ELSEVIER

Chemical Engineering Journal 89 (2002) 47–52

Chemical Engineering Journal

www.elsevier.com/locate/cej

Pumping efficiency of screw agitators in a tube

František Rieger*

Department of Process Engineering, Faculty of Mechanical Engineering, Czech Technical University, Technická 4, 166 07 Prague, Czech Republic

Accepted 4 February 2002

Abstract

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 the pumping efficiency on the Reynolds number extends our knowledge about the efficiency of classical impeller pumps restricted usually to turbulent region.

Keywords: Pumping efficiency; 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 changes during operation. The effect of the Reynolds number on pumping characteristics was shown in Ref. [1]. The influence of geometry on pumping characteristics of screw agitators was presented in [2]. Paper [3] was devoted to the effect of the Reynolds number on the power characteristics. Both the pumping and power characteristics enable us to calculate the pumping efficiency defined as the ratio of fluid power to the power input. The aim of this contribution is to show the effect of the Reynolds number on the pumping efficiency.

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 Q. As shown in [4] it is advantageous to express this in a dimensionless form as

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

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

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

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

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

independent of the Reynolds number.

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

$$P^* = P^*(e^*, Re) \tag{4}$$

As it 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, values of a and c/Re are independent of Re and the power characteristic can be approximated by the following equation:

$$Po = \frac{c}{Re} + ae^+ \tag{6}$$

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

$$\eta = \frac{eQ\rho}{P} \tag{7}$$

* Tel.: +42-2-2435-2548; fax: +42-2-2431-0292.
E-mail address: rieger@fsid.cvut.cz (F. Rieger).

1385-8947/02/$ – see front matter
PII: S1385-8947(02)00022-0

Nomenclature

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, $e^+ = e/n^2d^2$
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, $Re = nd^2/\nu$
s	pitch (m)

Greek letters

η	efficiency
μ	dynamic viscosity (Pa s)
ν	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})

or in dimensionless form:

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

3. Effect of the Reynolds number on the pumping efficiency of a screw agitator in a tube

The procedure of the pumping efficiency calculation will be illustrated on a screw agitator characterized by the following dimensionless geometrical parameters: $s/d = 1$, $d_1/d = 0.2$, $L/d = 1.5$, $D_t/d = 1.1$. 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 values presented in [2]. Inserting these values into Eq. (2) we receive pumping characteristics depicted in Fig. 3. Dimensionless specific energy e^+ instead of e^* is recommended for regions with high Reynolds number values. Dependence of e^+_{max} on the Reynolds number is depicted in Fig. 4. Inserting values from Figs. 1 and 4 into Eq. (3), pumping characteristics shown in Fig. 5 are obtained.

Dependence of c and a on the Reynolds number taken from Ref. [3] are shown in Figs. 6 and 7. Inserting these values into Eq. (5), the power characteristics depicted in Fig. 8 were obtained. Dependence of c/Re on the Reynolds number is shown in Fig. 9. Inserting values from

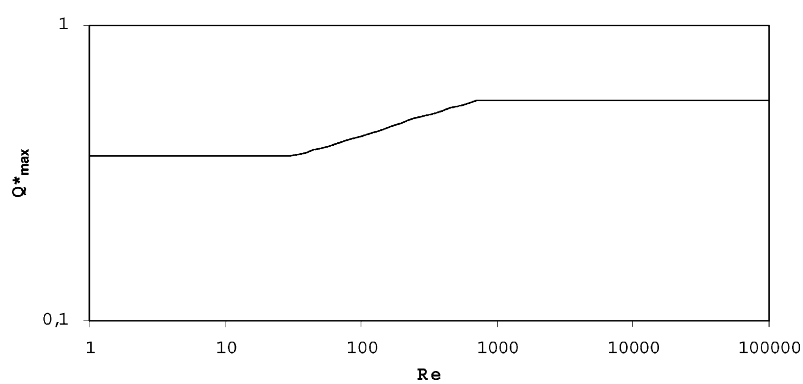

Fig. 1. The dependence of maximum dimensionless pumping capacity on the Reynolds number.

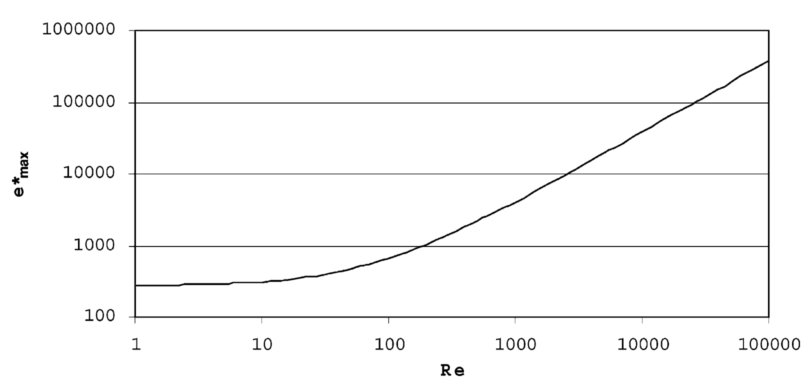

Fig. 2. The dependence of maximum dimensionless specific energy (e^*_{max}) on the Reynolds number.

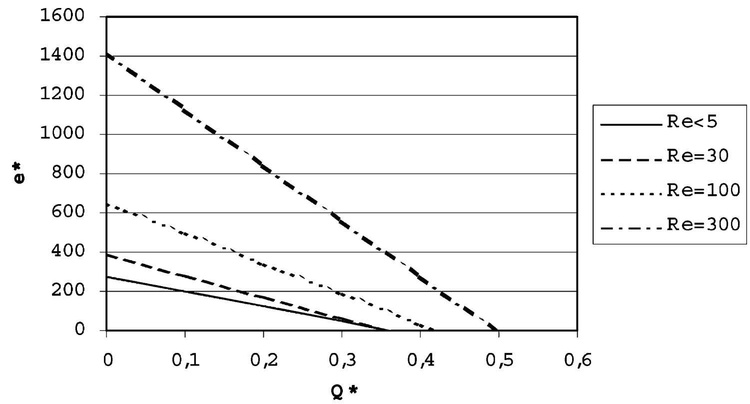

Fig. 3. The dimensionless pumping characteristics at low Reynolds number values.

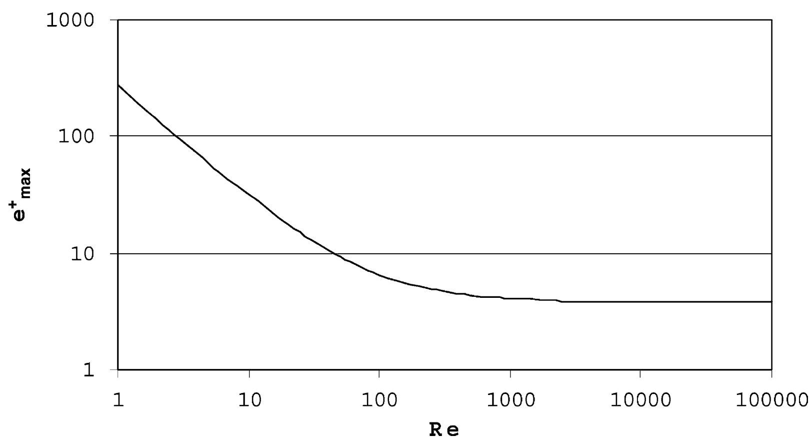

Fig. 4. The dependence of maximum dimensionless specific energy (e^{+}_{max}) on the Reynolds number.

Figs. 7 and 9 into Eq. (6), we receive power characteristics in a form more suitable at high Reynolds number values that are shown in Fig. 10.

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. 11. From this figure it can be seen that efficiency is very small in the creeping flow region ($Re < 5$). This is due to the fact that most of the energy is spent for viscous

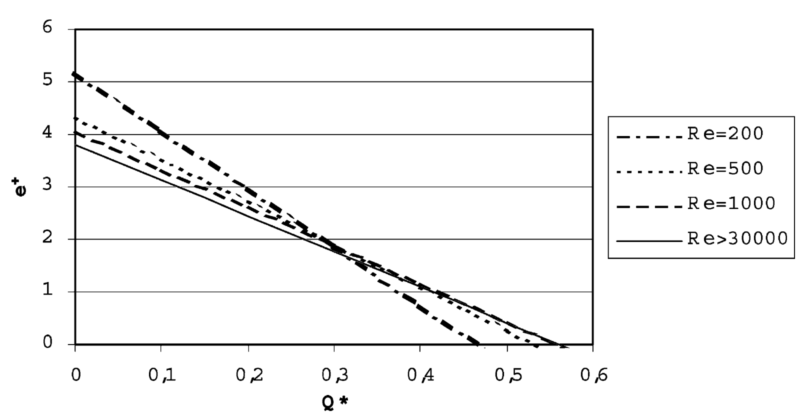

Fig. 5. The dimensionless pumping characteristics at high Reynolds number values.

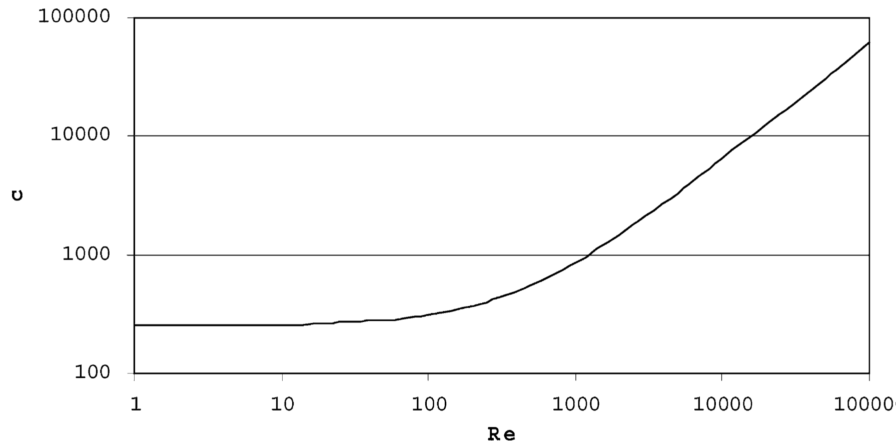

Fig. 6. The dependence of coefficient c on the Reynolds number.

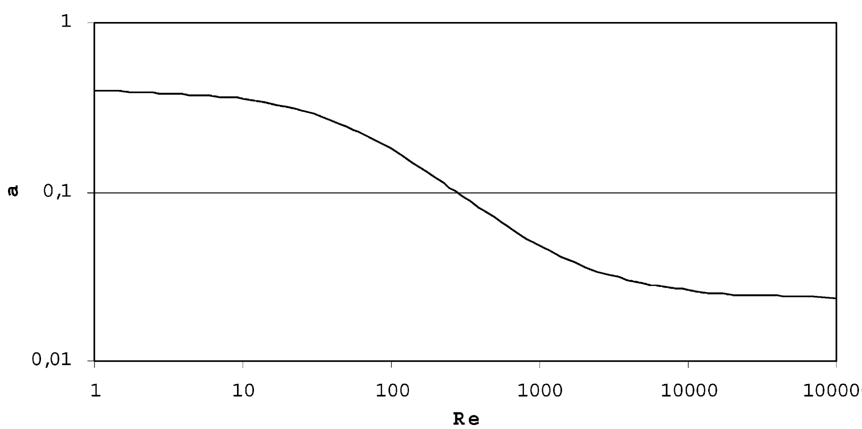

Fig. 7. The dependence of coefficient a on the Reynolds number.

friction in screw at low Reynolds number values. It can also be seen that with increasing Reynolds number values, efficiency increases and nearly 80% of power is transferred to the fluid near the maximum in the turbulent region. The relation between efficiency and Reynolds number presented in Fig. 11 extends our knowledge about the efficiency of classical impeller pumps for which valid results are, so far, restricted mostly to the turbulent flow region.

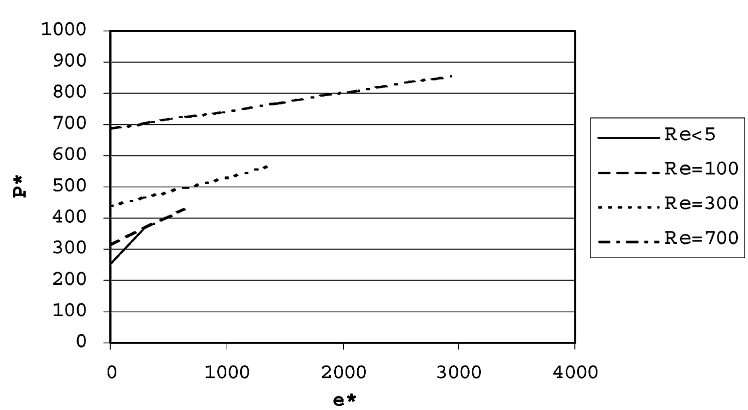

Fig. 8. The dimensionless power characteristics at low Reynolds number values.

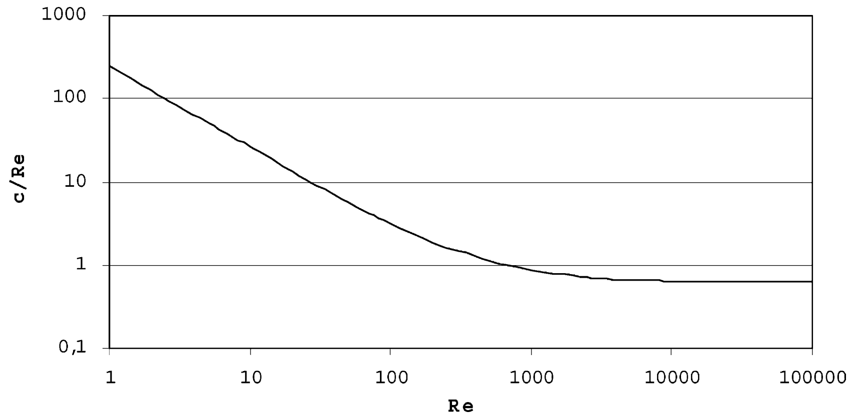

Fig. 9. The dependence of c/Re on the Reynolds number.

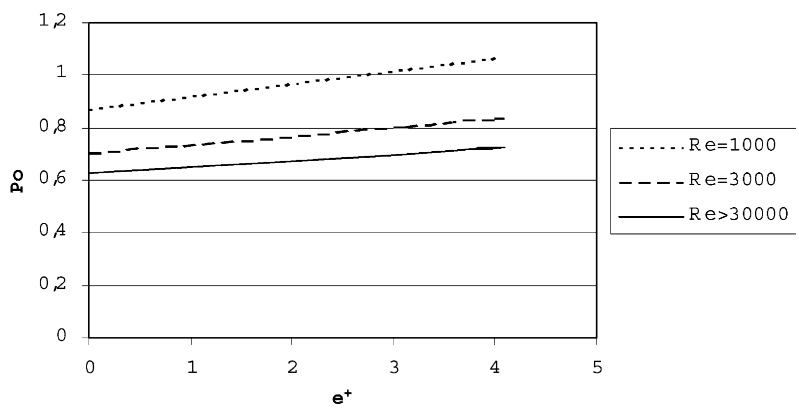

Fig. 10. The dimensionless power characteristics at high Reynolds number values.

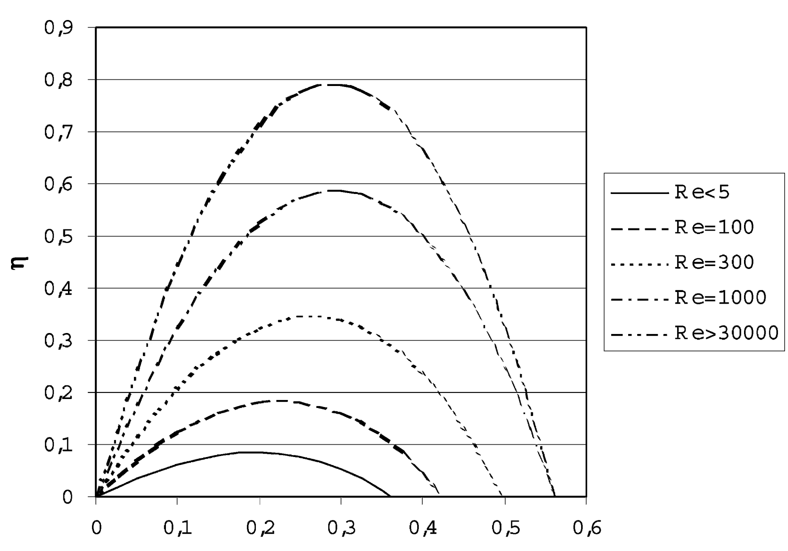

Fig. 11. The plots of pumping efficiency on dimensionless pumping capacity at different Reynolds number values.

Acknowledgements

This research was supported by the Grant Agency of the Czech Republic under the Project no. 101/99/0638.

References

[1] F. Rieger, Chem. Eng. J. 66 (1997) 73.
[2] L. Sedláček, F. Rieger, Coll. Czech. Chem. Commun. 62 (1997) 1871.
[3] F. Rieger, in: Proceedings of the Fourth International Symposium on Mixing in Industrial Processes, PROGEP, Toulouse, 2001 (CDROM).
[4] F. Rieger, H. Weiserová, Chem. Eng. Technol. 16 (1993) 172.
[5] W.L. McCabe, J.C. Smith, P. Harriott, Unit Operations of Chemical Engineering, McGraw-Hill, New York, 1993.