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**COURSE: CHE 524**

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# CHE 524: Principles Of Plant Design

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# CHE 524: PRINCIPLES OF PLANT DESIGN

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***Q1 Briefly discuss the general design considerations***

General Design Consideration

In designing, it is important to have information about the reaction chemical kinetic and desired capacity of production and then decide if the process should be continuous or batch and on method of charging and discharging.

Experiments are organized particularly for process whose mechanism are poorly understood or lack sufficient data for the researcher to work with and develop the kinetics. All experimental rates are an embodiment of kinetics and mass transfer phenomena. When technical grade or synthetic compounds are involved the derived rates can be a near representation of the global rate for the reaction as secondary reactions are almost eliminated. In reacting raw materials, it is not correct to refer to the obtained rate as a representative of the desired reaction; since there were lots of secondary reactions also occurring. For reacting natural raw materials experiments are performed to serve as a guide.

The choice of reactor is influenced by the fact that apart from chemical and physical processes (diffusion of reactants and products), the production and distribution of heat also takes place during the production process.

The method of technological calculations and choice of parameters differs with processes, depending on the type of reactor used. Classifications of reactors are primarily based on factors influencing the kinetics. Such factors include the hydrodynamic conditions and temperature regime. Reactors operating at extreme hydrodynamic regime are classified into ideal plug flow and well mixed and those at isothermal condition into adiabatic or polythermal. Such idealized classification helps in eliminating secondary influences during consideration of the reaction kinetics.

Industrial reactors are far more complex than the ideal ones. Calculations of industrial reactors' parameters are based on experimental data. The ideal model only serves as reference when determining the basic technological parameters and reactors' dimension. Investigation of reactor characteristics is performed by mathematical representation of the processes, that is investigation of changes in T, C, and P. Modeling can be performed for an infinite elementary size or the complete reactor using the material and energy balances.

**Reference**

Odigure J. O. (2013) Introduction to Principle of Chemical Processes. ISBN 987-2-639-51749-1 Scholar Press. Germany. 304p

Odigure J. O. (2013) Modeling and Simulation of Chemical Reacting Systems and Environment. ISBN 978-3-639-51981-5 Scholar Press. Germany. 287p.

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***Q2 Discuss the concept of a process design***

Process design organizes the sequence of bringing together the required physical and chemical operations. It involves defining the flowsheet, operation conditions obtained from the material and energy balance, specifications and materials of construction of the equipment, plant layout, technical and economic feasibility of the project etc. The degree of thoroughness of a process design depends on the complexity of the project. For some only a preliminary design will suffice. Others may require a detailed design to establish the technical and economic feasibility and safety of the project.

Practically all engineering process designs involve these basic components: transport – reaction – transport. The first transport involves the initial raw materials or semi finished products from their sources to the reaction zone or reactors. The second transport is for the removal of the finished products from the reaction zone to the packaging zone or warehouses. In each of these stages the focus is cost reduction.

***Q3. Discuss propriety and custom designed equipment. Which will you recommend for your project? How does it related to codes and standards?***

Process equipment can be propriety or custom designed. Propriety equipment are designed by the manufacturer based on the end user specifications like pumps, cooling towers, compressors, dryers, mixers, valves, furnaces, etc. Custom design of a part/unit of equipment is required to complete the standardization. In specifying for this equipment, only characteristics that define the process operating conditions are necessary. It is however advisable to use the standard manufacturer specification form in making any order for propriety equipment.

Propriety equipment are available “off the shelf” Custom-designed equipment may sometime be requested to meet specific characteristics like safety, extra large or miniature sizes etc. Both the propriety and custom designed equipment comply with approved standards and codes from government agencies, insurance and professional engineering bodies.

Standards and codes have been developed are being improved upon to meet present realities; to ensure safe and economic design, construction/fabrication, testing and maintenance of engineering equipment and structures. Manufacturers and even contractors can develop their own specific standards and codes to ensure high product quality and efficiency of production, handling and maintenance of processes. Although most standards and codes are not legalized by the Act, they are respected by stakeholders since they are seen as compendium of best experiences in their areas.

***Q4. What is a chemical technological sub units and unit? How will you differentiate a subunit from a unit?***

A system is a combination of various subsystems or units. The thorough knowledge of the fundamental sciences of any complex inter connected and inter dependent reacting system and its intra connections and intra reactions with others will greatly enhance the quality of the design to be developed. The development of any original product therefore starts from the understanding of the art of the science of the phenomena that brought it into existence. Each sub system is investigated on its own to determine its hierarchy, functions and the intra reactions with the other members of the system. Consequently, one of the major principles of system design is the analyses and syntheses of the reacting sub systems and their overall hierarchical relationship.

It is very important to know the main objectives/properties of any product to be designed. The extent to which the quality of the desired product is achieved in a furnace for example is dependent on physico-chemical properties of the raw materials, the prevailing internal atmospheric condition and the chemical composition of the refractory materials etc. If only a physical change in composition is desired then the possibility of chemical reaction of the raw materials components or its mineralization must be eliminated. When chemical transformation of the raw materials is desired then the prevailing technological conditions should ensure their maximum rate of reaction. Thermal treatment in furnace is also influenced by the prevailing physical and chemical atmospheric condition in the reaction camera. The atmospheric condition is determined by the firing regime, composition of the fuel, types and condition of burners, etc.

Heat treatment directed at physical transformation of the material often involves not only heat transfer but maybe complicated by mass transfer. The loss of moisture – mass transfer during the initial drying time significantly dictates the heat transfer mechanism and developed heating regime for a product. In a process like heating, cooling, condensation and evaporation only the first two is exclusively heat transfer. The others involve both heat and mass transfer. In the process of heating or cooling, a material may experience change in its aggregate structure due to evaporating, condensing, melting or crystallizing. In these cases, the heat is distributed not in one phase but into two phases. In designing for processes undergoing phase change the initial convective transfer criteria equation, have to be modified by introducing corrective coefficient to account for the new phase.

The quality of any design is therefore greatly depends on the available knowledge and experience of the design team. Thorough understanding of the physical and chemical principles interactions enhances the design processes.

***Q5 What are the factors that drive chemical technological process and their innovation?***

Growth of chemical industry is determined by the extent of modernization of the chemical technology. Increased productivity, better quality products and reduced overhead cost are the major parameters used in assessing a progressive technology. These parameters can be improved by:

1. Expansion of production system or the productivity of the chemical technological systems;
2. Intensification of the production efficiency;
3. Reducing electricity consumption and maximum utilization of heat of chemical reactions;
4. Reducing the production stages and conversion to closed circuit system;
5. Transition from batch to continuous process and
6. Automation of the production processes.

Productivity P can be defined as the quantity of product Q obtained or utilized raw material per unit time.

$$p = \frac{Q}{t}(kg/hr) \qquad \ldots 4$$

Productivity can also be measured in terms of volume $Q_v$ as

$$P = \frac{Q_v}{t}(m^3/hr) \qquad \ldots 5$$

Increased quantity of raw material per reaction volume enhances economy of product unit cost. Increased reactor's geometrical dimension and productivity reduces the amount of working capital by enhancing the heat utilization efficiency, utility coefficient of raw material and the human resources. As a result of these economic advantages, for quite a long time, intensification of production was directed at increasing the volume of reactors. However, increased reactor's volume is accompanied by corresponding technological problems particularly hydraulic instability, non-uniform temperature and concentration distribution. These problems have limited the scope of application of volume increase as a means of intensification of technological process.

At present greater emphasis is placed on increasing the efficiency of the reactors. Efficiency η can be defined as the productivity per unit volume v ($m^3$) or area ($m^2$) of the reactor.

$$\eta = \frac{P}{v} = \frac{Q}{tv} \quad \text{……6}$$

or $$\eta = \frac{Q_v}{tv} \quad \text{……7}$$

or $$\eta = \frac{P}{s} = \frac{Q}{ts} \quad \text{……8}$$

High efficiency can be achieved by:

1. Better design and construction of machines / reactors and
2. Modernization of technological processes.

Efficiency is proportional to the rate of reaction Therefore by studying the kinetics of technological processes, the act of designing, construction of reactors / machine and choice of technological regime can be improved upon. In most recent reactors or modernized ones, intensification of chemical processes is achieved by better mixing of the reacting components. Increased efficiency should not be accompanied with corresponding electricity consumption. Decreased electricity consumption per unit product can be achieved by:

1. Reducing the draught resistance in the system;
2. Reducing the extent of mixing, though this could affect the process kinetics;
3. Maximum utilization of heat of chemical reaction for mixing of raw materials and steam production.

The third point is considered as the most effective means of reducing energy loss in industry. In most reactors' with exothermic reactions, heat exchangers are installed to optimize reaction kinetics and increase the efficiency of heat utilization.

Reducing the production stages and transition to closed circuit system will reduce expenditure on fixed capital and cost of production. Transition to closed circuit system enhances the conversion from batch to continuous process. In the batch process materials are loaded into the reactor, where they undergo a series of physico-chemical transformations and then discharged after the required retention time. The units operations are labour intensive and may not be easily mechanized. Automation of batch process is very difficult to achieve due to the ever-changing technological parameters (temperature, pressure / concentration, residence time, etc.). In continuous process, loading of raw materials and discharging of the final product are continuous and systematized. The technological processes are synchronized with other secondary and transporting operations. At any given point in the reactor, the temperature, pressure, concentration, etc. are constant. Hence it is easy to observe the working regime, mechanize the loading and discharging operations; this could be enhanced by automation of the process. Better quality products may be produced and utilization of heat from chemical reaction better organized.

Mechanization of labour intensive operation and its automation is the prospective means of increasing efficiency. Mechanization is the substitution of human labour with machines. Mechanization enhances productivity by increasing the level of machines' participation while reducing that of man. Automation can be described as the exclusion of man from the production processes by automatic mechanisms. Automation is a higher form of mechanization. It greatly increases productivity and quality of product. In chemical industry, the common parameters easily automated are temperature, concentration, flow rate, etc.

Man's ability to obtain a 100% efficient process is still hampered by our limited knowledge in materials behavior, plant layout techniques and the consequent influence on plant operability, positioning and number of compressors, heaters, the desired products etc.

***Q6. Name and discuss three (3) baseline data for design processes, emphasizing how the information obtained can be used in a design process?***

Industrial machines/processes could be designed using:

- Experiences gained from existing ones or reverse engineering. It involves physical modeling of the process.
- Laboratory experimental data obtained using basic scientific laws and principles.
- Conceptual mathematical models derived using descriptive models of the process principles and laws.

***Q7 What are the factors that influence selection of plant site? How can you optimize the process?***

In designing new factory, it is necessary to perform technical and techno-economical evaluations to ascertain the viability of the project. Various engineering specialists in chemical, mechanical, electrical, civil –structure, are involved in the designing process.

The initial parameters required may include:

1. Location of factory.
2. The capacity.
3. Type of products.
4. Type and quantity of raw materials.
5. Technology of production.
6. Technological regime.
7. Type of reactors and secondary machines.
8. Process control. Etc.

Optimization of these parameters is necessary to ensure maximum productivity, not only for the individual processes, but also of the entire plant. For example the chemical preparedness of $Al_2O_3$, $Fe_2O_3$, $SiO_2$ and CaO in cement raw mix increases with higher fineness and homogeneity. However, increased fineness and homogeneity means higher cost of grinding, and de-dusting operations and consequently increased cost of production. Therefore optimum fineness and homogeneity should be determined considering the cost of grinding, homogenization and de-dusting operations.

***Q9 Why is the conceptual design stage of great importance in developing a viable process?***

The process of designing is performed in two basic phases: the initial or conceptual and the detailed design. Quality management should form an integ76ral part of the various stages of engineering design. This will enhance not only successful attainment of set goals, but maximization of available resources.

**Conceptual Design Stage**

Quality management of engineering design starts with "raw material" or information gathering and control. The engineering portion of quality management plan addresses the design activities that occur during the conceptual design stage. The main feature of design work is the technological calculations. This should be performed for various process routes before the choice of technology is made. The technological route (schematic diagram) shows the details of the chemico-technological processes and the position of each device, apparatus, reactors, communication network and the processes in general. The main technical characteristics should be shown in the technical drawings. These activities form the bases for the project cost estimation and consequently, the approval or disapproval of project funding. At this stage the quality management plan is to provide the design team with tools / documents that clearly state the requirements, quality expectations and ensure completeness of input data. In addition the quality management plan should enhance recognition of poorly defined units so that appropriate risk management measures can be considered.

Poorly defined scope-of-work results in design related rework. This normally manifests itself during detailed design stage. It results in schedule slippage, cost overruns and rework. On the average, design rework account for about 12% of total installed cost, with design deviations accounting for about 80% of it.

The scope of work should clearly define the project objectives. Such objectives include plant capacity, product quality, project schedule and cost, use of new technology, safety, maintainability, project expansionability, start up, running cost, etc.

***Q10 It is very important to optimize the conceptual design data. Why?***

a. Detailed material and energy balance;

b. Operating and design conditions for the various units and devices;

c. Construction materials, pipes and electrical fittings' specifications;

d. Appropriate selection of materials and equipment;

e. Feasibility report including guideline on pre-investment cost for future expansion;

f. Thorough evaluation of existing Federal, State and Local Governments regulatory and permitting requirements;

g. Site considerations: electrical power supply and distribution, real estate allowance, specifications for plant, soil condition, local building codes, existing utility systems, etc.;

h. Environmental requirements;

i. Safety, constructability and technology. These are the three issues that must be treated together during the conceptual design stage. The quality management plan must allow for the consideration of options of various disciplines – construction-structure, operations, maintenance, research and development, safety, industrial hygiene, contracting, etc.

j. Procurement. A detailed procurement plan showing the strategies and preferred suppliers should be prepared during the conceptual design stage. This will reduce uncertainties and quality problems particularly for the major electrical equipment, the control systems and fabricated mechanical parts.

Data gathering can be very difficult to achieve due to market influences and competitive nature of business operations. However, an alternative to incomplete data availability is to perform some thorough economic analysis. This will ascertain the feasibility of each design unit - raw materials' qualities / quantities, plan schedules, budgeting, procurement, construction, etc.

***Q13 What is the relationship between the calculated material balance are and the area of heat transfer obtained during the energy balance?***

The detailed design stage is the next after the conceptual design. It focuses on problems associated with communications and change management. Communication management problems include: not informing all participants of changes in the conceptual plan, not understanding project objectives, not understanding the market force, etc. Often, very few design errors result from technical incompetence. Therefore, the detailed design phase should focus on procedural matters associated with documentation, dissemination and monitoring of information. It should also provide feedback information and initiate corrective actions where necessary. Change management is the process of resisting or avoiding change on the conceptual design plan and ensuring that the inevitable change is communicated and implemented on time; observing all procedures.

After the choice of process route and direction of materials and products flow, the materials (mass) and energy balance are calculated. From these data, the technical and technological parameters of the reactors (size, capacity, residence time, etc.) are calculated. Mathematical modelling of the processes and reactors are also performed at this stage. The reactors' construction materials should be determined considering the corrosiveness of the medium, working temperature, pressure, service life, etc. From the overall capacity of the factory, the number of reactors and other devices are calculated. During the technological calculation, the hydrodynamic, heat and mass transfer and chemical kinetics data are evaluated to find the optimum technological regime and consequently choice of required equipment. Mass and energy balance are calculated during design of new factory or analyses of old ones. Examples will be considered later.

### *Material Balance*

According to the law of conservation of mass, mass cannot be destroyed or created during chemical reactions. That is the mass of reactant(s) must be equal to that of the product(s). Material balance is calculated from the main chemical reaction, taking into consideration all the secondary reactions and impurities.

For the continuous process, material balance is calculated for a given period. That is the feedstock to the reactor at a given time is equal to the output. The total mass of material in a reactor is constant. The quantity of material should be calculated independently for the solid, liquid and gas.

$$M_s + M_l + M_g = M_{s1} + M_{l1} + M_{g1} \qquad \text{..............................................9}$$

where $M_s$, $M_l$ and $M_g$ – mass of feedstock; $M_{s1}$, $M_{l1}$ and $M_{g1}$ – mass of output (product).

In most production processes, the reactants could exist in one or two phase(s), thus simplifying the equation 9. In designing, the productivity of a plant (factory) is usually given and consequently the quantity of raw materials required can be calculated. The ratio of the quantity of the raw materials required to produce a unit mass of the product is referred to as the utility coefficient. It expresses the amount of raw material required to produce a unit mass (kg, ton, mole) of the product. In calculating the material balance, it is necessary to:

1. Formulate and solve the mathematical equations (expression) that will represent the operating technological parameters in relation to the materials input.

2. Calculate the product output.

3. Investigate the chemical kinetic of the reacting compounds.

In some cases as a result of phase transition, the quantity of feedstock in a given phase may not be equal to that of the product. For a gaseous phase reactant, the material balance can be represented as in equation 10.

$$M_g + M_{g1} = M_g + M_{gd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

where $M_{g1}$ is the resultant increase in reactant mass, $M_{gd}$ – resultant increase as a result of mass transfer (adsorption, absorption, condensation, etc.).

For example, in plug flow reactor at stationary state, the material balance of reactant A, per unit time can be represented as in equation 11.

$$M_{A_o} = M_{A_f} + M_A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

where $M_{Ao}$ - feedstock (input) of reactant A, $M_{Af}$ – output of A, $M_A$ – quantity of A involved in chemical reaction. In the differential form, the material balance for a stationary state system can be expressed through the flow rate, w, per height or length H, of the reactor, or change in concentration $M_A$ or rate of change of A due to chemical reaction or mass transfer in gas phase $u_A$.

$$w(\frac{\partial C_A}{\partial H}) = -u_A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

where $w(\partial C_A/\partial H)$ – transfer of reactant A per unit height, that is the difference in mass of A entering an infinite elementary volume of reactor and that leaving it. This is equal to $M_{Ao} - M_{Af}$. In non-stationary regime where the feedstock is more than that used

$$\frac{\partial C_A}{\partial t_1} = -w(\frac{\partial C_A}{\partial H}) - u_A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

where $\partial C_A/\partial t_1$ – rate of increase of reactant A in an infinite elementary volume, $t_1$ – time required for the increase.

#### *Energy Balance*

According to the law of energy conservation, the total energy in a closed system is constant. In chemico-technological processes the law of conservation of mass is the bases on which energy balance is computed; the total amount of energy released to a system must be equal to that expended. Heat balance is calculated using the material balance and heat of physical and chemical changes occurring in the reactor, taking to account the external heat sources and losses through products removal and the reactor's wall.

The energy balance computation can be represented as

$$Q_s + Q_l + Q_g + Q_p + Q_r + Q_{in} = Q_{s'} + Q_{l'} + Q_{g'} + Q_{p'} + Q_{r'} + Q_{in'} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

where $Q_s$, $Q_l$, $Q_g$ – initial heat content of the solid, liquid and gaseous feeds respectively; $Q_{s'}$, $Q_{l'}$, $Q_{g'}$ – heat content of their products; $Q_r$, $Q_{r'}$ – exo- and endothermic heat of reaction; $Q_{in}$ – external heat source, $Q_{in'}$ – heat lost to the surrounding. $Q_s$, $Q_l$, $Q_g$ values are generally calculated as

$$Q = McT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

where M – mass (kg) or mass flow rate (kg/s), c – specific heat capacity (J/(mol.K) and T (K) temperature.

For gases the specific heat capacity at constant pressure and a given temperature T can be determined using

$$C_p = a_o a_1 T \pm a_2 T^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 16$$

The coefficients $a_o$, $a_1$ and $a_2$ are known values and can be got from chemical handbooks.

For mixtures, the specific heat capacity $c_m$ can be calculated applying the additive law. For example, in an n component mixture with $c_1$, $c_2$, $c_3$…$c_n$, the

$$c_m = \frac{m_1 c_1 + m_2 c_2 + m_3 c_3 + \ldots\ldots . m_n c_n}{m_1 + m_2 + m_3 \ldots\ldots\ldots m_n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

For solids, except for those shown below, the element's atomic heat content is the same and is approximately equal to 27J/(mol.K), while the molecular heat content is the sum of their atomic heat content.

| Elements | H | B | C | O | F | Si | P | S |
|---|---|---|---|---|---|---|---|---|
| $C_P$, J/(mol.K) | 14.4 | 13.9 | 7.5 | 14.6 | 20.9 | 20.2 | 22.6 | 16.28 |

The heat content of the liquids may also include the latent heat of fusion and in case of gases – heat of vaporization. Heat released during physical changes; crystallization, condensation, adsorption, etc. should also be computed during heat balance.

$$Q_p = m_1 r_1 + m_2 r_2 + m_3 r_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

where $m_1$, $m_2$, , $m_3$ .... – heat of phase transition. It is also necessary to compute the heat adsorbed as a result of desorption of gases, vaporization, fusion, etc. Heat of exothermic and endothermic reactions should be calculated form the chemical equation for each of the processes.

$$A + B = D \pm \Delta H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 19$$

The total heat is the sum of each individual reaction.

$Q_{in}$ – heat released to the chemical reactor should be calculated from the heat lost by the heat carrier (steam, air, water, etc.).

$$Q_{in} = mc(T_{in} - T_f) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 20$$

$$Q_{in} = mr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 21$$

It can also be calculated using the heat transfer formula

$$Q_{in} = k_t F(T_o - T_f)t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 22$$

where $k_t$ – coefficient of heat transfer, F – heat transfer surface area, $T_o$ – mean temperature of heat carrier, $T_f$ – mean temperature of the material in the reactor, r – heat of vaporization, t – time. Using the heat transfer formula, the quantity of heat lost to the surrounding can be calculated.

***Q14 How will you optimize your design based on the economy of production? Why is cost so important in the final designed product?***

Cost of production of a given product is a measure of the competiveness of a manufacturer for a given societal accepted quality. In our global market arena effective cost and quality management will define the existence of any nation economic survival. Cost is a function of the operation, fixed capital costs relative to the product output. The fixed capital is calculated as the depreciation cost of the investment and bank interest on the working capital. The operation cost is a function of the cost of the raw materials, labour, and maintenance, overheads like administrative cost, sales, research and development. Increasing investment on the fixed capital cost in form of automation may lead to fall in operation cost. However it is very important to remember that increased investment in automation may result to unemployment.

Many books on economic analyses and cost of process equipment are available but, it is important to note that the direct application of the calculated cost often do not reflect the prevailing market realities in most developing countries. It is therefore important that the calculated costs are subjected to reinterpretation considering the local capital, labour, utilities availability, security cost.

***Q15 At which stage of a design is safety considered? Discuss how safety considerations are built into a design process?***

## Safety Considerations

The safety of any design is the outward expression of its quality. It is a judgment on the state of societal acceptance. It is the embodiment of the quality of the analyses and syntheses of the various stages of the design. It in an indicator that all the elements of uncertainty and probability of error embedded in the conceptual, detailed and fabrication design stages are insignificant. These errors are contained in the physical data used, assumptions made on correlations of units and materials behavior, approximations of design calculations, change in operating conditions and environment, etc. Safety consideration starts from the very point of conceptualization of a project. The extent to which safety is applied should be determined by the prevailing government regulations and cost. Adequate safety can be ensured by allowing the inadequacy of equipment compensated for, by a higher more efficient one.

***Q16 What is a risk? How will you identify and prevent risk during design stage? What is normal and abnormal risk?***

Any project requires a rational approach in assessing the suitability to the environment and acceptability to man. Risk is the probability of occurrence of a hazardous event. It is the possibility of the plant transiting from normal to abnormal operating regime. The plant's impact on the environment should be studied from the conceptual stage of design.

A plant or system is design for normal operation. For automated system, any slight deviation of the process parameters is quickly corrected by the control mechanism. However, they do malfunction because of age, climatic condition, maintenance, inexperienced, etc. These could make their reading unreliable. Therefore, human intervention could be necessary to adjust the system to the set parameters by calculating the materials and energy balances, initiate long-term corrective measures, etc. to return the system to normal. Operator's intervention might not be necessary for computed controlled systems designed for abnormal situation because the adjustments are performed automatically.

Risk analysis is performed at the various stages of a process plant. Risk could be technical, social, economic, etc. Risk analyses are performed at the conceptual design, detail design, construction, commissioning and operation stages. There are various risk analyses techniques available to assess the suitability and acceptability of a process plant. They include the Check list, Hazard Operability Study (HAZOP), the Fault Tree, Event Tree, Dow Fire and Explosion Index, Explosion and Toxicity Index, Instantaneous Fractional Annual Loss, Cause Consequence Analysis, Pinch Analysis, etc.

***Q17 Discuss rick analysis technique.***

Early risk analysis at the conceptual design stage helps to identify possible technical, economic and social consequences of establishing the plant. At this stage, it is important:

- To identify potential failure causes
- Assess and quantify the consequences of the potential failure
- Estimate the probability of the event occurrence
- Carefully examine the design to eliminate the possibility of the event occurrence.

The risk analyses are normally considered for each unit individually. It could following the following methodology; starts from the

- Design concept;
- Systematic design appraisal and review of the conceptual and then the detailed technical drawings, feasibility and environmental impact assessment reports,
- List of top hazard at the various subunits and units using any risk analysis technique to establish,
- Estimate the probability of occurrence of the top event/hazard
- Assess the viability of the design units using:
    a. The existing rules and regulations,
    b. Operating standards and codes, and
    c. Documented historical records of possible event occurrence.
- Feed back the obtain results for design improvement and optimization of the process.
- Evaluation and reliability of the units and system;
- Assess the overall technical, economic and social safety of the plant.

The subunits or units that fall below or equal to the accept probability of occurrence are accepted as having passed. In case of the units with probabilities higher than the set standard there will be need to re design the process or introduce mitigating features like temperature control sensors, pressure release valves, level gauges, etc. The survivability of the plant is based on the total probability of the units and extent of accidental event harmful consequences. Survivability is about predicting the impact of any accidental event on the operating personnel or community or environment and is often quantified in terms of the economic implication.

All industrial processes are potential environmental sources of pollution as they by their activities release pollutants to the atmosphere; hence the need to give attention to possible environmental problems during the design and operation of chemical process plants. Elimination of potential accidental pollutants release can be achieved through proper understanding of the process chemistry, control of the process parameters, closed circuit production, etc.

***Q18 How are pollutants generated and identified during design process. How will you eliminate them?***

Pollution is preventable. It is a necessity because of the human factors and materials cost implications. Pollution prevention strategy could evolve through the following steps:

- Definition of the problems
- Developing some conceptual pollution prevention strategies and
- Performing a cost/benefit analyses to find the best alternative.

Definition of the problem start with understanding the process operation, the production technology and engineering design; relative to the technical, social, and economic. This will enhance early identification of the possible emission causes and sources. It is important to know where, when, how, and why these emissions and wastes are generated. The prevention should focus on mitigating the causes and release of the pollutants to the environment. Emission and waste are results of faulty process chemistry (materials and energy balances, reaction kinetics, etc.), technological processes design and poor human organization practices. In developing the conceptual pollution prevention strategies, it is necessary to address the fundamental causes, rather than the symptoms of the emissions and wastes. For example, odorous emission from poultry house is associated with compounds of ammonium and sulphides present in the excreta. Fresh excreta emit lesser odorous gases. Immediate evacuation of fresh excreta and proper ventilation will lead to less odorous environment. This will mean hard work. The long-term strategy will be to convert the compounds to less odorous ones.

Pollution prevention strategies include:

- Engineering design-based pollution prevention, in the following areas like storage and handling of materials, process equipment, process control and instrumentation, recycling and recovery equipment
- Process chemistry and technology-based strategies for the raw materials and unit operations,
- Operations-based pollution prevention strategies for inventory management, housekeeping practices, operating practices, and cleaning procedures
- Maintenance-based strategies, like enforcing existing preventive maintenance programmes and proactive preventive maintenance strategies.

***Q19 How will you calculate a plant layout. Diagrammatic presentation is required.***

**Plant Layout**

The choice of site is influenced by many factors. In this project it is assumed that the plant will be located at a site that will ensure easy availability of cassava tubers. Political consideration is ignored in this project. However it is expected that all administrative standards/laws enforced by the Local, State and Federal Governments will be met. It is expected that the factory will have basic utilities – water, electricity, access roads, etc.

The basic input data for the space requirement were obtained from the design calculations and techno-economic considerations. The constructionability and expliotatationability of the plant were also fully considered. These include size and configuration of space allocation, geotechnical and geology of soil, environmental factors, allowance for future expansion, possibility of corporation (Odigure 1998) with other plants, etc (Table 19).

Basic technical properties of the designed and selected equipment

1. Peeling unit Manual

| | |
|---|---|
| Productivity | 16,000kg/day |

2. Washing unit

Washing basins

| | |
|---|---|
| Number | 4 |
| Dimension | 3x4m |

Bucket lifting system

| | |
|---|---|
| Capacity | 150kg |

Figure 19 Spaces allocation for the major equipment

| S/N° | Unit | Space allocated, m | |
|---|---|---|---|
| | | Length | Width |
| 1 | Raw materials unit | 10 | 10 |
| 2 | Peeling unit | 5 | 5 |
| 3 | Washing Unit | 5 | 5 |
| 4 | Grating unit | 2 | 2 |
| 5 | Detoxification unit | 6 | 10 |
| 6 | Dewatering unit | 3 | 3 |
| 7 | Rotary disintegrator/classifier | 1.5 | 1 |
| 8 | Drying unit | 9 | 3 |
| 9 | Milling/classifier unit | 2 | 2 |
| 10 | Bagging unit | 3 | 3 |
| 11 | Storage unit | 10 | 10 |
| Subtotal | | 56.5 | 10 |

| | | | |
|---|---|---|---|
| | Safety and utility factor of 20% | 11.3 | 2 |
| Total | | 66.8 | 12 |

1. Hammer mill/grater

| | |
|---|---|
| Diameter of shaft | 600mm |
| Length of mill | 400mm |
| Velocity of bits | 1250rev/min |
| Dimension of mill | |
| Length | 0.45m |
| Width | 0.65 |
| Height | 1.10m |
| Productivity | 2000kg/hr |
| Electric motor power | 10kW |

2. Detoxification tank

| | |
|---|---|
| Number of tanks | 3 |
| Volume/Mass | $22m^3$/(7000kg/tank) |
| Length | 5.6m |
| Bottom diameter | 2.4m |
| Height | 1.3m |
| Number of blades | 8 |
| Shaft diameter | 95mm |

| | |
|---|---|
| Electric motor power | 6kW |
| Water jacket | |
| Height | 1m |
| Total area | $9.63m^3$ |
| Mass flow rate | $1x10^{-3}kg/s$ |
| Design space between jacket and tank | 50mm |

3. Cylindrical conical helical conveyor centrifuge

| | |
|---|---|
| Feed inlet diameter | 50mm |
| Speed | 2000rev/min |
| Through put | |
| Liquid | 300l/hr |
| Solid | 1000kg/hr |
| Bowl diameter | 700mm |
| Length | 1.4m |
| Electric power | 5kW |

4. Rotary disintegrator/classifier

| | |
|---|---|
| Length | 1.0m |
| Diameter | 0.4m |
| Electric motor | 5kW |

5. Dryer

| | |
|---|---|
| Length | 7.7m |
| Diameter | 1.6m |
| Heat exchanger | |

| | |
|---|---|
| Outer pipe diameter | 200mm |
| Inner pipe diameter | 50mm |
| Number of pipes | 4 |
| Electric motor power | 5.6kW |
| Productivity | 928.8kg/hr |

6. Hammer mill-cyclone classifier

| | |
|---|---|
| Diameter of mill shaft | 800mm |
| Velocity of bits | 40m/s |
| Height of mill-separator | 2.1m |
| Productivity | 2000kg/hr |
| Electric power | 5kW |
| Cut particle diameter | <180µm |

7. Collector

| | |
|---|---|
| Main cyclone: height | 2m |
| Diameter | 500mm |
| Feed inlet | 125x250mm |
| Outlet | 250mm |
| Flour outlet | 125mm |
| The 3 battery cyclone | Half the main cyclone |
| Electric power | 5kW |

8. Packaging unit

Storage tank

| | |
|---|---|
| Capacity | 4000kg |

| | |
|---|---|
| Number | 2 |
| Packaging equipment | |
| Productivity | 10000kg/day |

The plant layout is as presented in Figure 12

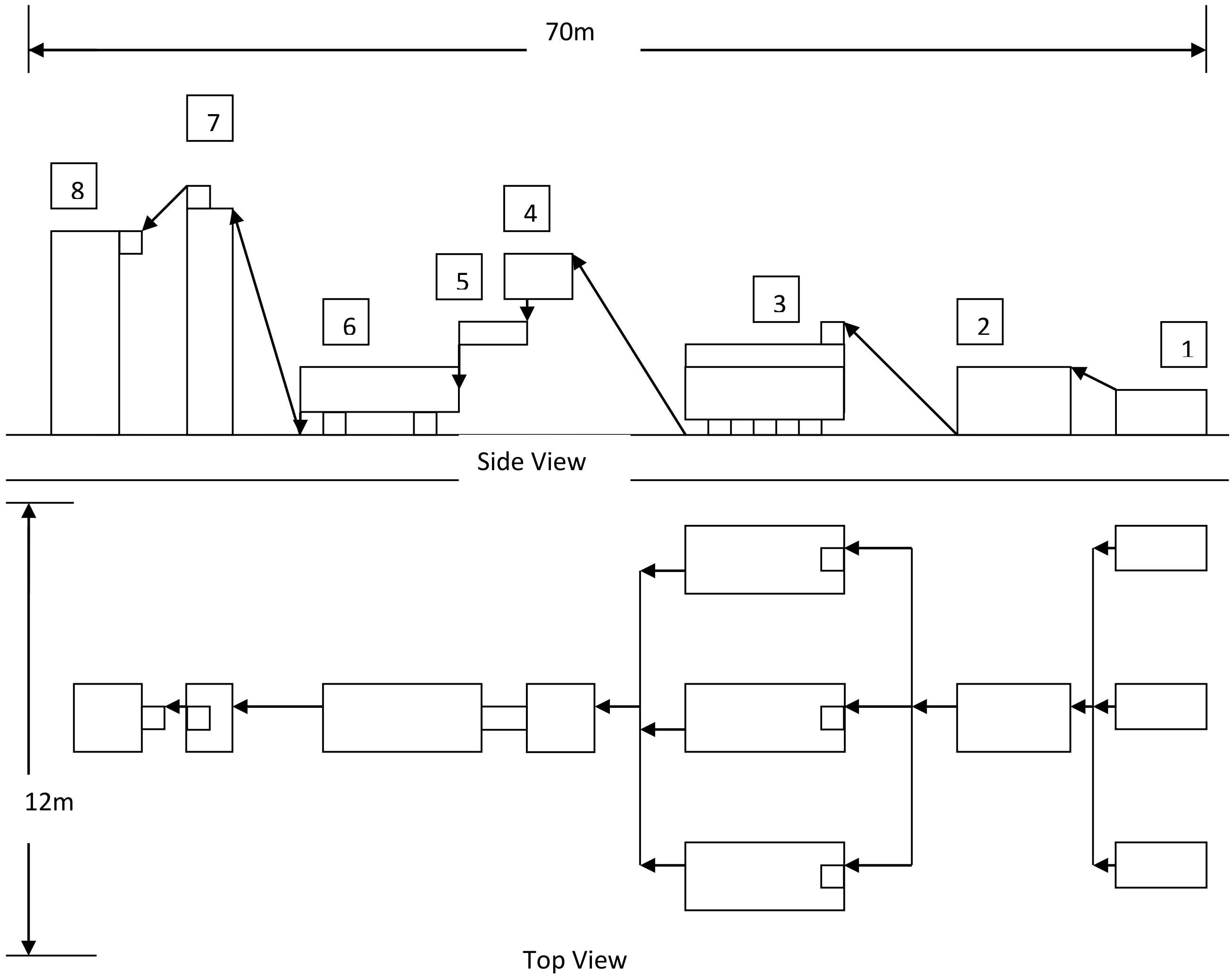


Figure 12 Plant layout of the cassava processing plant

Key: 1 – Washing basin, 2 – Hammer mill, 3 – Detoxification tank, 4 – Centrifuge filter, 5 – Rotary classifier, 6 – Dryer, 7 – Hammer mill – Cyclone classifier, 8 – Cyclone collector.