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POWER CHARACTERISTICS OF IN-LINE ROTOR STATOR MIXERS

CHARAKTERYSTYKI MOCY MIESZALNIKÓW PRZEPŁYWOWYCH TYPU ROTOR STATOR

A b s t r a c t

Methods that can be used to predict agitation power of the in-line rotor-stator mixers are considered in this paper. Results of experimental investigations and CFD modeling are presented and interpreted theoretically for the Silverson rotor-stator (150/250) MS mixer. Results of theoretical analysis lead to extended version of previously used correlation.

Keywords: *mixing*, *mixing power*, *rotor-stator*

S t r e s z c z e n i e

W artykule przedstawiono metody wyznaczania mocy mieszania dla mieszalników przepływowych typu rotor-stator. Przedstawiono interpretację wyników doświadczalnych i symulacji CFD.

Słowa kluczowe: *mieszanie*, *moc mieszania*, *rotor-stator*

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1. Introduction

Silverson high shear in-line rotor-stator mixers are widely used in many technologies in the chemical, pharmaceutical, biochemical, agricultural, cosmetic, health care and food processing industries for homogenization, dispersion, emulsification, grinding, dissolving, performing chemical reactions with high selectivity, cell disruption and shear coagulation. So wide industrial applications can be explained by the fact that using the high-shear rotor-stator mixers one is able to control the product quality. This is possible because the rotor-stator high-shear mixers can generate locally very high shear stresses due to focused delivery of energy and possibility to control residence time in these zones of high shear and high stresses.

Development of methods that can be used to predict agitation power is thus of high importance. Much has been done in recent years in development of methods for predicting the agitation power, including authors' work [1–6]. It has been shown that the power draw of in-line rotor-stator mixer in the turbulent flow regime can be expressed by

$$P = N_{P0} \rho N^3 D^5 + N_{P1} \rho Q N^2 D^2 \tag{1}$$

or

$$N_P = N_{P0} + N_{P1} Q / (ND^3) = N_{P0} + N_{P1} N_Q \tag{2}$$

where N_Q represents the flow or pumping number, $N_Q = Q/(ND^3)$.

However, there are still problems that cannot be explained by the methods that are currently used to interpret performance of high shear mixers. Namely, as shown in ref. [5] there are effects observed at small values of the flow number, that could not be explained using eqs (1) and (2). Eqs (1) and (2) predict that the flow rate, Q, increases the power draw, and this is observed at high enough flow rates. However, at low flow rates, the power draw increases as the flow rate decreases [5]. Two possible reasons were discussed to explain this behavior, namely either by a drop in pumping efficiency or by intensive recirculating flows in the vicinity of the rotor-stator screen. In present paper we use in what follows results of experimental investigations and CFD modeling of performance of the Silverson rotor-stator (150/250)observe and try to interpret theoretically this phenomenon.

2. Experimental investigations

The experimental investigation were carried out using the double screen pilot plant model type 150/250 MS. Such Silverson mixer has a double concentric rotor set which is placed within close fitting screens. The two numbers, 150 and 250, describe the model by referring to the diameter of the inner and outer rotor with 150 indicating that the inner rotor has a nominal diameter of 1.5 in and the 250 indicating an outer rotor had a nominal diameter of 2.5 in.

The inner screen has 6 rows of 50×1/16 in diameter (about 1.59 mm) circular holes on a 0.100 in tri pitch (300 holes). The outer screen has 7 rows of 80×1/16 in diameter circular holes on a 0.100 in tri pitch (560 holes). This is shown in Fig. 1.

a) b)

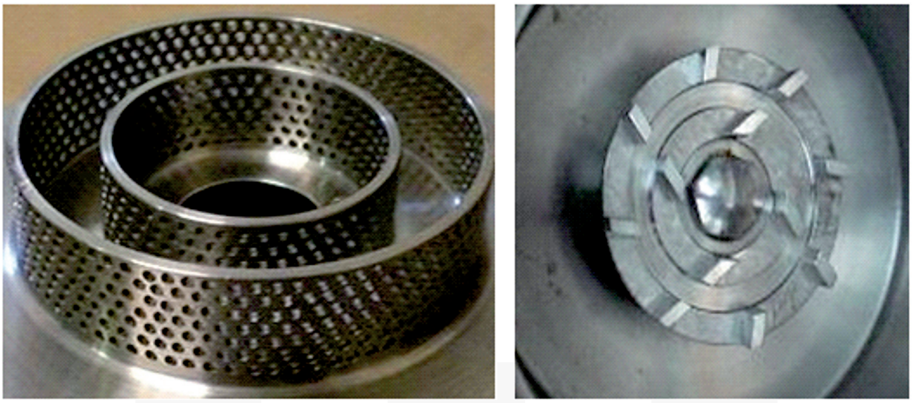

Fig. 1. Silverson 150/250 rotor (a) and stator (b)

The experimental system consisted of a supply of water from a constant head tank the Silverson and a valve on the outflow to regulate flow. The instrumentation included the torque meter. The natural pumping action of the Silverson was used to provide the flow and a Newtonian fluid (water) was used. Investigations were performed for mixer speeds from 4000 to 12,000 rpm in steps of 1000 rpm. Flow rates were controlled by a valve on the Silverson mixer outlet and measured by a Micro Motion Coriolis R-Series mass flowmeter. Temperature was measured by PT100 probes and all data logged by an Emersons Delta V System. More about experimental procedure one can find in ref. [5].

Figure 2a, b shows results of experiments and comparison with predictions of eq. (2).

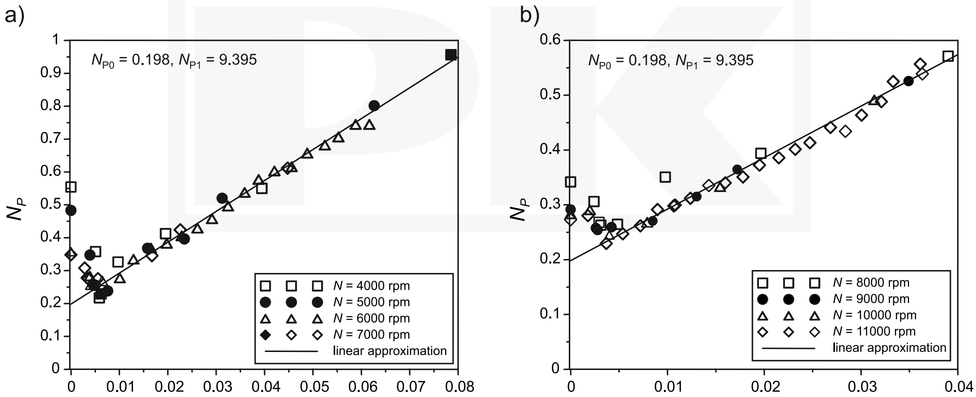

Fig. 2. Effect of the pumping number, N_Q, on the power number

As one can see eqs (1) and (2) give very good agreement for N_Q larger than 0.005–0.007. Below these values there is no agreement, which calls for better explanation.

3. Simulations and interpretations

Simulations of the Silverson rotor-stator mixer hydrodynamics were carried out using the standard $k - \varepsilon$ model of Fluent-Ansys and the multi-reference frame of reference. The 2D and 3D simulations were performed. An unstructured mesh consisting of 200 000 cells and 180 000 nodes was applied in 2D simulations; in 3D simulations the number of cells was equal to $4.6 \cdot 10^6$ with number of nodes equal to $4.8 \cdot 10^6$. We would like to check if CFD predicts this effect as well.

Figure 3 shows computation grid.

Fig. 3. Computational grid

Results of simulations confirm presence of minimum on the curve N_P versus N_Q, as shown in Figures 4 and 5. There is a good agreement between experimental data and results of CFD modeling including peculiar performance at low flow number.

Here we need to add that when there is a throttle valve in serial with the pump then if can change the system characteristics, and it is known from practice that a lower power consumption can be sometimes achieved by installing the throttle valve. This, however, depends on the power curve, so depends on details of the pump characteristics.

The specific speed, n_q, characterizes this behavior. The low n_q pumps have a radial outlet with large outlet diameter comparing to inlet diameter. The power curve has then a positive slope in the entire flow area [7]. Pumps with high specific speed, called high n_q pumps, have small outlet diameter axial outlet; they are characterized by decrease of power when the flow increases. In our case we can assume that throttling at large N_Q affects the system as for large n_q (effects of acceleration in radial direction dominates), whereas throttling at small N_Q affects the system as for small n_q.

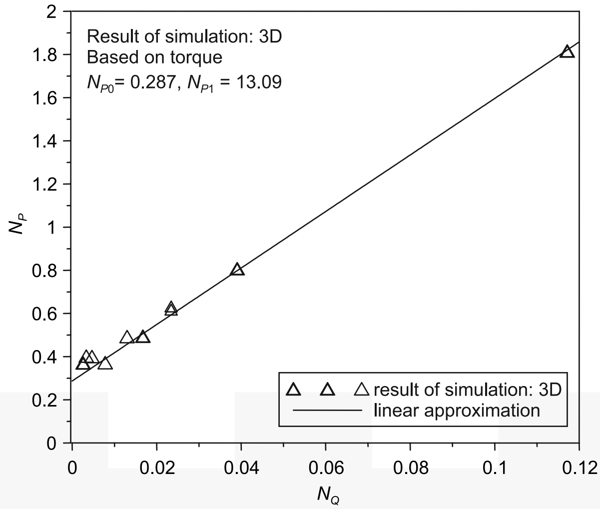

Fig. 4. Effect of the pumping number, N_Q, on the power number. Results of 3D simulations

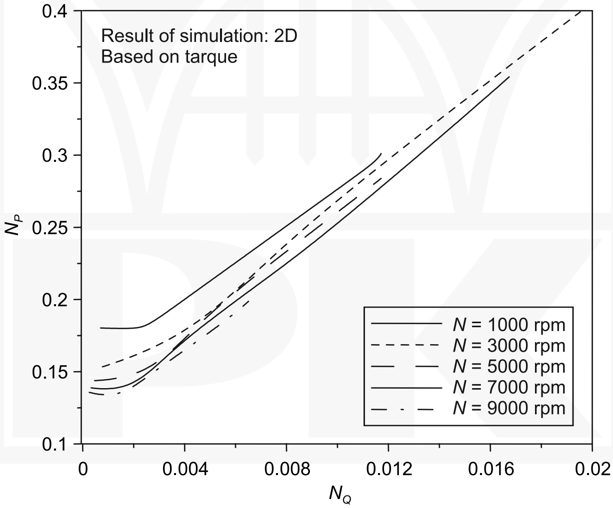

Fig. 5. Effect of the pumping number, N_Q, on the power number. Results of 2D simulations

Assuming transition by superposition of these effects, we can write instead of eqs (1) and (2)

$$P = N_{P0}\rho N^3 D^5 + N_{P1}\rho Q N^2 D^2 + \frac{(N_{P3}\rho N^3 D^5 - N_{P4}\rho Q N^2 D^2) + \left| N_{P3}\rho N^3 D^5 - N_{P4}\rho Q N^2 D^2 \right|}{2} \tag{3}$$

or

$$N_P = N_{P0} + N_{P1} N_Q + \frac{(N_{P2} - N_{P3} N_Q) + \left| N_{P2} - N_{P3} N_Q \right|}{2} \tag{4}$$

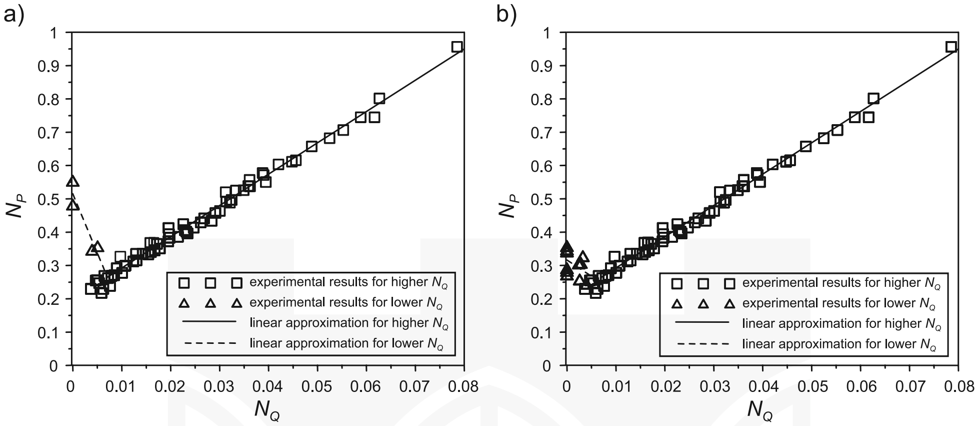

Fig. 6. Effect of the pumping number, N_Q, on the power number. Comparison of experimental data with equation (4): a) for N = 4000 rpm and 5000 rpm, b) for N > 5000 rpm

One can see that in this case agreement is very good. For N = 4000 rpm and 5000 rpm we see some effect of rotor speed; for 5000 < N ≤ 12 000 rpm effects of rotor speed disappears, which means that turbulence is well developed for N > 5000 rpm. Notice that presented explanation agrees to some extend with earlier discussions. Of course throttling affects pumping efficiency and can increases recirculation, however, present approach is the one that leads to more universal expression than applied earlier.

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