08
Process Design

Objective

When you have completed study of this chapter you should be able to :

- Apply the factors to be considered for process design;
- Understand the relevance of ISO in design and its implications;
- Choose the apt material of construction for plant construction;
- Be familiar with the “Rules of Thumb” to be applied during process design.

8.1 Process Design Considerations

The rapid developments in technology has warranted comprehensive review of both technical and economic evaluations. A modern chemical process involves a series of operations which are run round the clock throughout the year .It demands equipment of exceptional robustness, ingenuity and reliability. Also, these are to be achieved at an optimum cost.

8.1.1 The General Design Procedure

It is difficult to suggest a standard design procedure. Such a procedure, however, would involve the following steps:

- Specifying the problem
- Analyzing the probable solution
- Applying chemical process principles and theories of mechanics satisfying the conditions of the problem
- Selecting materials and stresses to suit processing conditions
- Evaluating and optimizing the design
- Preparing the drawings and specifications

Each step is to be checked both in terms of mathematical calculations and engineering feasibility. It is necessary to ascertain whether the results are consistent with experience and feasibility. It may take several iterations before the satisfactory solutions is obtained.

8.1.2 The Role of Heuristic Methods in Design

Process design engineers are often entrusted with the task of making preliminary design decisions on the basis of incomplete information and untested assumptions. As design proceeds and investment in the process is made, these decisions develop enormous "momentum" of their own, making it increasingly difficult to revise the choices. Compared to product design, where early prototyping can permit the parallel evaluation of several design options, process design "locks in" choices earlier and with more force, putting even more of a premium on making good choices early on.

In many aspects of process and product design, engineers rely heavily on the use of **design heuristics**. In the classic engineering design text by Pahl and Beitz, a heuristic is described as *"explicit knowledge [and] non-explicit knowledge…necessary in order to organize the sequence of thinking operations, including modifying operations (searching and finding) and testing operations (checking and assessing)."* More commonly, a heuristic is a general procedure or rule of thumb, which is used to suggest solutions or strategies for solving a problem, often in the absence of "deep" knowledge about a system.

A more complete listing of design heuristics for manufactured products is listed below.

Design for Material Recovery

- avoid composite materials
- specify recyclable materials
- use recyclable packaging

Design for disassembly

- optimize disassembly sequence
- avoid embedded parts
- simplify component interfaces
- avoid adhesives and welds
- avoid threaded fasteners

Design for simplicity

- reduce product complexity
- reduce number of parts or subassemblies
- utilize common (standardized) parts and components

Design for Waste Minimization

- reduce product dimensions
- reduce mass of components

Unfortunately, a comparable set of design heuristics for process designers does not yet exist.

Design to reduce maintenance wastes

Maintenance-related wastes include solvents used for vessel cleaning, process fluids drained during servicing of pumps and heat exchangers, cleaning agents and abrasive materials used in cleaning heat exchange tubes, and heavy-phase materials such as tank heels, suspended solids, and sludge which must be removed due to gradual accumulation in process vessels. Design strategies include providing interim storage for process and cleaning fluids, minimizing the volume of piping runs which must be drained for maintenance, reducing maintenance frequency by using foul-resistant coatings and materials, and insuring that frequently-cleaned vessels are provided with adequate drainage and line-of-sight clearance for high-pressure washing.

Design for selectivity

Another common source of wastes are byproducts created incidentally in separations equipment, heat exchangers, and other non-reactor vessels. Many of these operations result in the formation of byproducts from thermal decomposition or incidental reaction of process fluids. Design strategies include reduction of reboiler temperatures by elimination of process "hot spots," use of reduced distillation column pressures or specification of polymer-lined or high-polish finishes in heated vessels.

Design to reduce mechanical losses

Mechanical losses of materials include fugitive emissions due to tank vents, pump seals, and valve packing; they can also include losses due to steam-injection vacuum pumps, sampling loop purges, and spillage from dry solids transfer operations. Design strategies include specification of vent recovery systems, specification of sealless pumps or closed-circuit seal rinses, and reducing valve and flange counts.

Design to reduce transient wastes

Transient wastes occur during process upsets and start-up/shut-down operations. Design strategies include providing interim storage and recycle loops and tankage for recovering off-spec product, implementing parallel reactor systems, and improving process control techniques.

During the classification of design strategies and heuristics, it became obvious that not all of the strategies identified thus far can be applied equally well during all phases of design. Additionally, while some strategies apply well to reactor design, others are more aptly applied in separation processes. Table 8.1 provides more specific illustrations of strategies suggested by the process design heuristics, and indicates which phases of process design they are best applied.

Strategy	Applicable Design Phase Preliminary Design	 Equipment Specification	 P&ID
Design to reduce maintenance wastes			
• provide for drainage of vessels during cleaning and maintenance	*	*	
• use foul-resistant surface finishes or heat exchanger designs in foul-prone service		*	
• provide interim storage for vessels which must be drained for service	*		*
Design for selectivity			
• reduce thermal degradation in distillation columns			
-use structured packing to reduce pressure drop	*	*	
-use lower column pressures to reduce reboiler temperature	*		
• avoid direct contact heating	*	*	
• reduce catalytic sites and surfaces in heated vessels	*	*	
Design to reduce mechanical losses			
• provide for vapor recovery from process vents	*	*	*
• use sealless pumps or recycle seal flushes		*	
• specify floating-lid tanks for storage	*		
• minimize the number of pipe flanges and valves in the process	*	*	*
Design to reduce transient wastes			
• design for start-up/shut down	*	*	*
• provide process shunts in parallel process chains	*		*
• provide interim storage for off-spec material that can be recycled to the process	*		

Table 8.1
Applicability of Process Design Heuristics

8.2 ISO Standards

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from 100 countries, one from each country. This council decided upon a set of industrial standards in 1947 and has been updating them ever since. Recently, ISO9000 has become commonplace in the industrial world.

8.2.1 What does Standards Signify ?

Standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose.

For example, the format of the credit cards, phone cards, and "smart" cards that have become commonplace is derived from an ISO International Standard. Adhering to the standard, which defines such features as an optimal thickness (0,76 mm), means that the cards can be used worldwide.

International Standards thus contribute to making life simpler, and to increasing the reliability and effectiveness of the goods and services we use.

8.2.2 The Requirement of International Standardization

The existence of non-harmonized standards for similar technologies in different countries or regions can contribute to so-called "technical barriers to trade". Export-minded industries have long sensed the need to agree on world standards to help rationalize the international trading process. This was the origin of the establishment of ISO.

International standardization is well-established for many technologies in such diverse fields as information processing and communications, textiles, packaging, distribution of goods, energy production and utilization, shipbuilding, banking and financial services. It will continue to grow in importance for all sectors of industrial activity for the foreseeable future.

The main reasons are:

Worldwide growth in trade liberalization

Today's free-market economies increasingly encourage diverse sources of supply and provide opportunities for expanding markets. On the technology side, fair competition needs to be based on identifiable, clearly defined common references that are recognized from one country to the next, and from one region to the other. An industry-wide standard, internationally recognized, developed by consensus among trading partners, serves as the language of trade.

Interpenetration of varied sectors

No industry in today's world can truly claim to be completely independent of components, products, rules of application, etc., that have been developed in other sectors. Bolts are used in aviation and for agricultural machinery; welding plays a role in mechanical and nuclear engineering, and electronic data processing has penetrated all industries. Environmentally friendly products and processes, and recyclable or biodegradable packaging are pervasive concerns.

Worldwide communications networks

The computer industry offers a good example of technology that needs quickly and progressively to be standardized at a global level. Full compatibility among open systems fosters healthy competition among producers, and offers real options to users since it is a powerful catalyst for innovation, improved productivity and cost-cutting.

Global norms for emerging technologies

Standardization programmes in completely new fields are now being developed. Such fields include advanced materials, the environment, life sciences, urbanization and construction. In the very early stages of new technology development, applications can be imagined but functional prototypes do not exist. Here, the need for standardization is in defining terminology and accumulating databases of quantitative information.

Developing countries

Development agencies are increasingly recognizing that a standardization infrastructure is a basic condition for the success of economic policies aimed at achieving sustainable development. Creating such an infrastructure in developing countries is essential for improving productivity, market competitiveness, and export capability.

Industry-wide standardization is a condition existing within a particular industrial sector when the large majority of products or services conform to the same standards. It results from consensus agreements reached between all economic players in that industrial sector - suppliers, users, and often governments. They agree on specifications and criteria to be applied consistently in the choice and classification of materials, the manufacture of products, and the provision of services.

The aim is to facilitate trade, exchange and technology transfer through:

- enhanced product quality and reliability at a reasonable price;
- improved health, safety and environmental protection, and reduction of waste;
- greater compatibility and interoperability of goods and services;
- simplification for improved usability;
- reduction in the number of models, and thus reduction in costs;
- increased distribution efficiency, and ease of maintenance.

Users have more confidence in products and services that conform to International Standards. Assurance of conformity can be provided by manufacturers' declarations, or by audits carried out by independent bodies.

8.2.3 ISO's Achievements

Below are some examples of ISO standards that have been widely adopted, giving clear benefits to industry, trade and consumers.

The ***ISO film speed code***, among many other photographic equipment standards, has been adopted worldwide making things simpler for the general user.

Standardization of the format of ***telephone and banking cards*** means the cards can be used worldwide.

Tens of thousands of businesses are implementing ***ISO 9000*** which provides a framework for quality management and quality assurance. The ***ISO 14000*** series provides a similar framework for environmental management.

The ***internationally standardized freight container*** enables all components of a transport system - air and seaport facilities, railways, highways, and packages - to interface efficiently. This, combined with standardized documents to identify sensitive or dangerous cargoes makes international trade cheaper, faster and safer.

m, kg, s, A, K, mol, cd are the symbols representing the seven base units of the ***universal system of measurement known as SI*** (Système international d'unités). The SI system is covered by a series of 14 International Standards. Without these standards shopping and trade would be haphazard and technological development would be handicapped.

Paper sizes. The original standard was published by DIN in 1922. Now used worldwide as ISO 216, standard paper sizes allow economies of scale with cost benefits to both producers and consumers.

A well-designed symbol conveys a clearcut message in a multilingual world. The same ***symbols for automobile controls*** are displayed in cars all over the world, no matter where they are manufactured.

Safety of wire ropes: used on oil rigs, on fishing vessels, in mines, in all types of building operations, for lifts and cable cars, etc. ISO International Standards systematically define basic characteristics such as size, surface finish, type of construction, tensile grade of the wire, minimum breaking load and linear mass. Standardization of performance or safety requirements ensures that user requirements are met while allowing individual manufacturers the freedom to design their own solutions for meeting these basic needs. Consumers then benefit from the effects of competition among manufacturers.

The ***ISO international codes for country names, currencies and languages*** help to eliminate duplication and incompatibilities in the collection, processing and dissemination of information. As resource-saving tools, universally understandable codes play an important role in both automated and manual documentation.

The diversity of screw threads for identical applications used to represent an important technical obstacle to trade. It caused maintenance problems, and lost or damaged nuts or bolts could not easily be replaced. A global solution is supplied in the ISO standards for ***ISO metric screw threads***.

8.2.4 The Composition of ISO

ISO is made up of its members which are divided into three categories:

A member body of ISO is the national body "most representative of standardization in its country". Thus, only one body in each country may be admitted to membership of ISO.

A member body takes the responsibility for:

- informing potentially interested parties in their country of relevant international standardization opportunities and initiatives;
- ensuring that a concerted view of the country's interests is presented during international negotiations leading to standards agreements;
- providing their country's share of financial support for the central operations of ISO, through payment of membership dues.

Member bodies are entitled to participate and exercise full voting rights on any technical committee and policy committee of ISO.

A correspondent member is usually an organization in a country which does not yet have a fully developed national standards activity. Correspondent members do not take an active part in the technical and policy development work, but are entitled to be kept fully informed about the work of interest to them.

ISO has also established a third category, subscriber membership, for countries with very small economies. Subscriber members pay reduced membership fees that nevertheless allow them to maintain contact with international standardization.

8.2.5 The Scope of ISO

The technical work of ISO is highly decentralized, carried out in a hierarchy of some 2 850 technical committees, subcommittees and working groups. In these committees, qualified representatives of industry, research institutes, government authorities, consumer bodies, and international organizations from all over the world come together as equal partners in the resolution of global standardization problems. Some 30 000 experts participate in meetings each year.

The major responsibility for administrating a standards committee is accepted by one of the national standards bodies that make up the ISO membership - AFNOR, ANSI, BSI, DIN, SACS, SIS, etc. The member body holding the secretariat of a standards committee normally appoints one or two persons to do the technical and administrative work. A committee chairman assists committee members in reaching consensus. Generally, a consensus will mean that a particular solution to the problem at hand is the best possible one for international application at that time.

The Central Secretariat in Geneva acts to ensure the flow of documentation in all directions, to clarify technical points with secretariats and chairmen, and to ensure that the agreements approved by the technical committees are edited, printed, submitted as draft International Standards to ISO member bodies for voting, and published. Meetings of technical committees and subcommittees are convened by the Central Secretariat, which coordinates all such meetings with the committee secretariats before setting the date and place. Although the greater part of the ISO technical work is done by correspondence, there are, on average, a dozen ISO meetings taking place somewhere in the world every working day of the year.

Each member body interested in a subject has the right to be represented on a committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The publication ISO Memento provides information on the scope of responsibility, organizational structure and secretariats for each ISO technical committee. Detailed rules of procedure for the technical work are given in the ISO/IEC Directives. A list of the 500 international organizations in liaison with ISO's technical committees and subcommittees is given in the publication ISO Liaisons.

8.2.6 Purview of ISO

The scope of ISO is not limited to any particular branch; it covers all technical fields except electrical and electronic engineering standards, which is the responsibility of IEC. The work in the field of information technology is carried out by a joint ISO/IEC technical committee (JTC 1).

8.2.7 Development of ISO Standards

ISO standards are developed according to the following principles:

Consensus

The views of all interests are taken into account: manufacturers, vendors and users, consumer groups, testing laboratories, governments, engineering professions and research organizations.

Industry-wide

Global solutions to satisfy industries and customers worldwide.

Voluntary

International standardization is market-driven and therefore based on voluntary involvement of all interests in the market-place.

There are three main phases in the ISO standards development process.

The need for a standard is usually expressed by an industry sector, which communicates this need to a national member body. The latter proposes the new work item to ISO as a whole. Once the need for an International Standard has been recognized and formally agreed, the first phase involves definition of the technical scope of the future standard. This phase is usually carried out in working groups which comprise technical experts from countries interested in the subject matter.

Once agreement has been reached on which technical aspects are to be covered in the standard, a second phase is entered during which countries negotiate the detailed specifications within the standard. This is the consensus-building phase.

The final phase comprises the formal approval of the resulting draft International Standard (the acceptance criteria stipulate approval by two-thirds of the ISO members that have participated actively in the standards development process, and approval by 75 % of all members that vote), following which the agreed text is published as an ISO International Standard.

It is now also possible to publish interim documents at different stages in the standardization process.

Most standards require periodic revision. Several factors combine to render a standard out of date: technological evolution, new methods and materials, new quality and safety requirements. To take account of these factors, ISO has established the general rule that all ISO standards should be reviewed at intervals of not more than five years. On occasion, it is necessary to revise a standard earlier.

To date, ISO's work has resulted in some 12 000 International Standards, representing more than 300 000 pages in English and French (terminology is often provided in other languages as well).

8.2.8 ISO 14000

The ISO 14000 series of standards was published in 1996 and replaced the British Standard BS7750 during 1997. ISO 14000 provides guidance on the development and implementation of EMS (Environmental Management Systems) and their co-ordination with other management systems.

The model for this standard is the Quality Assurance standard BS EN ISO 9000. The structure of the management system generally follows the QA standard and comprises the following basic documented elements (BSI, 1996).

The EMS should be supported at an early stage by the organisation undertaking an Environmental Review.

Organisations wishing to seek accreditation to ISO 14000 are also required to undergo independent verification. There are 5 elements to a successful EMS:

- **Management Commitment and Policy (Environmental Policy)**

  Getting commitment from top management in the organisation is essential to the successful implementation of the EMS. Management need to support the principle of continuous improvement in environmental performance of the organisation.

- **Planning**

  Identifying the organisation's impacts on the environment, its legal and policy obligations affecting its activities, setting out its objectives and targets for improving environmental performance and establishing a management programme to deliver the improvements.

- **Implementation**

  Putting in place the mechanisms and providing the support for delivering the improvements. This can be approached in stages according to the capability of the organisation and resources available. Existing operational controls are identified and new controls introduced only where their absence would prevent the organisation from meeting its environmental policy commitments. Responsibility for delivering the improvements should be given to those with sufficient authority and competence to achieve them.

- **Measurement and Evaluation**

  Regular monitoring of the organisation's progress towards its environmental objectives is required in order to target those areas where the organisation is not complying with the law and/or environmental policy. Monitoring also assists in the allocation of resources to activities which are of particular concern. Regular audits of the elements of the EMS are required to test its effectiveness and to make sure that it remains appropriate to the needs of the organisation.

- **Review and Improvement**

  The review process ensures that the EMS, including its objectives, are relevant and address the environmental impacts of the organisation. Referring to the scope of the review, ISO 14001 states that it should be broad enough to address the effect of environmental improvements on financial performance and may take account of competitive position

- **Environmental Review**

  An Environmental Review involves an assessment of all the organisation's activities to identify those having a "significant" environmental impact. The findings can be used to focus the environmental policy and objectives on the areas of greatest impact. The information gathered during the review can also be used to establish a baseline for evaluating improvements in performance.

8.2.9 Frequently Asked Questions About ISO14000 and ISO14001

Are the standards available now?

Portions available now are:

- Environmental Management System
- Environmental Auditing

Still being developed are portions of the standards that will address:

- Environmental Performance Evaluation
- Life Cycle Assessment
- Environmental Labeling
- Environmental Aspects in Product Standards

Who developed the ISO 14000 standards?

International Organization for Standardization (ISO) Technical Committee (TC) 207. The scope of TC 207 is standardization in the field of environmental management tools and systems. The standards apply to environmental management tools and systems; they are not product standards, nor do they specify performance or pollutant/effluent levels. Specifically excluded are:

- Test methods for pollutants
- Setting limit values regarding pollutants or effluents
- Setting environmental performance levels
- Standardization of products.

TC 207 cooperates closely with ISO TC 176 on Quality Management (developers of ISO 9000) in the field of environmental management systems and audits.

What is covered by ISO 14000?

Environmental Management System and Environmental Auditing address a wide range of issues, including:

- Top management commitment to continuous improvement, compliance, and pollution prevention.
- Creating and implementing environmental policies, including setting and meeting appropriate targets.
- Integrating environmental considerations in operating procedures
- Training employees in regard to their environmental obligations.
- Conducting audits of the environmental management system.

What benefits are anticipated from ISO 14000?

- Benefits are many, including:
- Reduced noncompliance, fines;
- Intregation of environmental issues into other management systems, bring cost savings;
- Market advantage by demonstrating commitment to environmental management via independent certification.

How can a company get ready for ISO 14000?

- Review and improve the company's current environmental management programe against the ISO14001 standard
- Get committment from top management
- Tally current environmental expenditures, including end-of-pipe control equipment, fines, and permit fees; many of which could potentially be eliminated.

How do the ISO 14000 standards relate to the ISO 9000 standards?

Like ISO 9000, the ISO 14000 standards are management standards and not performance specifications. Like ISO 9000, ISO 14000 are voluntary standards expected to have a big influence in the marketplace.

The ISO 14000 standards take much of their approach, structure, and inspiration from the ISO 9000 standards. Just as ISO 9000 does not call for nor guarantee a quality product, ISO 14000 does not establish required performance levels nor set specific methodologies or targets.

8.3 Equipment Design Factors

A variety of equipment is required for storage, handling and processing of chemicals. Each piece of equipment is expected to serve a specific function, although in some cases, it can be suitably modified to perform a different function. Conditions such as temperature, pressure, etc under which the equipment is expected to perform, are stipulated by the process requirements. Although the maximum capacity or size of the equipment may be specified, it is necessary to assure satisfactory performance even with a certain amount of overloads. The overall satisfactory performance and reliability of the equipment will depend on the following factors

- Optimum processing conditions
- Appropriate materials of construction
- Strength and rigidity of components
- Satisfactory performance of mechanisms
- Reliable methods of fabrication
- Ease of maintenance and repairs
- Ease of operation and control
- Safety requirements

Equipment Classification

The classification of chemical equipments is normally based on the specific type of unit operation. Equipments may also be defined to emphasize certain common features which require similar design procedures These result in the following classification:

- Pressure Vessels

  This group of equipment has a cylinder or spherical vessel as the main component, which has a cylinder or vessel as the principal component and has to withstand variations in pressures and temperatures in addition to other loading conditions.

- Structural Group

  This essentially comprises of equipments or components which are stationary and have to sustain only dead loads. They are generally made up of structural sections and must satisfy conditions of elastic and structural stability .

- Rotary Equipments

  This section covers equipments or components where a rotational motion is necessary to satisfy process requirements . Considerations of torque ,dynamic stresses apart from other loading conditions

8.4 A Look at Common Industrial Chemicals

Sulfuric Acid -- Probably the most common industrial acid. Used widely in mineral leaching and gas scrubbing (removing dangerous substances). Also used to neutralize alkaline substances.

Nitrogen – Most common inert substance used in industry. Used for everything from tank blanketing (so vapors don't combine with oxygen to form explosive mixtures) to controlling reaction temperatures in exothermic reactions. Also widely used as a solid conveying gas carrier when air cannot be used due to explosion threats (ex/ fertilizers).

Oxygen – The ultimate oxidizer. Used in any application where the introduction of oxygen to the reaction mixture is necessary.

Ethylene – Probably the most popular industrial precursor to polymer manufacturing (ex/ polyethylene).

Ammonia – Very popular scrubbing solvent to remove pollutants from fossil fuel combustion streams before they can be released to the atmosphere. Also a popular refrigerant.

Phosphoric Acid – Main use is in fertilizer production, other uses include soft drinks and other food products.

Sodium Hydroxide – The most popular alkaline substance in industry. Widely used in dyes and soap manufacturing. Also a good cleaning agent and can be used to neutralize acids. Also known as lye.

Propylene – Another industrial polymer precursor (polypropylene).

Chlorine – Used in the manufacture of bleaching agents and titanium dioxide. Many of the bleaching agents based on chlorine are being replaced by hydrogen peroxide due to environmental restrictions placed on chlorine.

Sodium Carbonate – Most commonly known as soda ash, sodium carbonate is used in many cleaning agents and in glass making. Most soda ash is mined from trona ore, but it can be manufactured by reacting salt and sulfuric acid.

Sodium Silicate – Perhaps the most widely used industrial insulation.

Cyclohexane – While cyclohexane is a common organic solvent, it's crowning achievement is it's use as a reactant in the production of a nylon precursor (later).

Adipic Acid – This is the chemical that is made from cyclohexane and in turn is polymerized to nylon.

Nitrobenzene – Primary use is in the manufacture of aniline, which is in turn used as a rubber additive to prevent oxidation (antioxidant).

Butyraldehyde – Used to manufacture 2-ethylhexanol which is then used to manufacture hydraulic oils or synthetic lubricants.

Aluminum Sulfate – Widely used in the paper and wastewater treatment industries as a pH buffer.

Methyl tert-butyl ether – Also known as MTBE, it is most famous for its role as a gasoline additive (oxygenate). Due to its toxic affect on mammals, the EPA has been ordering a decrease in it's use and an increase in the use of ethanol as a replacement.

Ethylene Dichloride – Nearly all ethylene dichloride produced is used to produce vinyl chloride which is then polymerized to polyvinyl chloride (PVC).

Nitric Acid – Most common application is it's reaction with ammonia to form the solid fertilizer ammonium nitrate.

Ammonium Nitrate – Probably the most widely used solid fertilizer

Benzene – The two largest uses for benzene are as reactants to produce ethylbenzene (used to produce styrene) and cumene (used to produce phenols). Also a very common organic solvent as well as a precursor to cyclohexane.

Urea – The majority of urea is used in fertilizer production. Some is also used in the manufacture of livestock feed.

Vinyl Chloride – As previously mentioned, this is the monomer form of polyvinyl chloride (PVC) which finds uses as a building material and other durable plastics.

Ethylbenzene – Used almost exclusivley as a reactant for the production of styrene

Styrene – Monomer form of polystyrene. Polystyrene is used in pure form and expanded. Styrene can also be used in mixed forms or copolymers such as ABS (acrylonitrile-butadiene-styrene).

Methanol – Used as a reactant to make methyl tertbutyl ether (MTBE), formaldeyde, and acetic acid. Typically produced from synthesis gases, namely carbon monoxide and hydrogen.

Xylene – o-xylene (ortho) is used primarily to manufacture phthalic anhydride which is in turn used to make a variety of plasticizers and polymers. p-xylene is used to manufacture terephthalic acid, a polyester feedstock.

Formaldehyde – Commonly used as part of a copolymer series (Urea-formaldehyde resins) or as another polymer additive used to bring out desired characteristics.

Terephthalic Acid – Almost exclusively used in the manufacture of polyethylene terephthalate (PET) or polyester.

Ethylene Oxide – Majority of ethylene oxide is used to manufacture ethylene glycol which is described later.

Hydrochloric Acid – Two main uses include production of other chemicals (by acting as a reactant or a catalyst) and the pickling of steel. Also widely used in the pharmaceutical industry.

Toluene – Used primarily to manufacture benzoic acid. Benzoic acid is a precursor to phenol (later), various dyes, and rubber products.

Cumene – Nearly all cumene produced is oxidized to cumene hydroperoxide, then cleaved (splitting a molecule) to form phenol and acetone.

Ethylene Gylcol – Most common use is as a reactant to form polyethylene terephthalate (PET). Also used a primary ingredient in antifreeze.

Acetic Acid – Used primarily to manufacture vinyl acetate monomer (later) and acetic anhydride which is used to manufacture cellulose acetate.

Phenol – Used to manufacture Bispenol-A (later) as well as phenolic resins and caprolacturm.

Propylene Oxide – Two primary uses include urethane polyether polyols (both flexible and rigid foams) an propylene glycol which is used as a polymer additive as well as a common refrigerate.

Butadiene – Uses include styrene-butadiene rubber, polybutadiene, and other copolymers.

Carbon Black – Most common use is a rubber additive

Isobutylene – Most production is used to make butyl rubbers.

Potash – Used in agriculture as a crop fertilizer.

Acrylonitrile – Used as a reactant to form various copolymers along with acrylic fibers.

Vinyl Acetate – Monomer form a polyvinyl acetate, a common emulsion polymer and resin. PVA is the "sticky" agent in ordinary white glue.

Titanium Dioxide – Used as a white pigment for many products ranging from paints and polymers to pharmaceuticals and food items. In short, if it's white, it probably has titanium dioxide in it.

Acetone – Used primarily to manufacture methyl methacrylate and Bisphenol-A

Bisphenol-A – Used as the main feedstock for polycarbonate resins and epoxy resins.

8.5 Materials of Construction

The basic properties involved in material selection are :

- Composition
- Structure
- specific weight
- thermal conductivity

- expandability
- resistance to corrosion.

The mechanical properties that are to be kept in mind during material specification are:

- Strength
- elastic limit
- moduli of elasticity
- endurance limit, resilience
- toughness, ductility
- brittleness
- hardness.

From the point of view of fabrication, machinability, weldability and malleability might be considered as relevant properties.

8.5.1 Types of Corrosion

Uniform Attack

Uniform attack is a form of electrochemical corrosion that occurs with equal intensity of the entire surface of the metal. Iron rusts when exposed to air and water, and silver tarnishes due to exposure to air. Pontentially very risky, this type of corrosion is very easy to predict and is usually associated with "common sense" when making material decisions.

Galvanic Corrosion

Galvanic corrosion is a little more difficult to keep track of in the industrial world. Galvanic corrosion occurs when two metals having different composition are electrically coupled in the presence of an electrolyte. The more reactive metal will experience severe corrosion while the more noble metal will be quite well protected. Perhaps the most infamous examples of this type of corrosion are combinations such as steel and brass or copper and steel. Typically the steel will corrode the area near the brass or copper, even in a water environment and especially in a seawater environment. Probably the most common way of avoiding galvanic corrosion is to electrically attach a third, anodic metal to the other two. This is referred to as cathodic protection.

Crevice Corrosion

Another form of electrochemical corrosion is crevice corrosion. Crevice corrosion is a consequence of concentration differences of ions or dissolved gases in an electrolytic solution. A solution became trapped between a pipe and the flange on the left. The stagnant liquid in the crevice eventually had a lowered dissolved oxygen concentration and crevice corrosion took over and destroyed the flange. In the absence of oxygen, the metal and/or it's passive layer begin to oxidize. To prevent crevice corrosion, it is recommended to use welds rather than rivets or bolted joints whenever possible. Also consider nonabsorbing gaskets. Remove accumulated deposits frequently and design containment vessels to avoid stagnant areas as much as possible.

Pitting

Pitting, just as it sounds, is used to describe the formation of small pits on the surface of a metal or alloy. Pitting is suspected to occur in much the same way crevice corrosion does, but on a flat surface. A small imperfection in the metal is thought to begin the process, then a "snowball" effect takes place. Pitting can go on undetected for extended periods of time, until a failure occurs. A textbook example of pitting would be to subject stainless steel to a chloride containing stream such as seawater. Pitting would overrun the stainless steel in a matter of weeks due to it's very poor resistance to chlorides, which are notorious for their ability to initiate pitting corrosion. Alloy blends with more than 2% Molybdenum show better resistance to pitting attack. Titanium is usually the material of choice if chlorides are the main corrosion concern. (Pd stabilized forms of Ti are also used for more extreme cases).

Intergranular Corrosion

Occuring along grain boundaries for some alloys, intergranular corrosion can be a real danger in the right environment. On the left, a piece of stainless steel (especially suspectible to intergranular corrosion) has seen severe corrosion just an inch from a weld. The heating of some materials causes chromium carbide to form from the chromium and the carbon in the metals. This leaves a chromium deficient boundary just shy of the where the metal was heated for welding. To avoid this problem, the material can be subjected to high temperatures to redissolve the chromium carbide particles. Low carbon materials can also be used to minimize the formation of chromium carbide. Finally, the material can be alloyed with another material such as Titanium which forms carbides more readily so that the chromium remains in place.

Selective Leaching

When one element or constituent of a metal is selectively corroded out of a material it is referred to as selective leaching. The most common example is the dezincification of brass. On the right, nickel has be corroded out of a copper-nickel alloy exposed to stagnant seawater. After leaching has occurred, the mechanical properties of the metal are obviously impaired and some metal will begin to crack.

Erosion-Corrosion

Erosion-corrosion arises from a combination of chemical attack and the physical abrasion as a consequence of the fluid motion. Virtually all alloy or metals are susceptible to some type of erosion-corrosion as this type of corrosion is very dependent on the fluid. Materials that rely on a passive layer are especially sensitive to erosion-corrosion. Once the passive layer has been removed, the bare metal surface is exposed to the corrosive material. If the passive layer cannot be regenerated quickly enough, significant damage can be seen. Fluids that contain suspended solids are often times responsible for erosion-corrosion. The best way to limit erosion-corrosion is to design systems that will maintain a low fluid velocity and to minimize sudden line size changes and elbows. The photo above shows erosion-corrosion of a copper-nickel tube in a seawater surface. An imperfection on the tube surface probably cause an eddy current which provided a perfect location for erosion-corrosion.

Stress Corrosion

Stess corrosion can result from the combination of an applied tensile stress and a corrosive environment. In fact, some materials only become susceptible to corrosion in a given environment once a tensile stress is applied. Once the stress cracks begin, they easily propagate throughout the material, which in turn allows additional corrosion and cracking to take place. The tensile stress is usually the result of expansions and contractions that are caused by violent temperature changes or thermal cycles. The best defense against stress corrosion is to limit the magnitude and/or frequency of the tensile stress.

8.5.2 Choice of Material

Choice of the material cannot be made merely by choosing a suitable material having the requisite mechanical behavior and anticorrosive properties, but must be based on a sound economic analysis of competing materials.

The definitions s and properties of the various metals and process are included industrially are included in Appendix – D for reference.

8.5.3 Linings for Chemical Plants and Equipment

Storage tanks, reaction vessels, pipes, ducting, etc are covered with linings in order to

- Give the underlined structure protection against chemical attack
- Prevent contamination of the materials being processed
- Minimize the effect of abrasion

The various materials commonly used for lining are as follows

- Rubber
- Lead
- Glass
- Plastic

8.6 Rules of Thumb

Although experienced engineers know where to find information and how to make accurate computations, they also keep a minimum body of information in mind on the ready, made up largely of shortcuts and rules of thumb. The present compilation may fit into such a minimum body of information, as a boost to the memory or extension in some instances into less often encountered areas.

An Engineering Rule of Thumb is an outright statement regarding suitable sizes or performance of equipment that obviates all need for extended calculation. Because any brief statements are subject to varying degrees of qualification, they are most safely applied by engineers who are substantially familiar with the topics.

8.6.1 Compressors and Vacuum Pumps

- Fans are used to raise the pressure about 3% (12 in. water). Blowers raise to less than 40 psig, and compressors to higher pressures, although blower range commonly is included in the compressor range
- Vacuum pumps: reciprocating piston type decrease the pressure to 1 Torr; rotary piston down to 0.001 Torr, two-lobe rotary down to 0.0001 Torr; steam jet ejectors, one stage down to 100 Torr, three stages down to 1 Torr, five stages down to 0.05 Torr
- A three-stage ejector needs 100 lb steam/lb air to maintain a pressure of 1 Torr
- Efficiencies of reciprocating compressors: 65% at compression ratio of 1.5, 75% at 2.0. and 80-85% at 3-6
- Efficiencies of large centrifugal compressors, 6000-100,0000 ACFM at suction, are 76-78%
- Rotary compressors have efficiencies of 70%, except liquid liner type which have 50%

8.6.2 Conveyors for Particulate Solids

- Screw conveyors are suited to transport of even sticky and abrasive solids up inclines of 20 or so. They are limited to distances of 150 ft or so because of shaft torque strength. A 12 in. dia conveyor can handle 100-3000 cuft/hr, at speeds ranging from 40 to 60 rpm
- Belt conveyors are for high capacity and long distances a mile or more, but only several hundred feet in a plant), up inclines of 30 maximum. A 24 inchwide belt can carry 300 cuft/hr at a speed of 100 ft/min, but speeds up to 600 ft/min are suited to some materials. Power consumption is relatively low
- Bucket elevators are suited to vertical transport of sticky and abrasive materials. With buckets 20 X 20 inches, capacity can reach 100 cuft/hr at a speed of 100 ft/min, but speeds to 300 ft/min are used
- Drag-type conveyors (Redler) are suited to short distances in any direction and are completely enclosed. Units range in size from 3 in, square to 19 in square and may travel from 30ft/min (fly ash to 250ft min (grains). Power requirements are high.
- Pneumatic conveyors are for high capacity, short distance (400ft) transport simultaneously from several sources to several destinations. Either vacuum or low pressure (6-12 psig) is employed with a range of air velocities from 35 to 120 ft/sec depending on the material and pressure, air requirements from 1 to 7 cuft/cuft of solid transferred

8.6.3 Cooling Towers

- Water in contact with air under adiabatic conditions eventually cools to the wet bulb temperature
- In commercial units. 90% of saturation of the air is feasible
- Relative cooling tower size is sensitive to the difference between the exit and wet bulb temperatures:

T (F)	5	15	25
Relative volume	2.4	1.0	0.55

- Tower fill is of a highly open structure so as to minimize pressure drop, which is in standard practice a maximum of 2 inches of water
- Water circulation rate is 1-4 gpm/sqft and air rates are 1300-1800 lb/(hr)(sqft or 300-400 ft/min)
- Chimney-assisted natural draft towers are of hyperboloidal shapes because they have greater strength for a given thickness; a tower 250 ft high has concrete walls 5-6in. thick. The enlarged cross section at the top aids in dispersion of exit humid air into the atmosphere
- Countercurrent induced draft towers are the most common in process industries. They are able to cool water within 2 deg F of the wet bulb
- Evaporation losses are 1% of the circulation for every 10 deg F of cooling range. Windage or drift losses of mechanical draft towers are 0.1-0.3%. Blowdown of 2.5-3.0% of the circulation is necessary to prevent excessive salt buildup

8.6.4 Crystallization from Solution

- Complete recovery of dissolved solids is obtainable by evaporation but only to the eutectic composition by chilling. Recovery by melt crystallization is also limited by the eutectic composition
- Growth rates and ultimate sizes of crystals are controlled by limiting the extent of supersaturation at any time
- In crystallization by chilling, the temperature of the solution is kept at the most at 1-2 deg F below the saturation temperature at the prevailing concentration
- Rate of crystals under satisfactory conditions are in the range of 0.1-0.8 mm/hr. The growth rates are approximately the same in all directions
- Growth rates are influenced greatly by the presence of impurities and of certain specific additives that vary from case to case

8.6.5 Disintegration

- Percentages of material greater than 50% of the maximum size are about 50% from rolls, 15% from tumbling mills, and 5% from closed circuit ball mills
- Close circuit grinding employs external size classification and return of oversize for regrinding. The rules of pneumatic conveying are applied to design of air classifiers. Closed circuit is most common with ball and roller mills
- Jaw crushers take lumps of several feet in diameter down to 4 in stroke rates of 100-300/ min. The average feed is subjected to 9-10 strokes before small enough to escape. Gyratory crushers are suited to slabby feeds and make a more rounded product
- Roll crushers are made either smooth or with teeth. A 24 in. toothed roll can accept lumps 14in. dia. Smooth rolls effect reduction ratios up to about 4. Speeds are 50-900 rpm. Capacity is about 25% of the maximum corresponding to a continuous ribbon of material passing through the rolls
- Road mills are capable of taking feed as large as 50 mm and reducing it to 300 mesh, but normally the product ranges is 8-65 mesh. Rods are 25-150 mm

dia. Ratio of rod length to mill diameter is about 1.5. About 45% of the mill volume is occupied by rods. Rotation is at 50-65% of critical

- Ball mills are better suited than rod mills to fine grinding. The charge is of equal weights of 1.5, 2 and 3in ball for the finest grinding. Volume occupied by the balls is 50% of the mill volume. Rotation speed is 70-80% of critical. Ball mills have a length to diameter ratio in the range 1-1.5 Tube mills have a ratio of 4-5 and are capable of very fine grinding. Pebble mills have ceramic grind elements, used when contamination with metal is to be avoided
- Roller mills comply with cylindrical or tapered surfaces that roll along flatter surfaces and crush nipped particles. Products of 20-200 mesh are made.

8.6.6 Distillation and Gas Absorption

- Distillation usually is the most economical method of separating liquids, superior to extraction, adsorption, crystallization, or others
- Tower operating pressure is determined most often by the temperature of the available condensing medium, 100-120 F if cooling water; or by the maximum allowable reboiler temperature, 150 psig steam, 366 F
- Sequencing of columns for separating multicomponent mixtures: (a) perform the easiest separation first, that is, the one least demanding of trays and reflux, and leave the most difficult to the last; (b) when neither relative volatility nor feed concentration vary widely, remove the components one by one as overhead products; (c) When the adjacent ordered components in the feed vary widely in relative volatility; (d) when the concentrations in the feed vary widely but the relative volatilities do not, remove the components in the order of decreasing concentration in the feed
- Economically optimum reflux ratio is about 1.2 times the minimum reflux ratio
- The economically optimum number of trays is near twice the minimum value
- A safety factor of 10% of the number of trays calculated by the best means is advisable

8.6.7 Drivers and Power Recovery Equipment

- Efficiency is greater for larger machines. Motors are 85-95%; steam turbines are 42-78%; gas engines and turbines are 28-38%
- For under 100 HP, electric motors are used almost exclusively, they are made for up to 20,000 HP
- Induction motors are most popular. Synchronous motors are made for speeds as low as 150 rpm and are thus suited, for example, for low speed reciprocating compressors, but are not made smaller than 50 HP. A variety of enclosures is available, eg weatherproof
- Steam turbines are competitive above 100 HP. They are speed controllable. Frequently they are employed as spares in case of power failure
- Combustion engines and turbines are restricted to mobile and remote locations
- Gas expanders for power recovery may be justified at capacities of several hundred HP; otherwise any needed pressure reduction in process is effected with throttling valves

8.6.8 Drying Of Solids

- Drying times range from a few seconds in spray dryers to 1 hr or less in rotary dryers and up to several hours or even several days in tunnel shelf or belt dryers
- Continuous tray and belt dryers for granular material of natural size or pelleted to 3-15 mm have drying times in the range of 10-200 min
- Rotary cylindrical dryers operate with superficial air velocities of 5-10 ft/sec, sometimes up to 35 ft/sec when the material is coarse. Residence times are 50-90 min. Holdup of solid is 7-8%; an 85% free cross section is taken for design purposes. In countercurrent flow, the exit gas is 10-20 deg C above the solid; in parallel flow, the temperature of the exit solid is 100 deg C. Rotation speeds of about 4 rpm are used, but the product of rpm and diameter in feet is typically between 15 and 25
- Drum dryers for pastes and slurries operate with contact times of 3-12 sec, produce flakes 1-3 mm thick with evaporation rates of 15-30 kg/m2hr. Diameters are 1.5-5.0 ft; the rotation rate is 2-10 rpm. The greatest evaporative capacity is to the order of 3000 lb/hr in commercial units
- Pneumatic conveying dryers normally take particles 1-3 mm dia but up to 10mm when the moisture is mostly on the surface. Air velocities are 10-30m/sec. Single pass residence times are 0.5-3.0 sec but with normal recycling the average residence time is brought up to 60 sec. Units in use range from 0.2 m dia by 1 m high to 0.3 m dia by 38 m long. Air requirement is several SCFM/lb of dry product/hr
- Fluidized bed dryers work best on particles of a few tenths of a mm dia, but up to 4 mm dia have been processed. Gas velocities of twice the minimum fluidization velocity are a safe prescription. In continuous operation, drying times of 1-2 min are enough, but batch drying of some pharmaceutical products employs drying times of 2-3 hr
- Spray dryer: Surface moisture is removed in about 5sec, and most drying is completed in less than 60 sec. Parallel flow of air and stock is most common. Atomizing nozzles have openings 0.012-0.15in. and operate at pressures of 300-4000 psi. Atomizing spray wheels rotate at speeds to 20,000 rpm with peripheral speeds of 250-600 ft/sec. With nozzles, the ratio is 0.5-1.0. For the final design, the experts say pilot tests in a unit of 2m dia should be made

8.6.9 Evaporators

- Long tube vertical evaporators with either natural or force circulation are most popular. Tubes are 19-63 mm dia and 12-30 ft long
- In forced circulation, linear velocities in the tubes are 15-20 ft/sec
- Elevation of boiling point by dissolved solids results in differences of 3-10 deg F between solution and saturated vapor
- When the boiling point rise is appreciable, the economic number of effects in series with forward feed is 4-6
- When the boiling point rise is small, minimum cost is obtained with 8-10 effects in series
- In backward feed the more concentrated solution is heated with the highest temperature steam so that heating surface is lessened, but the solution must be pumped between stages

- The steam economy of an N-stage battery is approximately 0.8N lb evaporation/lb of outside steam
- Inter stage steam pressures can be boosted with steam jet compressors of 20-30% efficiency or with mechanical compressors of 70-75% efficiency

8.6.10 Filtration

- Processes are classified by their rate of cake buildup in a laboratory vacuum leaf filter: rapid 0.1-10.0 cm/scc; medium, 0.1-10.0 cm/min; slow, 0.l-10.0 cm/hr
- Continuous filtration should not be attempted if 1/8 inch cake thickness cannot be formed in less than 5 min
- Rapid filtering is accomplished with belts, top feed drums, or pusher-type centrifuges
- Medium rate filtering is accomplished with vacuum drums or disks or peeler-type centrifuges
- Slow filtering slurries are handled in pressure filters or sedimenting centrifuges
- Clarification with negligible cake buildup is accomplished with cartridges, precoat drums, or sand filters
- Laboratory tests are advisable when the filtering surface is expected to be more than a few square meters; when cake washing is critical; when cake drying may be a problem; or when precoating may be needed

8.6.11 Heat Exchangers

- Take true countercurrent flow in a shell-and-tube exchanger as a basis
- Standard tubes are 3/4 in. OD, an inch triangular spacing, 16 ft long; a shell 1 ft dia accommodates 100 sqft; 2ft dia, 400 sqft, 3ft dia, 1100sqft
- Tube side is for corrosive, folding, scaling, and high pressure fluids
- Shell side is for viscous and condensing fluids
- Pressure drops are 1.5 psi for boiling and 3-9 psi for other services
- Minimum temperature approach is 20 deg F with normal coolants. 10 deg F or less with refrigerants
- Water inlet temperature is 90 deg F, maximum outlet 120 F
- Double-pipe exchanger is competitive at duties requiring 100-200 sqft
- Compact (plate and fin) exchangers have 350sqft/cuft about 4 times the heat transfer per cuft of shell and tube
- Plate and frame exchangers are suited to high sanitation service, and are 25-50% cheaper in stainless construction than shell-and-tube units

8.6.12 Mixing and Agitation

- Mild agitation is obtained by circulating the liquid with an impeller at superficial velocities of 0.1-0.2ft/sec, and intense agitation at 0.7-1,0ft/sec
- Intensities of agitation with impellers in baffled tanks are measured by power input, HP/1000 gal and impeller tip speed

Operation	*HP/1000 gal*	*Tip speed (ft/min)*
Blending	0.2-0.5	75-10
Homogeneous reaction	0.5-1.5	10-15
Reaction with heat transfer	1.5-5.0	15-20
Liquid-liquid mixtures	5	15-20
Liquid-gas mixtures	5-10	
Slurries	10	

- Proportions of a stirred tank relative to the diameter D: liquid level=D; turbine impeller diameter=D/3; impeller level above bottom=D/3; impeller blade width=D/15; four vertical baffles with width=E/10
- Propellers are made a maximum of 18in., turbine impellers to 9ft. Gas bubbles sparged at the bottom of the vessel will result in mind agitation at a superficial gas velocity of 1ft/min, severe agitation at 4ft/min.
- Suspension of solids with a settling velocity of 0.03 t/sec is accomplished with either turbine or propeller impellers, but when the settling velocity is above 0.15ft/sec intense agitation with a propeller is needed.
- Power to drive a mixture of a gas and a liquid can be 25-50% less than the power to drive the liquid aline.
- In-line blenders are adequate when a second or two contact time is sufficient, with power inputs of 0.1-0.2 2 HP/gal