Chapter – 2

Literature Review
2. Literature Review

LITERATURE REVIEW

Numerous papers are available in the literature on the study of airlift pump. At the present time, no workable theory is known which can accurately predict the phenomena of airlift pump in configuration of practical interest. To derive the maximum benefit from the pump it is most essential to have an insight into the operating parameters of the pump. An attempt has been made in this direction in the present study.

2.1) Literature on operating criteria of airlift pump:

A good and thorough review of the state of the art on airlift design was found in White and Shelton and White (5). A total of 49 contributions are cited giving a detailed overview on the subject.

In the governing equations the submergence ratio of the airlift is used to describe the average pressure gradient along the lift tube which can be expressed in terms of velocities, geometrical parameters, and fluid properties by using momentum and mass balances. The two-phase friction factor and the two-phase density in the lift tube, both based on average properties of the liquid and gas, are as equation parameters. Thus most calculations of airlifts are based on assuming two-phase slug flow in vertical tube (Clark and Dabolt, 6).

Many of authors have investigated the design of airlifts, while two-phase vertical flow has been studied since almost the beginning of the last century (Stepanoff 7). Although the studies are available that deal with the optimization of airlift design, hardly one can be applied in practice (White).

Pickert (8) and many other authors developed the basics for two-phase flow theory. Nicklin (9) speculated that the efficiency of small diameter tubes (< 20 mm) and of low flow rates might be high (along with White and Beardmore
and Zakoski)(10,11). Stenning and Martin introduced the basic principles of two-phase flow (12). Delano produces the same plots in his study (operation at the maximum water flow rate)(13). Kouremenos and Staicos devised the experiments to obtain perfect slug flow (14). Clark and Dabolt published a model to predict the height to which an airlift pump operating in the slug flow regime can lift a given volumetric flow rate of liquid, given the air flow rate and the pressure at the point of gas introduction. de Cachard and del Rosay (15) used an approximation of the general Lockhart-Martinelli correlation(16). Chisholm provides a good starting point for basic definitions and flow patterns encountered in vertical pipe flows (but no optimization of the design)(17). Collier and Thome presented the basic flow patterns: bubbly, slug, churn and annular (18).

White describes the models available to calculate airlifts as followed: Along with Delano's model, several empirical models from previous works are compared to the experimental data to see if they are valid in the range of diameters, submergence ratios. For all models the theoretical model of Stenning and Martin is used as the starting point to setup the relationship between the submergence ratio and the velocities (through momentum and mass balances). Additionally, each model (except for Delano who uses an empirical constant) uses the method of Beattie and Whalley (19) to find the two-phase friction factor, and all but Delano uses the drift flux method (Zuber and Findlay (20) to find the gas void fraction. The difference between models is the value of the coefficients used in the drift flux model. Lockhart and Martinelli defined a two-phase multiplier, used with a single-phase pressure drop calculation. White Beattie and Whalley recommend using the Colebrook equation for friction using two-phase properties in the Reynolds number.
The drift flux model – the most widely accepted method – formalized by Zuber and Findlay provides a means to account for the effects of the local relative velocity between the phases as well as the effects of non-uniform phase velocity and concentration distributions. This theory is the basis to describe the model used today (Chexal et al) (21).

Three of these models are meant for slug regime only (Nicklin et al (22), de Cachard and Delhaye, and Reinemann et al (23)). The fourth model (Chexal and Lellouche) is not flow regime specific (24).

Nicklin et al formulated an equation based on the work of Dumitrescu (25) and Govan and Taylor (26). This equation is often considered the original slug flow model. De Cachard and Delhaye took surface tension effects into account (alternative empirical correlation’s, using distribution parameter Co = 1.2). Reinemann et al are altering the surface tension effects. Chexal and Lellouche devised an empirical program, in order to be able to use one model for all regimes. Disadvantage of the derived equations is that they are rather complex.

The model of Delano uses the analysis of Stenning and Martin.

An optimum efficiency to operate at for a specific diameter and submergence ratio was found very close to the transition from slug to churn flow. (Hewitt and Roberts (27)). Jayanti and Hewitt (28) concluded that the slug to churn transition is attributed to the flooding of the liquid film surrounding the Taylor bubble in slug flow. McQuillan and Whalley (29), Nicklin and Davidson, Wallis (30), and Govan et al (31) came to the same conclusion. From experiments it is expected that diameters less than 6 mm will have a high efficiency (Schaffer) (32).

The five different models – (1) Nicklin, (2) de Cachard, (3) Reinemann, (4) Chexal and Lellouche and (5) Delano were implemented in the Engineering Equation Solver (EES) by Klein and Alvarado (33). The resume is no single
model works for the entire range of submergence ratio and/or diameters and is not useful for installation point of view.

Pickert concluded that the narrow diameter pipes are better from efficiency point of view. Martin C.B. challenged the results obtained by Pickert with regard to the diameter of rising main describing that the larger diameter pipes are suitable for efficient airlift pump. The ambiguity was observed in the experimental results obtained by Pickert and Martin C.B. in terms of diameter of the rising main with concern to efficiency of pump.

As a pumping device, however, the airlift has wide variations in efficiency and reduction of flow below its optimal range increases hydraulic losses, irrespective of lower pipe friction loss. Due to this reason, a familiarity with the hydraulic performance of airlift is much more important than the knowledge of pipe friction loss. Hence the head loss due to friction is not focussed in the work because of the concern for the difficulty of isolating and measuring these losses.

All the studies depend on either an experimental data or empirical correlation factors pertaining to specific categories of practical application. The present work is focussed on the experimental analysis of the various parameters affecting the performance of airlift pump to predict the pumping performance in relation to the gas flow rate and to get the efficient operation of the airlift pump. The study is leading to development generalized mathematical functions that will find its usefulness in the optimum design of pump for its installation.

2.2) Literature on injecting device for airlift pump:

The air injector design has a considerable effect on the water discharge as well as on the whole performances of the airlift pump. G. J. Parker (34) reported the study of small airlift pump made from 24.3mm-bore glass tube using two different designs of air injection foot piece. In one (the air-jacket
design), air was injected radially inwards, and in the other (the nozzle design),
air was injected axially at inlet to the riser. Each design has been tested using a
variety of injection hole sizes and numbers. With the air-jacket design, the
pump discharge characteristic was found to be independent of the number and
sizes of the injection holes. The nozzle design showed greater pumping
capability at high airflow rates and with small orifice area, but the efficiency
then was very low. Some comparisons with the theoretical model of Stenning
and Martin have been made, and the model has been extended to take account
of the momentum of air injected in the nozzle foot piece.

D. A. Kouremenos and J. Staicos focussed on the pumping of liquids
using two-phase flow. The performance has been examined experimentally in
small airlift pumps with 12-19 mm bore Plexiglas tubes. An air injection system
was devised to create and maintain ‘perfect’ slug flow in the vertical riser tube.
An equation has been derived, based on momentum conservation
considerations, which correlates well with the measurements obtained. Slip
variation, or liquid holdup, between the two phases and the formation of the
‘entrance’ section part of the pump (suction pipe) were taken into consideration.
Unlike its predecessors, this equation predicts the reversal in the pump
performance curve observed experimentally.

Airlift pump performance was investigated experimentally by M.F.
Khalil et al (35) for different submergence ratio (the ratio between the
immersed length of the riser and its total length) using different designs of air
injection foot piece. For this purpose airlift pump with a riser 200 cm long and
2.54 cm in diameter, was designed and tested. Nine different air injection foot
piece designs were used at four-submergence ratios with different air injection
pressures (from 0.2 to 0.4 bar). An area of 10sq.mm was chosen and divided
into nine injections hole arrangements (1, 2, 3, 4, 6, 15, 25, 34 and 48 holes) to
cover the whole experimental range. Four submergence ratios were used for this work: 0.75, 0.7, 0.6 and 0.5. The experimental results showed a marked effect on the pump performance when operated with different types of injectors at different submergence ratios. The results indicated that the disk with three holes (D3) gives the highest efficiency at nearly all submergence ratios. Moreover, it is found that there is a suitable disk design for maximum water flow rate at every submergence ratio. Further, the highest efficiency resulted at the largest used submergence ratio, namely 0.75. The pump capacity and efficiency were found to be functions of airflow rate, lift ratio, and injection pressure.

G.J.Parkar focused on the effect of foot piece (air jacket) with number of holes of same diameter. The foot piece used in this study was orifice plate & it was observed that there is no effect of foot piece hole configuration on performance (discharge characteristics). Parkar had not focused on the issue of effect of different injection devices on performance of airlift pump.

The injection device proposed by Parkar is an integration of nozzle & orifice. This integrated device follow the different characteristic & orifice of smaller diameter results in the high pumping rate & quantity & it continues to increase with decrease in orifice area. Parkar does not study the effect of separate injection device. The foot piece proposed in the present study is different than the foot piece proposed by Parker. The submergence ratio parameter is neglected in the analysis of Parker.

M.F.Khalil focused on the effect of orifice plate as an injection device with number of holes of the same diameter. The effect of submergence ratio neglected by G.J.Parkar, which was presented by M.F.Khalil but the effect different injecting device is not considered in the study. The most important parameter for studying the characteristics of the airlift pump is rate of flow of water. In the study presented by Khalil this parameter was ignored.
T.K. Theyyunni (36) focussed the application of fluid technology in nuclear chemical plant. The author has proposed an empirical formula to determine diameter of orifice plate through which air can be introduced into the foot piece. The equation is \( D_2 = \frac{Q}{435} \left( \frac{P_1 - P_2}{P_2 r_f} \right) \).

The equation developed is based on theoretical consideration of the work done & expansion, which can not be justified for work of compression & expansion of air in foot piece. An adiabatic process justifies the compression & expansion of air.

The foot piece design has a considerable effect on the water discharge as well as on the complete performance of the airlift pump. The individual effect of design of foot piece is not yet reported in literature. The characteristic curves of one injecting device are not applicable to different shapes of injecting device. Therefore, the present study is focused on the experimental analysis of different designs of foot piece. The ignored parameters of rate of flow of water (Khalil) & submergence ratio (Parkar) are also studied experimentally. An adiabatic process justifies the compression & expansion of air. Hence, the analysis is carried out considering an adiabatic compression process of a compressor.

The published test results are not focused on the effective diameter of nozzle (injecting device) suitable to diameter of the rising main. The present work is leading to the development of mathematical function to determine the effective diameter of nozzle. Also the new design of injecting device is proposed to improve the effectiveness of a pump.

2.3) Literature on centrifugal pump handling two-phase flow:

Requirements of handling two phase mixtures are increasing day by day and published test results are few and are not suitable from the installation point of view. The ability of the centrifugal pump to handle entrained gases is very

S. G. Amravati University 16
limited. If the air / gas percentage increases beyond the 14 percent in volumetric ratio, the pump stops working and is said to be air bound. Entrained air in a centrifugal pump has undesirable effects on the pump operation and knowledge of the pump performance under air admitting conditions is needed for actual purpose.

In order to investigate the performance, a semi-open impeller pump with a transparent casing was employed and the behavior of the entrained air bubbles in the pump was observed. The impeller work and hydraulic loss of the pump, together with energy loss for air delivering are discussed. The total head of the pump is decreased by the air admission, but the head developed by the impeller remains substantially constant. The drop of the pump head is mainly caused by the energy consumption for air delivering within the range of \( q_s/Q \leq 0.02 \), and when \( q_s/Q \) is increased beyond this range the hydraulic loss due to the flow resistance of air bubbles increases its weight in the head drop. These relations are given in the empirical formulas proposed by the Mitsukiyo Murakami and Kiyoshi Minemura(37).

Sinz Sato et al (38) described the air/water two phase flow performance of a centrifugal pump for five kinds of closed impellers, each of which has different outlet or inlet angle. The results showed that (i) sudden pump head degradation due to gas accumulation in the impeller occurs at a lower air flow rate with increasing inlet or outlet blade angle of the impeller. (ii) The pump head remains high even under the condition of gas accumulation when the impeller has large blade outlet angle. These results are qualitatively discussed including numerical calculations of one-dimensional two-phase flow.

Air/water two-phase flow performance of centrifugal pump impellers with various blade angles were investigated through experiments and theoretical and calculations. The results are summarized as follows:
In the case of high incidence angle for an oncoming flow at low water flow rate and large blade inlet angle, the two-phase flow pattern is changed discontinuously from a bubbly flow along the blade pressure surface to a separated flow with an air cavity on the blade suction surface at a certain flow rate ratio of air/water, at which the pump head drops suddenly. In the case of low incidence angle, air cavity appears on the blade pressure surface and head is degraded continuously. The abrupt pump head degradation due to appearance of the air cavity occurs at lower air flow rate, as the blade outlet angle of the impeller becomes larger. However since water is able to flow with higher Euler’s head out of the impeller in a two-phase separated flow when the impeller has a larger blade outlet angle, the pump head remains high even with the existence of the air cavity.

The mechanism of air accumulation on the blade pressure surface in the case of low incidence angle can be explained from a bubbly flow calculation as an inviscid flow field. However, this calculation is powerful for predicting the discontinuous appearance of the air cavity on the blade suction surface. In order to elucidate its mechanism, the bubble behavior in the shear flow with flow separation near the suction surface should be considered.

The use of centrifugal pump for handling two-phase mixtures is limited. The two-phase mixtures of chemicals are to be transported in many of the chemical industries. The example in the process industry is that of pumping the mixture of vinyl chloride after oxychlorination of ethylene. Another example is that of the process hydration of propylene with sulphuric acid for the production of isopropanol. The characteristics of two-phase centrifugal pump cannot be applied to design the airlift pump. Hence the comparative study of the common parameters to airlift pump and centrifugal pump handling two phase mixtures is focussed in the present work.
2.4) Literature on Computational Fluid Dynamics (CFD) applied to two-phase flow:

The physics in the bubble columns and airlift pump is similar. Shah YT, Godbole SP, Deckwer WD (39) has given a very good review of superficial gas velocities in bubble column. Superficial gas velocity is the average velocity of the gas that is sparged into the column which is, simply expressed as the volumetric flow rate divided by the cross-sectional area of the column. Gas holdup in bubble columns depends mainly on superficial gas velocity. Hyndman CL (40) and Schumpe A, Grund G (41) have reported that for both bubble columns and slurry bubble columns, gas holdup has been found to increase with increasing superficial gas velocity. Although the systems investigated in these studies are quite different from each other, all conclude that the gas holdup increases with increasing superficial gas velocity.

Recently Veera et al. (42) reported an experimental study based on investigation of effect of gas velocity on gas holdup profiles in foaming liquids. They observed that the superficial gas velocity has a large influence on radial holdup profile at high foaming agent concentrations. At present time no literature is available for application of CFD simulation to airlift pump. The clear understanding of the physics of two-phase flow in the airlift pump is only possible with the CFD software. The present work is addressed to the development of two-phase CFD model to understand the of air water flow in airlift pump. The CFD analysis is carried out with the help of ANSYS-CFX software version 5.7.1. The author has received a research grant of Rs. 8.75 lacs from AICTE (TAPTEC Scheme), New Delhi, for establishing the CFD centre at the research laboratory of mechanical engineering department.
The purpose of present investigation is to analyze the two-phase flow and to evaluate the performance for the design of airlift pump. The recent papers without experimental data were of no use in the present work. It is not claimed that the author has processed data from all investigations. It was rather difficult to procure the data from many investigations because quite a large number of such investigations were carried out long ago. The author has tried to procure as much data as possible from

i) The journals available.

ii) The literature available in the library of IIT, Haus Khas, Delhi and IIT, Powai, Mumbai and IISc, Bangalore.

iii) The British Library Services, London

The literature cited at the end of the list on references was extremely helpful to the author in understanding the subject.