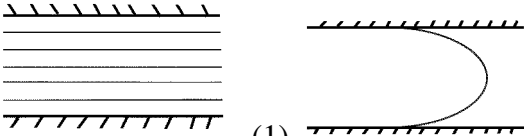


Nuffield Advanced Chemistry Special Study *Chemical engineering*

Exam questions: answers and marking guide

Q1 [Adapted from Edexcel Chemistry (Nuffield) 1996]

- (a) (i) Overall process is controlled by adjusting flow rates (1) (1)
- (ii) Substituting units for values
 units of $Re = \frac{4 \times \text{kg} \times \text{m} \times \text{s}}{\pi \times \text{s} \times \text{m} \times \text{kg}}$ (1)
 Re has no units (1)
 Value dictates whether flow is streamline or turbulent (1) (3)
- (iii) diagram should show
 (1) (1) (2)
- (iv) turbulent flow has back-eddies which have to be overcome (1) (1)
- (v) better mixing (1) / better heat transfer (1) / narrow pipes cheaper (1) *any two* (2)
- (b) (i) To provide a surface on which liquid-vapour equilibrium can be established (1) (1)
- (ii) To return condensate to the column (1) (1)
- (iii) Measure the temperature of the vapour (1)
 Refer to liquid-vapour phase diagram (1) (2)
- (iv) reflux ratio = $\frac{\text{reflux rate}}{\text{distillation rate}}$ (1)
- (v) Higher reflux ratio gives better quality (1)
 Column used more than once (1)
 Longer length gives better quality (1) More boiling / condensation steps (1) Packing affects efficiency of distillation (1) Depending on surface area (1) (6)
- (c) (i) Distillation (1) – waxy components have higher boiling point (1) (2)
- (ii) Filtration (1) – solid retained by filtration (1) (2)
- (iii) Distillation (1) – phenylbenzene has higher boiling point (2)
- (iv) Crystallisation (1)
 – solubility increases with temperature (1) (2)
- (v) Absorption (1) – hydrogen sulphide acidic, absorbed by alkalis (1) (2)

TOTAL 30

Q2 [Adapted from Edexcel Chemistry (Nuffield) 1997]

- (a) (i) $\text{CH}_3\text{CH}_2\text{CHOHCH}_3 \rightarrow \text{CH}_3\text{CH}_2\text{COCH}_3 + \text{H}_2$
 Hydrogen product (1) Rest of equation (1) (2)
- (ii) Generally $4 = 6 + 5$
 so $X = 170 - 155 = 15$ (1)
 $Y = 1350 - 1133 = 217$ (1)
 $Z = 38$ (1) (3)
- (iii) A heat exchange (1) hot products used to heat up reactants (1)
 C heat exchange (1) water used to cool products / condense liquids (1)
 D scrubber/separation (1) removes butanol and most of butanone (1) (6)
- (b) (i) Because vortex effect reduces volume of contents (1) (1)
- (ii) The temperature might be different (1) rate constant varies with temperature (1) (2)
- (iii) They are the same (1) (1)
- (iv) Average time a molecule spends in the reactor (1)
 Volume (1)
 (Total) flow rate (1) (3)
- (v) where reaction is very slow (1) Making small amounts (1)
 same reactor used for several products (1)
any two (2)
- (c) (i) One step/operation in a sequence (1)
 Transport of materials (1) /
 Separation of products (1) *any one* (2)
- (ii) Apparatus in which the heat energy in one fluid is transferred into another fluid (1)
 Pre-heating reactants (1) Cooling products (1) Economising in the use of energy (1)
any 2 (3)
- (iii) Units: substituting units:
 $\text{kJ hr}^{-1} = V \times m^2 \times K$
 $V = \text{kJ m}^{-2} \text{K}^{-1} \text{hr}^{-1}$ method (1) answer (1)
 Duty: heat transferred per hour (1)
 Advantage: temperature difference is greater (1) duty greater (1) (5)

TOTAL 30

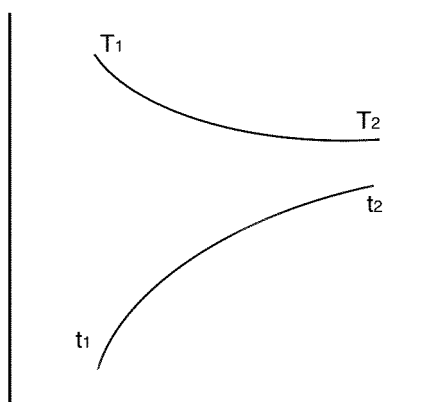
Q3 [Adapted from Edexcel Chemistry (Nuffield) 1998]

- (a) (i) Advantage: cheap (1) Disadvantage: liquid runs down walls / excessive weight (1) (2)
- (ii) Advantage: better contact between liquid and vapour (1)
Disadvantage: Not so resistant to corrosion (1) (2)
NB: flexibility in marking between (i) and (ii) is possible
- (iii) X: bubble cap (1)
Y: sieve (1)
Z: valve (1) (3)
- (iv) capital cost: cost of the plant falls initially because reflux reduces the need for long columns (1)
operating cost: higher reflux ratios mean low product rate / slow process (1)
total cost: capital cost + operating cost (1)
optimum reflux ratio corresponds to the minimum in the total curve (1) (4)
- (b) (i) tubular reactor equivalent to batch (1) tubular reactor smaller (1) (2)
- (ii) advantage: cheaper (for equivalent conversion rate) (1)
disadvantage: less favourable for most situations where there are competing reactions (1) (2)
- (iii) characteristic: the rate constant (1)
dimension: the (working) volume of the reactor (1) (2)
- (iv) the percentage of reactant used up (1) (1)
- (v) increase of temperature increases rate constant (1)
percentage conversion rises (1) (2)
- (c) (i) one step / operation in a sequence (1)
transport of materials (1) separation of products (1) (*any 1*) (2)
- (ii) heat exchanger: apparatus for transferring the heat energy in one fluid into another (1)
(Liebig) condenser (1) Shell-and-tube (1) (3)
- (iii) In turbulent flow there is a streamline layer next to the pipe-wall (1)
If flow rate is increased this layer is thinner (1)
Heat transfer through this layer is therefore quicker (1) (3)
- (iv) Substituting units for quantities:
 $\text{kJ hr}^{-1} = U \times \text{m}^2 \times K$
Units of $U = \text{kJ m}^{-2} \text{K}^{-1} \text{hr}^{-1}$
Method (1)
Units (1) (2)

TOTAL 30

Q4 [Adapted from Edexcel Chemistry (Nuffield) 1999]

- (a) (i) Mass balance: application of the principle of conservation of mass OWTTE (1) (1)
- (ii) Comparison of moles entering and moles leaving, taking into account the equation for the reaction (1) (1)
- (iii) $C_2H_4 + \frac{1}{2} O_2 \rightarrow (CH_2)_2O$
correct (2) each error (-1) (2)
- (iv) Boiling point is below room temperature (1)
Store under refrigeration conditions (1) / As a gas under pressure (1) (2)
- (v) A 3128 A correct (1)
B 1564 D, G correct (1)
C 0 B correct (1)
D 1564 E, H correct (1)
E 782 F correct (1)
F 1564 C, I correct (1)
G 1564
H 782
I 0 (6)
- (b) (i) measure temperature of vapour (1)
refer to phase diagram(1) (1)
- (ii) greater column length gives better distillate quality (1) (1)
- (iii) reflux ratio = $\frac{\text{reflux ratio}}{\text{distillate rate}}$ (1)
- higher reflux ratio gives better distillate quality (1) (2)
- (iv) different packing gives different surface area (1)
higher surface area gives better distillate quality (1) (2)
- (v) distillate quality deteriorates as distillation proceeds (1)
increasing reflux ratio compensates for this (1) (2)
- (vi) liquid runs down sides/packing too heavy (1) (1)
- (c) (i) parallel current (1) (1)
- (ii) counter current (1) (1)
- (iii)



upper graph essentially same (1) lower graph reversed (1) (2)

- (iv) P: temperature difference greater at first (1)
R: temperature difference more nearly equal giving easier automation (1) (2)
- (v) In streamline, middle of liquid in insulated (1)
In turbulent, only a thin streamline layer (1) (2)

TOTAL 30

Q5 [Adapted from Edexcel Chemistry (Nuffield) 2000]

- (a) (i) A vacuum filtration (1)
 B shell-and-tube heat exchanger (1)
 C solvent extraction (1) (3)
- (ii) A separation (1)
 B energy transfer (1)
 C separation (1) (3)
- (iii) A drum rotates, wash liquid sprayed on (1)
 liquid down to centre, solid scraped off drum (1) (2)
 B hot gas passes through pipes (1)
 cooling water passes around pipes, directed by
 baffles (1) (2)
 C aqueous liquid and solvent mixed mechanically (1)
 Product dissolves in solvent, solution separates from
 water (1) (2)
- (b) (i) P condenses vapour and returns liquid to column (1)
 Q removes distillate (1)
 S lagging to establish temperature gradient (1)
 T column packing to provide surface for liquid-vapour
 equilibrium (1) (4)
- (ii) temperature on T1 gives distillate composition (1)
 temperature on T2 gives kettle composition (1) (2)
- (iii) to observe the rate of reflux (1) (1)
- (iv) drop-rate from outlet from Q (1)

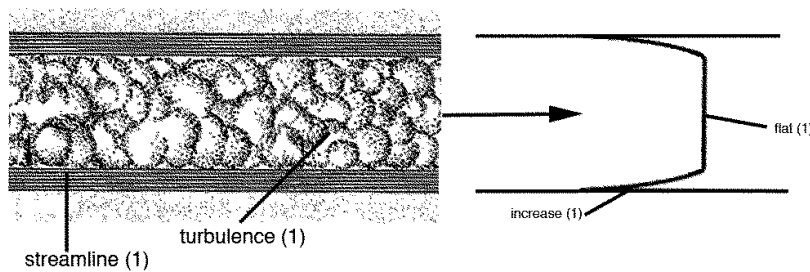
$$\text{reflux ratio} = \frac{\text{reflux drop-rate}}{\text{output drop-rate}} \quad (1)$$
 (2)
- (v) alter tap Q; this alters output rate and hence reflux ratio (1)
 higher reflux ratio gives better distillate quality (1) (2)
- (vi) use columns of different lengths, repeat measurements (1)
 larger columns give better distillate quality (1) (2)
- (vii) if high quality is required, reflux ratio needs to be high but
 output is slow (1)
 alternatively use larger column but this is more expensive
 to build (1) (2)

- (c) (i) storage large-scale demands big space – cost of land important (1) (1)
- (ii) heating large-scale demands economy of energy e.g. use of steam (1) (1)
- (iii) operation batch for small-scale / long reaction time / flexible between products (1)
OR continuous – no shut-down time / easier automation / lower workforce (1) (1)

TOTAL 30

Q6 [Adapted from Edexcel Chemistry (Nuffield) 2001]

- (a) (i) A boiling point of mixtures (1) (1)
 B compositions of vapours of boiling liquids (1) (1)
 C composition of liquid-vapour mixtures (1) in equilibrium (1) (2)
- (ii) 68 – 70 % propanone (1) (1)
- (iii) 4 (1) (1)
- (b) (i) use baffles in the reactor tank (1) (1)
 (ii) average time spent by a reactant molecule in the reactor (1) (1)
- (iii) A moles thiosulphate per minute = $\frac{3.5 \times 0.10}{1000} = 3.5 \times 10^{-4}$ (1)
 B moles I₂ per minute = 1.75×10^{-4} (1)
 C moles H₂O₂ reacting per minute = 1.75×10^{-4} (1) (3)
- (iv) rate = $k [\text{H}_2\text{O}_2]$ (1)
 $1.75 \times 10^{-4} = 300 \times 10^{-4} \times [\text{H}_2\text{O}_2]$
 $[\text{H}_2\text{O}_2] = \frac{1.75}{300} = 5.8 \times 10^{-3}$ (1)
 concentration decrease = $1.7 \times 10^{-3} \text{ mol dm}^{-3}$ (1)
 % conversion = $\frac{1.75}{7.5} \times 100 = 23 \%$ (1) (4)
- (v) $\tau = V/U$ so larger volume gives longer mean residence time (1)
 higher % conversion (1) (2)
- (c) (i) V: orifice-flow (meter) (1)
 pressure drops when fluid goes through hole (1)
 pressure drop proportional to flow rate (1)
 W: variable area (meter) (1) upward flow lifts float (1)
 until pressure drop just supports float (1) (6)



- (ii) (4)
- (iii) turbulent: mixing (1) cheaper pipes (1) better heat transfer (1)
 streamline: less energy for pumping (1) *any two* (3)

TOTAL 30

Q7 [Adapted from Edexcel Chemistry (Nuffield) January 2002]

- (a) (i) fluid velocity (1) fluid density (1) viscosity (1) pipe diameter (1)
any 3 (3)
- (ii) any method from students' text
 diagram (1) measurement (1) explanation (1) (3)
- (iii) energy required to counteract eddies in turbulent flow (1) (1)
- (iv) better mixing (1) better heat transfer (1) cheaper pipes (1)
any two (2)
- (b) (i) rate-constant is highly temperature-dependent (1) (1)
- (ii) concentration of overflow must be equal to that in the tank (1)
 concentration must be uniform (1) (2)
- (iii) $\frac{1.5}{u} = \frac{[A]_0(1 - 0.57)}{[A]_0 \times 0.15 \times 0.57}$ (1)
 $[A]_0$ cancels (1)
 $u = 0.298 \text{ dm}^3 \text{ min}^{-1}$ (1) (3)
- (iv) $\tau = \frac{V}{U}$ so $\frac{V}{U} / T$ is greater (1)
 % conversion greater (1) (2)
- (v) average time spent by molecule in tank (1)
 $\tau = \frac{V}{U}$ (1) (2)
- (vi) in CSTR only small adjustments need be made (1)
 these can be detected and fed back on corrections (1) (2)
- (c) (i) if volume increases, surface area increases much less (1)
 heat lost only from surface so rate increases (1)
 temperature rises uncontrollably (1) (3)
- (ii) 2 materials from list in students' text (1 each) (2)
 2 advantages (1 each) (2)
 2 disadvantages (1 each) (2)

TOTAL 30