STUDIES ON THE FLOW OF NON-UNIFORM PARTICULATE SLURRIES THROUGH STRAIGHT PIPES AND BENDS

by

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श्रीमद् भगवद्गीता

न कर्तृत्वं न कर्माणि लोकस्य सृजति प्रभुः ।
न कर्मफलसंयोगं स्वभावस्तु प्रवर्तते ॥१४॥

अध्याय - ५

***God Determines not the Doership,
nor the Doings of Men, nor Even Their Contact
with the Fruit of Actions;
But It is Nature Alone that Functions.***

**DEDICATED TO MY BELOVED
FATHER & MOTHER**

Shri Gopal Chandra Maheshwari
Smt. Sharda Devi

CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON THE FLOW OF NON-UNIFORM PARTICULATE SLURRIES THROUGH STRAIGHT PIPES AND BENDS"** being submitted by **UMESH KUMAR** to the **Indian Institute of Technology, Delhi (India)** for the award of the **Degree of Doctor of Philosophy in Applied Mechanics** is a record of bonafide research work carried out by him under our supervision and guidance. The thesis in our opinion has reached the requisite standard fulfilling the requirement of Doctor of Philosophy Degree.

The research report and the results presented in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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(Umesh Kumar)

ABSTRACT

The present day knowledge about hydraulic design of slurry pipelines is far from being complete which compels the designers to resort to the expensive, time consuming and material-specific pilot plant studies. Hence, the need arises to carry out extensive research to generate a database covering all aspects of slurry pipeline design to make it an optimum design methodology. Pressure drop besides having the complex dependence on the flow and geometrical parameters is also dependent on the different components used in the pipeline network. The in-depth review of the literature reveals that there is still a large gap in the knowledge for selection of optimised values of hydraulic parameters and hence the present study is aimed to generate some experimental data for the solid-liquid flow in horizontal straight pipelines.

Transportation of coal ash in the thermal power stations which is a combination of fine fly ash particles and coarse bottom ash particles, from the plant to the ash ponds is generally in slurry form using pipelines. Therefore in the first part of the thesis the flow characteristics for solid-liquid mixtures of fly ash, bottom ash and mixture of both in 50 mm, 100 mm and 150 mm NB pipe loops at high efflux concentrations of solids are experimentally evaluated. The measurements show that the pressure drops increases with increase in concentration and the values of pressure drop being lower for larger pipe size. The dependence of relative pressure drop on flow velocity, solid distribution and efflux concentration has also been established. Measurement of concentration distribution in mid-vertical plane for fully developed flow is highly skewed at velocities close to deposition, skewness being

higher for coarser slurry. Skewness in concentration distribution reduces with increase in efflux concentration and at higher efflux concentration it is nearly uniform for fly ash as well as for mixture slurry. The presence of significant amount of fly ash during the transportation of bottom ash makes the solid distribution across pipe cross-section more uniform. Deposition velocity decreases with increase in concentration and the magnitudes of this velocity are higher for coarse slurries.

The second phase of the study is directed towards understanding the mechanism of effect of fine particles in the flow of coarse particulate suspensions (bi-modal slurry). Therefore experimental data for different mix proportions of narrow-sized solids of silica sand and fine solids of fly ash is collected and analysed using a 50 mm NB pipeline pilot plant covering a wide range of efflux concentrations and flow velocities. For narrow-sized particulate slurry, the pressure drop at any given solid concentration increases with increase in velocity and at any given flow velocity, it also increases with increase in solid concentration. For a given efflux concentration, effect of flow velocity on relative pressure drop has also been analysed. For bi-modal slurry, the reduction in pressure drop is relatively lower at higher efflux concentration of 33.9% (by weight) as compared to lower efflux concentration of 20.4% (by weight), the reduction being less pronounced at higher velocities. The results for concentration distribution along the mid-vertical plane for narrow-sized particulate slurry highlight the reduction in skewness in the concentration distribution with increase in efflux concentration, a phenomena also exhibited by flow velocity at any given efflux concentration. Along mid-horizontal plane, the concentration distribution is slightly higher near the wall with parallel increase in concentration with increase in flow velocity at lowest concentration while it becomes more uniform at higher efflux concentration. For bi-modal slurry, the skewness in the concentration profile along the mid-vertical plane, reduces with increase in percentage of fines at any given flow velocity. Increase in flow velocity also reduces skewness in concentration profile along the plane. These effects are more significant at lower efflux concentrations. The concentration distribution for bi-modal slurry in mid-horizontal plane is uniform in the centre of the pipe with slightly higher concentration close to the wall. The coarser fraction in the bi-modal slurry almost follows the same trend as observed for pure coarse solids. The fine particles are uniformly distributed across the pipe cross-section in both the planes irrespective of the efflux concentration and the location. With increase in concentration of fines, uniformity in solid distribution increases at any given flow velocity for the tested efflux concentrations. An increase in the top concentration and decrease in bottom concentration of coarse particles suggest a better suspension medium provided to coarse particles by uniform distribution of fine particles leading to increased viscosity and density of the carrier medium. Marginal drop in the deposition velocity with efflux concentration is observed for the narrow-sized slurry. For the bi-modal slurry also, only minor reduction in deposition velocity is observed with increase in percentage of fines over the range tested.

Pipe bends are an integral part of any pipeline network system as they provide the flexibility in pipeline routing. The performance of conventional bends primarily developed for single-phase flow is checked for two-phase flows in the next part of the present study. The permanent pressure loss across the 90° horizontal circular pipe bends is experimentally analysed by incorporating the straight tangent lengths upstream and downstream of it. This is done to account for the disturbances created as a result of centrifugal force, the generation of secondary flows, gravitational force, particle-particle interaction etc. The flow development and re-distribution of solids downstream of the bend at specified locations is also investigated. The extensive experiments conducted on seven different radius ratio bends (range 0 to 5.9) with water establish the bend with radius ratio of 5.6 as the optimum bend. The permanent pressure loss as a function of efflux concentration and flow velocity for narrow-sized and bi-modal slurry of silica sand and fly ash is established using the optimum bend. The results from single phase flow show that the permanent pressure loss is nearly independent of Reynolds number except at low Reynolds numbers and the bend loss coefficient (k_t) is minimum for a bend having a radius ratio of 5.6 and is highest for the elbow (radius ratio 0.0). The bend loss coefficient values observed for these bends are much higher as these are rough bends. The distance over which perturbations (disturbances) persists is of the order of 40 to 60 pipe diameter downstream of the bend and is nearly same for both cases with no significant disturbance seen on the upstream side of the bend. The flow of narrow-sized as well as bi-modal slurry across the selected test bend reveals that except at lowest efflux concentration tested, the total bend loss coefficient decreases with increase in Reynolds number and increases with increase in efflux concentration. The low values of total bend loss coefficient (k_t) obtained in comparison to water at low Reynolds number may be attributed to the suppression of secondary motions generated in the bend due to the presence of solid particles. However, the substantial increase in k_t for the highest concentration at the lowest flow rate may be attributed to the presence of large number of particles tending to settle just after the bend as the flow velocity is very close to deposition velocity. For the bi-modal slurry, the permanent pressure loss decreases with increase in percentage of fine mix at any given Reynolds number. For bi-modal slurry at any given Reynolds number the bend loss coefficient decreases with increase in percentage of fine mix whereas the disturbances continue only upto a length of 30D to 40D downstream of the bend depending on the mix proportion. For the narrow-sized slurry a higher reduction in k_t value at a fixed mix proportion is observed with increase in efflux concentration. At higher efflux concentration of 33.9% (by weight) increase in percentage of fines does not show any significant change in the value of k_t. Concentration and particle size distribution measured downstream of the test bend at specified locations establishes the phenomena of re-distribution of particles belonging to the two size fractions of the bi-modal slurry. At mid-vertical plane, the re-distribution of solid particles downstream of the bend may be attributed to the interaction of centrifugal force and pressure driven secondary flows which is quite predominant close to the bend and decays with increase in distance. The concentration distribution is more uniform just downstream of the bend and the increased skewness in the concentration profile is observed with increase in downstream distance from the bend. The re-distribution of solid particles along the downstream tangent length of the bend is also seen in the mid-horizontal plane for both mixture as well as individual coarse particles. As in case of straight pipes, the finer fraction of the solid particles is observed to be distributed uniformly across the pipe cross-section at all flow velocities, which basically provides a better suspension medium to coarse particles as a result of increased viscosity making the the re-distribution of particles to decay at much faster rate after the bend. The length required for complete decaying of bend disturbances for narrow-sized silica sand-water slurry is of the order of 50 diameter from the bend exit, which reduces for bi-modal slurry. No effect of bend beyond 50D downstream of the bend is seen from measurements of concentration profiles along the length of the pipe.

In most of the commercial applications, the flow of solid-liquid mixture is in the heterogeneous regime and invariably in the range of asymmetric suspension. The flow under these conditions is quite complicated. Over the last two decades, various improvements have been suggested and incorporated in the existing empirical correlations for improved predictions for pipelines. Hence, in the final part of the thesis Modified Gillies model as proposed by Mishra et al [64] and Modified Karabelas model as proposed by Kaushal et al [9] for pressure drop and concentration distribution respectively for straight pipeline have been used. The comparison of predictions for narrow-sized and bi-modal slurries with experimental results shows a reasonable matching except in the region close to the deposition velocity. The Modified Karabelas model as proposed by Kaushal et al [9] predicts the concentration distribution quite accurately at low solid concentrations compared to the high solid concentrations and for bi-modal slurry the predicted results are reasonably in good agreement for average efflux concentration of 20.4% (by weight). Predictions for an average efflux concentration of 33.9% (by weight) show somewhat higher deviation from the experimental results, which reduces with increase in the percentage of fines. It is concluded that wall interaction effects have to be more realistically incorporated in the flow model to improve the accuracy of predictions.

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