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Short communication

Pumping characteristics of a screw agitator in a tube

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Abstract

Most information on pumping characteristics that is available in the literature is limited either to the turbulent region (centrifugal pumps) or to the creeping flow regime (screws). The aim of this paper is to investigate the effect of the Reynolds number on the pumping characteristics of agitators. The results of measurements using the new dynamic method are illustrated for a screw agitator in a tube. The characteristics, in the form of the dependence of the dimensionless specific energy on the dimensionless pumping capacity, were obtained for a wide range of Reynolds number values. The experimental creeping flow characteristic was compared with the theoretical prediction.

Keywords: Pumping capacity; Screw agitator

1. Introduction

Screw agitators rotating in tubes are very efficient tools for the mixing and pumping of viscous liquids. They are also suitable for cases where the viscosity of the liquid changes during operation. The pumping characteristic of the agitator in the tube must be known to enable calculation of its pumping capacity in a given configuration [1].

The methods for calculating the pumping characteristics of screws in the creeping flow regime are summarized in the literature on polymer processing (see, for example, [2]). These methods are limited to the creeping flow that is usually acceptable in polymer processing. The screw agitators are often used in transition and turbulent regimes. The pumping characteristics at higher Reynolds number values must be determined experimentally. The stationary methods for measuring pumping characteristics have been reported previously [3,4]. Both methods are time consuming. In one method [3], the pumping capacity is measured volumetrically and a relatively long time and large amount of liquid are necessary to attain the steady state. In the second method [4], the flow follower is used in the pumping capacity measurements. However, this overestimates the pumping capacity [5] and more configurations are necessary to obtain one pumping characteristic.

The new dynamic method used in this paper removes the disadvantages of the procedures reported previously [3,4]. Using this method, the pumping characteristics of screw agitators were obtained for a wide range of Reynolds number values.

2. Theoretical background

The pumping characteristic is the dependence of the specific energy e (transferred to the unit mass of fluid by the agitator) on the pumping capacity $\dot{V}$. As shown previously [4], it is advantageous to express this in a dimensionless form as

$$e^* = \frac{e}{vn} = f(\dot{V}^*, Re) \qquad (1)$$

where $\dot{V}^* = \dot{V}/nd^3$. In the creeping flow regime, the Reynolds number has no effect and Eq. (1) transforms to the linear form

$$e^* = A - B\dot{V}^* \qquad (2)$$

As was shown previously [6], in the turbulent region, the Reynolds number also does not appear and the equation of dimensionless pumping capacity can be expressed in the form

$$e^+ = f(\dot{V}^*) \qquad (3)$$

where $e^+ = e^*/\mathrm{Re}$.

3. Experimental details

The experimental device for dynamic measurement of pumping characteristics of agitators in a tube is depicted in

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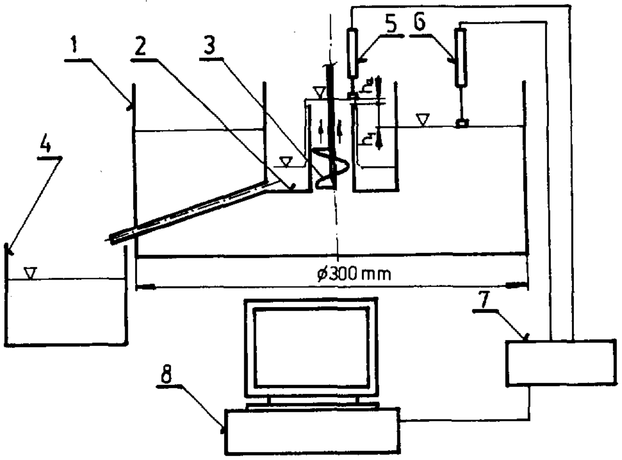

Fig. 1. Experimental equipment for dynamic measurement of the pumping characteristics.

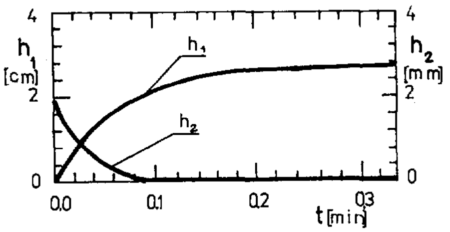

Fig. 2. The time course of the liquid levels.

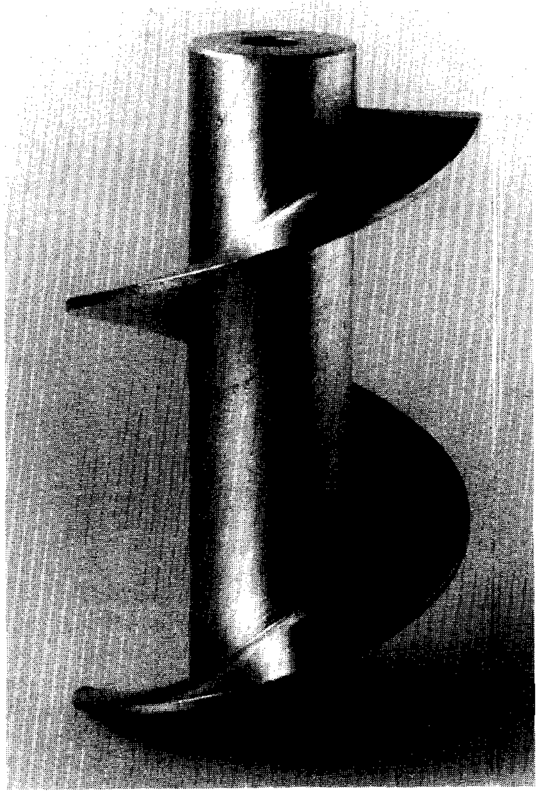

Fig. 3. The screw agitator used in the experiments.

Fig. 1. The liquid is pumped from the cylindrical vessel (1) by the agitator (3) to the space between the cylindrical coating and the draught tube (2), from where it flows to the reservoir (4). In the beginning, the cylindrical vessel is filled by the liquid, so that the level is determined by the upper edge of the draught tube. Subsequently, the agitator drive is engaged and the liquid is pumped out of the vessel (1). The time course of the decrease in the level of the vessel h_1 and the increase in the level of overflow h_2 are measured by induction sensors (5 and 6). The signals from these sensors are amplified by an amplifier (7) and their course is fed to the memory of a computer (8). The typical course of the liquid levels with time is shown in Fig. 2.

The pumping capacity can be calculated from the time course of the level decrease by

$$\dot{V} = S\,\mathrm{d}h_1/\mathrm{d}t \tag{4}$$

The specific energy can be determined from

$$e = g(h_1 + h_2) \tag{5}$$

From the course of the levels shown in Fig. 2, it can be seen that the total head $(h_1 + h_2)$ increases and the flow rate given by Eq. (4) decreases. In this way, the complete characteristic of the agitator is obtained from a single measurement that takes from several seconds to several minutes, depending on the viscosity. The characteristics at different Reynolds number values were obtained while changing the agitator speed in the range from 10 to 350 rev min^{-1} and the viscosities of the corn syrup solutions from 0.001 to 8 N s m^{-2}. A screw agitator of diameter $d = 75$ mm, and with a root diameter of 30 mm, a pitch of 75 mm and of length 112.5 mm (shown in Fig. 3) was used in the experiments. The draught tube diameter was 82.5 mm and the vessel diameter was 300 mm.

4. Results and discussion

Typical pumping characteristics in the form of Eq. (1) are presented in Fig. 4 for different Reynolds number values. From this figure, it can be seen that, in the creeping flow regime, the pumping characteristics obtained for different Reynolds number values almost coincide and can be approximated by a straight line given by Eq. (2). The characteristics in the transition region depend on the Reynolds number and are situated above the creeping flow characteristics. The broken line represents the creeping flow characteristic calculated theoretically by an equation recommended previously [7]. By comparing the creeping flow characteristics, it follows that the experimental characteristics are situated below the theoretical prediction. This is probably caused by the fact that the end effects were neglected in the theoretical equation (which means that fully developed flow in the entire screw

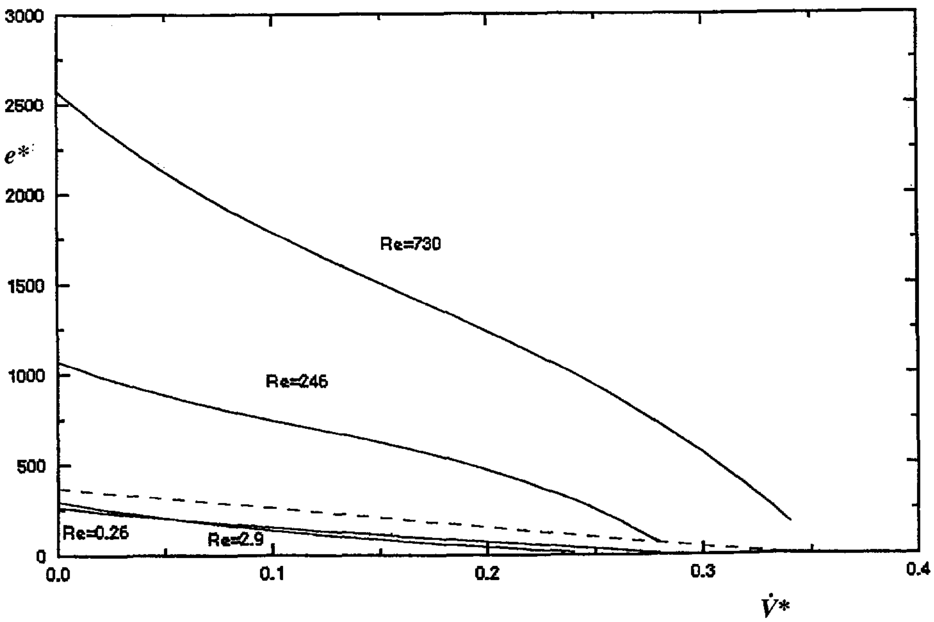

Fig. 4. The dimensionless pumping characteristics at low Reynolds number values.

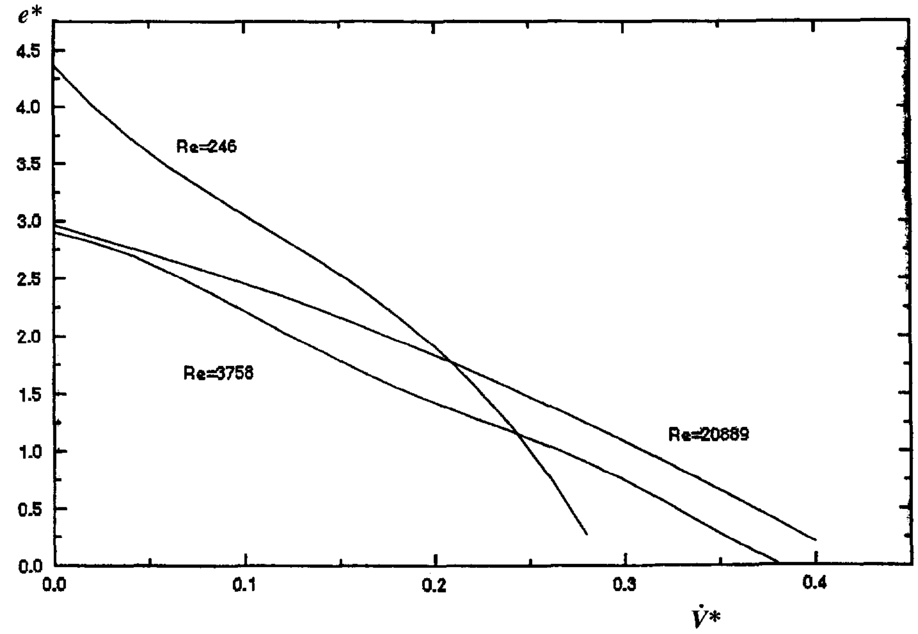

Fig. 5. The dimensionless pumping characteristics at high Reynolds number values.

channel was assumed), which is not acceptable for short screws.

The characteristics for the same agitator in the form $e^+ = f(\dot{V}^*,\mathrm{Re})$ are shown in Fig. 5. From this figure, it is obvious that the characteristics obtained at different values of the Reynolds number in the turbulent regime do not differ significantly. This is in agreement with Eq. (3). The characteristic in the transition region (Re = 246) is also depicted in Fig. 5.

The typical dependence of the maximum dimensionless flow rate $\dot{V}^*_{\max}$ (given by the intersection of the characteristic with the horizontal axis) on the Reynolds number is shown in Fig. 6. From this figure, it follows that, in the creeping flow and turbulent regimes, $\dot{V}^*_{\max}$ is independent of Re; in the transition region, it increases with increasing Re.

The typical dependence of the maximum dimensionless specific energy $e^*_{\max}$ (given by the intersection of the pumping characteristic with the vertical axis) on the Reynolds

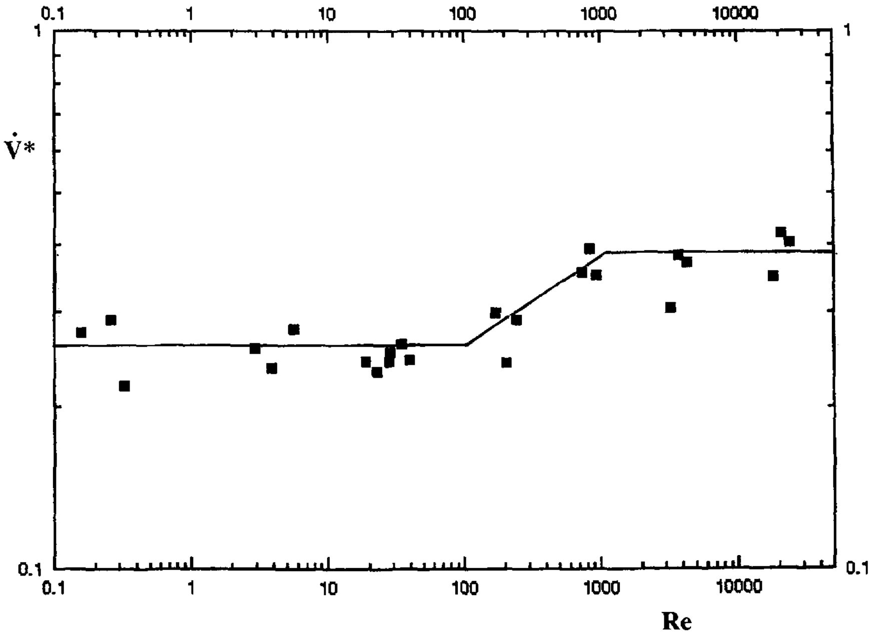

Fig. 6. The dependence of the maximum dimensionless flow rate on the Reynolds number.

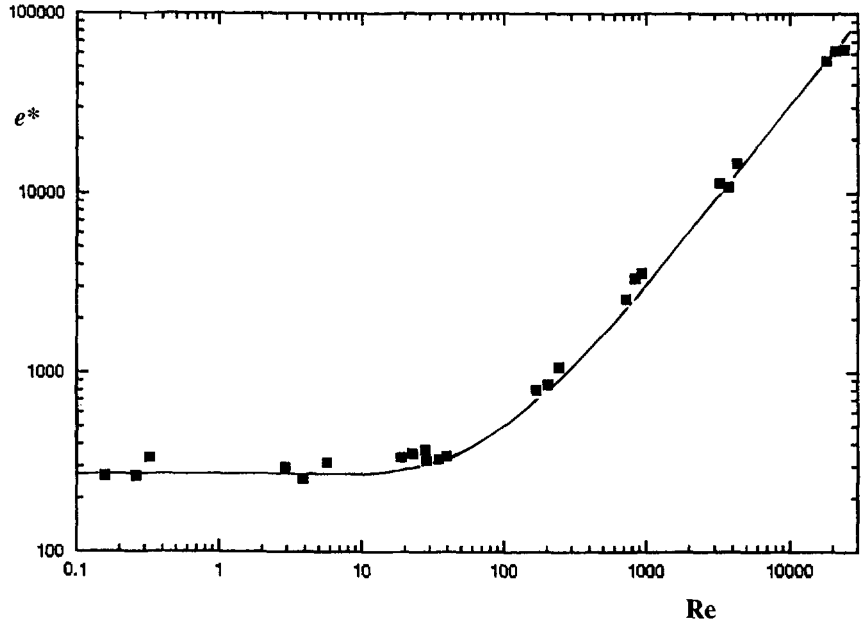

Fig. 7. The dependence of the maximum dimensionless specific energy on the Reynolds number.

number is given in Fig. 7. From this figure, it can be seen that, in the creeping flow regime, $e^*_{\max}$ is independent of Re but then increases with increasing Re at higher Reynolds numbers. At high values of the Reynolds number in the turbulent region, $e^*_{\max}$ is directly proportional to Re, which means that $e^+_{\max}$ is constant. This fact can be seen from Fig. 8, where the alternative dependence of $e^+_{\max}$ on Re is depicted.

5. Conclusions

The pumping characteristics of a screw agitator rotating in a tube were obtained using new dynamic experimental method. Measurements carried out for a wide range of Reynolds number values from the creeping to the turbulent flow regimes confirmed qualitative theoretical assumptions presented in Section 2. The relatively short screw agitators

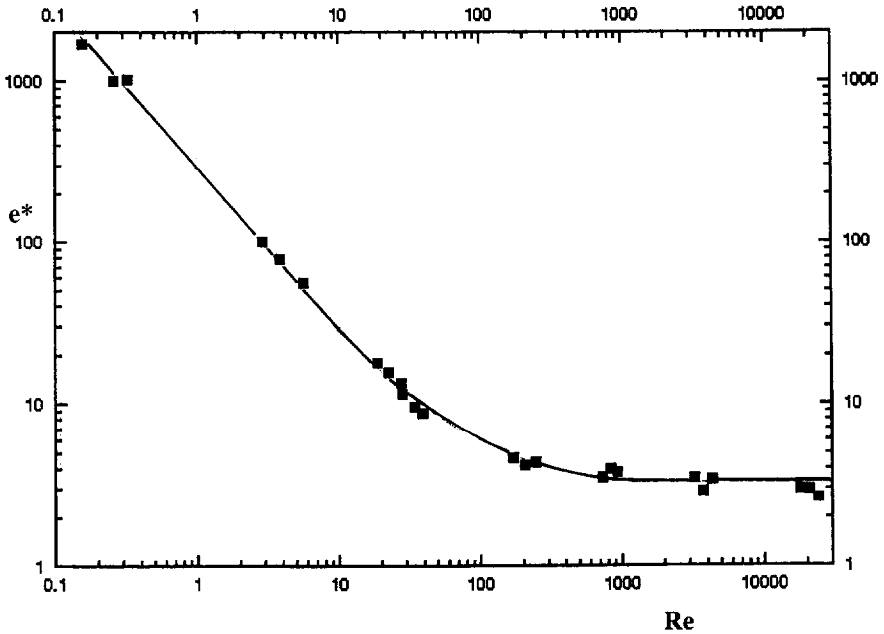

Fig. 8. The dependence of the modified maximum dimensionless specific energy on the Reynolds number.

exhibit a lower pumping capacity than that calculated theoretically for long screws in the creeping flow regime.

Acknowledgements

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Appendix A. Nomenclature

A, B	constants in Eq. (2)
d	agitator diameter (m)
e	specific energy ($\mathrm{J\,kg^{-1}}$)
e^*	dimensionless specific energy, $e^* = e/\upsilon n$
e^+	dimensionless specific energy, $e^+ = e/n^2d^2$
g	gravity acceleration ($\mathrm{m\,s^{-2}}$)
h_1	level decrease in vessel (m)
h_2	level increase in overflow (m)
n	agitator speed ($\mathrm{s^{-1}}$)
Re	Reynolds number, $\mathrm{Re} = nd^2/\upsilon$
S	area of cross-section between the vessel wall and tube coating ($\mathrm{m^2}$)
$\dot{V}$	volumetric flow rate ($\mathrm{m^3\,s^{-1}}$)
$\dot{V}^*$	dimensionless pumping capacity, $\dot{V}^* = \dot{V}/nd^3$

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