Loughborough University

23CGP060

Mixing of Fluids and Particles

Semester 1 2023/24 — In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

<u>Help during the exam</u>

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Attempt **THREE** questions in total. Each question carries 25 marks.

Candidates should show full working for all calculations and derivations.

Relevant expressions and data can be found at the end of the examination paper.

1. (a) Describe briefly an experimental technique that can be used to evaluate the spatial distribution of solids in a stirred tank. Explain what useful information may be obtained using this technique. State any limitations of the technique you have chosen. [5 marks]

   (b) You have taken on a new role to evaluate and decide between two alternative designs for a process requiring off-bottom suspension of heavy solids in a stirred tank. An intern has performed experiments with two types of impeller. One of these impellers, A, has a power number of Po = 1.4 and the other, B, has a power number of 1.2. The trials were performed in a cylindrical tank of standard geometry, i.e. the liquid height is equal to the tank diameter ($H = T$), and it has a flat base. The tank diameter is T = 0.30 m. Both impellers are of a diameter of $D = T/3$.

   The intern is not sure whether they have confused the data sets and hence does not know whether to choose impeller A or B for the process. As the project engineer, you are tasked to perform supporting calculations that would enable a recommendation to be made for impeller choice to achieve the process requirement, i.e. off bottom suspension of solids whilst maintaining low operating costs.

   Values for the constant "s" were provided as 4.3 and 4.5 for impellers A and B respectively.

   The particles have diameter, d_p = 180 μm and density, ρ_s = 2200 kg m^{-3}. They are used at a mass fraction of X = 10%. The liquid phase viscosity is μ = 0.018 Pa s and the density is ρ_L = 1080 kg m^{-3}.

   Show your relevant supporting calculations to enable an engineering decision regarding impeller choice to be made. What is your conclusion / recommendation? [10 marks]

Continued/…

Q1 Continued/…

(c) A gas-liquid mixing process is carried out in a cylindrical, flat bottomed, fully baffled tank of T = 0.6 m, where the liquid height, H, is equal to the tank diameter. The tank is equipped with a concave bladed disc turbine of a diameter of D = 0.3 m, which has a power number of Po = 1.5. It is rotated at an impeller speed of N = 120 rpm. The physical properties of the medium can be considered to be water-like. Upon gassing at a flow rate, Q_G, of 0.003 $m^3\ s^{-1}$, the power consumption reduces by about 5%. These conditions result in the target product profile.

The process is then scaled up to a geometrically similar tank of T = 1.8 m. The impeller rotation speed and gas flow rate are kept constant at 120 rpm and 0.003 $m^3\ s^{-1}$, respectively. Under these conditions gassing results in a reduction in power input by about 5%.

Based on the information above, state whether you would anticipate a comparable process performance from the large scale.

If you conclude that the performance of the mixing process will be similar, show the calculations that support this conclusion.

If you conclude that the performance of the mixing process will be different, show your relevant calculations on what the operating conditions should be. [10 marks]

2. (a) What is the main goal of scale up of a mixing process? Explain three potential complications that may be encountered during the scale up of a mixing process.

[7 marks]

(b) Define “coalescence rate” in the context of immiscible liquid dispersions. State three factors that affect coalescence rate. [5 marks]

(c) Briefly explain the principle of an experimental technique that can be used to determine homogeneity during a liquid blending process. State an advantage and a disadvantage of the chosen technique. [3 marks]

(d) A miscible liquid blending process is required to achieve 95% homogeneity. The process is carried out in a standard geometry stirred tank, i.e. the liquid height is $H = T$. The tank has a diameter of $T = 3.0$ m. It is equipped with a pitched blade turbine of diameter, $D = T/2$. The characteristic power number for this impeller is $Po = 1.2$. The impeller speed is 75 rpm. The rheology of the liquid can be modelled using the following expression: $\tau = 1.7\,\dot{\gamma}^{0.68}$, where τ (Pa) is and $\dot{\gamma}$ (s^{-1}) is the shear rate. The liquid density is 1095 kg m^{-3}.

Calculate the energy consumption for this blending process. [10 marks]

3. (a) Describe the differences between induction behaviour and steady growth behaviour in high shear granulation. Include sketches in your answer. [5 marks]

(b) Sketch a typical bed pressure drop versus superficial velocity plot for a gaseous spouted bed system, labelling key values of interest. State the range over which this would be valid in terms of the relationships between column diameter, inlet diameter and particle diameter. [5 marks]

(c) 1 kg of salted corn snacks, consisting of 4% flavouring by mass, is packed into 30 g bags. The densities of the snacks and flavouring are 1000 kg m^{-3} and 3000 kg m^{-3} respectively. The particle size distributions of the pure components are given in Table Q3.

Table Q3: Particle size distribution of ingredients

Particle size (μm)	Snack % w/w	Flavouring % w/w
500-550	20	0
450-500	60	0
400-450	20	0
200-250	0	20
150-200	0	30
100-150	0	30
0-100	0	20

Using the Poole *et al.* relationship for the variance of random mixing:

$$\sigma_R^2 = \frac{PQ}{M}\left[P\overline{W}_Q + Q\overline{W}_P\right]$$

estimate the 95% confidence limits for the mass of flavouring in each of the 30 g bags. State any reasonable simplifications you have made. [10 marks]

(d) Discuss reasons why this answer may not be accurate. [5 marks]

4. A continuous crystallisation stage of a full-scale pharmaceutical process is to be performed in a dished bottom, glass-lined vessel containing a retreat curve impeller and a single beavertail baffle. The main feed to the crystalliser is a low viscosity, saturated solution of the active pharmaceutical ingredient (API) in a solvent. Supersaturation for crystal growth is created by addition of a low flow rate of anti-solvent to the API + solvent feed solution, lowering its saturation concentration. The geometric design of the crystalliser is to be investigated using computational fluid dynamics (CFD), with a view to identifying ways to enhance off-bottom suspension of the crystals and to improve the blending between the anti-solvent and the API solution.

(a) Why are such geometries often used in pharmaceutical processes? Comment on their suitability of the vessel and impeller type for this process operation. [4 marks]

(b) Consider the problem definition and pre-processing steps, prior to running the CFD simulation.

(i) Discuss the key elements of physics and chemistry that need to be included in the CFD model and describe the additional information and data that would be required. [5 marks]

(ii) Hence, describe the transport equations, constitutive equations and boundary conditions that would be used for this model. [5 marks]

(c) The beavertail baffle has been placed in close proximity to the passing impeller blades. Select and justify a suitable method to represent the impeller in this simulation. [3 marks]

(d) Assuming the flow has a high Reynolds number, discuss the selection of a suitable turbulence model for these industrial scale simulations. [3 marks]

(e) Validation of the predicted flow field is to be conducted by comparison to results from a small-scale experiment. Discuss the requirements for the design of this experiment and describe the methods available to collect velocity and solids suspension data to validate the predicted flow and solids concentration fields. [5 marks]

END OF PAPER

Dr NG Özcan-Taşkin, Dr M Leaper, Professor CD Rielly

Relevant Expressions and Data

Zwietering correlation for just suspension speed

$$N_{JS} = s\nu^{0.1}\left[\frac{g\Delta\rho}{\rho_L}\right]^{0.45} {d_p}^{0.2} X^{0.13} D^{-0.85}$$

Power number $$Po = \frac{P}{\rho N^3 D^5}$$

Fourier number $$\frac{1}{Fo} = \frac{\rho T^2}{\mu\vartheta}$$

Reynolds number $$Re = \frac{\rho N D^2}{\mu}$$

Mixing time correlation for 95% homogeneity in the turbulent blending regime:

$$Po^{1/3}\ Re\ Fo = 5.2\ \pm 10\%$$

$$\theta_{95} = \frac{5.2\ T^{1.5} H^{0.5}}{Po^{1/3} N D^2}$$

Mixing time correlation for 95% homogeneity in the transitional blending regime:

$$Po^{1/3} Re Fo^{1/2} = 183 \pm 31.1\%$$

$$\theta_{95} = \frac{183^2 T^2}{Po^{2/3} N^2 D^4}\frac{\mu}{\rho} \pm 31.1\%$$

Wall shear stress:

$$\tau_w = \frac{1}{1.622}\left(\frac{\Lambda}{T^3}\right)$$