INFLUENCE OF GEOMETRY ON PUMPING CHARACTERISTICS OF SCREW AGITATORS IN A TUBE

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The pumping characteristics of screw agitators in tubes were measured using a new dynamic method. Two inductive sensors record the difference of liquid surfaces in the tank while the liquid is pumped out. The characteristics in the form of dependence of the dimensionless specific energy on the dimensionless pumping capacity were obtained over a wide range of Reynolds number values. Screw agitators with different root diameter, pitch and number of flights were used in the experiments. The influence of above-mentioned geometrical parameters on pumping characteristics is discussed.
Key words: Screw agitator; Draught tube; Pumping characteristics.

Screw agitators rotating in tubes are very efficient for mixing and pumping of viscous liquids. They are also suitable for the cases where viscosity of charge changes during operation. The pumping characteristic of agitator in tube is necessary for the calculation of its pumping capacity in a given configuration of mixing device.

The stationary methods for measurement of pumping characteristics were reported in our previous papers[1,2]. In ref.[1], the pumping capacity was measured volumetrically and a relatively long time and large amount of liquid was necessary to attain the steady state. In ref.[2], the flow follower was used in the pumping capacity measurements. This method, however, overestimates the pumping capacity, and measurements in different configurations of mixing device are necessary to get one pumping characteristic. That means that the above-mentioned stationary methods are time-consuming.

The new original dynamic method, used in this paper, removes the disadvantages of procedures reported in refs[1,2], as measurement of pumping capacities is very short. Moreover, it can be carried out in one geometrical system. This method is based on measuring the time dependence of the difference of liquid surfaces heights by means of induction sensors.

The measured dependence can be changed to the pumping characteristic very simply. The aim of this paper is to obtain (using this method) the pumping characteristics of screw agitators over a wide range of Reynolds number values and discuss the influence of geometrical parameters of screw agitators on their pumping characteristics.

THEORETICAL

The pumping characteristics is the dependence of the specific energy e (transferred to the unit mass of fluid by agitator) on the pumping capacity $\dot{V}$. As shown in ref.[2], it is advantageous to express it in the dimensionless form

$$e^* = \frac{e}{\nu n} = f(Kp, Re) \,, \qquad (1)$$

where

$$Kp = \dot{V} / nd^3 \qquad (2)$$

and

$$Re = nd^2/\nu \,. \qquad (3)$$

In the creeping flow regime, the Reynolds number has no influence on the specific energy, and Eq. (*1*) can be simplified to the linear form[1].

$$e^* = A - B\,Kp \,. \qquad (4)$$

As it was shown in ref.[3], in the turbulent region, the Reynolds number also does not influence the dimensionless specific energy expressed in the form

$$e^+ = \frac{e}{n^2 d^2} = \frac{e^*}{Re} = f(Kp) \,. \qquad (5)$$

EXPERIMENTAL

The experimental device for the dynamic measurement of pumping characteristics of screw agitators in a draught tube is shown in Fig. 1. It is necessary to note that the draught tube 2 (diameter 82.5 mm, length 130 mm) is equipped with the outer cylinder 3 (diameter 130 mm, length 160 mm) closed at the bottom where the pumped out liquid overflows. The liquid is pumped upwards from the cylindrical vessel 1 (diameter 300 mm, length 230 mm) by the screw agitator 4 (see Table I, Fig. 2) to the space between the draught tube and the above-mentioned cylinder 3 wherefrom it flows out through the pipes 5 to the reservoir (not shown). The ratio of the agitator and the inside wall of draught tube diameters is approximately 1.1. At the beginning, the cylindrical vessel is filled with the liquid so that the level is determined by the upper edge of the inner cylinder of draught tube. Thereafter, the agitator drive (a hydraulic motor, maximum pressure 4 MPa, maximum revolutions 15 s^{-1}) is switched on and the liquid is pumped out of the vessel 1. The time course of the level decrease in vessel, h_1, and the level increase of overflow, h_2, are measured by the inductive sensors 6 and 7. The float attached to the sensor core copies the liquid surface changes. The core movement inside the sensor solenoid induces a voltage which is proportional to the sensor core displacement. These voltage signals from sensors are amplified in an transistor amplifier and their course is fed to the memory of a computer. The typical course of liquid levels h_1 and h_2 on time is shown in Fig. 3.

TABLE I
The geometrical parameters of diferent screw agitators (see Fig. 2) used in the measurements and the results of experiments

Parameters	Symbols	Agitator			
		a	b	c	d
		Geometry			
Diameter	*d*, mm	75	75	75	75
Relative height	*L*/*d*	1.5	1.5	1.4	1.4
Relative root diameter	d_0/d	0.2	0.6	0.2	0.2
Relative pitch	*s*/*d*	1	1	2	2
Number of flights	*i*	1	1	1	3
		Results			
Re_{cr}		33	42	30	65
Re_t		690	3 240	545	350
Creeping flow regime	Kp_{max}	0.36	0.20	0.35	0.34
	e^*_{max}	274	422	139	236
Turbulent region	Kp_{max}	0.56	0.51	0.61	0.49
	e^+_{max}	3.8	3.6	3.3	3.1

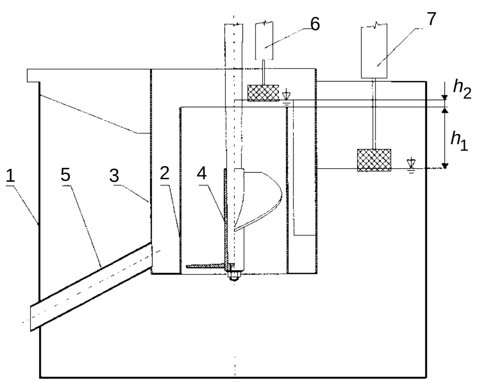

FIG. 1
Scheme of experimental device for dynamic measurement of pumping characteristics of screw agitators in a tube: 1 cylindrical vessel, 2 draught tube, 3 outer cylinder, 4 agitator, 5 pipe, 6, 7 inductive sensors with floats

The pumping capacity $\dot{V}$ can be calculated from the time course of the level decrease by the equation

$$\dot{V} = S \frac{dh_1}{dt} \,. \tag{6}$$

The specific energy e can be determined from the relation (derived from the macroscopic mechanical energy balance, sometimes called the engineering Bernoulli equation[4]):

$$e = g(h_1 + h_2) \,. \tag{7}$$

The main point of data processing is to get the rate of liquid surface decrease. This value is needed for relation (*6*). We approximate the dependence $h_1 = f(t)$ with a continuous function by means of numerical regression. Then we can simply get the derivative dh_1/dt. Using the expressions (*6*), (*7*) and (*2*), (*3*), we can obtain the pumping characteristics in the discrete form, which can be replaced (after new regression) by the continuous function, as shown in Fig. 4. Then we can find the points of intersection of this new function with the Cartesian coordinates – these intersections are the maximum values of dimensionless specific energy e^*_{max} and the maximum dimensionless pumping capacities Kp_{max}. Finally we can plot dependences of these values on the Reynolds number (Figs 5 and 6).

The pumping characteristics at different Reynolds number values were obtained changing the agitator speed in the range from 0.167 to 6 s^{-1} (10 to 360 rpm) and dynamic viscosities of the corn sirup solutions from 0.001 to 7 Pa s.

The screw agitators shown in Fig. 2 were used in the experiments. Their geometrical parameters are presented in the upper part of Table I.

RESULTS AND DISCUSSION

We can distinguish (see, *e.g.*, Fig. 5) three parts of the measured flow region – a creeping regime ($0 < Re < Re_{cr}$), transition region ($Re_{cr} < Re < Re_t$) and turbulent region ($Re_t < Re < \infty$). Critical values Re_{cr} and Re_t depend on the agitator geometry. Watching results given in the lower part of Table I, we see that Re_{cr} lies approximately between 30 and 70, Re_t is between 350 and 3 500 for the agitators investigated. The dimensionless pumping charac-

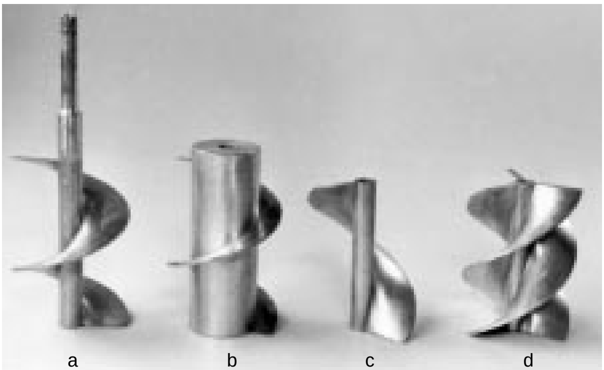

FIG. 2
The screw agitators used in the experiments (their geometrical parameters are given in Table I)

teristics of agitator b at different Reynolds number values determined according to relation (*1*) are shown in Fig. 4. It can be seen from this figure that in the creeping flow regime, the pumping characteristics obtained at different Reynolds number values practically coincide and can be approximated by an only straight line given by Eq. (*4*). The characteristics in the transition region depend on the Reynolds number and are situated above the creeping flow characteristics.

The dependence of the maximum dimensionless pumping capacity Kp_{max} defined as the pumping capacity corresponding to a zero specific energy on the Reynolds number is shown in Fig. 5. It follows from this figure that in the creeping flow and turbulent

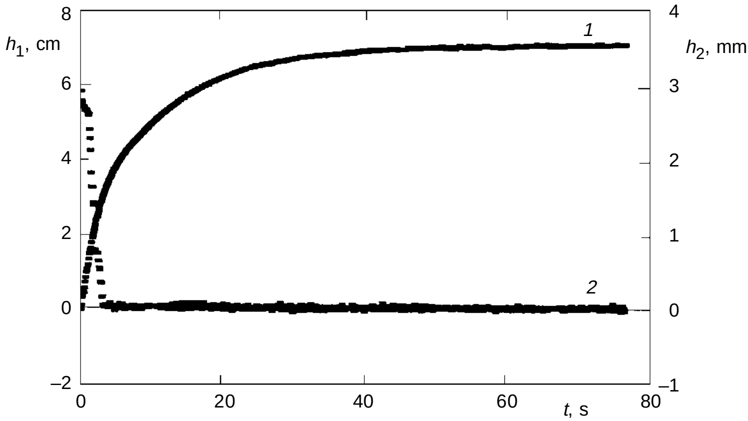

FIG. 3
Typical time courses of liquid levels h_1 (*1*) and h_2 (*2*) (geometry b, *Re* = 313)

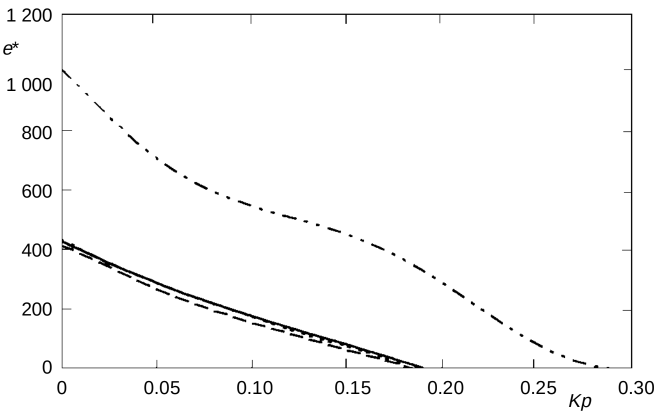

FIG. 4
The dimensionless pumping characteristics of agitator b at different Reynolds numbers: *Re* = 214 (– ·· –), 43 (———), 32 (· · · ·), 3.5 (– – – –)

regimes, Kp_{max} is independent of *Re*; in the transition region it increases with increasing *Re*.

The typical dependence of maximum dimensionless specific energy e^*_{max}, the value corresponding to a zero pumping capacity, on the Reynolds number is shown in Fig. 6. It can be seen from this figure that in the creeping flow regime, e^*_{max} is independent of *Re* and then at higher Reynolds numbers, it increases with increasing *Re*. 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. The creeping flow values Kp_{max} and corresponding

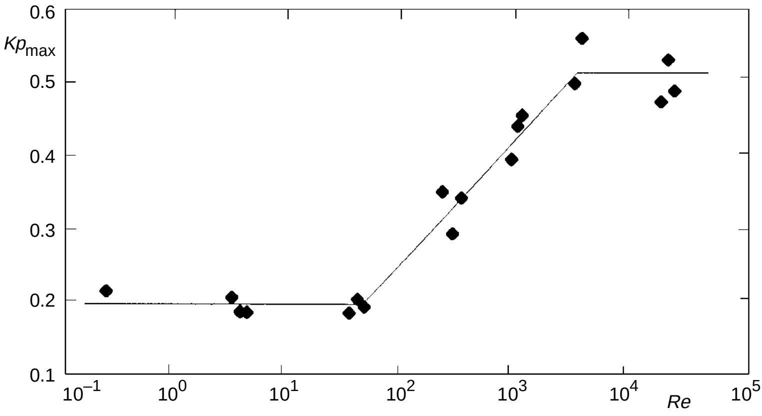

FIG. 5
The dependence of maximum dimensionless pumping capacity Kp_{max} on the Reynolds number *Re* for agitator b

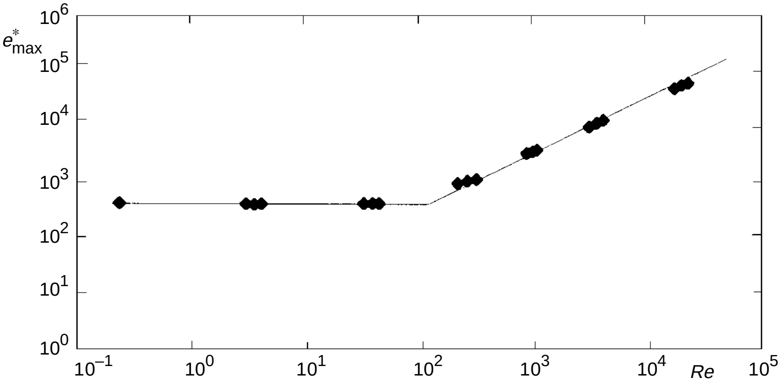

FIG. 6
The dependence of maximum dimensionless specific energy e^*_{max} on the Reynolds number *Re* for agitator b

values of Kp_{max} for turbulent region for screw agitators shown in Fig. 2 are summarized in Table I. It can be seen from this table that the maximum dimensionless pumping capacities are smaller for greater value of root diameter (geometry b *versus* a), the influence of screw root is more pronounced in the creeping flow regime. The influence of pitch in given range is very small as it can be seen from comparison of geometries a and c. The number of flights decreases maximum pumping capacity as it can be seen from comparison of geometries c and d. The comparison of values e^*_{max} in creeping flow regime and e^+_{max} values in turbulent region are presented in Table I, too. It can be seen that the maximum specific energy is smaller for greater pitch in both the regimes (geometry a *versus* c) and greater for greater root diameter in creeping flow regime (geometry a *versus* b). However, the influence of pitch on e^+_{max} is reverse in turbulent region. The number of flights increases the dimensionless maximum specific energy in the creeping flow region (geometry c *versus* d) but its influence in turbulent region seems to be insignificant.

CONCLUSIONS

The pumping characteristics of screw agitator rotating in draught tube were obtained using a new dynamic experimental method. On the basis of measurements carried out over a wide range of the Reynolds number, the influence of main geometrical parameters on pumping characteristics was discussed.

SYMBOLS

A	coefficient in Eq. (*3*), maximum dimensionless specific energy in creeping flow region ($Kp = 0$)
B	line slope of Eq. (*3*), ratio of maximum dimensionless specific energy and maximum dimensionless pumping capacity in creeping flow region (Kp_{max})
d	agitator diameter, m
d_0	root diameter of agitator, m
e	specific energy, J kg^{-1}
$e^* \equiv e/(\nu n)$	dimensionless specific energy
$e^+ = e/(n^2 d^2)$	dimensionless specific energy
g	gravity acceleration, m s^{-2}
h_1	liquid surface decrease related to the initial state in vessel, m
h_2	liquid surface increase related to the initial state above the agitator, m
i	number of agitator flights
$Kp = \dot{V}/(n d^3)$	dimensionless pumping capacity
L	agitator height, m
n	agitator speed, s^{-1}
$Re = n d^2/\nu$	Reynolds number
s	agitator pitch, m
S	area of cross-section between the vessel wall and outer cylinder, m^2
$\dot{V}$	pumping capacity, m^3 s^{-1}
ν	kinematic viscosity, m^2 s^{-1}

$\mu = \nu \rho$ dynamic viscosity, Pa s
ρ density, kg m^{-3}

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