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BREAKAGE OF PARTICLES IN BENDS OF PNEUMATIC AND HYDRAULIC CONVEYING

Dmitry Portnikov[2], Nir Santo[2] and Haim Kalman[1,2]

1. Aaron Fish Chair in Mechanical Engineering – Fracture Mechanics
2. Lab for Conveying and Handling of Particulate Solids, Department of Mechanical Engineering, Ben-Gurion University of the Negev, Beer Sheva 8410501, Israel

The current work concerns experimental investigation of particle breakage in different types of bends during pneumatic and hydraulic conveying. The experiments performed using a hydraulic and pneumatic conveying experimental systems, which consists of 2 inch galvanized steel pipes. Several types of bends were checked, including: regular bends with various R/D ratios, blind T bend with various L/D ratios and flexible bends made of polymer material. By comparing between hydraulic and pneumatic conveying, the results show similar behaviour. The use of blind T bend with deeper pocket will result in less breakage than the regular bend in both conveying systems. The effect of particle velocity on the breakage of salt particles was checked by impact tests in liquid and air. In addition, the strength of dry and wet salt particles was checked by compression tests. It was found that the dry and wet salt particles have the same strength. Moreover, the approach particle velocity during the impact tests in liquid was found to be different from the real impact velocity. The analysis showed that the real impact velocity is half of the approach velocity for salt particles.

KEY WORDS: pneumatic conveying, hydraulic conveying, particle's breakage.

1. INTRODUCTION

Breakage of particles in pneumatic and hydraulic conveying is an important phenomenon that should be considered during design or operating such systems. As the particles being conveyed through a pipeline, they are always subjected to collisions at different velocities and angles resulting the particles to break. It follows that various flow and structural parameters affecting the breakage, such as: fluid velocity, pipeline geometry, different types of bends and etc. Previous experimental studies shows that the air velocity in pneumatic conveying has a major effect on the particle attrition and the most of the damage occurs in the bends (Kalman, 2000; Salman et al., 2002). A similar phenomenon occurs in hydraulic conveying. It is found that a disproportionate amount of particle attrition takes place in pumps, bends and fittings (Wilson et al., 2006). In pneumatic conveying the breakage is dominant with respect to hydraulic conveying since the air velocity is usually much higher than the liquid velocity. Therefore, breakage of particles in pneumatic conveying is a subject with a higher point of interest than in hydraulic conveying, and this is reflected in the number of reported works.

The purpose of this study is to compare the breakage of particles in different types of bends between hydraulic and pneumatic conveying, and try to explain the phenomenon by parameters that affect it.

2. EXPERIMENTAL

The experiments performed using hydraulic and pneumatic conveying experimental systems, which consists of 2 inch galvanized steel pipes. Several types of bends were checked in both systems, including: regular bends with various R/D ratios, blind T bend with various L/D ratios and flexible bend made of polymer material. Figure 1-a shows schematic view of the tested bends. The R/D ratio defines the geometry of the regular and flexible bend as the ratio between the bend radius and internal diameter of the conveying pipe. The blind T bend was designed in such a way that the pocket is adjustable in order to check different pocket depths. The geometry of this bend defined by L/D ratio, where L is the blind T pocket depth. During the experiment, the examined bend is connected in between the horizontal-horizontal pipeline route. The tested particles are inserted into the conveying pipe using a home-made feeder and they pass the route which consist of: horizontal pipe, the examined bend, another horizontal pipe and finally, they are collected using a bag-filter (see Fig. 1-b).

In order to get statistically representative results, every test for specific material, size, velocity and bend type was carried out with a sample of no less than 50 g. Each sample is weighed and sieved before each experiment. Then, the examined material was fed into the conveying pipeline at a specific velocity of the conveying fluid and collected at the filter bag to measure the percentage of broken particles by weight. The process recurs in cycles and only the survived particles are fed again for the next cycle. The air velocity for the pneumatic conveying system is measured using an air mass flow meter and for the hydraulic conveying system, the liquid velocity is measured using a magnetic volumetric flow meter.

3. RESULTS AND ANALYSIS

Figure 2 presents experimental results of percentage of broken particles versus number of cycles the particles pass the examined bend for various types of bends. Figure 2-a shows data of experiments performed in a pneumatic conveying system using salt particles with initial size fraction of +0.71-1 mm, while Fig. 2-b shows data for a hydraulic conveying system using the same material, however, with initial size fraction of +2.38-3.36 mm. Brine was used as the liquid during hydraulic conveying in order to prevent dissolving the salt during the experiments. It is clear that the particle breakage increasing with the number of cycles and is affected by the type of bend that was used. The breakage is also affected by the R/D and L/D ratios. According to Fig. 2-a, as the bend radius R and pocket depth L increases, it results in less breakage. The reason for less attrition in long radius bends is a lower collision angles between the particles and the bend walls. Previous studies showed that the normal collision provides the maximum damage and as the collision angle reduces, it results in less damage to the particles (Portnikov and Kalman, 2017). In addition, by comparing different types of bends, we can conclude that the flexible one provides the lowest damage to the particles, while the regular bend with the shortest radius provides the highest damage. The results obtained in hydraulic conveying are similar. According to Fig. 2-b, regular bend provides the highest damage, while the damage in blind T bend is lower and as the pocket of the blind T bend is deeper, it results in less breakage of particles. In addition, it can be seen that the pocket depth ratio of 1.5 reduces the damage twice after five cycles with respect to regular bend with radius ratio of 6.6.

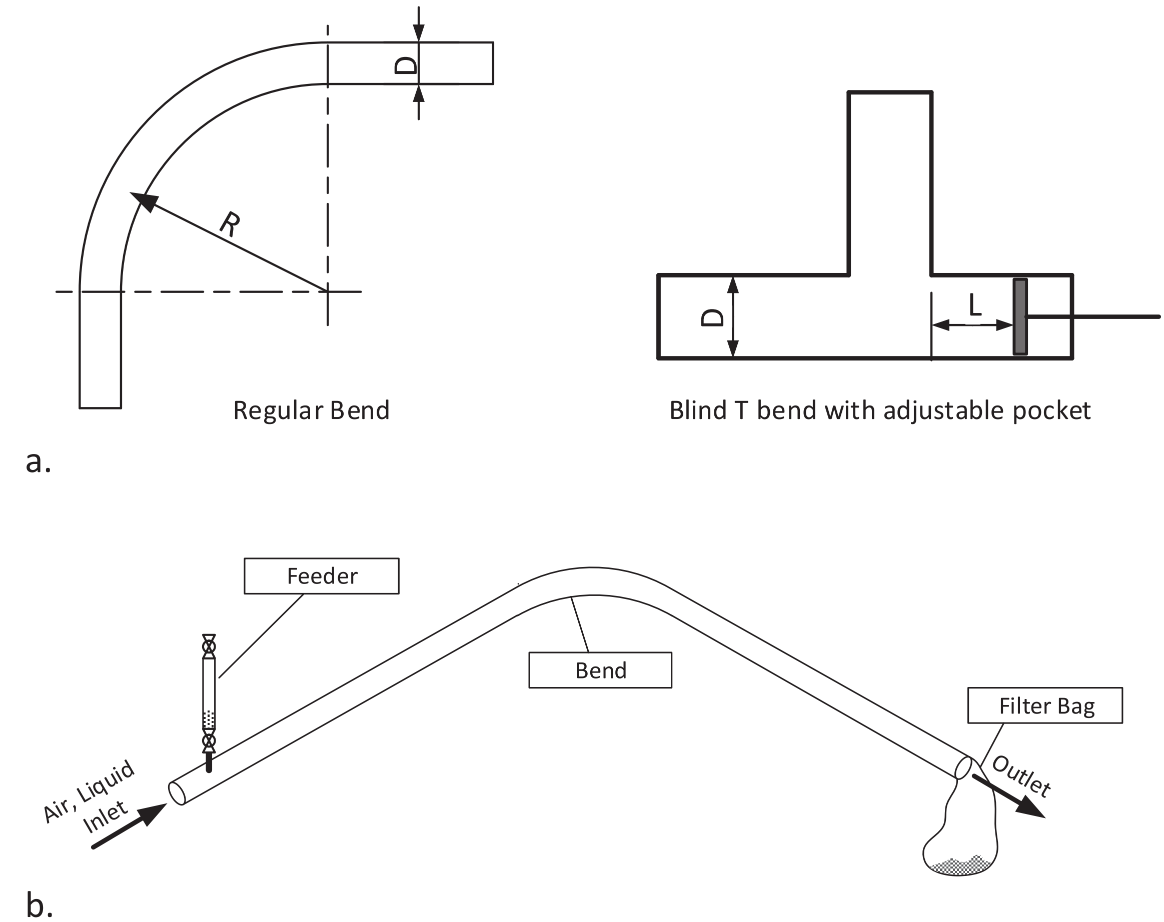
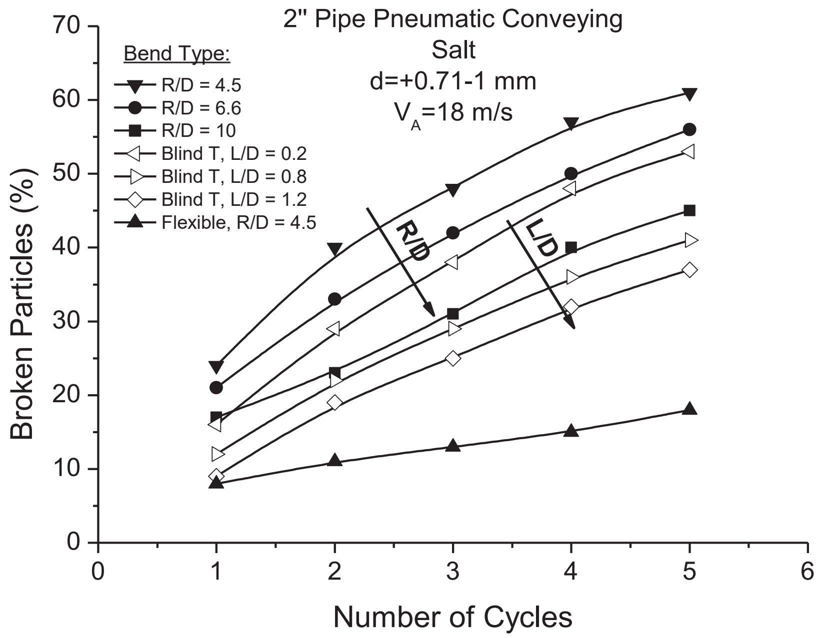
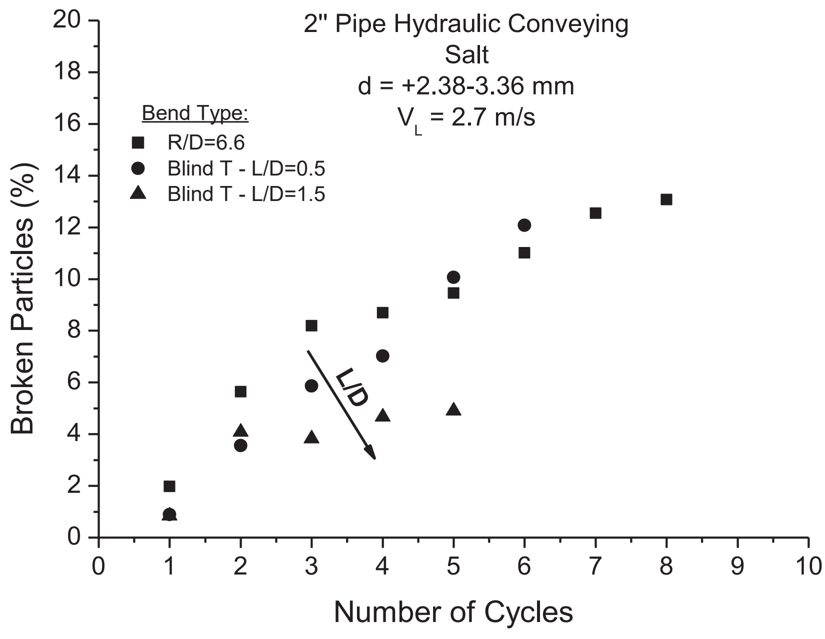


Fig. 1 – Experiment setup. Schematic view of the tested bends (a); concept of the pipeline route for both, pneumatic and hydraulic systems (b).

Using blind T bend in pneumatic conveying is common and based on the reported results above, it provides less attrition to the particles than using regular bends. However, in hydraulic conveying the use of such bends is rare if ever, as it results in higher resistance to the flow and requires higher power consumption than the regular bends. On the other hand, if the attrition of particles in particular system is the main concern, the use of blind T bends in hydraulic conveying should be considered positively.



a.



b.

Fig. 2 – Breakage of salt particles during pneumatic conveying (a) and hydraulic conveying (b) for various types of bends.

Experimental results of particle breakage in bends during pneumatic and hydraulic conveying reported in Fig. 2 shows natural behaviour. This behaviour combines various parameters affecting the breakage, such as: particle velocity, collision angle, particle size and shape and conveying material. In order to isolate one of the parameters, we checked how the impact velocity of normal collision affects the breakage in both fluids: air and liquid. Fallowing this further, Fig. 3 shows experimental data for impact tests conducted with salt particles in liquid (brine) and air. The experiments in air conducted using a home-made impact system (Rozenblat et al., 2012). The system is in fact an air gun, which accelerates the particles towards a rigid target providing normal collision between the particle and the target. The approach particle velocity is controlled and measured using a high-speed video camera and each data point on the chart represents a percentage of broken particles measured for a particular velocity and particle size. The experiments in liquids conducted using a similar experimental system, however, for this case the brine was used as the fluid. It is clear, according to Fig. 3 that as the particle size decreases, the experimental curves are shifted to the right providing higher velocities for the same damage, both for liquid and air. Meaning that smaller particles are stronger. By comparing results between the wet and dry experiments, it is clear that for the same velocity (i.e. the same load), the damage for dry particles is significantly higher.

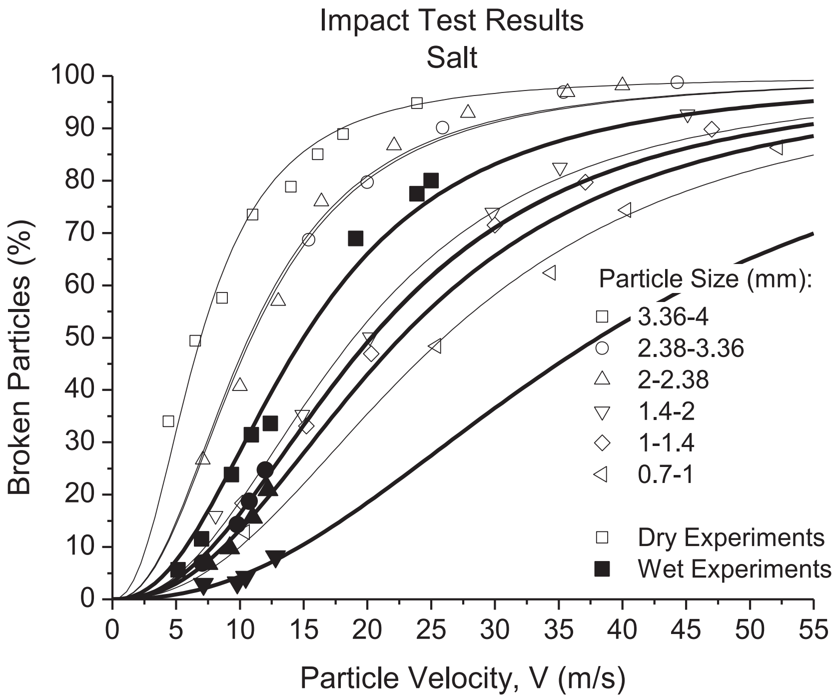


Fig. 3 – Impact test results for salt particles. A comparison between experiments conducted in liquid and air.

At a glance, Fig. 3 shows that the strength of salt particles in liquid is higher than the strength of the same material in air. However, experimental results of strength measured by compression of individual particles shows otherwise. Following this further, Fig. 4 shows experimental results obtained from a single particle compression test. These experiments performed using a home-made compression tester (Portnikov et al., 2013).

The tester is able to measure the quasi static breakage force of individual particles with sizes between 100 μm and 6 mm. During the experiment, the particle is placed between two rigid plates: the upper punch and the lower horizontal surface. The punch is loading the particle with a constant compression force rate until the first breakage appears and the breakage force is measured by a load-cell connected to the lower plate. In addition, the displacement is measured simultaneously by a LVDT sensor connected to the moving punch and the size of the particle is measured then as the height between the two platens at the contact event with the particle. Then, the apparent breakage stress that appears in Fig. 4 is calculated by dividing the breakage force into the cross-sectional area of an equivalent sphere with a diameter of the measured height of the particle. For the wet experiments, the setup of the system was the same, however, the particles were placed in a liquid bath during the entire experiment.

It is clear according to Fig. 4 that the smaller particles are stronger which confirms the previous results. However, the strength of the wet particles is the same as of dry particles which shows a kind of anomaly in respect to the results reported in Fig. 3. One possible reason for that might be that the approach particle velocity measured in wet experiments reported in Fig. 3 is not the real impact velocity. It was observed during experiments in liquid that the stream of the fluid, which accelerates the particles towards a target, creates a thin boundary layer on the target surface. This layer force the particles to decelerate a moment before the impact. Since the deceleration zone is very small, we could not measure the real impact velocity accurately using high-speed camera. However, by comparing the compression test results with the impact test results for both: wet and dry materials, this phenomenon can be analyzed for different materials in further studies.

In the case of salt particles, the strength of wet particles is the same as of dry particles. Meaning that the damage or the percentage of broken particles in impact test results provided in Fig. 3 should be the same for wet and dry experiments. By comparing the percentage of broken particles for the same particle size between wet and dry experimental results, the ratio between the real impact velocity and the measured approach velocity can be found. In the case of salt particles, it was found that the real impact velocity is about half of the measured approach velocity and is not dependent on the particle size.

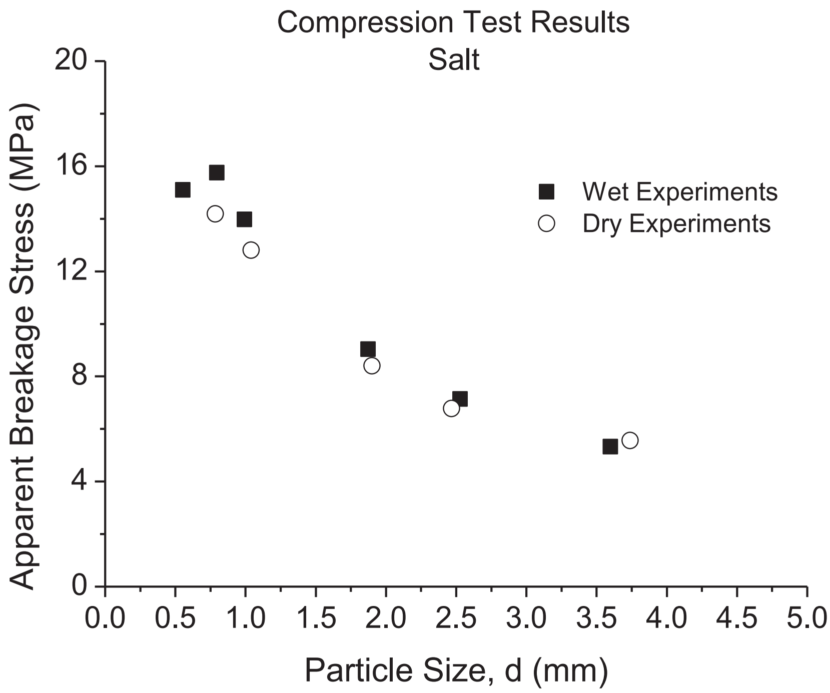


Fig. 4 – Compression test results for salt particles. A comparison between experiments conducted in liquid and air.

4. CONCLUSIONS

In the current study the breakage of particles in bends of pneumatic and hydraulic conveying was tested. The experiments conducted with salt particles and various types of bends, including: regular bends with various R/D ratios, blind T bends with various L/D ratios and flexible bend made of polymer material. By comparing between hydraulic and pneumatic conveying, the results show similar behaviour. Regular bend provides higher damage than the blind T bend and as the pocket of the blind T bend is deeper, it results in less breakage of particles. In addition, it showed that the flexible bend in pneumatic conveying provides the lowest damage. In order to examine the effect of particle velocity, the breakage of salt particles was checked by impact tests with both fluids: air and liquid (brine). Moreover, compression tests performed for measuring the strength of dry and wet individual salt particles. The results show that the dry and wet salt particles have the same strength. Meaning that for the same impact velocity, the damage for dry and wet salt particles is the same. Furthermore, the analysis led to conclusion that the approach particle velocity measured during impact test in liquid is not the real impact velocity. The particles decelerate a moment before the impact due to a thin boundary layer of liquid created on the target surface. It was found that for salt particles the real impact velocity is half of the measured approach velocity and is not dependent on particle size. This phenomenon should be analyzed for different materials in further studies.

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