

The Effect of Stirrers at low Re Numbers

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During glass melt homogenisation, the stirrers are often required to show not only the homogenisation, but also a pumping effect. This effect can be achieved by means of two mechanisms. The first one is paddle uplift, applied for plane wings, airscrews, ventilation fans and turbines. This devices operates at high values of the Re number, usually $10^5 - 10^6$. Fig. 1.

The second phenomenon that can be used for pumping is a shearing force, appearing as a consequence of a drawing force which appears due to the movement of planes in a viscous liquid. Worms, extruders and feeders of various media, e.g. plastics, work on this principle. In liquids of high viscosity and with very slow movements resulting from this, inertia becomes negligible. The liquid moves only according to resultants of forces affecting at the moment. This flow is called creeping flow, or flow in Stokes' area. Worm pumps operate in this range. The mechanism of screw effect can be seen in Fig. 2. This devices operates at very low Re number – e.g. for the transport of plastics polymers $Re=0.006$.

Glass melt pumping zone

Glass melt pumping gets, due to needed magnitude of glass melt volume, its viscosity, standard size of used furnaces and positioning of stirrers in the furnace, into the area where advantages of both pumping mechanisms are meeting. Both principles are in the area of worsen efficiency and it can be hardly said which of them is better. Required performance conditions are sometimes changed in so wide range that we have to answer also the question if pumping mechanism has not been changed as well. That is why we have also dealt with this question.

Many types of stirrers have been designed and tested in glass industry. In cases when it is possible to create a tube around a rotor (screw), the pumping

mechanism is the same as with worm pumps. Another case appears if there is not a tube around the rotor. In this case the rotor is covered with flowing glass melt, the space between paddles is filled with it and a “pear” is created which rotates as a whole and has only a low pumping effect.

Paddle resistance

We have tried to deduce the pumping effect by means of paddle resistance, more accurately, resistance component of the moving paddle. For this purpose we have designed stirrers whose construction could suppress the phenomenon of the glass melt taken along by the rotor. The rotor paddles have been designed as wings fitted on thin wires in a greater distance from the rotor centre and so model liquid could pass through this centre.

The description is based on the fact that a body passing through a liquid is affected by some resistance. It is known that the resistance of a by-passed particle depends on orientation. It also introduces a graph showing dependency of resistance on Re for a circular disc turned towards the flow with the largest area, and a plate facing the liquid with its edge. Fig. 3. In the Stokes' area the particle is during settling oriented in the same way as it was put into the liquid. As we have verified by putting in a circular disc oriented in various directions.

Modelling

We have investigated the lateral component of velocity during the rotor movement through a medium. There has been constructed a model consisting of a cylindrical vessel with inner diameter 144 mm filled with model liquid, and a rotor that was pulled out of the liquid or immersed into it with adjustable speed. During experiments the angular displacement of the rotor on the path 300 mm has been monitored.

Dimensions of rotors [mm]

rotor	D	r	l	a	b	thickness	ø	No of paddles	rotation
R1	100	50	100	25	25	0.8	2	4	left-handed
R2	53	15	60	19	19	0.8	2	2	right-handed
R3a	22	10	35	6	6	0.5	0.5	2	left-handed
R3b	22	10	35	6	6	0.5	0.5	2	right-handed

The quantities are introduced in Fig. 4, the values a, b, thickness giving real dimensions of the wing and not their projection into a 45° inclination. To be able to neglect torsion resistance (stiffness) of the suspension, a fibre with torsion constant 1.1×10^{-7} N.m/rad has been used for the model liquid (7.3×10^{-9} N.m/rad for water).

Results

Results can be concluded in the following way: the influence of the velocity of rotor pulling out ranging between 0.7 mm/s and 70 mm/s on the angular displacement hasn't been registered for the model liquid. Therefore the given series of performances with a particular rotor has been characterised by the average value of the angular displacement:

rotor	viscosity [Pa.s]	diameter [mm]	angle [deg]	rotation path [mm]	path rate [%]
R1	2.6	100	139°	121	40.3
R1	4.0	100	143°	125	41.6
R1	9.1	100	143°	125	41.6
R2	9.1	53	166°	77	26.0
R3a	9.1	22	217°	42	13.9
R3b	9.1	22	220°	42	14.1
R1	0.001	100	360°	314	105.0 (water)

As we can see from the table, the angular displacement is not changed considerably even with the change of liquid viscosity. The movement of rotor is connected with neither movement velocity, nor liquid capacity, and not even with Re number value. (Except of water, where slight dependence of the angular replacement on the pulling out velocity has appeared). The only quantity influencing the angular displacement has been a rotor diameter.

Discussion and Conclusions

The path covered by the paddle end related to the path on which the rotor has been drawn decreases with decreasing rotor diameter. It means that for the smaller rotor smaller lateral component, i.e. lower pumping effect, has been observed in comparison with the larger one. The independence on Re number confirms the premise that rotation of the rotor in the model liquid is not caused by

dynamic uplift. Its cause can be found in the lateral component of the paddle wing resistance. Differences among particular rotors are caused by:

- a) different rotor construction, i.e. that not all dimensions are in the same rate
- b) different distance of the rotor wing from the vessel wall
- c) different quality of produced rotor, mainly due to inaccuracies during manufacture
- d) greater rotation taking along of glass melt in case of rotor diameter reduction

Our work has shown that in some practical cases the pumping effect of the stirrers in glass melt cannot be caused by dynamic uplift. It cannot be also easily described by means of created velocity gradient. It was proposed to take it as the effect of lateral component of resistance (above all a frictional one) of the passing paddle. This interpretation has formed the base of stirrer rotor construction principles.

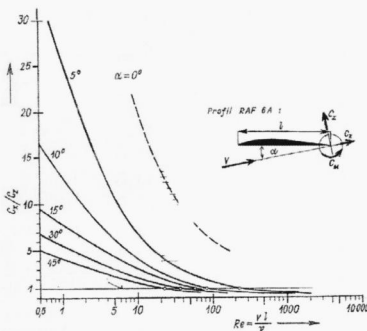


Fig. 1 Drag lift ratio

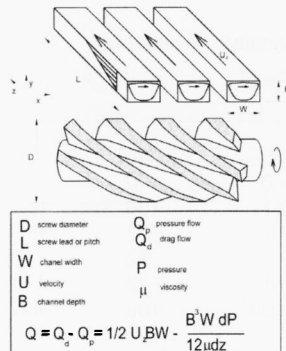


Fig. 2 Flow inside an extruder

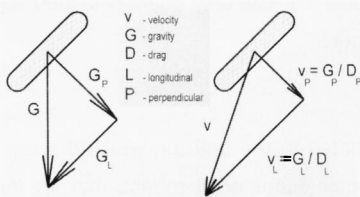


Fig. 3 Sedimentation of a skew tabular particle

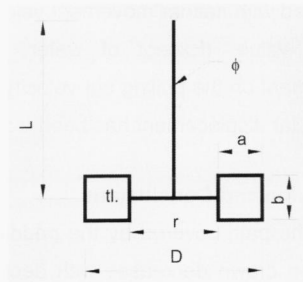


Fig.4 Rotor dimensions

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