Fuel Processing Technology 171 (2018) 265–276

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Research article

Hydrodynamics and oxygen transfer characterization in a net draft tube airlift reactor with water-in-diesel microemulsion

Azita Dejaloud[a], Farzaneh Vahabzadeh[a], Alireza Habibi[b,*]

[a] Department of Chemical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[b] Department of Chemical Engineering, Razi University, Kermanshah, Iran

ARTICLE INFO

Keywords:
Gas holdup
Aeration rate
Hydrodynamic flow regimes
Mass transfer correlation
Diesel-based microemulsion

ABSTRACT

The objective of the present work was to characterize gas holdup (ε_G), volumetric oxygen mass transfer coefficient (k_La), and specific gas-liquid interfacial area (a) in a water-in-diesel microemulsion (WDME) as a liquid model for aerobic biodesulfurization inside an airlift reactor with a net draft tube (ALR-NDT) when aerated at different rates ranging from 0.05 to 1 vvm. For comparison, the hydrodynamics of ALR (with solid draft tube) and bubble column reactor ('BCR', with no use of draft tube) were also studied for water, diesel and WDME systems. In all reactors, the ε_G and k_La values for diesel-based liquids were higher compared to the water system. This indicates the coalescence-inhibiting tendency of petroleum liquids mainly due to the lower surface tension which resulted to a decrease in bubble size distribution (i.e., 0.29–1.90 mm for the WDME versus 0.43–14.17 mm for water in the ALR-NDT). Although the k_La values in ALR-NDT were maintained between those values obtained in ALR and BCR for all fluids; however, the transition points from homogeneous to heterogeneous regime were shifted to higher aerations in the ALR-NDT. In this regard, empirical correlations were developed by considering the physicochemical properties of the liquid phase and superficial gas velocity.

1. Introduction

Gas-liquid-solid contacting devices operated pneumatically for contents agitation are defined as airlift and bubble column reactors (ALR and BCR), and applications of these reactors have recently been studied in the biodesulfurization (BDS) process [1–3]. The absence of any moving parts in these reactors makes them suitable for culturing microorganisms as shear stress sensitive items. Since the low solubility of oxygen has been reported as a limiting factor for the BDS process, due to its two-phase nature, higher oxygen transfer rate and relatively lower energy requirement are the other advantages of ALRs and BCRs when compared to conventional stirred bioreactors [4]. The required energy for fluid circulation is introduced focally at a single point in the bottom of BCRs using a gas sparger and it results to wide variations of shear forces in these bioreactors. The potentiality of cell damage at the immediate vicinity of that point should also be considered due to the shear stress effect. The circulation of liquid and gas in ALRs, however, is facilitated as a result of the difference in hydrostatic pressure or gas holdup between the riser and the downcomer sections [5].

To improve the liquid mixing behavior in an ALR and also increase the oxygen transport capability, the solid wall draft tube was replaced by a net draft tube (ALR-NDT) [6,7]. A better local liquid circulation in the ALR-NDT compared to the ALR and BCR is attributed to optimum mass transfer between uprising and down-coming liquid streams and the intensity of this type of interaction between the streams can be optimized by balancing the pattern of flow distribution in both axial and radial directions [6]. Actually, the column geometry, physicochemical properties of the liquid phase, and superficial gas velocity are important factors in the determination of a hydrodynamic transition point from homogeneous to heterogeneous regime in the reactors [8,9]. The homogeneous regime is most desirable for practical applications due to the lower shear rate on microbial cells and provides a higher contact area for oxygen transfer to the liquid medium.

Although, several extensive studies have been reported on the hydrodynamics of BCRs and ALRs for aqueous solutions [10–12]; however, limited information is available for biphasic systems such as the petroleum BDS process in reactors [13–15]. In the BDS experiments, petroleum hydrocarbons and the aqueous culture of microbial cells are both present as the liquid phase with usual water-to-oil ratios ranging from 5:95 to 90:10. However, in order to reduce vessel size, reduce the cost of downstream processing operations and minimize biocatalyst and water utilization with respect to the amount of oil, the trend towards the use of lower ratios is appreciated. For well mixing and operational stability, the application of water-in-oil microemulsions with the aid of

---

[*] Corresponding author.
E-mail address: a.habibi@razi.ac.ir (A. Habibi).

https://doi.org/10.1016/j.fuproc.2017.11.027
Received 23 July 2017; Received in revised form 24 November 2017; Accepted 27 November 2017

surface agents inside the BCRs and ALRs is preferable. The selection of particular surfactants for the microemulsion preparation is often based on stability of the emulsion and compatibility of the surfactant with the utilized microorganism. Commonly, nonionic surfactants in comparison with ionic ones bind weakly to proteins and have less toxicity towards microbial growth [16]. In biological processes, Span® 80 (sorbitan monooleate) and TWEEN 80 (polysorbate 80) are nonionic commercial surfactants widely used for microemulsion preparation from hydrophobic substances in aqueous media [17,18].

With respect to the complexity of petroleum BDS experiments, it is easier to examine the ALR performance, first by simulating the reactor characteristics in response to the test liquids in the absence of the microbial cells. In the present study, the gas holdups and volumetric oxygen-liquid mass transfer coefficients for water, diesel and a water-in-diesel microemulsion (WDME) with 20:80 ratio were determined in an ALR-NDT, ALR, and BCR, where the influence of some physical properties (density ‘ρ’, kinematic viscosity ‘ν’, and surface tension ‘σ’) of the test liquids was of the interest, in order to determine the dependence of the fluid behaviors on these properties. Further studies on the variations of Sauter mean diameter of bubbles, interfacial area, and liquid-side mass transfer coefficient (k_L) were comparatively carried out in the ALR-NDT and BCR when the liquid phase was the WDME and diesel.

2. Materials and methods

2.1. Materials and microemulsion preparation

The diesel used in the present study (as the oil phase) was obtained from the Tehran Oil Refinery Company, Iran. On the basis of the FID chromatography analysis (Agilent, 6820 N, Rtx®-5 capillary column, 1 mL min^{-1} of helium as carrier phase, and injector and detector temperature at 300 °C), the hydrocarbon fractions in the diesel were determined as follows (% w/w): < $C_{10,}$ 10.65; C_{11}–$C_{20,}$ 84.28; and > $C_{20,}$ 5.07. The Span 80 and Tween 80 utilized were of commercial grade and kindly provided by the Academic Center of Education, Culture and Research (Tehran, Iran). For preparation of WDME with 20:80 ratio, Span 80 and Tween 80 were dissolved in the oil phase, and distilled water was added dropwise to the continuous phase, followed by homogenization (1500 rpm) (Janke & Kunkel, IKA-Werke, Staufen, Germany) until the mixture was visually transparent. Table 1 shows some physical properties of interest for the liquid phases in the present study, where surface tension and viscosity were measured using the KRUSS tensiometer K100 (Germany) and Brookfield viscometer DV-II + Pro (USA), respectively.

2.2. Experimental setup

The schematic diagram presented in Fig. 1 shows the experimental setup used in the present study including ALR-NDT with its structural details. The constructed ALR-NDT was made of Pyrex and the NDT was made of stainless steel with mesh size of 12. The geometric specifications of the ALR-NDT are given in Table 2. The reactor using the solid draft tube was evaluated as an ALR while the reactor without any draft tubes behaved as a BCR. The working volume of the test reactors was 2.1 L and air was sparged into the NDT through a gas diffuser (ROBU VitraPOR Borosilicate gas distribution) with 2.5 cm in diameter and a pore size of 100–160 μm which was placed at a height of 0.05 m above the bottom of the reactor. The pressure drop created by the glass filter sparger was not considered in all the aeration rates used in this study, according to the technical specifications provided by the manufacturer (ROBU VitraPOR) [21]. In the present study, the aeration rate was reported in terms of volume of air per volume of liquid per minute (vvm). A calibrated rotameter was used for controlling aeration rate and the environmental temperature was set at 25 ± 2 °C.

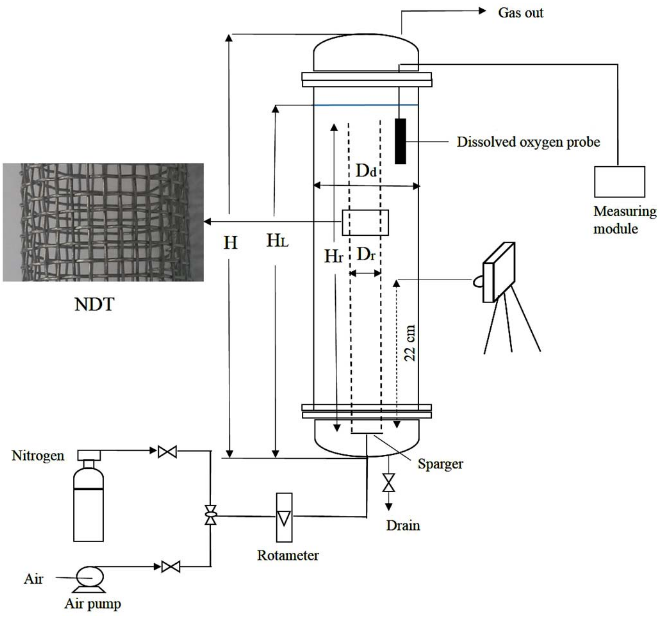

Fig. 1. Schematic view of the experimental setup including ALR-NDT with its structural details.

Table 2
Geometric specifications of the ALR-NDT reactor.

Reactor descriptions			Value
Riser diameter, D_r (m)			0.025
Downcomer diameter[a], D_d (m)			0.08
Height of the NDT, H_r (m)			0.43
Height of the reactor, H (m)			0.70
Gas-free liquid Height, H_L (m)			0.50
Downcomer to riser cross-sectional area, A_d/A_r (−)			10.24
Mesh size of NDT	Nominal wire diameter[b] (mm)	Sieve opening[b] (mm)	Solidness[c] (%)
12	0.725	1.41	56.4

[a] The value also shows the reactor diameter.

[b] According to Green and Perry [20].

[c] The area percentage of the NDT which the fluid cannot pass through it.

Table 1
Properties of the liquids at 25 °C.

Liquid	Water/diesel ratio (%)	Surfactants (% v/v)		ρ (kg m^{-3})	ν (× 10^{-6} m^2 s^{-1})	σ (mN m^{-1})	D_{O2}[a] (× 10^9 m^2 s^{-1})	C^* (mg L^{-1})
		Span 80	Tween 80					
Diesel	0	–	–	815.23	3.46	25.6	1.66	8.9
WDME	20	9.0	10.5	874.64	9.74	25.9	0.68	7.7
Water	–	–	–	996.67	1.007	65.6	1.99	8.0

[a] According to Wilke and Chang equation, 1955 [19].