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Hydrodynamics of spray column for enzymatic reactions of oil

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ABSTRACT

The hydrodynamic characteristics of a spray column for oil–water system have been investigated in the present work in a column of 5 cm inner diameter and 250 cm height, operated in a semi batch manner. The effect of dispersed phase flow rate and nozzle diameter on different hydrodynamic parameters such as drop diameter, dispersed phase hold up, terminal rise velocity and jetting velocity has been studied. It has been observed that the drop diameter, dispersed phase hold up, terminal rise velocity and jetting velocity increase with an increase in nozzle diameter. Also, dispersed phase hold up increases with dispersed phase velocity whereas terminal rise velocity and drop diameter show a marginal dependency. Correlations have been developed, using nonlinear regression, for the prediction of drop diameter, dispersed phase hold up, terminal rise velocity and jetting velocity.

Keywords: Spray column; Castor oil; Hydrodynamics; Dispersed phase hold up; Drop diameter; Jetting velocity

1. Introduction

Enzyme catalyzed reactions are usually carried out in a batch reactor. Although, batch reactors are extremely versatile and easy to operate, they have many limitations such as batch to batch variations, high labor costs, frequent start up and shut down requirements, and the need to recover or separate the enzyme (in case of enzyme being used in a solubilized form) after each batch. Similarly, the size of reactor for large scale production is large which requires higher initial investment. Since enzymatic reactions are very slow, the batch reactor is not recommended for enzymatic hydrolysis of oil (Puthli et al., 2006) although a lot of research is generally being carried out using batch reactor (Malcata et al., 1990). An attempt to increase the rate of enzyme catalyzed hydrolysis reaction using different additives showed no significant improvement in the rate of reaction (Rathod and Pandit, 2009). The reason attributed for the slow rate of reaction is the accumulation of the product fatty acid on the interface (Puthli et al., 2006). Thus, continuous removal of fatty acid from the reaction mixture can be an excellent alternative to increase the rate of reaction as it has been already established that the intermittent removal of fatty acid results in increase in the rate. Thus, a continuous reactor can be a preferred configuration for enzymatic reactions. In order to carry out the enzyme catalyzed reaction in a continuous manner, spray column is one of the best alternatives especially when the enzyme used is in a solubilized form.

Spray columns (Fig. 1) are simple and inexpensive liquid–liquid contactors. Spray columns are usually used for the liquid–liquid extraction and Jafrabad et al. (1990) have extensively reviewed the literature on the spray columns especially considering mass transfer and hydrodynamic characteristics for different systems. Although, the use of spray column for the extraction of enzyme from the mixture has also been investigated (Sawant et al., 1990; Jafrabad et al., 1992; Srinivas et al., 2002; Arsalani et al., 2005), its application in the enzymatic catalyzed reaction has not been reported to the best of our knowledge. Since, enzymatic reactions are interfacial reactions, knowledge of drop size and terminal rise velocity is very important in the design of the spray column as it has a direct influence on the fractional dispersed phase hold-up and the interfacial area. The interfacial area in the spray column is dependent on the flow rate of both the dispersed phase and the continuous phases and also on the size of the drop of the dispersed phase formed at the entrance of nozzles. The size of the dispersed phase drop formed at the nozzle depends on many factors and various correlations are available for the

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Nomenclature

a	interfacial area (m^2/m^3)
d_N	nozzle diameter (m)
d_p	diameter of drop (m)
Eö	Eötvös number, $\Delta\rho g d_N^2/\sigma$
g	acceleration due gravity (m/s^2)
H	clear liquid height (m)
H_d	height of dispersion (m)
N_d	number of drop formed for time t
t	time required to form number of drops (N_d) (s)
Q	volumetric flow rate of dispersed phase (m^3/s)
Re	Reynolds number for the drop, $dpV_\infty \rho/\mu_d$
V_∞	terminal rise velocity of the individual drop (m/s)
V_d	superficial dispersed phase velocity (m/s)
V_j	jetting velocity (m/s)
We	Weber number, $\Delta\rho d_N V_d^2/\sigma$

Greek letters

$\Delta\rho$	density difference (kg/m^3)
ε_d	dispersed phase hold up
μ	viscosity of the phases (Pa s)
ρ	density of the phases (kg/m^3)
σ	surface/interfacial tension (N/m)

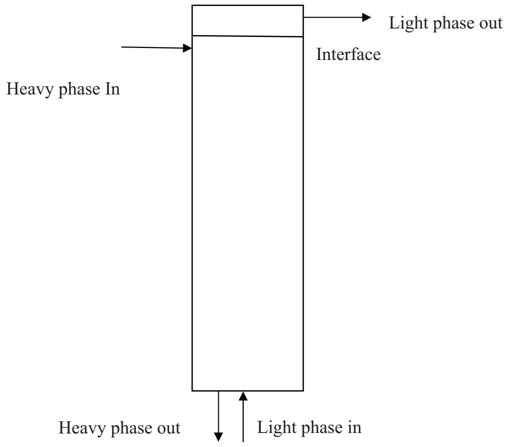

Fig. 1 – Schematic representation of spray column.

estimation of the drop volume and terminal velocity of drops. However, the various correlations available for the drop volume (Hayworth and Treybal, 1950; Skellend, 1992; Bhavasar et al., 1996) are not adequate for the oil–water system as they are proposed either for conventional systems or two phase aqueous systems.

The primary objective of this study is to determine the effect of various operational parameters in a spray column on the drop volume, terminal rise velocity and hence the interfacial area using oil–water system.

2. Experimental details

2.1. Materials

The two phase system of castor oil–water has been used. The castor oil was procured from Ashwin Chemicals, India.

2.2. Estimation of physical properties

Phase densities were measured using specific gravity bottle at room temperature and viscosities were measured using Brook Field viscometer. Table 1 gives the physical properties of the phases used in the present work.

2.3. Measurement of drop size

The drop size of the castor oil i.e. dispersed phase in a column reactor is required for the estimation of the interfacial area available for the enzymatic hydrolysis of the oil. The castor oil was passed through a stagnant vertical liquid column (batch wise) of the water and single drops formed at the nozzle tip were allowed to rise through this column. The flow rate of the dispersed phase (i.e. oil) was monitored with the help of the peristaltic pump by determining the time required for a measured quantity of the castor oil to flow through the pump. The numbers of drops (N_d) were measured over a required period of time (t) and the diameter of the drop was estimated as follows:

$$d_p = \left(\frac{6tQ}{\pi N_d}\right)^{1/3} \tag{1}$$

2.4. Measurement of rise velocity and residence time

The time required for a drop to rise from bottom to the top level of water (i.e. residence time of the drop in the column) for one pass was measured using stop watch for number of runs and average residence time was then estimated. The terminal rise velocity of the drop was determined by determining the time taken by a drop to travel between two marks on the column after allowing for the acceleration period from its detachment from the nozzle at the bottom of the reactor.

2.5. Measurement of dispersed phase hold up

Dispersed phase hold up has been calculated by using following equation:

$$\varepsilon_d = \frac{H_d - H}{H_d} \tag{2}$$

2.6. Measurement of interfacial area

For spherical drops, effective interfacial area has been calculated using following equation (Laddha and Degaleesan, 1976):

$$a = \frac{6\varepsilon_d}{d_p} \tag{3}$$

2.7. Experimental setup

Spray column reactor, used to study the hydrodynamic characteristics, consists of an acrylic column with 5 cm inner diameter and 2.5 m height (Fig. 2). The continuous phase (water) was placed in the column in such a way that there was always an oil layer at the top and a fixed interface between the oil and the water is obtained. This arrangement prevents the transfer of the water along with the oil during the collection of the oil after every pass of the dispersed oil phase through the outlet of column.

In order to study the effect of reversal of phases, the continuous phase used earlier was used as dispersed phase and dispersed phase used earlier was used as continuous phase.