ABSTRACT

The main objective of the research is to study the energy conversion process in the impeller and diffuser of centrifugal mixed flow multistage submersible pump using numerical simulation. A mixed flow pump model that suits 150 mm borewell size produced by the manufacturer M/s Aquasub Engineering, Coimbatore was selected. This model is required by the irrigation sector all over India in huge volume. The present level of pump overall efficiency of this model was studied and it varied within a band of 64 - 68% with an average value of 66%. From the Pump Handbook chart, the efficiency for this specific speed N_s 54.15,(Equivalent US specific speed 2796) is 76%. So there is scope for improvement in efficiency from existing 66 to 76%. In this era of energy conservation this efficiency improvement will lead to conserve considerable energy in the irrigation sector.

The methodology carried out in this research work consists of five phases. In the first phase, the experimental testing of existing mixed flow pump for present level of performance was done. In the second phase, numerical simulation of the existing pump was done. In the third phase, detailed loss analysis was made using numerical results. In the fourth phase, numerical simulations for the modifications in surface finish of flow passages, impeller & diffuser geometry were carried out and results were analysed. In fifth phase i.e. the last phase, experimental testing of the modified prototype pump was done and compared with numerical results.

The multistage pumps were tested in the experimental test set-up as per the ISO pump testing standard ISO 9906. Five sample pumps were manufactured in single stage and multistage construction and the performance tests were conducted. This study revealed that the performance

of single stage pump was higher than that of multistage pumps. The single stage maximum pump efficiency was higher when compared with the maximum efficiency of the multistage pumps. The efficiency value is 69% at nominal flow for the single stage pump and for the multistage pumps it is 66% average. The head, input power and efficiency of single stage pump are higher than the per stage head, per stage input power and efficiency of multistage pumps.

Numerical analyses of these pumps were made by a commercial CFD code Ansys Fluent. The grid dependency study with the selected grid cells and various turbulence models were analysed. K-Omega SST model has been selected for the performance simulation and was validated with the performance of a test pump with static pressure tapings. The single and three stage pump performance was simulated numerically and compared with experimental results. The detailed analysis of pressure and velocity distributions revealed the difference in performance of single and three stage pumps. Secondary flows were observed at the impeller outlets. Further the primary flow is not following the diffuser shroud, hub walls and diffuser vanes. Secondary flows were seen at the diffuser passage even at the nominal flow rate Q_n. The various losses were determined numerically for this pump and it is estimated as 25% for flow friction and mixing losses, 5% for disk friction losses and 3% for leakage flow losses. The flow friction and mixing losses of 25% and disc friction loss of 5% are predominant. The leakage loss and mechanical loss are minimal. Based on this loss analysis, modifications were made and flow was simulated using numerical simulation to study the flow friction loss, mixing loss and disc friction loss in the impeller and diffuser. It is observed that these modifications have improved the efficiency of the pump.

To reduce the flow friction losses, the performance of the 3 stage pump was simulated for the existing surface roughness of 2.5µm R_a in the cast iron diffuser passage and bronze impeller passage. The same model was simulated with reduced surface roughness values viz. 0.2µm R_a surface roughness equivalent of polymeric coating and 0.8µm R_a surface roughness equivalent of ceramic enamel coating. The surface finish improvement in the components resulted in reducing the flow friction losses and disc friction losses considerably. The impellers and diffusers having surface roughness of 0.8µm Ra value show a marginal reduction of 200 watts average power in the operating region of 0.5 Q_n to 1.75 Q_n and an efficiency increase of 2.5% at Q_n. The impellers and diffusers having surface roughness of 0.2µm R_a value give a substantial reduction of 300 to 500 watts average power in the entire operating region and an efficiency increase of 4.5% at Q_n. The polymeric coating process was selected for efficiency improvement in the final prototype pump.

To reduce losses in impeller, first numerical simulation was done using Ansys Fluent for the existing impeller. The meridional shape of the impeller and vane curvature were thoroughly analysed and modified using the inverse design code TURBOdesign1. Modifications were done in the impeller meridional shape and impeller vane curvature to reduce impeller losses and improve the efficiency. Optimising the blade shape using inverse design method helps to suppress the secondary flows across blade to blade. Optimum blade loading that is loading the front portion of the shroud and rear portion of the hub along with positive stacking at trailing edge of the impeller blades reduces the flow disturbance at impeller exit. The results showed that the pump efficiency is improved by 4%. The flow mixing losses were reduced in the impeller passage after the modifications. These impeller modifications were selected for the final prototype pump.

The detailed analysis of numerical simulation of the existing diffuser revealed that the primary flow was not following the diffuser shroud, hub walls and diffuser vanes. Secondary flows were seen at the diffuser passage even at the nominal flow rate Q_n. The meridional shape of the diffuser and diffuser vane shape were thoroughly analysed numerically. An annular conical shape was introduced in the meridional section to eliminate sudden changes in flow direction. This modification was done to reduce recirculation along the hub to shroud passage. Also, the diffuser vane inlet angle was modified to suit the absolute flow angle from the impeller outlet. Diffuser vane curvature was modified to reduce the recirculation in the blade to blade passage. By doing these changes in diffuser the mixing loss was reduced. Numerical analysis showed efficiency increase in the entire flow range. Also the difference in inlet velocity of subsequent impellers in multistage pump was reduced. These modifications in diffuser were selected for the final prototype pump.

To conclude, the loss analysis using numerical simulation helped in determining various losses and the appropriate modifications needed to reduce the loss. Polymeric surface coating resulted in reducing the flow friction losses along the flow passages and showed a considerable increase in efficiency. Modifying the impeller blade shape using inverse design method helps to suppress the secondary flows across the blade to blade view. When the flow separations are reduced in the impeller passage and uniform velocity field is maintained, the pump efficiency increases at nominal flow rate. Modification of the existing diffuser meridional shape into annular conical shape to eliminate sudden changes in flow and modifications in inlet vane angle and vane curvature of diffuser to reduce the mixing losses of flow resulted in increase in efficiency at off-duty flow conditions to give a flat efficiency performance curve. This resulted in a wide operating range with higher efficiency in the field. A modified prototype pump using impellers and diffusers made by rapid prototyping 3D printing method was made and tested. The experimental performance of the modified pump was matching with the numerical results. Finally a cast metal pump with these modifications was made and tested and the test results were found matching with numerical results.

In future, similar works can be carried out for all other flow ranges of submersible mixed flow and radial flow multistage pumps for improvement of efficiency. This will result in substantial energy saving in the irrigation sector in India and other countries when these pumps are used.