UNIVERSITY OF PRETORIA

DEPARTMENT OF CHEMICAL ENGINEERING

REACTOR DESIGN (CRO 410)

25 July 2020 **Supplementary Exam** **TIME: 2.5 hours**

TOTAL 30

Question 1 [14]

Consider the following *reversible* elementary liquid phase reaction:

$$A \rightleftharpoons B$$

Rate and thermodynamic data of the reaction is given in the table below

K_c @ ***T_{ref} = 300 K***	2000
ΔH^o_{RX}	-30000 J.mol^{-1}
$C_{p_A} = C_{p_B}$	80 J.mol^{-1}K^{-1}
k_o (Pre-exponential rate constant)	193 $m^3.kg^{-1}s^{-1}$
E (Activation energy)	60000 J.mol^{-1}

Pure A at $\boldsymbol{C_{A_o} = 100}$ **mol.m^{-3}** with a volumetric flow rate of $\boldsymbol{Q = 10 \times 10^{-3}\ m^3.s^{-1}}$ is converted in a reactor set-up consisting of two ***adiabatic*** CSTR's in series. The same type of solid catalyst is used in each reactor. The inlet temperature to the ***first*** reactor is $\boldsymbol{T_o = 310\ K}$ and the conversion of A achieved in this reactor is $\boldsymbol{x_A = 40\%}$.

After the first reactor, the formed product B is separated from the product stream, so that the resultant feed stream to the second reactor contains only pure A again. The second reactor must be operated in such a way that an ***overall conversion*** of A of ***85%*** is achieved. After separation, the inlet stream to Reactor 2 can be cooled or heated in a heat exchanger before processing in reactor 2.

a) What is the concentration of component A in the second reactor? – give in units of $mol.m^{-3}$ [2]

b) What is the concentration of component B in the second reactor? give in units of $mol.m^{-3}$ [2]

c) Specify the amount of inter-cooling (give in **kW**, round to 3 significant numbers) necessary to minimize the mass of catalyst required in the second reactor to achieve the required conversion. [10]

Assumptions:

Densities of all liquid streams are equal and $\boldsymbol{\rho_l = 950\ kg.m^{-3}}$.

All mass transfer effects are negligible

The separation process does not result in a change in temperature

Question 2 [16]

The first order reaction where A is converted to B is carried out in a laboratory scale CSTR at different stirrer speeds (in rpm), at different temperatures and catalyst particle sizes. The results at a fixed concentration of A, $\boldsymbol{C_A = 16.9 \times 10^3\ mol/m^3}$, is shown on the attached figure. The catalyst is porous and $\boldsymbol{\rho_{cat} = 1200\ kg.m^{-3}}$. It is also known that the total catalyst surface area (S_i) is 100 m^2/g.

a) Quantify the mass based intrinsic rate constant for this reaction (I.e. calculate the pre-exponential constant and the activation energy) [4]

b) In addition to its dependence on particle diameter, it is known that the specific mass transfer coefficient, (k_c), in the CSTR where the studies were done, is related to the stirrer speed such that $k_c \propto (rpm)^n$. Determine the value of n [6]

c) Calculate the temperature above which it can be assumed that the apparent rate is in the internal mass transfer limited regime for the 5 mm catalyst particles. (*Assume D_e to be independent of temperature*) [6]

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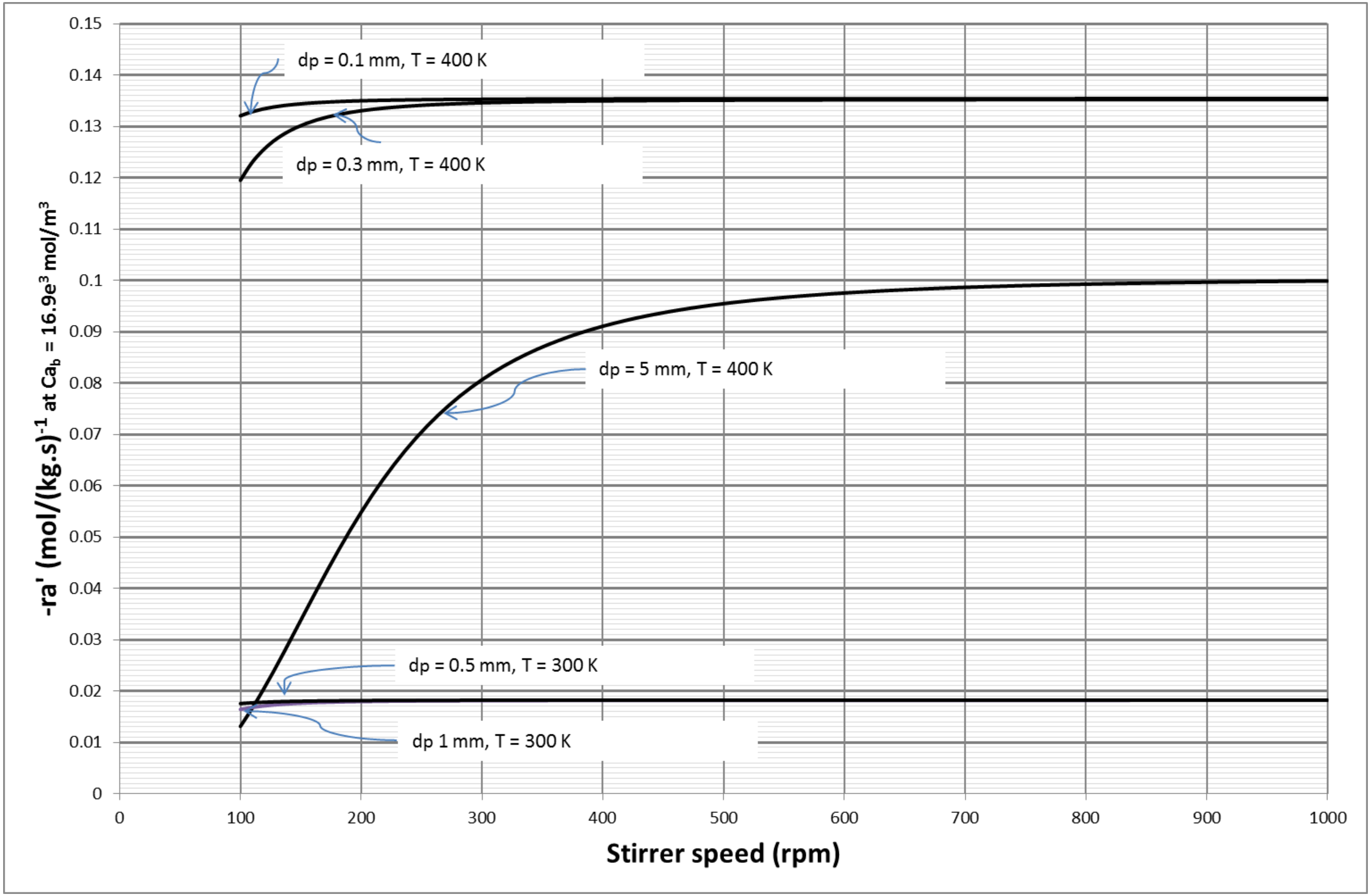
Start ALL file names with your Surname and Initials, followed by your student number and any distinguising details about the information in that file.

(e.g. DuToit_EL_123456_written.pdf OR *DuToit_EL123456_notebook.pdf*).



dp = 0.1 mm, T = 400 K
dp = 0.3 mm, T = 400 K
dp = 5 mm, T = 400 K
dp = 0.5 mm, T = 300 K
dp 1 mm, T = 300 K
-ra' (mol/(kg.s))^-1 at Ca_b = 16.9e^3 mol/m^3
Stirrer speed (rpm)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
100
200
300
400
500
600
700
800
900
1000