CHEE2052 2021 Sample Solutions

Question 1 (20 marks)

(a) Define sustainability and briefly describe how it relates to sustainable development.

[5]

- *Consensus is that a sustainable world has a perfect balance between a healthy economy, a healthy society and a healthy environment; older definition such as the intergenerational justice argument ('planet borrowed from our children'), are acceptable; the general idea that such a world is fair, provides basic needs of all (including non-human species) and can last forever without depletion or deterioration of natural resources should come across; sustainability is the ideal we seek*
- *Sustainable development is the (global) management system providing a framework for the initiatives that strive to get us closer to sustainability, including setting goals ad measuring progress; any project, policy or means to improve health, wellbeing, financial stability, ecological resistance etc can be part of sustainable development*

2 our 3 marks each depending how well it is expressed

(b) How would a company measure its progress towards greater sustainability? Give examples of indicators for all three of the 'pillars of sustainability'

[8]

- *Economic indicators – turnover, sales, profit, value added, typically per tonnes of product, or number of employees; proportion of profit re-invested; proportion of investment for R&D +++*
- *Social indicators: mostly workplace based- number of employees, percentage directly employed, full time, permanent; money spent or hours given for training or further education; manhours lost through illness; staff retention; new hire; gender balance; gender pay gap; minority and disadvantaged groups employees; money donated for charity/community projects; hours / events for stakeholder engagement +++*
- *Environmental indicators: resource use based on energy, water and land per production volume, profit or manhours; proportion of renewable energy or grey water used; pollution based indicators for different impacts – acidification, greenhouse effect, human health, ecotoxicity, eutrophication, ozone depletion ; wastes and hazardous wastes; emissions of specific compounds especially relevant for the process (eg VOC's for solvent users) +++*

1 mark per reasonable indicator; max 3 marks for a single category

(c) Elaborate what we would consider a 'sustainable process' , and describe the design decisions that contribute to achieving it

[7]

A truly sustainable process is micro-version of the circular economy, or an industrial copy of an ecosystem. It uses only inputs/feedstocks that are renewable or can be entirely recycled. Thus its inputs do not deplete any natural resources. All outputs are useful or can be made into something useful. There is no waste. Everything that is not leaving as a product or somebody else's feedstock is recycled. There are no emissions that are in any way harmful or can turn into anything harmful. The production uses minimal land resources and the land is returned to the natural state when production ceases. The plant units and infrastructure can be dismantled easily and used elsewhere or at worst recycled. No construction materials are used that cannot be continued to be used or turned into other useful items.
Design contributes by considering sustainability such as the carbon footprint and avoids specifications that require materials that are only possible using rare, toxic or difficult to process /impossible to recycle element, compounds and components. An important issues are that the supply chain is considered, and unsustainable production requirements before and after the process are not ignored. Most prominently the end of life of product and production means need to be taken into account as early as during product and process selection. No/low waste must be prioritised, and options rejected where potential wastes cannot be utilised, as the last option at least as a fuel (though that is not ideal). Wastes that cannot be broken down and re-integrated into the production cycle are not permitted as they would make the process unsustainable. Water should be cleaned and re-used, without the removal of contaminants leading to waste. If water is generated it needs to be released into the environment as clean or ideally cleaner than the water it is released into. Energy demand should be kept low, the process should be optimised for maximum energy efficiency, and the energy source should be renewable and release no harmful emissions.

1 or 2 marks for each valid point, not limited to points included in the sample solution

Question 2 [40]

A new catalyst has been proposed that converts CO_2 to methanol, and a commercial scale reactor is to be built to test it further. While the process works at the moderate temperature of 200°C, a pressure of 130 bar is required. The reactor is designed as a cylindrical vessel with hemispherical ends, with an inner diameter of 1.2 m and an internal height of 3.7 m. A decision needs to be made as to whether it is preferable to use low alloy steel or a titanium alloy to build the reactor. Relevant data for both is given in Table T2

Table Q2 - Material Properties

	Steel	Titanium
Cost per tonne / USD/t	1100	9900
Density / kg/m^3	7850	4600
Yield strength / MPa	550	1000
Ultimate strength / MPa	700	2300
Young's modulus / GPa	210	115
Fracture toughness / MPa.m$^{(1/2)}$	60	65
Poisson's ratio	0.31	0.18

a) Estimate the cost of building the reactor from each of the materials. Explain choices you made for the calculations, and clearly state the resulting total cost in USD.
If you require the design strength you may assume it here to be 0.7 times the yield strength. [15]

This question requires the student to calculate a 'safe' wall thickness for the pressure vessel assuming 200C is low enough to use room temperature strength with a generous safety margin.
There are two ways – using the formulae provided from BS5500 with my 'design strength' estimate for f, or using hoop and longitudinal stress with a generous safety margin.
Full marks for this step require a separate calculation for the main cylinder and the hemispherical ends.
The volume of the walls is then calculated, converted using density to weight, and multiplied by the cost.
Bonus mark for presenting this neatly in a table. Also for drawing and annotating the vessel, or otherwise defining the variables

b) For the vessels costed in a), what is the difference in height between atmospheric and the operating pressure? [10]

This requires calculating hoop and longitudinal strain. For full marks Poisson's ratio needs to be used to calculate the lateral strain for each and subtract it from the other (perpendicular) strain. The hemispherical ends can be neglected.

c) Will both materials/vessels leak before they burst? [6]

Check if the critical crack length at the operating pressure is larger than the wall thickness (if yes, a crack can slowly grow through the entire wall without sudden and catastrophic failure. ie LLB).

d) Which material would you propose to use based on the calculations in a)-c). Briefly state why? [4]

Steel, as it does the job (minus the LBB) and is much cheaper and stiffer; if for some reason light weight is required titanium alloy (but it better be very important at nearly 3 times the price); neither, look for a tougher material that has a critical crack length >>wall thickness may be used as an answer

e) State which other properties you may wish to consider before making a final decision, and how they could affect your decision? [5]

If you assume continuous operation - creep, esp if the lifetime is meant to be long you'll need to set a specification as to how much creep is acceptable after how long and check it is met
If the operation is intermittent – fatigue (pressurising- depressurising cycles); check expected N and proceed according to if it is low or high cycle
There may be H2 involved – that may be in favour of TA after all, to avoid H2 embrittlement
If there is moisture, maybe consider corrosion

Question 3

A community of householders and small businesses produced 30 tonnes of waste a day, which is currently collected mixed and taken to a central incinerator, where all of it except the metal is burnt for energy together with the waste from other areas in the city. The average composition of the waste collected is given in Table Q3.

Table Q3- MSW Composition

Component	Energy (as discarded)	Percentage by weight	Moisture content
	MJ/kg	%	%
Organic waste	2.5	54.9	64
Plastic	37	14.7	3
Paper	13.2	10.0	7
Textiles	5.7	2.0	13
Glass	0	6.6	1
Metal	0	3.1	2
Other	4.3	8.7	18

a) Calculate the dry composition of the waste, and the overall calorific value on a dry basis. [10]

Convert to weight, calculate energy content , subtract moisture, add up dry weight, calculate dry percentage , divide energy content by dry weight

b) How much energy is recovered from the waste per year if the incinerator has a conversion efficiency of 40% ? [3]

Have energy per day from a), multiply by 365 and 0.4

c) How would the answer to b) change if a new waste management system succeeded in the reduction of the organic waste by 50%, and of paper and plastic by 70% each? [7]

Repeat listing wet waste including the reductions and multiply by energy content (down by ¾)

d) Propose two alternative ways to process the organic waste, and discuss the advantages and disadvantages of them compared with incineration and one another. [10]

The expectation is that composting and anaerobic digestion are mentioned. Advantages are the outcomes, ie returning nutrients to the soil in the former, obtaining a fuel gas that can be stored in the latter. Both can be done small, community or even household based. Composting is safer, but needs more

land area, an, if open, may attract pests. It requires sorting, and moisture control, and tends to be slow. Anaerobic digestion is enclosed and wet by design, and can also deal with (sewage) sludges. Composting is the only one of the 3 that does not return all the carbon to the atmosphere, and thus may have climate advantage, as well as soil improvement and the potential to avoid synthetic fertilisers.

e) Describe what would need to be installed and operated in order to extract the plastic from the mixed waste for recycling. Discuss the limitations of such an undertaking. [10]

The expectation is that the sorting trail is described in some detail , starting with bag splitting, shredding, magnetic removal of metals, washing, drying, and various density methods to separate out first other materials (paper, glass) and then various techniques for recognising different plastic types, manually and automatically. It should be mentioned that the more sorting at source occurs, the easier this becomes. That sorting methods only work on clean relatively undamaged plastics, and that even then most techniques are recovering low-ish proportion in a single pass and multiple passes are common. The price for recovered plastic is low, as is the quality of the products from it typically. economically it is not favourable until such time that 'new' plastic becomes a lot more expensive.