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Chemical Engineering - an Insight into the Fundamentals and Interdisciplinary Approach

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Abstract*: Chemical engineering is very diverse field. It has wide scope in terms of applications and understanding. A chemical engineer needs the sound knowledge of chemistry. In addition to this, a good chemical engineer has sound knowledge of mathematics, numerical methods, hydraulics, strength of materials, electrical engineering and material science. Multitasking is commonly used word in the industries. An engineer is recognized for his ability to trouble shoot problems in the industries. It is envisaged that the chemical engineering student acquire the knowledge of science and mathematics along with fundamentals of electrical, civil and mechanical engineering. This article sheds light on multidisciplinary nature of expectations from chemical engineering.

Index Terms: Unit operation, process, reaction, mechanical operation, instrumentation.

I. INTRODUCTION

Chemical engineering students need to study all their subjects for deep knowledge of the subject. This article is an effort to emphasize importance of various chemical engineering subjects in the modern engineering applications. Also relation of chemical engineering with other engineering disciplines is demonstrated. Process calculation deals with almost all the unit operations from energy and material balance perspectives [1-4]. Fluid flow deals with flow through pipes of compressible and incompressible fluids. Types of fluids and their properties are also discussed [5-7]. Subjects such as communication skills, chemistry, mathematics, material sciences are required to be taught to polish the soft skills and fundamental scientific background of the budding chemical engineers [8-10]. The unit operations like heat, mass and momentum transfer are core chemical engineering subjects [11-15]. Also thermodynamics, chemical reaction engineering are integral subjects for the chemical engineer [16-18]. Process engineering, instrumentation, process control, energy system design helps in understanding and practically implementing the chemical engineering knowledge with respect to unit operations, thermodynamics and reaction engineering to the process. Chemical technology deals with flow sheets of typical processes for manufacture of fertilizers, sulphuric acid, nitric acid, paints, pigments and other pharmaceutical, polymer and chemical products [19-23]. The subjects like biotechnology [24], computational fluid dynamics (CFD) (25), piping engineering [26] operation research are also important in specific fields and students who have special interest are taught these subjects. There are many other optional subjects which are taught according to need of the students and industry [27-34].Chemical engineering and chemical engineer needs to have sound fundamental knowledge of mechanical, civil, electrical and computer engineering to become successful as a process engineer or executive in chemical and allied industries and consultancies.

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II. VARIOUS COURSES IN CHEMICAL ENGINEERING

A. Process Calculation:

Process is sequence of independent or linked procedures. These procedures can be physical or chemical in nature. The physical changes are carried out in procedure called as unit operations. Chemical reactions can be the present in the chain of sequence if chemical changes are required for obtaining products. The size reduction, solid mixing and other solid-solid, solid-liquid operations like blending, screening are termed as mechanical operations. Process means whatever happens to the raw material till it is converted into product. Process calculation involves basic chemical calculations like normality, molality and molarity. These calculations are very basic but most important. The material balance without and with chemical reactions for almost all the unit operations are included in the process calculations. One can say that process calculation is one of the four most important core chemical engineering subjects. Material balances for the distillation, adsorption, extraction, crystallization, drying, humidification, leaching etc are studied this subject. The energy balance calculation includes revision of the concepts like latent heat, sensible heat, laws of conservations, calorific values and heats of reaction. If we consider all these aspects, it can be said that process calculation is base of all the subjects to be studied at undergraduate level. We will discuss importance of process calculation in the other subjects in detail.

B. Fluid mechanics-

Fluid mechanics is divided into static and dynamic studies. The calculation of energy balances studied in process calculations comes handy while studying energy balance. The Bernoulli's equation is derived from law of mass and energy balance.

Compressible fluids are the ones whose properties changes with pressure.

Incompressible fluids are the ones whose density changes are not considerable with pressure. Usually vapours and gases fall under compressible fluids category. Flow of the fluid through pipes is required for the chemical engineers as it involves energy costs, material selection for pipes and valves, other fittings such as steam traps, relief or emergency out lets required if any. Pumps, compressors and blowers also involved fluids. Various aspects of fluid pumping are also studied in these subjects. For reactors, the mixing, blending of the reactants, especially for liquids, termed as agitation is very important aspect of fluid flow. The agitated tanks are designed by chemical engineers. This calculation involves the fluid properties. This in all walks of chemical engineering fluid flow becomes important subject. Selection of pumps, compressors, piping systems is infact a specialized area covered under piping engineering.

C. Mechanical operations:

Screening and size reduction is required in chemical processes. In adsorption, screening of adsorbent particles is required. The raw material is required to be screened and separated from other solid impurities by physical separations. Sometimes the solid is separated from the slurry of the reactant-product mixture by using centrifugal separations, hydro cyclones etc. Inertial separators, fabric filters are also used for specific applications. Various simple separation techniques are studied like gravity settling, decantation, jazzing etc. Also in case of mass transfer and reaction engineering, irregular packing and irregular size solids are involved. In such cases surface volume ratio, sphericity becomes important parameter. Operations such as blending and mixing are covered in this subject.

D. Material science and technology*:*

Properties of materials are studied in material science and technology. These properties include chemical and physical properties. Tensile strength, malleability, ductility, shear strength, Young's modulus are important properties for machinability of the metals. Corrosion properties are important in chemical industries. Also reactivity of the material to certain chemicals is required for safe storage of the chemicals. The chemical engineer with sound knowledge of material properties is always an asset to any company. Lack of this knowledge may sometime result into bizarre incidents.

E. Applied mathematics:

Mathematics is required in all walks of life. More so for the chemical engineer. If we consider various subjects, solving of differential and partial differential equation is required while determining optimum values. Also various laws in mass transfer such as Fick's law, In heat transfer, equations for conductivity; in transport processes, equations for molar flux and many other equations governing the mass, heat and momentum transfer have derivatives involved in their calculation. Also integration is inherent part of many mathematical modeling derivations. Laplace transform is basis for the process control. Other numerical methods are crucial in obtaining solution to many problems. Along with this, many other analytical and numerical problems needs mathematics as basic tool. A good chemical engineer is also sound in his mathematical skills.

F. Communication skills:

The skills such as the letter writing, application writing, report writing, thesis writing, paper writing makes the chemical engineer competitive. Also soft speaking skills are doors for opportunities in the corporate world. Person having good technical background may not get proper opportunity due to poor communication skills. Activities such as conference, paper presentations, debate, and group discussion enhance the communication skills and make us more presentable.

G. Advance chemistry:

Chemistry is the backbone of chemical engineering. Chemical reactions, chemical structure, chemical properties, chemical synthesis is very basic to any chemical engineer.

H. Heat transfer:

Heat exchangers are most commonly used heat transfer equipments in chemical industry. In heat transfer, three modes of heat transfer namely conduction; convection and radiation are studied in detail along with equation for heat fluxes. Also calculation on heat transfer coefficients for laminar and turbulent conditions is studied. Design of heat exchanger, calculation of number of tubes is important to chemical engineers. Types of heat exchangers based on use, geometry, structure and construction are also studied.

I. Mass transfer operations:

Mass transfer is the most important and fundamental subject in chemical engineering and process engineering. Fundamentals of molecular diffusion, mass transfer coefficients, and equipments for interphase mass transfer operations are studied. Governing equations for diffusional and convective mass transfer are studied. Design of plate and packed bed columns for absorption, distillation, extraction and leaching are studied. Fundamentals of adsorption and design of adsorption beds, chromatography are studied in the subject. Drying fundamentals and types of dryers are also studied. Humidification and cooling towers are important in chemical plant as utility. The mass transfer aspects of these operations are studied. Also advance process intensification methods such as reactive distillation, reactive extraction, membrane distillation and reactive chromatography are important for chemical engineers. Fundamentals of these methods are introduced to the budding engineers in mass transfer operations.

J. Chemical reaction engineering

Chemical reactions are needed for synthesis of products. Their kinetics and thermodynamics is studied in the subjects. Homogenous and heterogeneous reactions and reactor design is studied in the chemical reaction engineering. Chemical reactions can be catalyzed and non-catalyzed. The solid, liquid and gaseous phases in combination of any two or three phases are involved in synthesis. Multiphase reactors design fundamentals are also studied in the subject.

Decision of reactors along with basic types like plug flow, mixed flow reactors, their performance equations and applications are studied in chemical reactions. Solid catalyzed reactions and reactor design is also studied. These studies need fundamental knowledge of chemistry.

K. Process equipment design:

Chemical designs of vessels, supports are studied. Reactors, storage vessels, distillation, absorption and extraction column design is studied in the subjects. Various aspects of design such as material selection, material thickness, clearance, feed space, weir height, stack height etc are studied along with their design equations.

L. Mechanical equipment design:

Mechanical design of all the equipments studied in process engineering design is carried out with all details.

M. Chemical technology:

Synthesis of soap, ethanol, starch, citric acid and many such compounds is carried out in laboratory scale synthesis.

N. Chemical engineering thermodynamics:

Chemical engineering thermodynamics includes laws of thermodynamics. The concepts of enthalpy, entropy, Gibb's free energy, and Maxwell relations are discussed. Phase equilibrium and phase rule are important part of thermodynamics. The degrees of freedom analysis for a system is important in determining number of manipulated, controlled and measured variables. The calculation of heat requirements for refrigeration, heat pumps, and compressors is also studied in the subject. Chemical engineering thermodynamics deals with chemical reaction equilibrium and equilibrium conversion. Studies on Carnot engine are important for a chemical engineer. Reversibility of the reaction and the process along with the concept of entropy are very crucial aspect of thermodynamic studies.

Chemical processes: Various chemical processes are studied in detail in chemical processes. The flow sheets for important products like sulphuric acid, hydrochloric acid, polymers like rayon, sugar, lime, glass, paints and pigments, nitrates, nitrites etc. are studied in details. Detail studies on raw materials, their properties, reactions, reaction conditions, process thermodynamics, utilities and salient features of the process is discussed.

Process engineering: The functions of process engineers and skill required for process engineers are studied. Process selection steps are discussed in detail. Development of process flow diagrams and P and I diagrams is also discussed in project engineering. Designing of distillation columns, absorption columns by using shortcut methods is also discussed in this subject. Process engineering needs fundamental knowledge of all the chemical engineering subjects. In process calculation and other transfer operations the material balances are studies for individual unit operations. Also in chemical reaction engineering, the reactor design is studied for various types of reactors. In process engineering all these unit operations and reactors are studied from process point of view. From raw material to the products, all the unit operations and reactions are interconnected by using various equations. The thermodynamics, the properties of materials, physical and chemistry laws, some familiar laws such as ideal gas law, Rault's law, equations of phase rule and many more chemical engineering laws and equations are used for relating the operations and reactions with each other. Also sizing of vessels, pumps, compressors and columns carried out. Safety aspects and HAZOP studies are also carried out. The process engineering is practical approach to almost all the subjects studied at undergraduate studies.

O. Instrumentation:

Any process or unit operation needs measurement and control of various variables. The controllers are placed at appropriate places. Operation of the controller and measuring devices involves various types of valves, ventury and orifice meters, pitot tubes and other variable area and flow meters. Many other instruments such as pressure gauges, temperature sensors are involved in these processes. Also pneumatic valves and their operations are studied. Mechanisms of various valves used for safety are studied. Analysis of the gases and liquids for their composition or other characterizations are important part of the instrumentation.

P. Process control:

The control on various variables is needed for the process. In process control, various interacting and non interacting systems are studied. The meaning of stability of a process and stability criteria are discussed. The process control needs a controller. The controller can be proportional, proportional-integral or proportional-integral-derivative type. The type of process and its nature help in deciding the type of controllers to be used. The transfer function relates input to the output for the controller or instrument. These transfer functions are defined and obtained for various controller and instruments. Phase rule and degrees of freedom along with constraints and outside factors affecting process are determinants of number of measured, manipulated and controlled variables.

Q. Environmental engineering:

The chemical and process engineer needs to be aware of the liquid and gaseous effluent emitting from the plant. Chemical engineer has his work cut out in environmental engineering field. The liquid and gaseous effluent analysis, their controls are paramount for the environment friendly operations of the plant. The regulatory norms and ethical guidelines call for careful watch on the pollutants emitted by chemical plant. Also chemical plants which produce hazardous waste, need to treat the waste and reuse recycle or dispose it. In environmental engineering the classification and analysis of pollutants is discussed. Also primary, secondary and tertiary treatments for wastewater treatments are discussed. The design of equipments for equipments like electrostatic separator, cyclone separators, fabric filters are discussed in detail. Various methods for treatment of hazardous waste are studied. Also noise pollution and its abatement measures are discussed.

R. Energy system design-

Sustainable development of the mankind is at the centre of all the economical progress. Use of solid, liquid and gaseous fuel derived from natural resources is not going to last forever. The alternative sources needs to be explored. Also optimization of available resources is important aspect.

The alternate nonconventional energy resources like wind energy, tidal energy, solar energy are most talked about energy resources nowadays. Also synthesis of energy from microbial fuel cells is being investigated. Also synthesis of biodiesel from waste feedstock materials is attracting the investigators. All these topics are introduced to the students in energy system design. The heat exchangers are common heat transfer equipments used in chemical industry. The development of heat exchanger network (HEN) diagram and calculation of pinch temperature and calculation of heat utility requirements are discussed in this subject.

S. Project engineering management:

Various aspects of project engineering management are discussed. Types of organizations, project scheduling, project monitoring are discussed. The analysis of the project execution, work break down is also discussed in detail. The studies on inventory analysis are carried out. Project evaluation and review techniques are also discussed. The procedure for obtaining critical path is studied with example. The projects overrun and under run and possible reasons for the same is also part of these studies. Also types of enterprises, entrepreneurship management, steps in entrepreneurship, qualities required to become entrepreneur are discussed. The duties of project engineer, his responsibilities are highlighted.

T. Biotechnology:

Biotechnology is a branch allied to chemical engineering. As they say, our body is one process plant. Biotechnology deals with various biological processes. DNA technology, RNA fundamentals, cell fusion, protoplast fusion, synthesis of drugs and chemicals by biological pathways. Growth kinetics, growth curve is also discussed. Biochemical pathways for producing the compounds demands less energy compared to chemical methods. These reactions are highly specific. Enzymes act as catalysts for these reactions. Enzyme kinetics is important part of biotechnology. Synthesis of ethanol, lactic, amino, citric, picric acids and many other compounds is done by biological methods. Fermentation is one the commonly used technique for synthesis of compounds like ethanol.

U. Polymer engineering:

Synthesis of various polymer compounds, chain reaction and other aspects of polymer technology are studied in polymer engineering.

V. Piping engineering:

Types of materials for piping, fittings are studied in piping. Piping symbols, types of valves, pressure calculations, thickness calculations, insulation thickness, optimum insulation thickness, friction factor, power requirement calculation are important aspects of these studies.

III. INTERDISCIPLINARY APPROACH

A. Civil engineering

Strength of material is taught to chemical engineering students. The students need to know the fundamental concepts and calculation of load, load bearing capacity of the material. Also dynamics of the moving objects. Mechanics is one key subject in first year which deals with statics and dynamics. Also environmental engineering has many topics common in chemical and civil engineering. Nowadays use of low cost materials for construction, roads, pavements has increased the need of civil engineers to acquire knowledge of chemistry and polymers. Fluid mechanics is also studied in chemical as well as civil engineering. In civil engineering the emphasis is on civil engineering aspects and working fluid is water. The subject is also termed as hydraulics. Piping for drainages, water supplies is learnt. Also environmental engineering is taught to both the curriculum. The civil engineers normally learn about pollution from his perspectives. Civil engineering design of sewage treatment is studied. The chemical engineer studies the environmental engineering from chemical engineering point of view. The water pollution control in chemical industries needs thorough knowledge of the process and compositions of raw materials. Various chemical treatment methods are also included in the treatment process.

B. Mechanical engineering

Strength of material is again important course in mechanical engineering. Also fluid mechanics, heat and mass transfer are subjects common to mechanical and chemical engineering. Chemical engineers learn the subject from their perspective. In thermodynamics along with phase equilibrium, chemical reaction equilibrium is most important. Fluid mechanics for chemical engineering deals with compressible and incompressible fluids. Chemical engineers mainly deal with agitators, flow of chemicals, viscous fluids, and pumps to be used for dense liquids. Heat exchangers are used in chemical engineering for cooling the fluid, condensers, and evaporators. Heat transfer is involved in almost all the chemical processes. Nowadays computational fluid dynamics is studied and it has many applications across branches.

C. Computer engineering

Various softwares are used in designing, piping, flow sheet preparation, layout preparation. AutoCAD, Aspen HYSYS, are some software's used by chemical engineers. The use of advanced computational and optimization techniques calls for knowledge of computers and related soft-wares.

D. Electrical engineering

Basic knowledge of electrical engineering is required for a chemical engineer. Calculation of power, heat duty, and efficiency of the equipment needs basic knowledge of electrical engineering. The process safety aspect also demands electrical know how.

IV. CONCLUSION

The chemical engineering needs fundamentals of physics, chemistry and mathematics. To become successful chemical engineer, these subjects need to be taught in detail for fundamental understanding. Many times studies become mark or percentage oriented and student tend to forget their science basic. Also the approach of the learner should be based on knowledge and not the marks. Also there is need to move ahead from this branch wise learning of the subjects.

Industry oriented leaning is the future of engineering stream. If petroleum industry is considered for example, all the science and technical knowledge related to that industry should be acquired. It can be related to any branch of engineering. It starts with raw material properties, design of the infrastructure up to the effluent treatment and quality control, packaging. Industry based leaning is need of the hour. One faculty must be appointed on the basis of industrial experience and should be teaching practical and industrial approach in chemical engineering.

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