FRI–LCR-1-CT(R)-03

POWER CONSUMPTION REDUCTION BY MODIFYING THE SHAPE OF MIXING IMPELLERS IN CHEMICAL REACTORS

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Abstract: *Referring to the global climate changes caused by the energy production and consumption in all industries, part of the actions to reduce this indiscriminate waste is the search for methods to decrease power consumption in all possible units. Some of the significant energy consuming units in the chemical industry are chemical reactors because of theirs mixing and temperature requirements. Therefore, reducing their power consumption is an important optimization task. In the present study, an attempt is made to explore the possibility whether the mixing impellers can homogenize reacting fluid with less energy input. The Rushton turbine was selected to be the basis on which alterations of impeller geometry will be applied to check if this will lead to power saving and at the same time – preserve mixing intensity. Mixing power numbers and flow coefficients were the primary performance characteristics that were monitored during the research. Some significant evidence has been found to support the main aim. All experiments were executed by CFD methodology using RANS equations and k-ε turbulence model.*

Keywords: *mixing, chemical reactors, impeller modifications, energy-saving, CFD.*

INTRODUCTION

The mixing in tank reactors is a key technological process which guarantees the homogenization of the reacting flows and minimizes the temperature and concentration differences in the reactor volume. The homogenization level effected by mixing determines the quantity and quality of the products. There are numerous data for substantial losses in leading industries as a result of poor mixing. In large scale chemical and biochemical reactors, the energy consumed by the impeller (especially with viscous media and stationary conditions) leads to significant power consumption. In the context of the actual international appeals for reduction of power consumption in the industry aiming to prevent the accumulation of greenhouse gases and climate change, the search for energy-saving effects in all possible aspects is a major optimization task.

In the present paper, an attempt is made to find energy saving effect by the operation of classic Rushton turbine with flat blades (the most often used impeller) by various modifications in the shape of the blades. The basic idea was to answer the question: will small changes in the geometry of the shape result in lower energy consumption (estimated by the power number, P_o) while preserving (or improving) the effects of homogenization. Form fluid mechanic point of view, searching for effects is stipulated by the fact that the geometry of the blade is the main factor exerting resistance to the shaft thus affecting the power consumed at the same operational rotation speed (Georgiev, D., & Vlaev, S.D., 2006; Vlaev, S.D., & Georgiev, D., 2014).

EXPOSITION

Analysis and considerations of the modifications studied

As the basic object for modification and, simultaneously, a reference, the classic Rushton turbine was selected (a turbine with 6 flat blades mounted on a disk, FB). The following geometric changes were applied expecting positive effect on the power number (Fig.1):

- FB – (flat blade) Rushton turbine impeller;
- AB – variant with upper leading edge bent to 45^o;
- CB – “semi-tube” type turbine aiming to obtain hydrofoil effect;
- PuB – reduced working area, “fish tail” shaped;
- PfB – flat blade with multiple perforations;
- SB2 – symmetric rectangular perforations on flat blade
- SCB – a variant of SB but on “semi-tube” blade

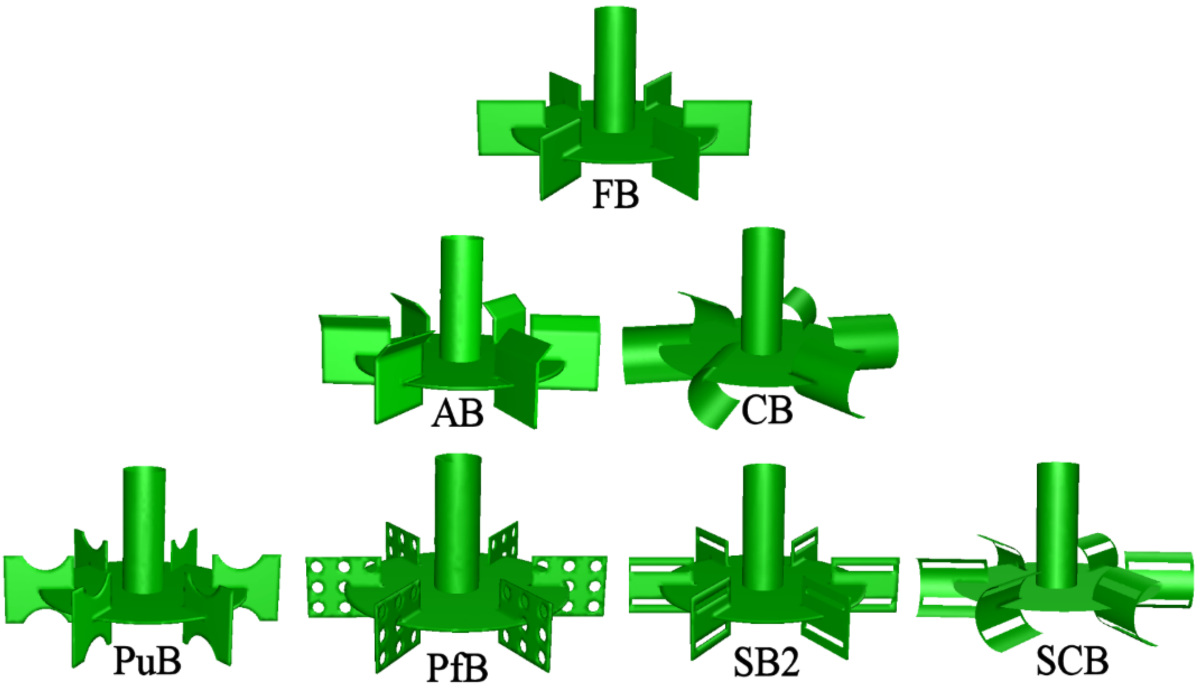

Fig. 1 Overview of the geometric modifications studied

All the changes were made following the hypothesis that they will reduce the resistance of the blade shape, reduce the intensity of the counter-gradients behind the blades and, hopefully, reduced consumption of energy which would give the energy saving effect. The creation of round and rectangular perforations makes it possible for the fluid to flow through at substantial speed. However, it raises the question whether the “kinetic tunnel” created will contribute not only to the more efficient operation of the turbine but also for the intensification of the homogenization itself.

Methods

Aiming to obtain fast and exact comparative data on the performance of the individual modifications, a complex approach was employed in the present work which combined the modern achievements of computer technics and the classic methods of laboratory analysis. The major part of the data was obtained by simulation experiments based on the method CFD (Computational Fluid Dynamic). To substantiate the numeric experiments, laboratory ones were carried out with part of the objects.

CFD procedure:

For the application of CFD, 3D geometric models of all the impeller modifications were built. The models obtained were first discretized to split the volume to a mesh of computational cells. The computational grid created was imported into the CFD solver software to solve the Navier-Stokes equations for each computational cell. After reaching the criterion of convergence (the difference between two consecutive iterations is less than 10^{-6}), the fluid dynamic simulation data was additionally treated in order toobtain the power number $P_0$and the circulation coefficients F_l for each modification. The procedure has been described in detail in our previous works (Georgiev, D., & Ivanov, Zh., 2016; Georgiev, D., Ivanov, Zh., & Georgieva, A., 2016; Georgiev, D., & Vlaev, S.D., 2012). P_0 and the power consumed were determined based on the torque of the impeller calculated by CFD and the relationships:

$$P = P_0 \rho N^3 D^5$$
$$P = 2\pi N T_q \qquad (1)$$

In eq. (1), P – power input [W], ρ – density of the fluid [kg/m^3], N – angular velocity of the impeller [s^{-1}], D – turbine diameter [m], T_q – torque of the shaft [N.m].

The circulation coefficients (a measure for the pumping capability of the impeller) were determined from the fluid flux Q pumped in radial direction through a cylindric surface encompassing the impeller, according to the equation:

$$Fl = \frac{Q}{ND^3} \qquad (2)$$

Laboratory experiments

Aiming to validate the computational data, real prototypes were manufactured for some of the modifications and they were tested with respect to the power number in a laboratory reactor equipped with a torque gauge mounted in the shaft (Vlaev, S.D., Martinov, M., Pavlova, K.,Ruseinova, S., & Georgiev, D., 2014). The laboratory results obtained for the value of P_0 fully coincided with simulation ones and for this reason they are not shown in the present paper.

Results and discussion

The first group of results was intended for the estimation of the power consumption of the impellers. The worldwide accepted dimensionless criterion for comparing the individual impellers with respect to their power consumption is P_0 – power number. To make the comparison under equivalent conditions, all the modifications were tested at 600rpm angular velocity of the shaft, fluid density 998 kg/m^3 and viscosity 10^{-3} Pa.s.

The results obtained for the individual modifications are presented in Fig.2. it clearly indicates that the device consuming the most energy is the conventional type of unmodified turbine (FT).

The highest energy saving in the group of flat blades was observed for the samples PfB and SB2 (P_0 decreased by about 40%). In the group of bended blades, the decrease of the power number was even higher to reach quite low values for the SCB sample (2,64 – more than 50% lower power number compared to the baseline blades).

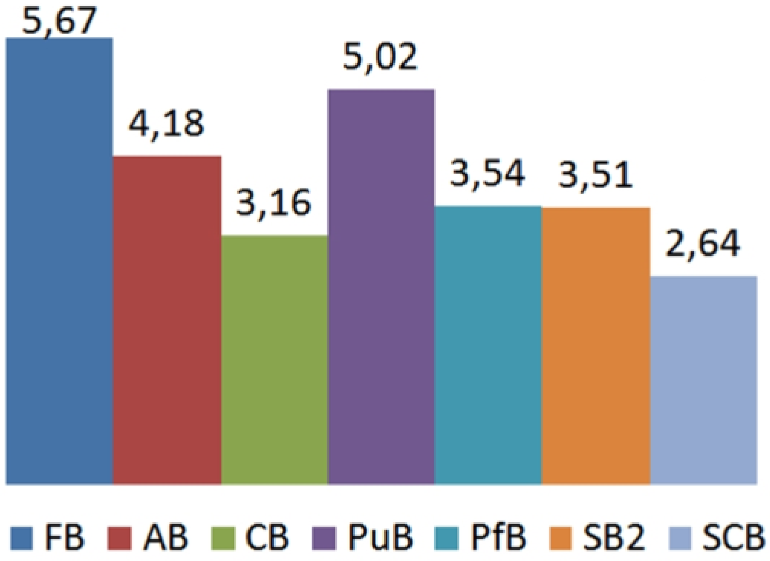

Fig. 2 Bar diagram for comparing the power number P_0 of the individual modifications

In the course of the study, the quastion whether the effects of energy saving observed were obtained at the expense of worsening of the stirring characteristics. To find the answer, the circulation coefficient F_l was selected as the criterion indicating whether the mixing proceeded with the necessary intensity and as a characteristic of the pumping action of the individual impellers by which they can be compared. The data obtained under the same conditions are shown in Fig.3. the analysis of the diagram shows that the circulation coefficients have similar values (due to the comparatively equal area of blades of the different modifications). However, taking thesse values per unit energy consumed, the results indicate that the mixing intensity with the perforated blades was achieved at significantly lower consumption of power.

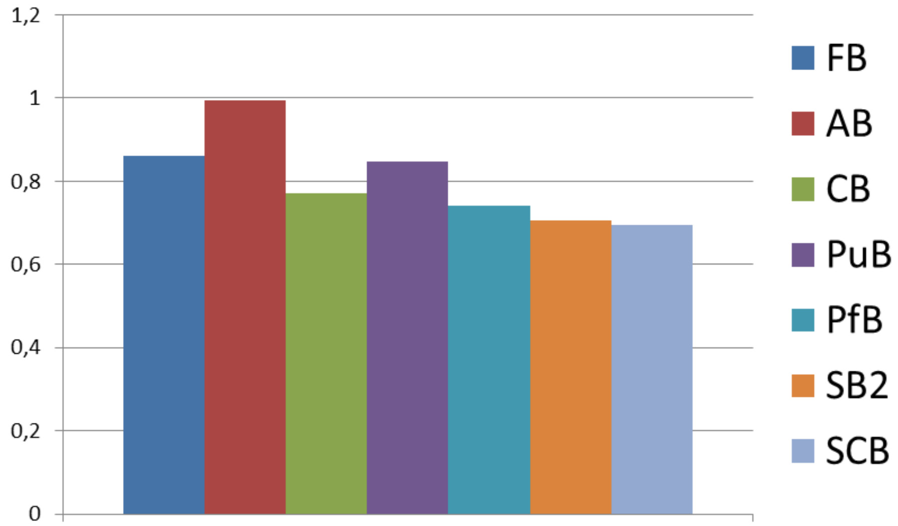

Fig. 3 Bar diagram comparing the pumping capasity (using the circulation coefficients F_l) of the individual modifications

CONCLUSIONS

Six geometric modifications of the classic turbine with flat blades were suggested in an attempt to reduce the power consumption. The hypothesis that small changes in the shape of the blades will result in reduced power consumption was proved by the smaller power numbers observed with some of the modifications together with preserved mixing intensity (according to the circulation coefficients). The data obtained are of certain interest for a number of industries using stirred vessels (including chemical and biochemical reactors). The results can be use also as a basis for further studies to clarify the complex relationship between the shape of the stirring device and the mass transfer characteristics under conditions of complex dynamic environment.

REFERENCES

Georgiev, D., & Ivanov, Zh. (2016) On the fluid dynamic generated by 4-inclined-blade modified mixing impellers in stirred reactors, *Annual of "Assen Zlatarov" University*, XLV (1), 37-41.

Georgiev, D., Ivanov, Zh., & Georgieva, A. (2016) Turbulence models' comparison for external flows with high-Reynolds number around flat object, *Science & Technologies*, Volume VI, Number 3, Natural and Mathematical Science, 95-102.

Georgiev, D., & Vlaev, S.D. (2012) Bioprocess improvement by design-modified bioreactor flow properties, *Biotechnology and Biotechnological Equipment*, Vol. 26 (4), 3182-3186.

Georgiev, D., & Vlaev, S.D. (2006) Flow filed characteristics of modified inclined blade mixing impellers, *Journal of the University of Chemical Technology and Metallurgy*, Vol. 41, 45-50.

Vlaev, S.D., & Georgiev, D. (2014) CFD-characterization of the MV-impeller related to polysaccharide dispersion mixing, *Scientific works of University of food technologies*, Volume LXI, 745-749.

Vlaev, S.D., Martinov, M., Pavlova, K., Ruseinova, S., & Georgiev, D. (2014) Callanging the biogeochemical potential of antarctic yeast: bioreactor dynamics in viscous broths containing exopolysaccharides, *14th GeoConference on nano, bio and green – technologies for a sustainable future*, Conference proceedings Volume I, 293-300.