The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

Department of Chemical and Environmental Engineering

Booklet 01 – Basic Concepts and Terms

H81PEF

Semester One

Name………………………………………………………

Module Convenor: J. J. Turner

Basic Concepts and Terms

Keywords: skills, independence, cooperation

Lesson objectives: To provide an understanding of the fundamental material and energy balances that underpins process engineering. To provide knowledge and understanding of the methods of calculating material and energy balances around a process flowsheet and to practical laboratory experience in engineering processes.

Safety Considerations: N/A

Lesson outcomes:

A2.2.1 – Understand the principles of material and energy balances.

Exemplar material balances based on rudimentary designs.

A2.3.1 – Be familiar with, and able to apply, a range of appropriate tools such as dimensional analysis and mathematical modelling.

For unit conversion.

Tasks:

1. Get organised, which involves a copy of the notes, a pen/pencil and appropriate recording material.

2. Note the date and read the lecture help sheet to familiarise yourself with the lecture outcomes.

3. **The learning environment –** Explore the style and type of learning environment the department has to offer.

4. **Who we are and what we do? –** Explore the concepts of being a chemical process engineer. Through an understanding of what we are expected to do you gain an insight into what we are expected to understand.

5. **Concept of Process Design Engineering –** Investigate the fundamental concept behind process design, explore the fact that no single event can be interpreted in a single manner and how diversity comes from the interpretation of need.

Tasks:

6. **Glossary of Chemical Process Terms** – Interpretation is an important factor when it comes to recall and understanding. The glossary of terms used by engineers is vast and sometimes very specific. Remembering them all would be a huge challenge, but some are more essential than others. Explore the selection of terms and try to create some triggers to aid your recall, something that will allow you to later remember what they mean.

7. **The Kroll Process** – You have explored the concept of process design, now apply the concept to the actual industrial examples. Discuss and debate the assignment of the process design to the Kroll Cycle, see how that all processes have elements that are related.

8. **Exit Tickets** – Explore what you learnt in the lecture, establish the areas you are strongest in and those that you require assistance.

Further reading: Read through the notes for the next lecture, over the next two weeks we are going to be doing a lot of mathematic principles and it would be good if you could have an idea of the direction prior to the lectures.

Basic Concepts and Terms

Process Engineering – There is no universally accepted definition of Process Engineering so: Process engineering focuses on the design, operation and maintenance of chemical and other process manufacturing activities.

Process engineering is often a synonym for chemical engineering but process engineers are found in a vast range of industries, such as the petrochemical, mineral processing, material, Information Technology, food and pharmaceutical and biotechnological industries. Process engineering also involves developing new processes, project engineering and troubleshooting.

In most cases, chemical engineering is to design and operate chemical processes safely to produce useful products with:

1. Minimum input of energy, raw material and labor,
2. Simplest equipment, route(s) and operation(s).
3. Least wasteful and harmful by-products, which do not influence production, products, facilities, devices,

So how does the Environmental Engineer fit into this picture?

To prevent chemical processes from damaging environment and life.

Processes –

Common Sense: A process is the course of something moving or changing from one position or state to another in a period, or continuously. Examples: The Sun rises from the east and falls to the west in about 12 hours; this lecture starts from 9 am and finishes at 9:50am; eyes blink because....	
Thermodynamics: The variation or change that takes place over a certain time or continuously in a system (an open or isolated collection of substances or vacuum under consideration). Examples: A balloon expands due to the temperature rise in air; The heat from a radiator warms up a room; the entropy of an isolated systems increases continuously......	
Engineering: A process is any operation or series of operations by which a particular objective is accomplished. (*Felder & Rousseau*) In terms of engineering, a process may or may not include spontaneous or naturally occurring phenomena.	

Chemical Processes – These are processes in which substance(s), including chemical(s) [substance(s) whose reactivity is of interest or concern], undergo chemical or physical changes at a constant or varying rate, often accompanied by energy input and/or release, to give rise to new substance(s) or new state(s) of the substances.

Chemical changes: reactions in which added substances (reactants) are consumed and new substances (products) are formed in terms of molecular differences.	Physical changes: changes beyond molecular level caused by heating/cooling, mixing/separation, evaporation / condensation / solidification.
Chemical changes:	Physical changes:

An engineered chemical process (or a chemically engineered process?) is an operation that causes chemical and/or physical changes in a substance or mixture of substances. You should be able to identify 6 stages.

Concept of Process Design Engineering

D. The identification / sourcing of **raw materials / feedstock**.

A. Involves collection /extraction / reaction/ separation of the **useful product(s).**

C. Handling **the by-product(s).**

E. Recycling non-reactive or unreacted feed material(s).

F. **input** or **feed** plus energy entering the process

B. The feed in reactors, through controlled reactions (*at a maximum and safe rate*), undergoes conversion to useful product(s) and unwanted by-product(s) (**output**).

The feed/input of a chemical process includes both consumable (reactants and/or energy) and non-consumable (catalysts, reaction media, product carriers and *etc.*) substances.

The product/output from a chemical process includes materials (metals, ceramics, polymers), medicines, functional chemicals (pesticides, dyes/pigment), fuels (petrol and gas), and/or various forms of energy (heat, electricity, light, work).

Glossary of Chemical Process Terms

Absorption A process in which a gas mixture contacts a liquid solvent and a component (or several components) of the gas dissolves in the liquid. In an *absorption column* or *absorption tower* (or simply *absorber*), the solvent enters th top of a column, flows down, and emerges at the bottom, and the gas enters at the bottom, flows up (contacting the liquid), and leaves at the top.

Adiabatic ~~A term applied~~ to a process in which no heat is transferred between the process system and its surroundings.

Adsorption A process in which a gas or liquid mixture contacts a solid (the *adsorbent*) and a mixture component (the *adsorbate*) adheres to the surface of the solid.

Barometer A device that measures atmospheric pressure.

Boiler A process unit in which tubes pass through a combustion furnace. *Boiler feedwate* is fed into the tubes, and heat transferred from the hot combustion products through the tube walls converts the feedwater to steam.

Boiling point (at a given pressure) For a pure species, the temperature at which the liquid and vapor can coexist in equilibrium at the given pressure. When applied to the heating of mixture of liquids exposed to a gas at the given pressure, the temperature at which the mixture begins to boil.

Bottoms product The product that leaves the bottom of a distillation column. The bottoms product is relatively rich in the less volatile components of the feed to the column.

Bubble point (of a mixture of liquids at a given pressure) The temperature at which the first vapor bubble appears when the mixture is heated.

Calibration (of a process variable measuremen instrument) A procedure in which an instrument is used to measure several independently known process variable valu and a *calibration curve* of known variable values versus the corresponding instrument readings is plotted. Once the instrument ha been calibrated, readings obtained with it c be converted to equivalent process variable values directly from the calibration curve.

Catalyst A substance that significantly incre the rate of a chemical reaction, although it i neither a reactant nor a product.

Compressibility factor $z = PV/nRT$ for a ga $z = 1$, then $PV = nRT$ (the ideal gas equat of state) and the gas is said to behave ideall

Compressor A device that raises the pressur a gas.

Condensation A process in which an enterin gas is cooled and/or compressed, causing or or more of the gas components to liquefy. Uncondensed gases and liquid *condensate* l the condenser as separate streams.

Critical pressure, P_c The highest pressure at which distinct vapor and liquid phases can coexist for a species.

Critical temperature, T_c The highest temperature at which distinct vapor and liquid phases can coexist for a species. The critical temperature and pressure, collectively referred to as the *critical constants,* are listed for various species in Table B.1.

Crystallization A process in which a liquid solution is cooled or solvent is evaporated to an extent that solid crystals of solute form. The crystals in the *slurry* (suspension of solids in a liquid) leaving the crystallizer may subsequently be separated from the liquid in a filter or centrifuge.

Decanter A device in which two liquid phases or liquid and solid phases separate by gravity.

Degrees of freedom When applied to a general process, the difference between the number of unknown process variables and the number of equations relating those variables; the number of unknown variables for which values must be specified before the remaining values can be calculated. When applied to a system at equilibrium, the number of intensive system variables for which values must be specified before the remaining values can be calculated. The degrees of freedom in the second sense is determined using the Gibbs Phase Rule.

Dew point (of a gas mixture) The temperature at which the first liquid droplet appears when the mixture is cooled at constant pressure.

Distillation A process in which a mixture of two or more species is fed to a vertical column that contains either a series of vertically spaced horizontal plates or solid packing through which fluid can flow. Liquid mixtures of the feed components flow down the column and vapor mixtures flow up. Interphase contact, al condensation of the vapor, and partial rization of the liquid all take place ughout the column. The vapor flowing ie column becomes progressively richer e more volatile components of the feed, he liquid flowing down becomes richer in ess volatile components. The vapor leaving op of the column is condensed: part of the ensate is taken off as the *overhead product* he rest is recycled to the reactor as *reflux,* ming the liquid stream that flows down olumn. The liquid leaving the bottom of olumn is partially vaporized: the vapor ycled to the reactor as *boilup,* becoming apor stream that flows up the column, and esidual liquid is taken off as the *bottoms product.*

Drying A process in which a wet solid is heated or contacted with a hot gas stream, causing some or all of the liquid wetting the solid to evaporate. The vapor and the gas it evaporates into emerge as one outlet stream, and the solid and remaining residual liquid emerge as a second outlet stream.

Enthalpy (kJ) Property of a system defined as $H = U + PV$, where U = internal energy, P = absolute pressure, and V = volume of the system.

Evaporation (vaporization) A process in which a pure liquid, liquid mixture, or solvent in a solution is vaporized.

Extraction (liquid extraction) A process in which a liquid mixture of two species (the *solute* and the *feed carrier*) is contacted in a mixer with a third liquid (the *solvent*) that is immiscible or nearly immiscible with the feed carrier. When the liquids are contacted, solute transfers from the feed carrier to the solvent. The combined mixture is then allowed to settle into two phases that are then separated by gravity in a decanter.

Filtration A process in which a *slurry* of solid particles suspended in a liquid passes through a porous medium. Most of the liquid passes through the medium (e.g., a filter) to form the *filtrate,* and the solids and some entrained liquid are retained on the filter to form the *filter cake.* Filtration may also be used to separate solids or liquids from gases.

Flash vaporization A process in which a liquid feed at a high pressure is suddenly exposed to a lower pressure, causing some vaporization to occur. The vapor product is rich in the more volatile components of the feed and the residual liquid is rich in the less volatile components.

Flue gas See stack gas.

Heat Energy transferred between a system and its surroundings as a consequence of a temperature difference. Heat always flows a higher temperature to a lower one.

Heat exchanger A process unit through wh two fluid streams at different temperature flow on opposite sides of a metal barrier. H is transferred from the stream at the highe temperature through the barrier to the oth stream.

Internal energy (U) The total energy posse by the individual molecules in a system (as opposed to the kinetic and potential energ of the system as a whole). U is a strong function of temperature, phase, and molec structure and a weak function of pressure (is independent of pressure for ideal gases). absolute value cannot be determined, so it always expressed relative to a reference st which it is defined to be zero.

Membrane A thin solid or liquid film throu which one or more species in a process stre can permeate.

Overhead product The product that leaves top of a distillation column. The overhead product is relatively rich in the most volatile components of the feed to the column.

Pump A device used to propel a liquid or slurry from one location to another, usually through a pipe or tube.

Scrubber An absorption column designed to remove an undesirable component from a gas stream.

Settler See decanter.

Shaft work All work transferred between a continuous system and its surroundings other than that done by or on the process fluid at the system entrance and exit.

Stack gas The gaseous products exiting from a combustion furnace.

Stripping A process in which a liquid containing a dissolved gas flows down a column and a gas (stripping gas) flows up the column at conditions such that the dissolved gas comes out of solution and is carried off with the stripping gas.

Vapor pressure The pressure at which pure liquid A can coexist with its vapor at a given temperature. In this text, vapor pressures can be determined from tabulated data (e.g., Tables B.3 and B.5–B.7 for water), the Antoine equation (Table B.4), or the Cox chart (Figure 6.1-4).

Volume percent (% v/v) For liquid mixtures, the percentage of the total volume occupied by a particular component; for ideal gases, the same as mole percent. For nonideal gases, the volume percent has no meaningful physical significance.

Work Energy transferred between a system, and its surroundings as a consequence of motion against a restraining force, electricity or radiation, or any other driving force except a temperature difference.

The Kroll Process (Summary)

Carbo-chlorination
(~900ºC)

$TiO_{2\ (rutile)} + 1.5\ C + 2Cl_{2\ (g)} \rightarrow TiCl_{4\ (g)} + 0.5\ CO_{2\ (g)} + CO_{\ (g)}$

Magnesium reduction
(~900ºC, some heat from reaction, slow)

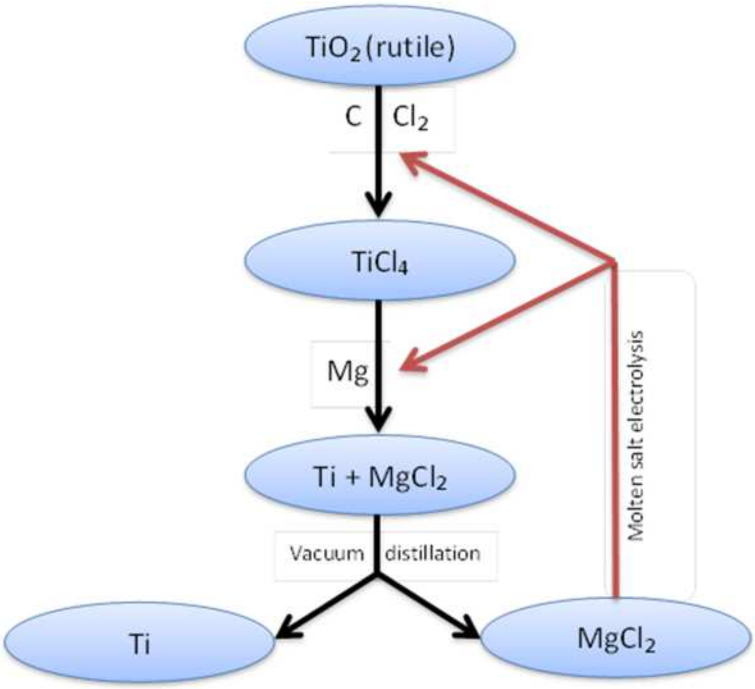
$TiCl_{4\ (g)} + 2\ Mg \rightarrow Ti_{\ (sponge)} + 2\ MgCl_2$

Vacuum distillation *(>1000ºC, slow)*

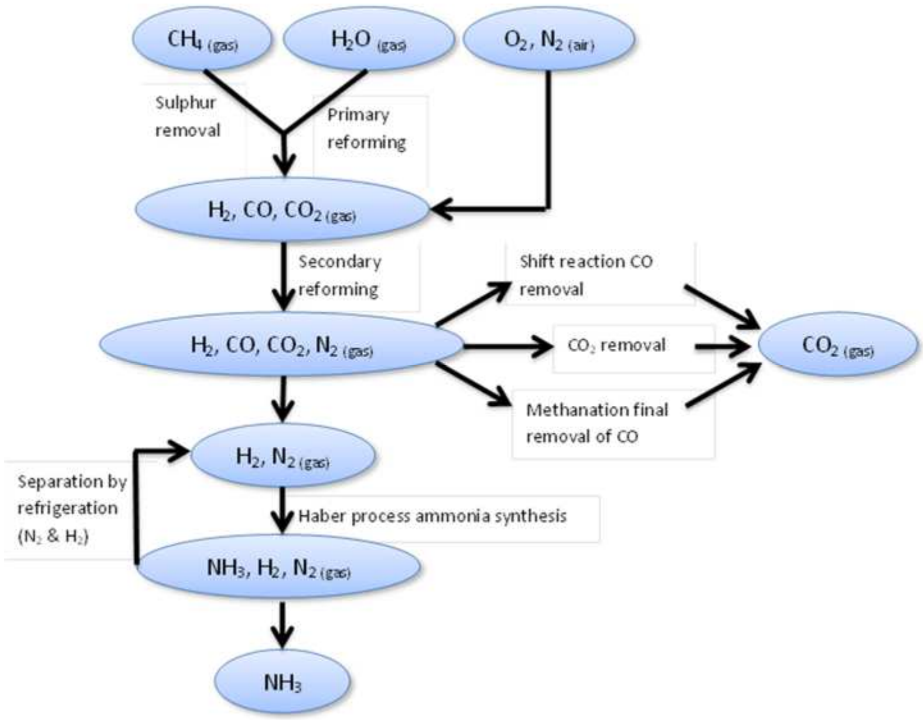
Pneumatic collection

Electrolytic recycling of by product
(~500ºC, molten salt, continuous)

$MgCl_2 \rightarrow Mg + Cl_{2\ (g)}$



The Kroll Process is a multi-step and batch type pyrometallurgical process and runs for a couple of weeks to produce a few tonnes of titanium sponge in a modern reactor.



The Haber process is an artificial nitrogen fixation process and is the main industrial procedure for the production of ammonia today. It is named after its inventors, the German chemists Fritz Haber and Carl Bosch, who developed it in the first half of the twentieth century. The process converts atmospheric nitrogen (N_2) to ammonia (NH_3) by a reaction with hydrogen (H_2) using a metal catalyst under high temperatures and pressures.