KNOWLEDGE BASED DESIGN OF PUMP-MIX MIXER SETTLERS

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Mr. K.K. Singh is the recipient of the DAE Young Engineer Award for the year 2008

Abstract
This research work taken up under a Xth Plan R&D project, was a blend of experimental and computational studies. The experimental work involved measurement of head and power numbers of different configurations of pump-mix mixers, residence time distribution studies on pump-mix mixer, two-phase studies to determine the quality of dispersion in the mixer, measurement of dispersion band thickness in the settler and profiling of holdup and drop size along the length and height of the dispersion band. Computational work involved single-phase, two-phase flow simulations and population balance modeling. Finally a methodology for knowledge based design of pump-mix mixer settlers was outlined.

Keywords: pump-mix mixer, head number, power number, dispersion

Introduction
A mixer-settler in which the impeller of the mixer itself does inter-stage and/or intra-stage pumping is called a Pump-Mix Mixer Settler (PMMS). Using a PMMS leads to reduction in turbo machinery in the plant, associated capital, operating and maintenance costs and simplification of plant layout. PMMSs are very useful for large scale operation such as for recovery of value material from lean streams. Fig. 1 shows the sketch of a PMMS having intra-stage recycle of the light phase.

To ensure recycling of the light phase the head to be generated by the impeller can be expressed as

$$h > \frac{\rho_m H_m - \rho_l H_l}{\rho_w}$$

(1)

Here $h$ is the head, $\rho_m$, $\rho_l$, and $\rho_w$ are the densities of the mixed phase, light phase and water. Capacity of an impeller to generate head is defined by the head number expressed as

$$N_h = \frac{gh}{N^2 D^2}$$

(2)

Where $g$ is acceleration due to gravity, $N$ is the impeller rotational speed, $D$ is impeller diameter. The power input by the impeller is characterized by a dimensionless number called power number defined as

$$N_p = \frac{P}{\rho N^3 D^5}$$

(3)

The power input into the mixer should be within a range as very small power input will lead to low quality of dispersion, very high power input will lead to creation of undesirably fine and hence difficult to separate dispersion. Ideally, the pumping requirement should be met while keeping specific power input in the mixer close to a value just enough to ensure good stage efficiency. Meeting the pumping requirement without excessive power input is the main issue making the design of a high throughput pump-mix mixer a challenging task.

Single-phase studies on pump-mix mixers

Single-phase experiments have been carried out on bench-scale (10L) and pilot-scale (270L) pump-mix mixers to determine head and power numbers of top shrouded
turbines under different geometric settings and for different operating conditions. Effect of impeller type, impeller off-bottom clearance, impeller diameter, impeller blade width, number of blades in the impeller, flow rate and impeller speed on head and power numbers were studied experimentally. For bench-scale mixer, residence time distribution experiments were also carried out. Single-phase flow simulations were carried out and validated using experimental data. Fig. 2 shows a typical computational domain. Good agreement between measured and predicted values was observed\(^1,2,3,4\). Compartment modeling to describe a real pump-mix mixer as a series combination of ideal flow vessels was also carried out\(^2\).

**Flow simulations to understand the pump-mix action**

Flow simulations for different impellers, some of them shown in Fig. 3, were carried out and the resulting wealth of information on flow field was used to develop an insight into the pump-mix action.

The impellers were rated on the basis of head generated by them for equal specific power input. On analyzing the data obtained from flow simulations, the interaction between the liquid in the lower recirculation loop of the mixer and the liquid coming from the inlet was found to decide the head generated by the impeller\(^3\). How this understanding can be used to design better pump-mix impellers was also illustrated.

**Two-phase studies on pump-mix mixer**

Experiments with the phase system consisting of dilute phosphoric acid dispersed in a mixture of di-2-ethyl hexyl...
phosphoric acid (DEHPA), tributyl phosphate (TBP) and n-paraffin were carried out. Effects of impeller speed, feed holdup and residence time on drop size distributions and holdup were studied. A method based on stabilization using surfactant was developed to freeze the dispersion and carry out the measurements of drop size distributions. Fig. 4 shows a typical image of the stabilized dispersion used for measurement of drop size distributions. Using experimental data empirical correlations for Sauter mean diameter, maximum stable drop diameter and holdup as a function of impeller speed, feed holdup and residence time were obtained. Population balance modeling to predict the quality of dispersion was also carried out. Three population balance models differing in droplet breakage rate model were evaluated and the one which giving closer match with the experimental drop size distributions was identified. Fig. 5 shows the comparison of the drop size distribution obtained from experiment and predicted by population balance modeling. To predict the holdup of
Fig. 6: Computational domain of the model used to study the effect of internal circulation on droplet drag coefficient.

Fig. 7: The setup used in the experiments for profiling of drop size and holdup in dispersion band.
the dispersed phase in the mixer, two-phase flow simulations are required. In these simulations correct modeling of drag term is very important. A two-dimensional flow model, computational domain of which is shown in Fig. 6, was developed to understand the effect of internal circulation on droplet drag coefficient and to derive a drag coefficient model. This drag coefficient model when embedded in two-phase flow model was found to perform better than empirical models for prediction of dispersed phase holdup in the mixer.

Studies on settler

Settling characteristics of the phase system of interest were obtained experimentally in two different types of settler, a conventional settler with a full width launder and a modified settler having side entry of the dispersion. Using experimental data correlations were obtained for the specific settling rate. For identical conditions the specific settling rate was found to be better in the modified settler. Experiments were also done to see the variation of holdup and drop size along the height and length of the dispersion band in the experimental setup shown in Fig. 7. The measurements indicated that variation of holdup and droplet diameters is mainly along the height of the dispersion band with variation along the length of the dispersion band being negligible.

Conclusion

Based on the research work outlined above a knowledge based methodology to design a pump-mix mixer settler has been developed. The methodology has been illustrated through a case study aimed at designing a 30 m³/hr pump-mix mixer-settler. The methodology has also been used to design a pump-mix mixer for 50 m³/hr for Heavy Water Board.

References