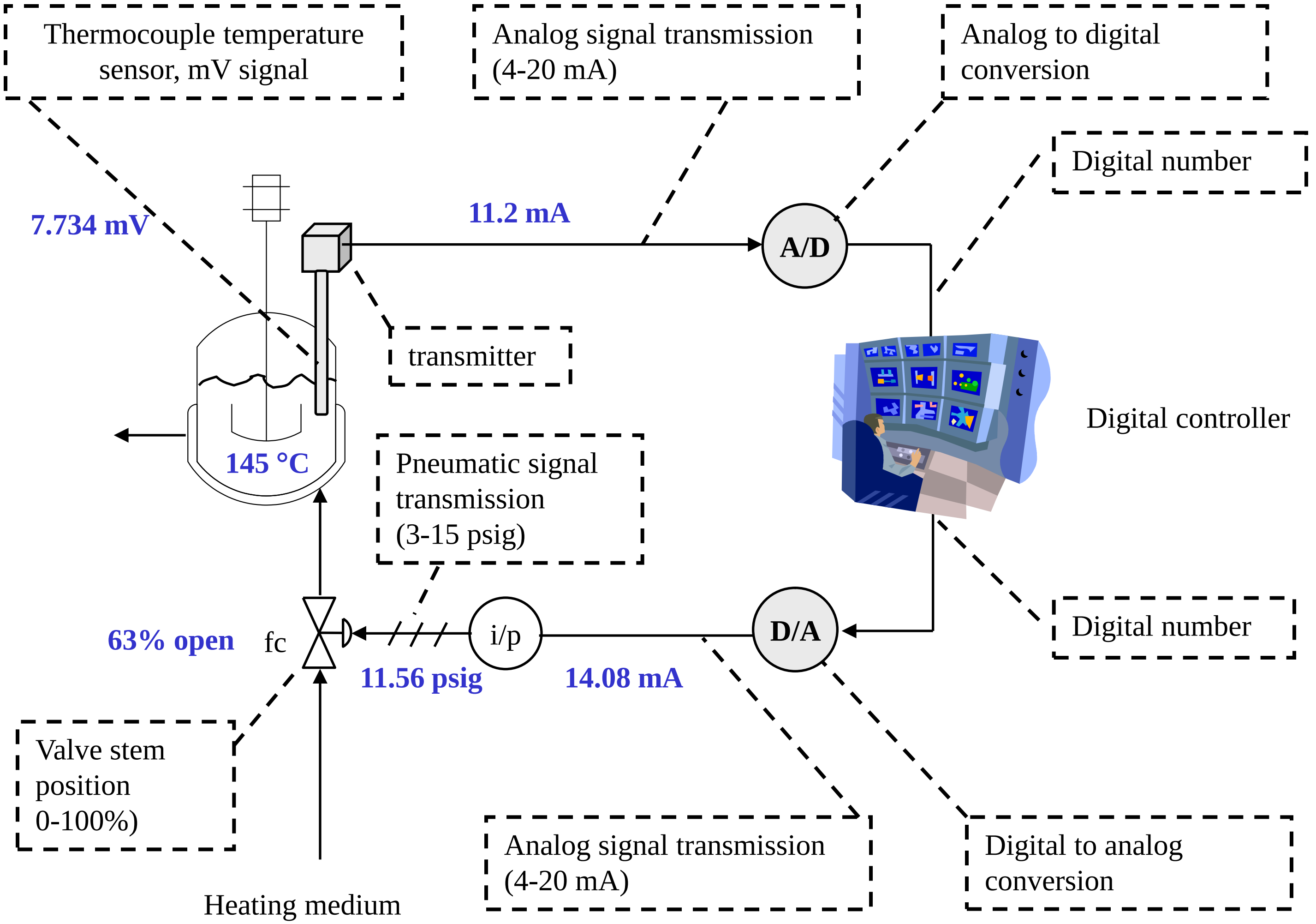
Structure: Simple ***series*** structure.



What equipment has to function well for the process to be operable?

Reliability

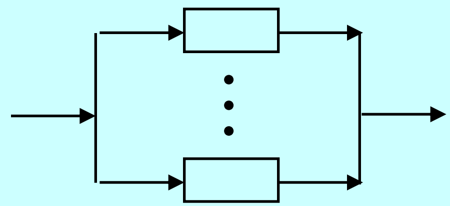
Structure: Simple *series* structure.



Reliability

Structure: Simple ***parallel*** structure with no common cause faults.

System functions when either path (or both) function



Two Parallel: The system fails when both fail at the same time.

$$R_{2-parallel} = 1 - (1 - R_1)(1 - R_2)$$

***N* Parallel: The system fails when *all fail* at the same time.**

$$R_{N-parallel} = 1 - \underset{i=1}{\overset{N}{\pi}} (1 - R_i)$$

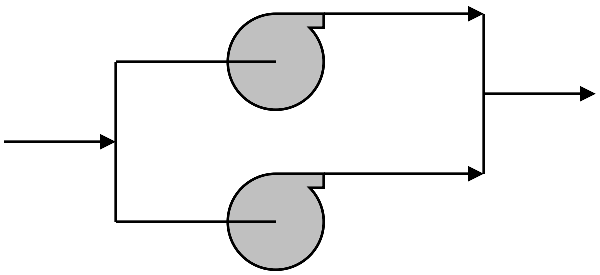
Reliability

Give some examples of parallel equipment in process plants.

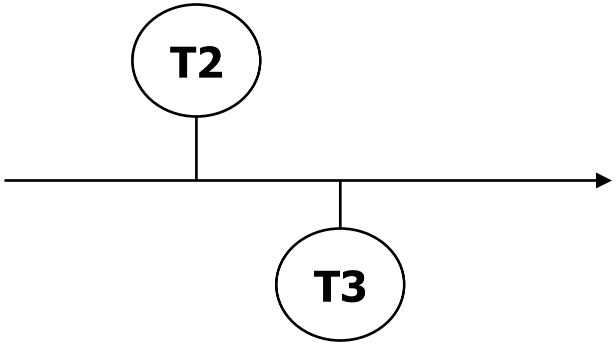
Reliability

Give some examples of parallel equipment in process plants.

Parallel pumps



Redundant sensors on same stream



Key Operability issues

1. Operating window

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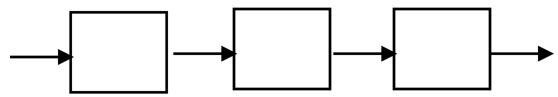
Process structures

Reliability

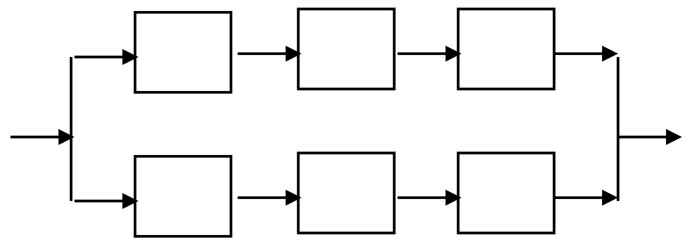
System functions successfully if at least one path from input to output functions

Determine the reliability of structures by condensing simple series or parallel sections.

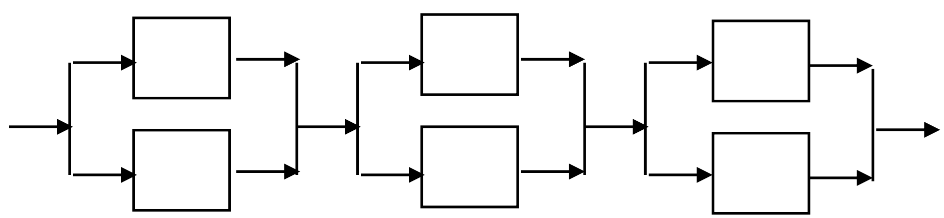
A)



B)



C)



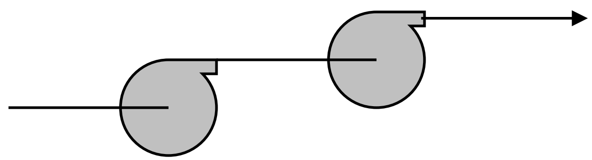
Assume the each device (box) has a reliability of 0.90

Reliability

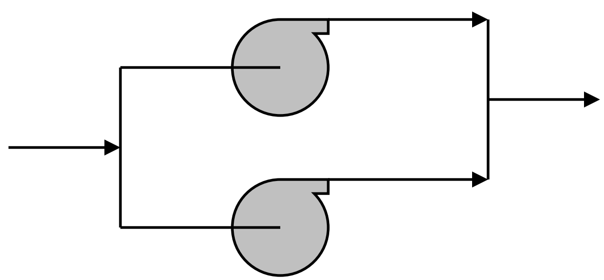
Which pump configuration has the highest reliability (longest mean time between failures) when only one is needed to perform the function?

Centrifugal pumps

Series



Parallel



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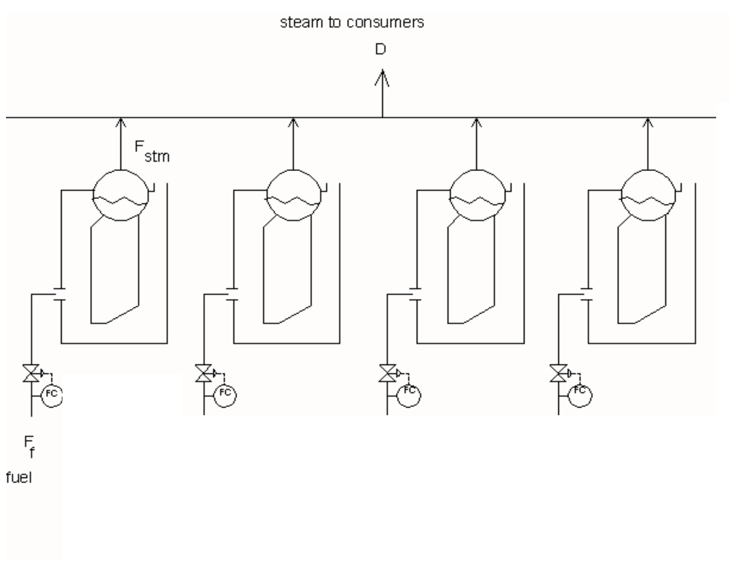
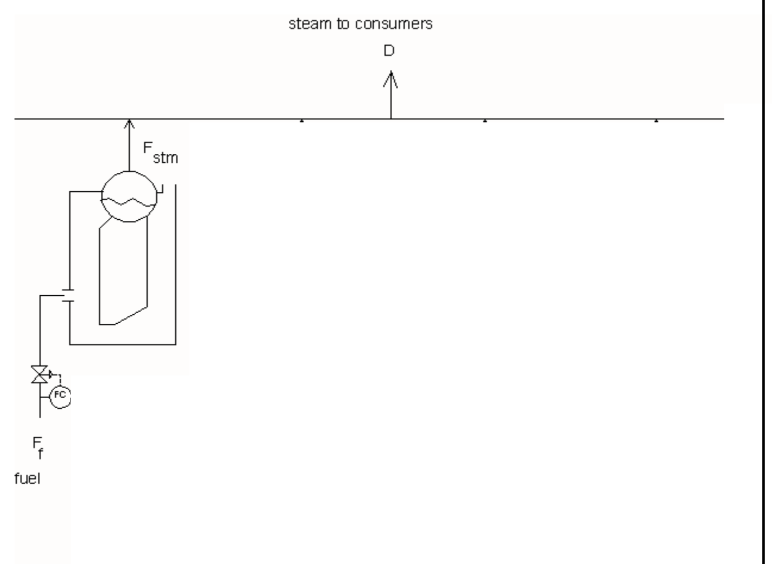
Reliability

When no steam is available, everything freezes in a Canadian winter. Which boiler system is more reliable?

Design A: Several smaller boilers



Design B: One large boiler



Reliability

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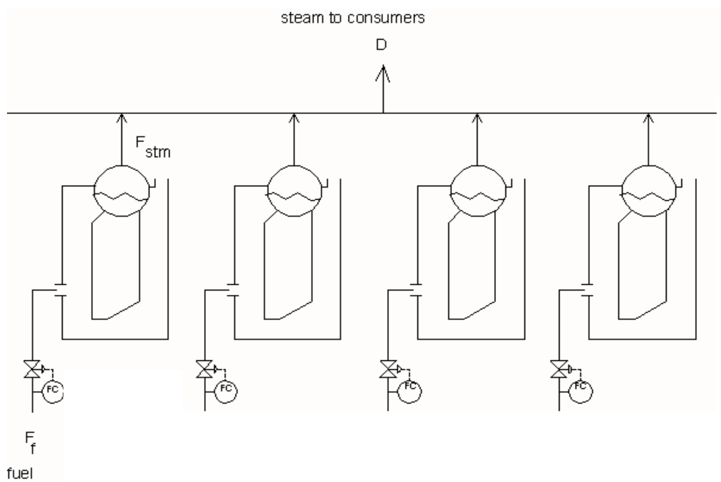
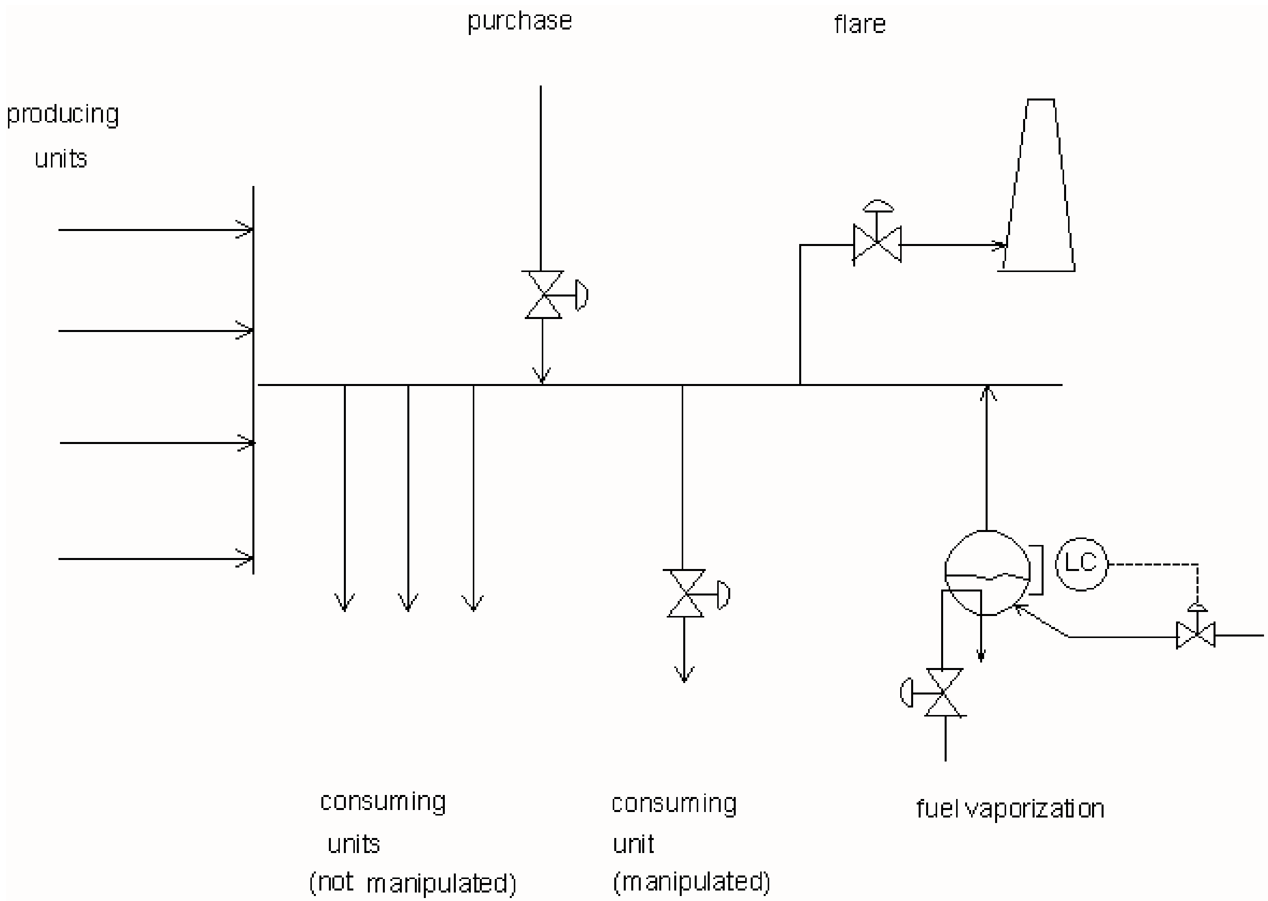


By having many boilers in operation, we can replace one failure by increasing the steam from the remaining.

Also, we dramatically reduce the probability of having all boilers fail simultaneously.

Reliability

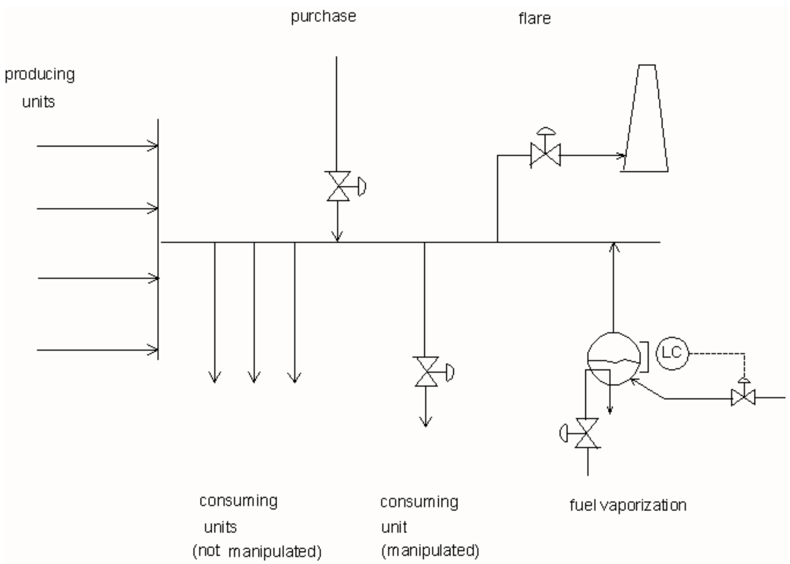
Fuel gas is produced and consumed in many places in a plant. Discuss the good and poor aspects of this fuel gas distribution network.



Reliability

Distribution Network.

Networks have high reliability with shared redundancy. For example, a spare source can serve any consumer.

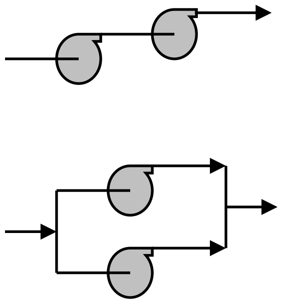


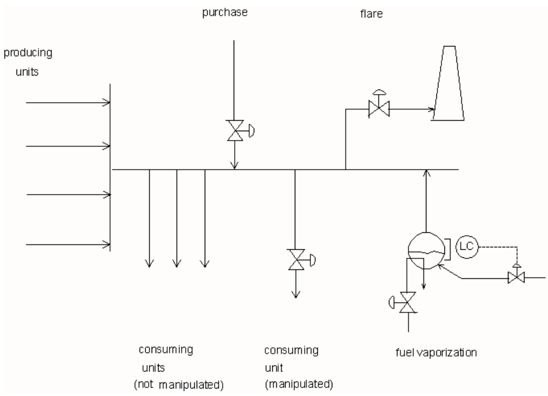
Networks are used for many "utilities"; steam, fuel, cooling water, hot oil, hydrogen, nitrogen oxygen, and so forth.

Reliability

Lesson Learned

When equipment is essential and component reliability is too low, redundancy can be provided in various plant structures to increase system reliability.





Results:

Low reliability equipment: Redundancy

Highly critical functions: Networks of suppliers and consumers

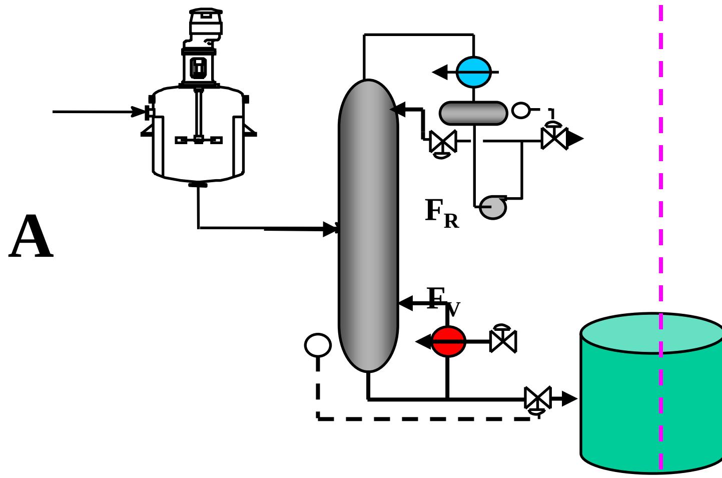
Process inventory

Reliability

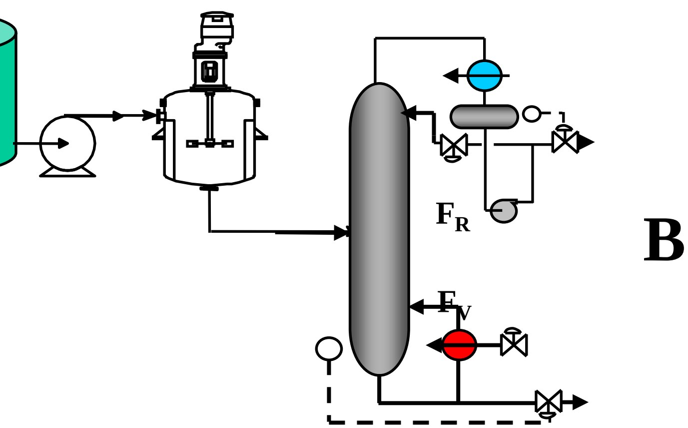
How does a tank affect the reliability of a system? How would you determine the appropriate size of the tank?

Unit A can function without Unit B

Unit B can function without Unit A



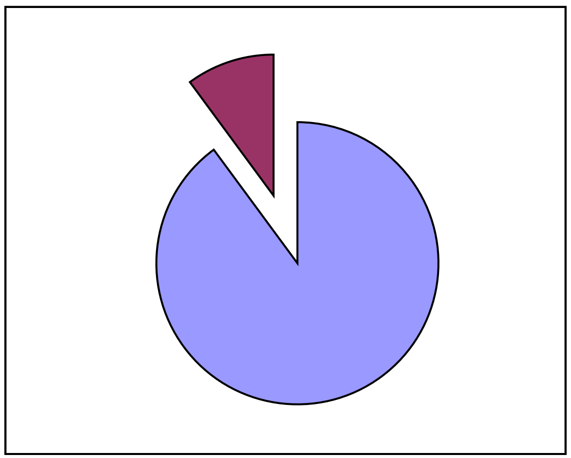
If the failure probability for each plant is nearly the same, the tank should be maintained near half full.

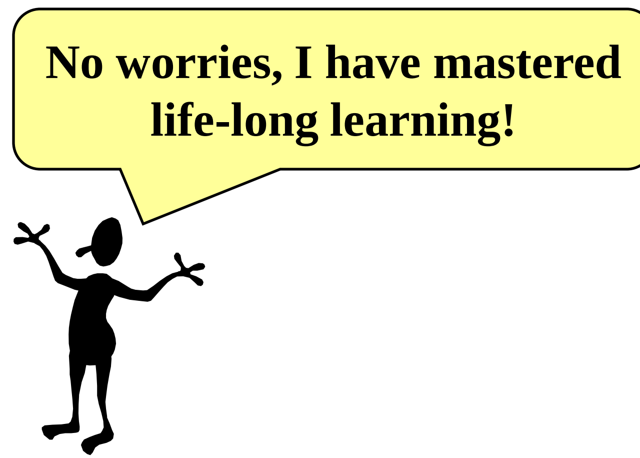


Rough guideline: The tank holdup should equal 2 times the time to repair failed equipment.

Reliability

This is a big topic, and we have covered only a small slice! Many topics would require further study.





- **We can determine reliability for typical structures and the advantages/disadvantages of these structures.**
- **We cannot determine reliability, MTBF or Availability for complex structures, with maintenance, etc.**

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Reliability

Industrial practice

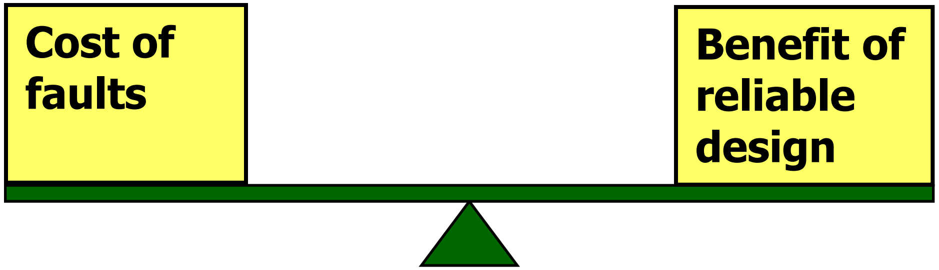
- **We design a highly reliable process structure (e.g., redundant equipment in a parallel) when**

  - The consequence of a failure is high
  - The probability of a failure is too large

- **We design to prevent a single cause from affecting several units or equipment.**

  - Prevent common cause failures

- **Safety first! Then, economics (NPV, DCFRR, etc.).**



Reliability

Industrial practice

- **We automate the adjustment of redundant elements when the time to respond to an incident is short**
- **We provide by-passes around equipment that can be removed without requiring a process shutdown**
- **We isolate sections of a large plant with inventory to reduce the impact of a single failure**
- **We ensure that repair and replacement can be effected rapidly**

PROCESS OPERABILITY: Reliability

In this Lesson, we will learn

- The importance of reliability
- Key terms and definitions

  - Reliability, Failure Rate, Availability
- Process design to remove/replace equipment

  - Pump, valve, heat exchangers
- Process structures to increase reliability?-

  - Calculate system reliability
  - Pump, Boiler, Fuel system
- Inventory location for reliability

  - Tankage