Pumping Efficiency of Screw Agitators in a Tube

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Most information on pumping efficiency that is available in the literature is limited to the turbulent region (centrifugal pumps). The aim of this paper is to show the effect of the Reynolds number on the pumping efficiency of screw agitators for a wide range of Reynolds number values from creeping to the turbulent flow region. The dependence of pumping efficiency on Reynolds number extends our knowledge about the efficiency of classical impeller pumps restricted usually to the turbulent region.

Keywords: Pumping efficiency, screw agitator.

1 Introduction

Screw agitators rotating in tubes are very efficient tools for mixing and pumping viscous liquids. They are also suitable for cases where the viscosity changes during operation. The effect of Reynolds number on pumping characteristics was shown in [1]. The influence of geometry on pumping characteristics of screw agitators was presented in [2]. Paper [3] was devoted to the effect of Reynolds number on power characteristics. Both the pumping and the power characteristics enable us to calculate pumping efficiency, defined as the ratio of fluid power to power input. The aim of this paper is to show the effect of Reynolds number on pumping efficiency.

2 Theoretical background

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

$$e^* = \mathrm{f}(Q^*, \mathrm{Re}). \tag{1}$$

As can be seen from [1] and [2] for screw agitators, the dependence of e^* on Q^*, for a given Re, can be approximated by a straight line

$$e^* = e^*_{\max}\left(1 - Q^*/Q^*_{\max}\right). \tag{2}$$

The values $e^*_{\max}$ and $Q^*_{\max}$ are independent of the Reynolds number in the creeping flow region. In the turbulent region, the value $e^*_{\max} \approx \mathrm{Re}$ and Eq. (2) transforms to the form

$$e^+ = e^+_{\max}\left(1 - Q^*/Q^*_{\max}\right) \tag{3}$$

independent of the Reynolds number.

The power characteristic is a dependence of power consumption P on specific energy e. After an inspection analysis of the governing equations, the following relationship for the dimensionless power characteristic was proposed in [4]

$$P^* = P^*\left(e^*, \mathrm{Re}\right). \tag{4}$$

As was shown in [3], the dimensionless power characteristic can be approximated by a linear relation

$$P^* = c + ae^*. \tag{5}$$

The values of coefficients c and a are independent of the Reynolds number in the creeping flow region. In the turbulent region, the values of a and c/Re are independent of Re, and the power characteristic can be approximated by the following equation

$$Po = c/\mathrm{Re} + ae^+. \tag{6}$$

Pumping efficiency η (defined as the ratio of fluid power to power input) can be calculated by the following relation (see e.g. [5])

$$\eta = e\,Q\rho/P \tag{7}$$

or in dimensionless form

$$\eta = Q^* e^*/P^* = Q^* e^+/Po. \tag{8}$$

3 Effect of Reynolds number on pumping efficiency

The procedure for calculating pumping efficiency will be illustrated on a screw agitator characterized by the following dimensionless geometrical parameters: $s/d = 2$, $d_1/\mathrm{d} = 0.2$, $L/d = 1.4$, $D_t/d = 1.1$ (see Fig. 3 in [3]). With reference to [1] the plot of parameters $Q^*_{\max}$ and $e^*_{\max}$ on the Reynolds number shown in Figs. 1 and 2 can be obtained using the values presented in [2]. Inserting these values into Eq. (2) we receive the pumping characteristics depicted in Fig. 3. Dimensionless specific energy e^+ instead of e^* is recommended for regions with high Reynolds number values. The dependence of $e^+_{\max}$ on Reynolds number is depicted in Fig. 4. Inserting values from Figs. 1 and 4 into Eq. (3), the pumping characteristics shown in Fig. 5 are obtained. The dependencies of c and a on the Reynolds number and power characteristics of a given screw agitator were presented in [3].

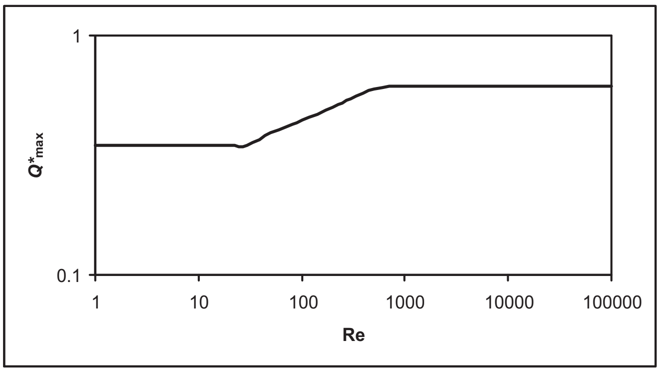

Fig. 1: Dependence of maximum dimensionless pumping capacity on Reynolds number

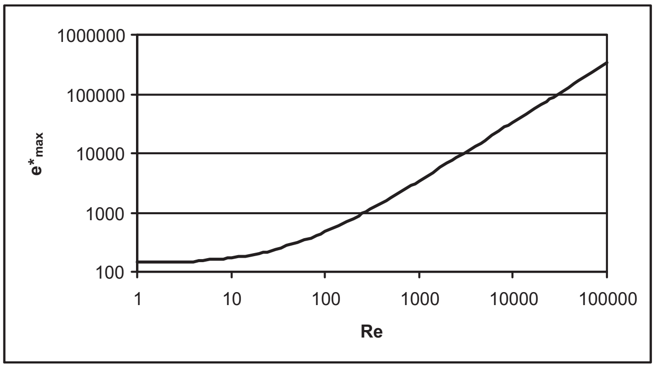

Fig. 2: Dependence of maximum dimensionless specific energy on Reynolds number

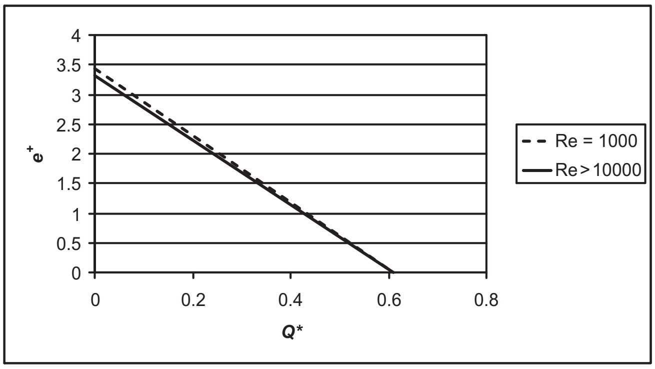

Fig. 5: Dimensionless pumping characteristics at high Reynolds number values

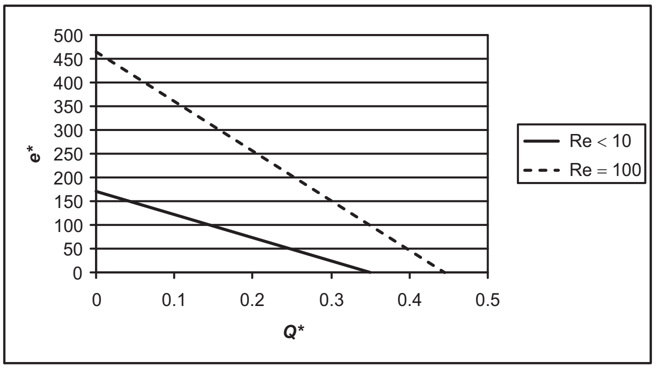

Fig. 3: Dimensionless pumping characteristics at low Reynolds number values

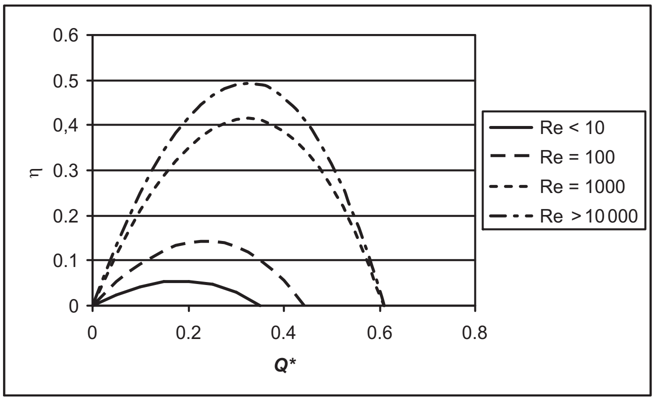

Fig. 6: Plots of pumping efficiency on dimensionless pumping capacity at different Reynolds number values

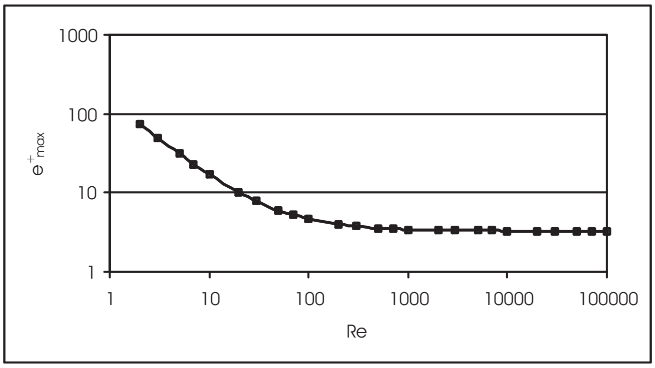

Fig. 4: Dependence of maximum dimensionless specific energy on Reynolds number

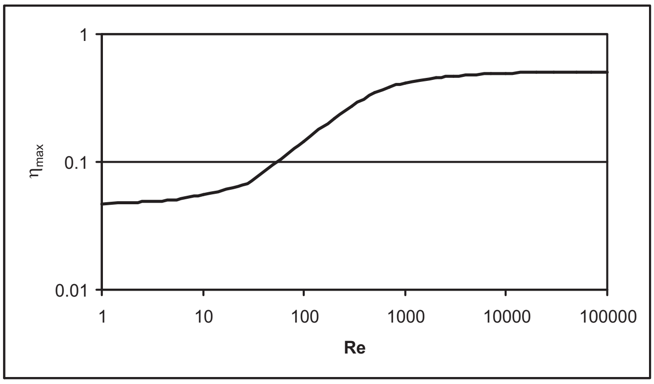

Fig. 7: Dependence of maximum efficiency on Reynolds number

Using pumping and power characteristics, the values of pumping efficiency can be calculated from Eq. (8). The dependence of efficiency on dimensionless pumping capacity calculated for selected Reynolds number values is shown in Fig. 6. From this figure it can be seen that efficiency is very low in the creeping flow region ($Re < 10$). This is due to the fact that most of the energy is spent for viscous friction in the screw at low Reynolds number values. It can also be seen that with increasing Reynolds number values the efficiency increases. The dependence of maximum efficiency on the Reynolds number is shown in Fig. 7. From this figure it can be seen that maximum efficiency increases from 4.7 % in the creeping flow region to 50 % in the turbulent region. This means that only 4.7 % of the power is transferred to the fluid near the maximum in the creeping flow region, and 50 % in the turbulent region. The relation between efficiency and Reynolds number presented in Fig. 6 extends our knowledge about the efficiency of classical impeller pumps, for which valid results have until now been restricted mostly to the turbulent flow region.

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Symbols

a, c coefficients in Eq. (5)
d agitator diameter [m]
d_1 root diameter [m]
D_t tube diameter [m]
e specific energy [J kg^{-1}]
e^* dimensionless specific energy, $e^* = e/\nu n$
e^*_{max} maximum dimensionless specific energy
e^+ dimensionless specific energy, $e^+ = e/n^2 d^2$
e^+_{max} maximum dimensionless specific energy
L length [m]
n agitator speed [s^{-1}]
P power [W]
P^* dimensionless power, $P^* = P/\mu n^2 d^3$
Po power number, $Po = P/\rho n^3 d^5$
Q volumetric flow rate [m^3 s^{-1}]
Q^* dimensionless pumping capacity, $Q^* = Q/nd^3$
Q^*_{max} maximum dimensionless pumping capacity
Re Reynolds number, $\mathrm{Re} = nd^2/\nu$
s pitch [m]
η efficiency
μ dynamic viscosity [Pa s]
ν kinematic viscosity [m^2 s^{-1}]
ρ density [kg m^{-3}]

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