ABSTRACT

Until very recently, we were in the advantageous position of having a plentiful and inexpensive conventional fuel supply. During the past 20 years, the rising cost of fuel and their increasing trend has forced all major industries to make comprehensive energy audit to reduce their fuel/power cost. Advanced design of many products in globe has led industries to change their present inefficient utility equipments or to change their utility equipment selection practice.

Centrifugal fans and blowers are widely used utility turbomachine equipments in all kinds of modern industrial and domestic life. Manufacturing industries of fans and blowers seldom follows optimum design solution for individual fan/blower. Mostly their design and fabrication is based on series of successful past models or derived from fan laws and geometrical similarities. They were purchased earlier by user solely on the basis of their cost. Little attention was given to monitor and evaluate their reliability, economic life span and their optimum efficiency.

This research work is based on an industrial requirement for redesigning of fume extraction centrifugal fan used in SDS-9 texturising machine. Here variable flow is required at constant head under dust laden conditions. Radial blades are ideal for dust laden air or gas because they are less prone to blockage, dust erosion and failure. It has ideal zero slope in H-Q (head-discharge) curve to give variable discharge at constant head. Hence radial blades are selected. Comparative study for forward and backward curved radial tip blade impeller fan is also planned during the course of this work.

Accurate tests had revealed breaks in the characteristic curves. These indicate sudden changes in the flow conditions in the impeller as well as departure from the ideal assumptions upon which the theory is based. W. J. Kearton had studied these breaks in characteristic curves and found inactive flow on the trailing face of the vane which is equivalent to increasing vane thickness. This is also known as dead pockets on the vanes. This has shown that flow is not properly guided by number of vanes in the impeller. This has led him to initiate the process of optimization of number of blades. It is reflected in his paper entitled “Influence of the Number of Impeller Blades on the Pressure Generated in a Centrifugal Compressor and on its General Performance.” Unlike the case with axial impeller, there is no mathematical method to determine an optimum number of blades for a radial impeller. Care must be exercised
in the design of the blade passages to ensure reasonable flow of the streamlines so that no separation occurs. This is very important aspect and hence finite number of blades should be decided with utmost care and with theoretical optimization. However in literature various correlations or empirical formulae are available. Number of blades calculated as these correlations, all differs widely. Hence number of blades must be optimized experimentally under design and off design conditions. Off design conditions include variable flow rate and speed of impeller rotation. Experiments are conducted on transparent laboratory test set up at design and off design conditions by varying number of blades in four steps. Experimental results have clearly indicated that the best performance is achieved with 16 number of impeller blades for present case and conditions. This has attributed to the fact that with 16 numbers of blades, the flow is guided with minimum separation and contributing lower frictional losses with least dead pockets. The optimum values of the discharge coefficient, head coefficient and power coefficient obtained for this case are 0.2894, 0.0084 and 2.3034, respectively for 16 numbers of blades.

During extensive literature review on design and performance evaluation of pumps, blowers and fans, it is observed that much research work has been carried out on local flow physics, aerodynamics and phenomena of energy transfer. It is also studied that the design methodologies suggested by different researchers differ widely. To ascertain above conclusions and evaluate suggested design methodologies by different researchers, attempts are made to design, fabricate and record performance evaluation of radial tipped centrifugal fans as per design methodology traced out by using fundamental principles of fluid flow and other design methodologies suggested by Church A. H and Osborne W. C.

Each fan has been tested on experimental set up laid as per IS: 4894-1987, Indian Standard Specification for Centrifugal Fans (First Revision), Reaffirmed 1994. Observations are recorded for static pressure distribution along the flow path at variable flow rate. These are accompanied with measurements of electrical and air power parameters. Comparative study is made using forward and backward curved radial tipped vane impellers. This is done at designed and off designed rotational speeds to make better comparative performance assessment of suggested design methodologies. Experimental evaluation of these fans has shown performance variation at different flow sections. The performance appraisal for each design methodology concludes that design method as an individual is not performing as
marked. It has revealed lacuna of explicit centrifugal fan design methodology which can give desired performance. It has shown that there is a need to develop unified design methodology.

Based on this realization, the unified design procedure is developed which is based more on fundamental concepts and involving minimum assumptions. Best performances at different flow sections of fundamental, Church and Osborne designs are compiled together and unified design methodology is outlined. Afterward the fans are fabricated as per unified design methodology with forward and backward curved radial tipped impellers. Their performance is critically examined as per procedure on test set up described for individual design methodology. The results obtained under unified design are very much encouraging. Major performance parameters achieved are on higher side of design point during series of experiments. This shows that fan based on unified design is good enough to achieve desired performance, which not only validates the proposed unified design methodology, but also proves its strength and usefulness.

This design methodology is coded and user friendly software in visual basic for design of radial tipped centrifugal fan is developed. Impeller stress analysis is carried out using Ansys’s software in order to obtain optimum vane thickness. This is done to gain advantages like reduction in rotating mass of impeller and hence saving in power consumption. This is very useful for reducing initial and long term operating cost.

The value of slip factor is essential parameter to find how much amount of energy is transferred to the fluid. It is a variable parameter and dependent of impeller geometry, flow rate, specific speed and various other factors. Experiments are made to find out variation of slip factor along blade profile at exit and normal to circumference of impeller. Special three-hole and five-hole probes are designed, developed and calibrated by standard Pitot tube for measuring and sensing the local velocities. Overall value of slip factor is calculated by averaging all local values. The experimental value of slip factor is found to be 3 to 12% less as compared to various correlations available in literature. Evidences of present experimental results support the work of Yedidiah Sh. presenting that the slip factor for a given impeller is not constant, but varies with the flow rate, \( R \). Ajithkumar has concluded in his research work that slip factor is a function of number of vanes, and flow conditions after impeller. It is reaffirmed by present experimental studies that slip factor improves as
number of blades increases. It is also seen from experimental results that slip factor profile over blade width at impeller exit shows negative parabolic profile. Hence design of exit blade section must be of parabolic shape to improve blade tip slip factor.

Losses proposed by various researchers differ widely. Hence, experimental investigations on losses are made to get enhanced performance of radial tipped centrifugal fan. According to A. H. Church, W. C. Osborne, Eck Bruno and D. J. Myles, theoretical leakage loss is 2.52%, 14.47%, 15.79% and 31.75%, respectively. Experimental value of leakage loss is found 4% of design flow rate. Similarly A. H. Church, W. C. Osborne, Eck Bruno and D. J. Myles observe theoretical hydraulic losses as 38.27%, 25.26%, 26.89% and 31.45%, respectively. While experimentally it is in the vicinity of 35.59%. The mechanical losses as per A. H. Church, W. C. Osborne, Eck Bruno and D. J. Myles are 16.32%, 1.57%, 10.18% and 10%, respectively. Experimentally it is found as 12% of total power consumption. Duct friction losses are negligible as being less than 1%.

Among all hydraulic losses, impeller losses are experimentally found 68% while volute casing losses are observed 31% of total hydraulic losses. This confirms the study of Andre Kovats and R J Kind. Volute losses are also significant and are one of the major sources of hydraulic losses and their contribution is equally important to impeller losses. This acknowledges the work of Y. Senoo and H. Hayami, stating that 30% or more kinetic energy at diffuser exit remains unconverted to pressure energy.

In the case of phase V experiments, the average value of slip factor is found 0.67. This is less than the empirical value of 0.8 considered for design purpose. Experimental value of slip factor is found 16% less than empirical value suggested by Stodola. Slip factor has closer agreement at design point conditions but deviates at off design conditions. This indicates that there is more deviation in actual and the theoretical flow direction at off design conditions and in small size impellers. It confirms that shorter blade passage height \((r_2 - r_1)\) produces more slip. This is due to absence of proper flow guidance within blade passage. Blade height is important parameter and should be considered while evaluating the slip factor.

An uncertainty analysis is carried out according to Kline and McLintock method. All the uncertainties in measurements are observed to be well within \(\pm 5.0\%\) of design point values.
In order to study flow behavior, 3-D CFD flow simulation is carried out for backward and forward curved radial tipped blade centrifugal fan using ANSYS’ GAMBIT and FLUENT software. The flow simulation results again validate the design methodology and offers standard fan performance parameters. The results of CFD analysis are closer to experimental results. The careful study of flow simulation reveals the existence of recirculation of flow in the vicinity of tongue region and thus focuses towards the need of redesigning the tongue radius.

In nutshell, the numerically and experimentally validated unified design methodology, experimental evaluation of slip factor of radial tipped fans, loss analysis and the 3-D CFD analysis for flow simulation, emerges as the major outcome of this work.