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Gassed and ungassed power draw in a pilot scale 550 litre fermentor retrofitted with up-pumping hydrofoil B2 impellers in media of different viscosity and with very high power draw

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ABSTRACT

A number of modern impellers have been designed in the pursuit of an alternative to the traditional Rushton turbine, which has a number of well recognized deficiencies. A dual up-pumping combination of the Hayward Tyler B2 (former APV-B2 or simply B2), a high solidity ratio hydrofoil impeller, was retrofitted using traditional methods to a pilot scale fermentor based on cited reference studies of the impeller performance. Using water as a media and comparatively low power draws, the B2 impeller has previously been shown to have good gas handling properties and a low ungassed power number allowing for use at high impeller-to-tank diameter ratio. In the present study a power characterization of the B2 impeller was undertaken in order to extend the available data to viscous media resembling fermentation broths and to very high power draws. Power characterizations were carried out with specific energy input rates up to 12.9 kW/m^3 using different shear-thinning media.

The ungassed power number of the B2 impeller was determined (3.3 for power draws in the range 0–11.6 kW/m^3) and our findings confirm those of previous studies and extend the trends to media of high viscosity. Upon aeration the B2 impellers loose little power compared to the traditional impeller even when applying a very high power draw (10–20% power loss at 450 rpm and 1.28 vvm corresponding to 11.6 kW/m^3). Torque fluctuations are found to be small (< 5%) for this impeller at high power draw and high viscosity media. Finally it is shown that the B2 impeller can be retrofitted to pilot scale fermentors using traditional methods with a high degree of confidence.

1. Introduction

The stirred aerated fermentation vessel is used for a wide variety of industrial products. The design and operation of the production vessel is under constant improvement and the on-going debate around the most suitable agitator type for gas–liquid mixing in reactors and bioreactors has shown that the traditional Rushton turbine (RDT) is inferior to new impeller designs in one or more respects (Nienow, 1996). Disadvantages of the RDT include the reduction of power draw by about 50% upon aeration and the occurrence of "flow barriers" (or zoning) when used in multiples (Nienow and Bujalski, 2004).

In order to find alternatives to the RDT several modern impellers, including down-pumping, high solidity ratio hydrofoil impellers have been designed and tested. However these have had other shortcomings such as flow and torque instabilities (see for example McFarlane et al., 1995; Nienow, 1998).

Recently a new axial flow hydrofoil impeller, the Hayward Tyler B2 (formerly titled APV-B2 or simply B2), has been designed for use in the upward pumping mode (Nienow, 1996). The ungassed power numbers were found to be low, hence compared to a RDT it can be used at a larger impeller-to-tank diameter without increasing the torque requirements. Furthermore the relative power consumption upon aeration, P_g/P, remains close to 1 with gas flow rates up to 1 vvm and specific power input rates of 1 kW/m^3 (Nienow and Bujalski, 2004). Besides the improved power characteristics, studies have shown that the good gas dispersion and low torque fluctuations of a single B2 impeller are maintained when using dual and triple combinations (Hari-Prajitno et al., 1998). A strikingly similar impeller design has been proposed by Moucha et al., (2003), namely the Techmix 335. This impeller also provides higher dispersion mixing intensities but lower mass transfer performance than high power number impellers such as the RDT (Moucha et al., 2003; Fujasová et al., 2003).

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In the present study B2 impellers are retrofitted to draw the same gassed power draw as traditional RDTs. It was decided to investigate the combination of dual up-pumping B2s with differently pitched blades (30° and 45° blade angles). The power reduction of this dual combination, $(P_g/P)_2$, was actually smaller than for the single impeller configurations, $(P_g/P)_1$ (Hari-Prajitno et al., 1998). In addition, low mixing time (in the order of 60% of that reported for the Rushton turbines) and low torque fluctuations compared to the down-pumping (reversed) operation mode of B2s were reported (Hari-Prajitno et al., 1998). Given the good performance that is reported, this particular B2 combination was chosen. The aim of this study was to investigate the possibility of retrofitting to actual pilot scale conditions based on cited impeller data and to produce data which might later enable correlation of impeller performance to product yield and productivity. For the single, up-pumping 30° blade angle of attack B2 impeller (B2-30U) the reported power number Po is 1.1. For the 45° impeller (B2-45U), Po is reported 2.1. The $(\mathrm{Po})_2$ of the dual up-pumping configuration was found to be 3.2, approximately equal to the sum of the individual impellers. The study of Hari–Prajitno et al., (1998) was carried out using standard geometry, whereas this study is undertaken using a pilot scale fermentor. The atypical geometry of this vessel includes a dished bottom (in contrast to the flat bottom) and low bottom impeller clearance.

Most studies of gas–liquid mixing are not conducted with a fermentation perspective. Industrial operations require power inputs up to 7 kW/m^3 and in some cases even more (Harnby et al., 1992), and no data is available at conditions that imitate this. This study will investigate the performance of the B2s at viscosities representative of filamentous fermentation broths and at very high power draws and compare the findings with the existing data.

2. Methods

The experiments were conducted in a cylindrical, dished base stainless steel vessel of 0.68 m diameter with a fill of 0.350 m^3. It was equipped with four equally spaced baffles, T/10 width. A two-head sparger was used to introduce air at the bottom of the vessel. The vessel equipment and geometrical definitions are seen in Fig. 1.

Two impeller configurations were tested. The Rushton disc turbine ($D/T = 0.39$) was run with dual twin impellers with low clearance off the vessel base as this is the standard configuration in the pilot size fermentor. Full geometrical specifications are given in Table 1.

Two types of B2 impellers of $D/T = 0.44$, B2-30 and B2-45, were used for the dual up-pumping hydrofoil system. The B2-30 has a 30° blade angle of attack whilst the B2-45 has a 45° blade angle of attack (Figs. 2 and 3, respectively).

The B2-30,45U/U configuration was retrofitted in order to achieve the same specific gassed power as the RDTs when operated at maximum speed ($N = 475$ rpm) and with 1 vvm aeration. The higher angle of attack of the top impeller was chosen because of previous problems experienced with splashing at high speeds and low tank fillings (e.g. fed batch fermentations).

2.1. Media

Experiments were carried out in media of four different viscosities. Xanthan gum is used for the control of viscosity to give yield stress or shear-thinning properties to products of e.g. the food industry. Three different concentrations of xanthan gum (0.0625–1.00% w/w) were used in order to achieve high viscosity shear-thinning media that resemble fermentation media and give Reynolds numbers in the desired range. Furthermore, sodium benzoate (0.43% w/w) and potassium dihydrogen phosphate (0.21% w/w) were added to avoid infections and to control pH. Water was used as the final medium as water is also used in cited reference studies. All experiments were carried out at 27 °C.

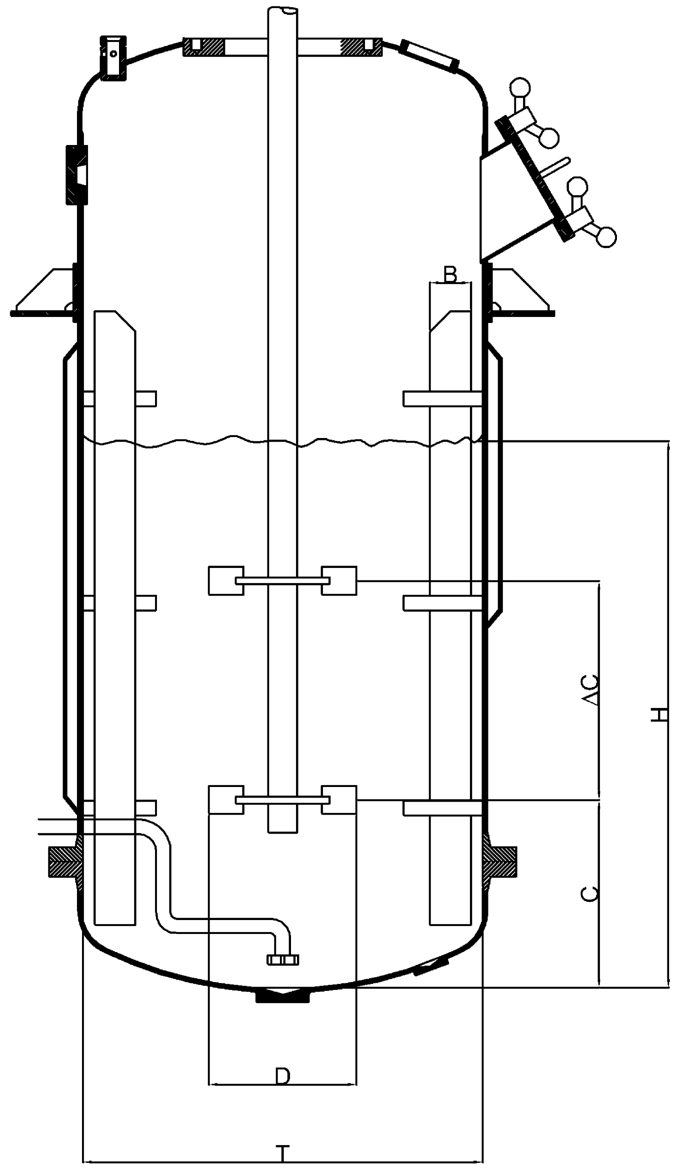

Fig. 1. Geometry of a pilot scale fermentor agitated by Rushton turbines. Relative dimensions of different components compared with fermentor diameter (T) are: $B/T = 0.1$; $H/T = 1.42$. Other dimensions are given in Table 1.

2.2. Media rheology

The rheological properties of the media were determined using a controlled stress rheometer (Carri-Med CSL100 K, TA Instruments) with a 2° gap angle cone-and-plate with a truncation of 57 μm loaded with 2.4 ml sample. The method for rheological determination is as follows: Pre shear 20 s, 300 1/s^{-1}, which brings the instrument to the correct speed for the measurement to begin. Then measurements were made by reducing the rate from 300 to 0 s^{-1} over 1 min. Measurements were done in triplicates and the media rheology was determined at the same temperature as the fermentor experiments. A Herschel–Bulkley model was used to fit the data (TA instruments rheology solutions software) in the shear rate range of 20–300 s^{-1} and the apparent viscosity at the tank agitation speed was calculated with the commonly used Metzner and Otto correlation (Tatterson, 1991).