UNIT II

Hazops: Principles - Risk ranking - Guide word - Parameter - Deviation – Causes - Consequences - Recommendation - Coarse HAZOP study - Case studies - Pumping system - Reactor System - Mass transfer system.

HAZOPS

A **hazard and operability study** (HAZOP) is a structured and systematic examination of a complex planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment. The intention of performing a HAZOP is to review the design to pick up design and engineering issues that may otherwise not have been found. The technique is based on breaking the overall complex design of the process into a number of simpler sections called 'nodes' which are then individually reviewed. It is carried out by a suitably experienced multi-disciplinary team (HAZOP) during a series of meetings. The HAZOP technique is qualitative, and aims to stimulate the imagination of participants to identify potential hazards and operability problems. Structure and direction are given to the review process by applying standardised guide-word prompts to the review of each node. The relevant international standard [1] calls for team members to display 'intuition and good judgement' and for the meetings to be held in 'a climate of positive thinking and frank discussion'.

The HAZOP technique was initially developed in the 1960s to analyze major chemical process systems but has since been extended to other areas, including mining operations and other types of process systems and other complex systems such as nuclear power plant operation and software development. It is also used as the basis for reviewing Batch processes and operating procedures.

RISK RANKING

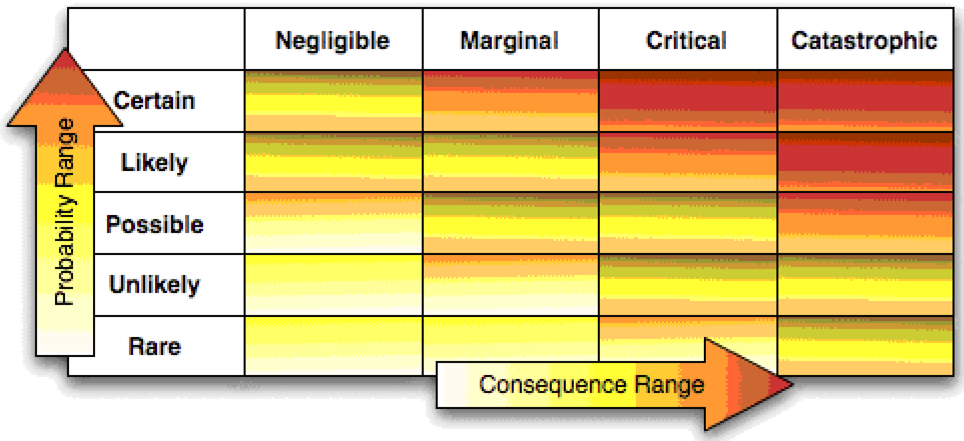
Risk is a concept that denotes a potential negative impact to an asset or some characteristic of value that may arise from some present process or future event. In everyday usage, risk is often used synonymously with the probability of a known loss. Risk is measured in terms of impact and likelihood. Since risk is directly correlated to loss, it is important to be able to assess risks in one's business and to address them. Needless to say, inattention to risks can definitely affect a company's bottom line.

1. IDENTIFY WHAT THE RISK MATRIX IS TO BE USED FOR

Normally a risk matrix is called for during exercises involving hazard analyses, facility siting studies, and safety audits. Depending on the intended use of the matrix, one may need to establish tolerance or risk acceptability levels and a means of assessing the effectiveness of risk mitigation measures.

2. DEFINE CONSEQUENCE AND LIKELIHOOD RANGES

A typical risk matrix is a four by four grid. On the Y (vertical) axis is the "probability/likelihood" description range while on the X (horizontal) axis is the "consequence" range.



Sample Risk Matrix

Consequences of risks as laid down in the grid use descriptive words and are ranked according to severity: Negligible, Marginal, Critical, and Catastrophic. Negligible risks are the least severe and would be assigned the lowest rank. Inversely, catastrophic risks are those that would be first in the severity ranking. Determine tolerance by assigning dollar values to each severity ranking, as well as some qualitative characteristics of the consequence being described. For example, Negligible Risks are those that involve USD 2,000 but less than USD 10,000 and could result in minor illness or injury to employees not exceeding a day, does not violate laws, or has little or minimal environmental damage and will be assigned Rank 1 in the matrix. Catastrophic Risks are those that involve USD 1M, could result in death or permanent disability, result in irreversible environmental damage or permanent closure to business, and will be assigned Rank 4 in the matrix.

Rank	Range	Amount of Loss in USD	Description of Loss
4	Catastrophic	1M or more	• Results in death or permanent disability of employees • Irreversible environmental damage • Closure to business
3	Critical	200,000 but less than 1M	• Results in partial permanent disability, injuries or illness of 3 employees or more • Reversible environmental damage • Violation of law/regulation
2	Marginal	10,000 but less than 200,000	• Injury or illness of resulting in one or more work days lost • Mitigable environmental damage where restoration activities can be done
1	Negligible	2,000 but less than 10,000	• Minor illness or injury to employees resulting in one day's absence • Does not violate laws • Little or minimal environmental damage

Sample Consequence Ranking

The Probability axis describes the likelihood of the risk happening and can be assigned either Frequent, Probable, Occasional, Remote, or Improbable, or simply Certain, Likely, Possible, Unlikely, or Rare. Again, it would be helpful to state the likelihood criteria in numeric terms (example, "Possible" means the risk will occur several times in a lifetime but not less than 10 times nor over 100 times in that lifetime) and to assign logical rankings.

Rank	**Range**	**Probability (over the life of a business)**	**Description**
5	Certain	Once in 2 years	Continually experienced
4	Likely	Once in 4 years	Will occur frequently
3	Possible	Once in 6 years	Will occur several times
2	Unlikely	Once in 12 years	Unlikely, but can be reasonably expected to occur
1	Rare	Once in 24 years	Unlikely to occur, but possible

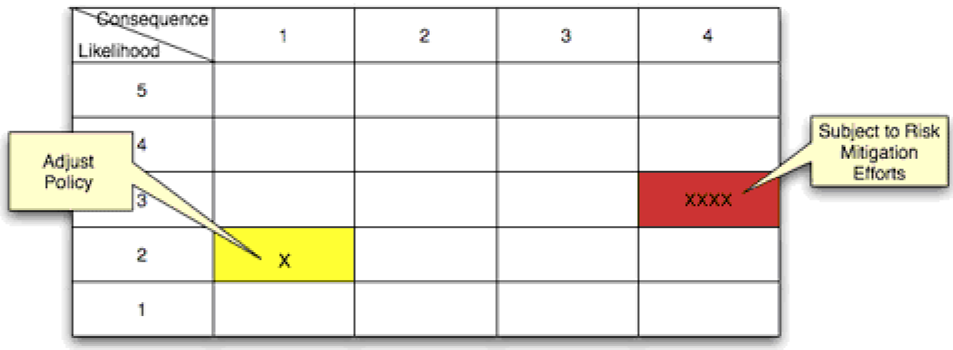
Sample Probability Ranking

Once the criteria for consequence and likelihood has been laid down, proceed to determine specific incidents, events or conditions that pose risk for the business and assign them along the blocks in the matrix. Example of an incident in the office would be "burst pipes and leaks" - this could be assigned in the block Rare (Rank 5 Likelihood) and Negligible (Rank 1 Consequence).

3. TRANSLATE THE TOLERABILITY CRITERIA INTO THE MATRIX

The design of the matrix should be able to show clearly which of the blocks are intolerable or tolerable. For example, a Possible (Rank 3 Likelihood) intersecting with a Catastrophic (Rank 4

Consequence) would be intolerable for any business, given the description and values you have previously assigned. This block is a clear subject of risk mitigation efforts in the organisation compared to a block (risk) pertaining to a Negligible (Rank 1 Consequence) intersecting with a Certain (Rank 2 Likelihood) which could be addressed, say, with a simple change or adjustment in organisational policy.



Determining Tolerance Points in the Matrix

CARE IN ASSIGNING VALUES

Risk matrices are fairly easy to construct and understand. However, one has to be careful in assigning values, taking care not to be overly quantitative and not affording to include what is called a "layer of protection" approach, a means of including protective measures, which, when applied, brings down the risk a level lower. As in all planning and risk management efforts, it is recommended that the risk planner or analyst, even the manager, exercise conservatism in its design as well as point out areas of alarm. Decision makers are recommended to use this tool in policy formulation and include budgetary allocations to address not only persistent risks but also be ready for potentially catastrophic ones.

HAZOPS GUIDE WORDS AND PARAMETER DEVIATION CAUSES CONSEQUENSES RECOMMENDATION

A HAZOP study identifies hazards and operability problems. The concept involves investigating how the plant might deviate from the design intent. If, in the process of identifying problems during a HAZOP study, a solution becomes apparent, it is recorded as part of the HAZOP result; however, care must be taken to avoid trying to find solutions which are not so apparent, because the prime objective for the HAZOP is problem identification. Although the HAZOP study was developed to supplement experience based practices when a new design or technology is involved, its use has expanded to almost all phases of a plant's life. HAZOP is based on the principle that several experts with different backgrounds can interact and identify more problems when working together than when working separately and combining their results. The "Guide-Word" HAZOP is the most well known of the HAZOPs; however, several specialisations of this basic method have been developed.

CONCEPT

Plant design, following the structure provided by the guide words and the team leader's experience. The primary advantage of this brainstorming is that it stimulates creativity and generates ideas. This creativity results from the interaction of the team and their diverse backgrounds. Consequently the process requires that all team members participate (quantity breeds quality in this case), and team members must refrain from criticizing each other to the point that members hesitate to suggest ideas. The team focuses on specific points of the design (called "study nodes"), one at a time. At each of these study nodes, deviations in the process parameters are examined using the guide words. The guide words are used to ensure that the design is explored in every conceivable way. Thus the team must identify a fairly large number of deviations, each of which must then be considered so that their potential causes and consequences can be identified. The best time to conduct a HAZOP is when the design is fairly firm. At this point, the design is well enough defined to allow meaningful answers to the questions raised in the HAZOP process. Also, at this point it is still possible to change the design without a major cost. However, HAZOPs can be done at any stage after the design is nearly firm. For example, many older plants are upgrading their control and instrumentation systems. The success or failure of the HAZOP depends on several factors: • The completeness and accuracy of drawings and other data used as a basis for the study • The technical skills and insights of the team • The ability of the team to use the approach as an aid to their imagination in visualizing deviations, causes, and consequences • The ability of the team to concentrate on the more serious hazards which are identified.

The process is systematic and it is helpful to define the terms that are used:

a. STUDY NODES - The locations (on piping and instrumentation drawings and procedures) at which the process parameters are investigated for deviations.

b. **INTENTION** - The intention defines how the plant is expected to operate in the absence of deviations at the study nodes. This can take a number of forms and can either be descriptive or diagrammatic; e.g., flowsheets, line diagrams, P&IDS.

c. DEVIATIONS - These are departures from the intention which are discovered by systematically applying the guide words (e.g., "more pressure").

d. CAUSES - These are the reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human errors, an unanticipated process state (e.g., change of composition), external disruptions (e.g., loss of power), etc.

e. **CONSEQUENCES -** These are the results of the deviations should they occur (e.g., release of toxic materials). Trivial consequences, relative to the study objective, are dropped.

f. **GUIDE WORDS -** These are simple words which are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations. The guide words shown in the following table are the ones most often used in a HAZOP; some organisations have made this list specific to their operations, to guide the team more quickly to the areas where they have previously found problems. Each guide word is applied to the process variables at the point in the plant (study node) which is being examined.

In order to identify deviations, the team applies systematically, in order a set of **Guide Words** to each node in the process. To prompt discussion, or to ensure completeness, it may also be helpful to explicitly consider appropriate **parameters** which apply to the design intent. These are general words such as Flow, Temperature, Pressure, Composition. The current standard notes that Guide words should be chosen which are appropriate to the study and neither too specific (limiting ideas and discussion) nor too general (allowing loss of focus). A fairly standard set of Guide Words is as follows:

Guide Word	**Meaning**
NO OR NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/increase
PART OF	Qualitative modification/decrease
REVERSE	Logical opposite of the design intent
OTHER THAN / INSTEAD	Complete substitution
EARLY	Relative to the clock time
LATE	Relative to the clock time
BEFORE	Relating to order or sequence
AFTER	Relating to order or sequence

(The last five guide words are applicable to batch or sequential operations.) Where a guide word is meaningfully applicable to a parameter e.g. NO FLOW, MORE TEMPERATURE, their combination should be recorded as a credible potential deviation (from the design intent) that requires review.

Guidelines for Using Procedure The concepts presented above are put into practice in the following steps:

1. Define the purpose, objectives, and scope of the study

2. Select the team

3.- Prepare for the study

4. Carry out the team review

5. Record the results.

6. Follow up to ensure results are implemented.

It is important to recognize that some of these steps can take place at the same time. For example, the team reviews the design, records the findings, and follows up on the findings continuously. (Refer also to the diagrammatic representation of the HAZOP procedure attached).

HAZOP-type studies may also be carried out by considering applicable guide words and identifying elements to which they are applicable[1] or by considering the parameters associated with plant elements and systematically applying guide words to them; although this last approach is not mentioned in the relevant standard, its examples of output include a study (B3) recorded in this way.[1] The following table gives an overview of commonly used guide word - parameter pairs and common interpretations of them.

Parameter / Guide Word	More	Less	None	Reverse	As well as	Part of	Other than
Flow	high flow	low flow	no flow	reverse flow	deviating concentration	contamination	deviating material
Pressure	high pressure	low pressure	vacuum		delta-p		explosion
Temperature	high temperature	low temperature					

Level	high level	low level	no level		different level		
Time	too long / too late	too short / too soon	sequence step skipped	backwards	missing actions	extra actions	wrong time
Agitation	fast mixing	slow mixing	no mixing				
Reaction	fast reaction / runaway	slow reaction	no reaction				unwanted reaction
Start-up / Shut-down	too fast	too slow			actions missed		wrong recipe
Draining / Venting	too long	too short	none		deviating pressure	wrong timing	
Inertising	high pressure	low pressure	none			contamination	wrong material
Utility failure (instrument air, power)			failure				

DCS failure			failure				
Maintenance			none				
Vibrations	too low	too high	none				wrong frequency

Once the causes and effects of any potential hazards have been established, the system being studied can then be modified to improve its safety. The modified design should then be subject to another HAZOP, to ensure that no new problems have been added.

The *technique* can also be applied where design information is not fully available and doing so may be useful in eliminating alternative designs, before too much time is invested in them. However, where a design is required to have a HAZOP performed to meet legislative or regulatory requirements, such an 'early' meeting cannot be considered to comply with this requirement.

"The term HAZOP has been often associated, in a generic sense, with some other hazard identification technique. The use of the term with such techniques is considered to be inappropriate and is excluded from this document..

Team

A HAZOP study is a team effort. The team should be as small as possible consistent with their having relevant skills and experience. A minimum team size of 4-5 is recommended. In a large process there will be many HAZOP meetings and the individuals within the team may change as different specialists are required and deputies are required for the various roles. As many as 20 individuals may be involved but is recommended that the team should not exceed 7-8 at any time (a larger team will make slower progress adding considerably to the costs). Each team member should have a definite role as follows Note that duplication of roles (e.g. Client, Contractor & Project Management representatives) should be avoided:

Name	**Role**	**Comment**
Study Leader / Chairman / Facilitator (Full-time attendee)	To manage the team meetings	Someone experienced in leading HAZOPs, who is familiar with this type of process but is independent of the design team. Responsible for progressing through the series of nodes, moderating the team discussions, maintaining the accuracy of the record, ensuring the clarity of the recommended actions and identifying appropriate actionees.

Recorder / Secretary / Scribe (Full-time attendee)	To minute the team meetings	To document the Causes, Consequences, Safeguards and Actions identified for each deviation, to record the conclusions of team discussions (accurately but comprehensibly), [e] to document problems and recommendations
Process Designer / Engineer (Full-time attendee)	Representing the team which has designed the process	To provide design intent details or explain any further information
Operator / User (Full-time attendee)	Representing those who will operate the process	To consider the operation, and the potential causes and consequences of deviations To question its operability of the process
Discipline / Vendor Specialist (Part-time attendee)	Providing specialist guidance to the team; e.g. Instrumentation, Human Factors Specialist, 3rd-party equipment	To provide specialist technical knowledge not available within the team, e.g. instrumented control systems, human reliability analysis, design & operation of 3rd-party (vendor) equipment
Maintainer (Part-time attendee)	Providing specialist guidance to the team on maintainability issues	To consider the maintenance of the plant equipment and question its maintainability.

In earlier publications it was suggested that the Study Leader could also be the Recorder but separate roles are now generally recommended.

The use of computers and projector screens can enhance the recording of meeting minutes (the team can see what is minuted and ensure that it is accurate), the display of P&IDs for the team to review, the provision of supplemental documented information to the team and the logging of non-HAZOP issues that may arise during the review, e.g. drawing/document corrections and clarifications. Specialist software is now available from several suppliers to support the recording of meeting minutes and tracking the completion of recommended actions.

THE HAZOP REPORT

AIMS

The report should provide sufficient information on each element so that, either read alone or together with available and clearly cross referenced documents, an assessment can be made of the adequacy of the HAZOP study carried out.

TITLE PAGE

The study title should be displayed both on the cover and on a separate title sheet. The title should clearly and unambiguously identify the facility covered by the Study. The title page should also show the type of operation, whether it is a proposed operation or an existing facility and its location.

The title sheet should specify on whose authority the report was prepared and the date it was authorised. The name/s/ of the chairperson and organisation she or he represents should be stated.

TABLE OF CONTENTS

A table of contents should be included at the beginning of the report. It should include a list of figures, tables and appendices.

Glossary and Abbreviations

A glossary of any special terms or titles and a list of abbreviations should be included to ensure that the report can be readily and clearly understood.

SUMMARY OF MAIN FINDINGS AND RECOMMENDATIONS

This Summary should briefly outline the nature of the proposal or existing facility and the scope of the report. A list of the main conclusions and recommendations arising from the HAZOP should be presented. An indicative implementation timetable is also useful.

SCOPE OF REPORT

This section should give a brief description of the aims and purpose of the study and the reason for its preparation. For example, is the study being prepared to satisfy conditions of development consent or at the company's initiative as part of safety upgrading? Is it for an entirely new development or for the modification of, or extension to, an existing development? Reference should be made to any other relevant safety related studies completed or under preparation.

DESCRIPTION OF THE FACILITY

This section should give an overview of the site, plant and materials used/stored. Where this information is already available through an EIS, hazard analysis or other document, clear cross reference to these documents or inclusion in the form of appendices would suffice.

The description should include: a) Site locational sketch with identification of adjacent / surrounding land uses. b) A schematic diagram of the plant under study along with a brief description of each process step involved. The location and nature of raw materials and product storage should also be shown as well as loading/unloading facilities. The plant does not have to be described in detail, though some process conditions such as pressure in pressurised vessels may be necessary to gain an understanding of the plant. c) Clearly identified P&IDs with plant and line numbers as used in the HAZOP.

Instrumentation and equipment symbols should be explained. Alternatives used (photographs, plans, etc.) should also carry appropriate identification. Where a large number of P&IDs are involved in the study, only those relevant to the recommendations need be appended to the report.

HAZOP TEAM MEMBERS

This section should list the HAZOP participants, together with their affiliations and positions. Their responsibility, qualifications, and relevant experience should also be given. The chairperson and the secretary of the group should also each be identified. The dates of the meetings and their duration should be provided. Where some members were not present at all meetings, the extent of their participation should be indicated. Special visitors and occasional members should be listed in a manner similar to the continuing members, with the reasons for their attendance detailed. For example, specialist instrumentation engineer/consultants may be required to overcome specific design problems.

HAZOP METHODOLOGY

The general approach used should be briefly outlined. Any changes to the accepted standard methodology used for a HAZOP should be detailed and explained.

GUIDE WORDS

The guide words used to identify possible deviations in this HAZOP should be listed. An explanation of any specialised words used for the facility should also be given.

PLANT OVERVIEW

This section should outline what general conditions and situations likely to result in a potentially hazardous outcome were considered in the HAZOP (following line by line analysis) for the overall P&ID or section including overview issues, such as:

• first start-up procedures

• emergency shutdown procedures

• alarms and instrumentation trip testing

• pre-commissioning operator training

• plant protection systems

• failure of services

• breakdowns

• effluent (gas, liquid, solid/

• noise.

Any issues raised and considered necessary for review outside the HAZOP should be detailed.
A set of overview guide words is included in Appendix 1.

ANALYSIS OF MAIN FINDINGS

An indication of the criteria used to determine whether or not action was chosen to be taken regarding the outcome of a deviation is required.

The results of the HAZOP, giving deviations, consequences and actions required, should be provided. Those events on which the decision of no action was made should also be listed, along with the events for which consequence or risk analysis was considered necessary. The decisions made after such further analyses should also be given. Any alternative actions generated and considered should be detailed.

ACTIONS ARISING FROM THE HAZOP

This section should highlight those actions which are potentially hazardous to plant personnel, the public or the environment or have the potential to jeopardise the operability of the plant. Also included should be a clear statement of commitment to modify the design or operational procedures in accordance with the identified required actions and a timetable for implementation. Justification as to why no action was chosen for any actions identified should also be made. The current status of the recommended actions at the time of the report should also be given together with the names/designations of persons responsible for their implementation.

PUMPING SYSTEM

A **pump** is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: *direct lift*, *displacement*, and *gravity* pumps.

Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps.

Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.

Single stage pump – When a casing contains only one revolving impeller, it is called a single stage pump.

Double/multi-stage pump – When a casing contains two or more revolving impellers, it is called a double or multi-stage pump.

In biology, many different types of chemical and bio-mechanical pumps have evolved, and biomimicry is sometimes used in developing new types of mechanical pumps.

WHY SAFETY PUMPING SYSTEMS?

THE GREEN SOLUTION FOR OIL TRANSPORT

Heavy Duty Innovations, LLC (HDI) enables the safe, environmentally friendly transloading of hazardous liquids during transport. Building on our success in refined petroleum and crude oil truck transport systems, HDI's vision is to be the interface between the driver/operator and all types of hazardous liquids during trans-loading operations.

ELIMINATE BLOWING HOSES DURING PUMPING OPERATIONS

Safety Pumping System from HDI mount on the tractor or trailer of petroleum truck tankers with models optimized for crude or refined oil products. Our systems prevent the biggest causes of environmental contamination and driver injury – blowing hoses and overfilling the truck's tank.

RETURN ON INVESTMENT

The costof a spill or accident goes far beyond the cost of the environmental cleanup, fines and medical liability in the case of driver injury. Environmental contamination accidents also causes insurance premiums to increase. These costs dwarf the cost of a Safety Pumping System™.

CORPORATE RESPONSIBILITY

More importantly, the oil companies are under increasing environmental scrutiny, particularly in fields that involve fracking. Preventing damage to the environment and promoting environmental protection creates significant strategic value as it affects regulators, environmentalists and public perception. BP and Exxon have experienced the adverse effects that a high profile environmental contamination can have on market capitalization and their brand.

Implementing Safety Pumping Systems is part of a zero tolerance, 100% compliance strategy when it comes to the environment and driver safety.

SAFETY FEATURE	WHY IT'S IMPORTANT
Full Pump Relief Valve Protection in both directions of flow	Prevents over pressurization and failures of hoses, fittings and other components that cause a spill.

SAFETY FEATURE	WHY IT'S IMPORTANT
A Neutral Position	When the pump system starts up there is no flow of crude and no pressure. Even if there is a problem somewhere, there is no spill.
Tactile Feedback	Pushing an on/off button provides no warning of a pending accident. The driver should be able to "feel" if there is a problem and be able to correct it before there is a spill.
Proportional Flow Control in Both Directions of Flow	Moving slowly from Neutral to one GPM, two GPM, etc. allows the driver to feel if there is a problem in any of his connections. It also enables low pressure operations when required.
Immediate Stop or Reversal of Flow	If a problem develops, the driver must be able to immediately stop or reverse the flow and resulting pressure to prevent or minimize the impact of a spill.
Standardized, Simple Operating Procedures	Trucks, trailer and pump operating procedures vary between fleets and often between trucks. Simplifying and standardizing operating procedures for all pump systems prevents confusion when drivers move truck- to-truck or fleet-to-fleet.

SAFETY FEATURE	WHY IT'S IMPORTANT
Driver Training & Certification	Standardized system operating procedures make it easier to train drivers and to develop an effective Driver Certification program.
Visual Cues	Drivers and supervisors can observe the handle position of the SPS system and know exactly what is happening during pumping operations; loading on, loading off, rate of flow, etc.
Pump Controls at the Pump System	The pump system should be fully controlled at the pump, not from inside the cab of the truck. The driver should be at the pump system during trans-loading in case a problem arises.

REACTOR SYSTEM

REACTION

Choosing the correct reactor technology and equipment sizes for your process system is vital. If the reaction rate occurs to fast or too slow, too hot or cold or the proper kinetics are not achieved, your production rates and the quality of your product are at stake. Let EPIC's chemical process experts help you select the best reactor vessel for your modular process system.

Important factors: There are many important factors that affect reactions. Vessel size, fluid velocity, reaction kinetics, these all weigh into reactors design and selection. EPIC's expert process chemical engineers will work with your specific product to specify the important factors for reaction vessel selection, including:

- Reaction kinetics
- Rate of reaction
  - Temperature effects
  - Concentration of moles
  - Partial pressure
  - Mole fraction
  - Stoichiometric balances

- Diffusion between phases
- Catalysis
- Chemical equilibrium
- Material and energy balances
- Steady states
- Direction of flow

BATCH REACTOR

TYPE OF REACTOR	**USES**
General batch reactors	• Relatively slow reactions • Include heat transfer mechanisms to maintain steady temperature range • Majority = liquid phase • Most flexible reactor type – can have wide range of reaction times for a wide-variety of reactions

CONTINUOUS REACTORS

YPE OF REACTOR	**USES**
General continuous reactors	• For large quantities • Feed rate controls reaction rate

YPE OF REACTOR	USES
	• Residence time and volume are relatively fixed • Product is more consistent in quality • Generate less waste than batch
Continuous stirred tank reactors (CSTR reactors)	• Used for greater production rates with relatively short reactions • Can be used singularly or in-series • Steady state reactions in liquid phase are the most common application • Best for immiscible liquids
Tubular	• Gas-phase and liquid phase reactors • Short reaction times are typical • Elevated temperatures

YPE OF REACTOR	USES
	• Frictional pressure drop is an important factor for this type of reactor
Plug flow(PFR reactors)	• Low and medium temperature capabilities • Variable residence times • Low cost • Best used with diluted reactants
Packed bed flow reactors (fixed bed reactor)	• Similar to a plug flow reactor, but packed with catalyst beads • Catalyst helps maintain reaction at a level temperature
Fluid bed reactor (FBR)	• Used for multi-phase reactions • Catalysts are optional

YPE OF REACTOR	USES
	• Medium to high velocity • Uniform particle mixing and uniform temperature gradients

Reactors are used in a variety of common applications that EPIC builds, including:

- Batch reactor systems
- Pilot plant reactors and reactor systems
- Continuous reactor systems
- Production plant reactor systems

Contact an engineer to start designing your custom reactor system today.

MASS TRANSFER SYSTEM

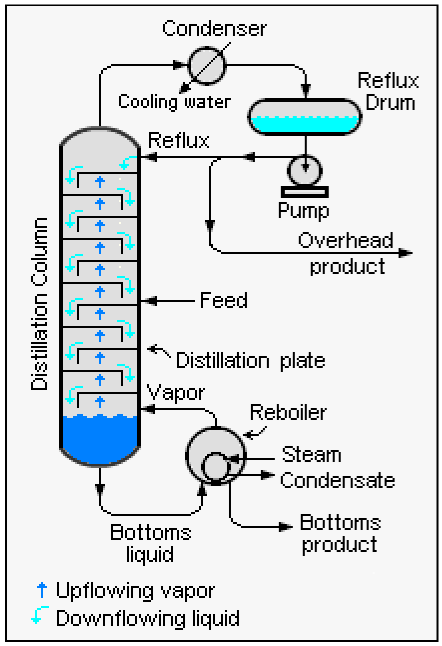
Mass transfer is the net movement of mass from one location, usually meaning stream, phase, fraction or component, to another. Mass transfer occurs in many processes, such as absorption, evaporation, drying, precipitation, membrane filtration, and distillation. Mass transfer is used by different scientific disciplines for different processes and mechanisms. The phrase is commonly used in engineering for physical processes that involve diffusive and convective transport of chemical species within physical systems.

Some common examples of mass transfer processes are the evaporation of water from a pond to the atmosphere, the purification of blood in the kidneys and liver, and the distillation of alcohol. In industrial processes, mass transfer operations include separation of chemical components in distillation columns, absorbers such as scrubbers or stripping, adsorbers such as activated carbon beds, and liquid-liquid extraction. Mass transfer is often coupled to additional transport processes, for instance in industrial cooling towers. These towers couple heat transfer to mass transfer by allowing hot water to flow in contact with air. The water is cooled by expelling some of its content in the form of water vapor.

The typical gas-liquid contacting operations include distillation, absorption, stripping, leaching and humidification. Distillation and absorption are two most widely used mass transfer processes in chemical industries. Design of plate column for absorption and distillation involves many common steps of calculation such as determination of number of theoretical plates, column diameter, plate hydraulic design, etc. In absorption process, a soluble component is absorbed in a liquid (called solvent) from a gaseous mixture. The gas and liquid streams leaving the tray are in equilibrium under the ideal condition. The separation in distillation is based on the relative volatility of the components. Additional vapor phase is generated by the vaporization of more volatile components (called stripping) and by condensation of relatively less volatile components(called absorption) adds to the liquid phase.

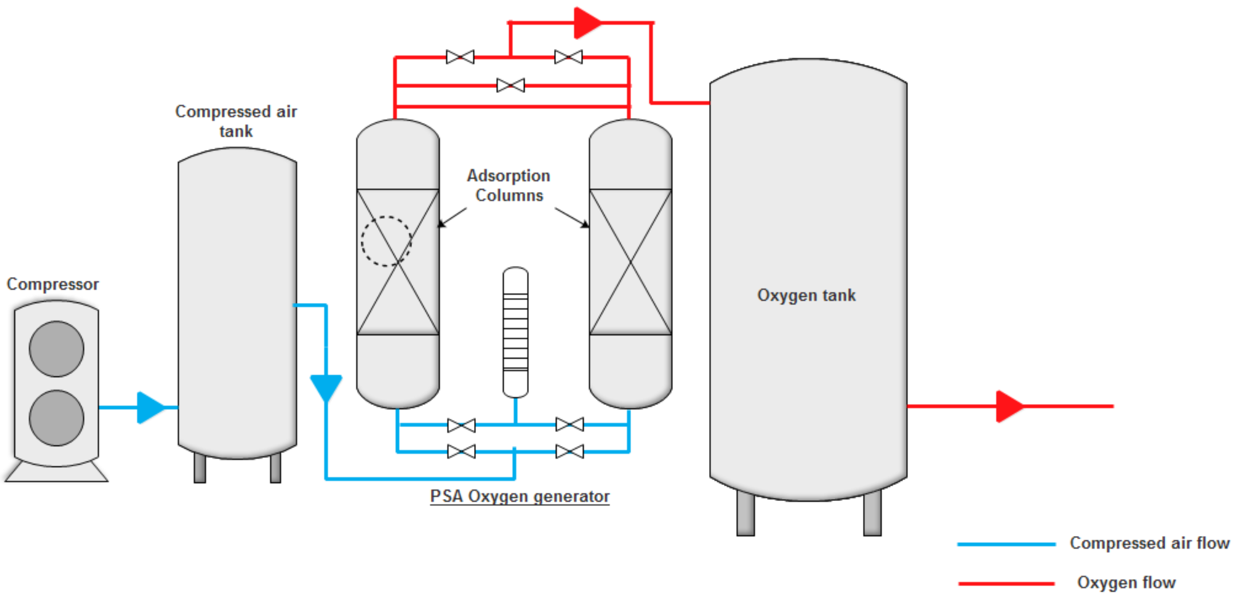
DISTILLATION

Distillation is a method of separating mixtures based on differences in their volatiles in a boiling liquid mixture. **Distillation** is a unit operation, or a physical separation **process**, and not a chemical reaction. ... Water is distilled to remove impurities, such as salt from seawater.



ADSORPTION

Adsorption is the adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface. This process creates a film of the *adsorbate* on the surface of the *adsorbent*. This process differs from absorption, in which a fluid (the *absorbate*) is dissolved by or permeates a liquid or solid (the *absorbent*), respectively. Adsorption is a surface-based process while absorption involves the whole volume of the material. The term *sorption* encompasses both processes, while *desorption* is the reverse of it. Adsorption is a *surface phenomenon*.



ABSORPTION

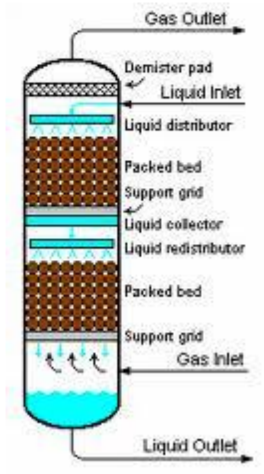
In chemistry, **absorption** is a physical or chemical phenomenon or a process in which atoms, molecules or ions enter some bulk phase – liquid or solid material. This is a different process from adsorption, since molecules undergoing absorption are taken up by the volume, not by the surface (as in the case for adsorption). A more general term is *sorption*, which covers absorption, adsorption, and ion exchange. Absorption is a condition in which something takes in another substance.

In many processes important in technology, the chemical absorption is used in place of the physical process, e.g., absorption of carbon dioxide by sodium hydroxide – such acid-base processes do not follow the Nernst partition law.

For some examples of this effect, see liquid-liquid extraction. It is possible to extract from one liquid phase to another a solute without a chemical reaction. Examples of such solutes are noble gases and osmium tetroxide.[1]

The process of absorption means that a substance captures and transforms energy. The absorbent distributes the material it captures throughout whole and adsorbent only distributes it through the surface.

The process of gas or liquid which penetrate into the body of adsorbent is commonly known as absorption.



EXTRACTION

Extraction in chemistry is a separation process consisting in the separation of a substance from a matrix. It includes *Liquid-liquid extraction*, and *Solid phase extraction*. The distribution of a solute between two phases is an equilibrium condition described by partition theory. This is based on exactly how the analyte move from the water into an organic layer.

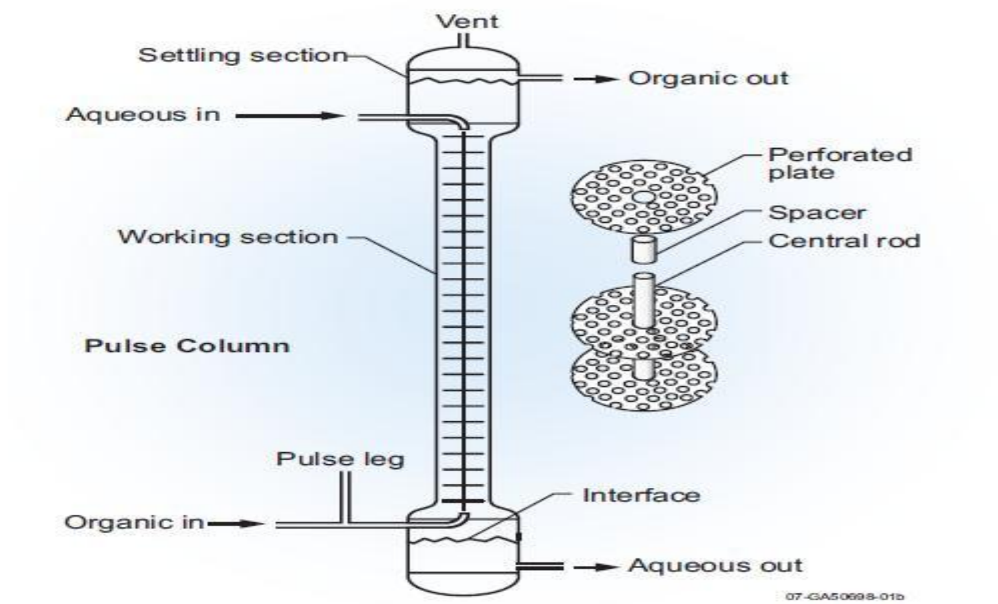


Figure 4. Pulse Column with perforated plates