SLURRY FLOW IN MILLS : GRATE-PULP LIFTER DISCHARGE SYSTEMS (Part 2)

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ABSTRACT

Pulp lifters, also known as pan lifters are an integral part of the majority of autogenous (AG), semi-autogenous (SAG) and grate discharge ball mills. The performance of the pulp lifters in conjunction with grate design determines the ultimate flow capacity of these mills. Although the function of the pulp lifters is simply to transport the slurry passed through the discharge grate into the discharge trunnion, their performance depends on their design as well as that of the grate and operating conditions such as mill speed and charge level. However, little or no work has been reported on the performance of grate-pulp lifter assemblies and in particular the influence of pulp lifter design on slurry transport.

Ideally, the discharge rate through a grate-pulp lifter assembly should be equal to the discharge rate through at a given mill hold-up. However, the results obtained have shown that conventional pulp lifter designs cause considerable restrictions to flow resulting in reduced flow capacity.

In this second of a two-part series of papers the performance of conventional pulp lifters (radial and spiral designs) is described and is based on extensive test work carried out in a 1 meter diameter pilot sag mill.

Keywords
Autogenous, Semi-autogenous, Grate, Pulp lifters, Hold-up.

INTRODUCTION

In the first of this two-part series of papers the flow characteristics of a grate-only laboratory mill was reported. However, in industry, although grate-only mills are found (mostly in South Africa), by far the majority are designed with the addition of pulp lifters. The role of the pulp lifters is to lift the slurry which passes through the grate into the discharge trunnion. They are incorporated in both flat- and conical-ended mills (Figure 1) and are normally either radial or spiral in design (Figure 2).

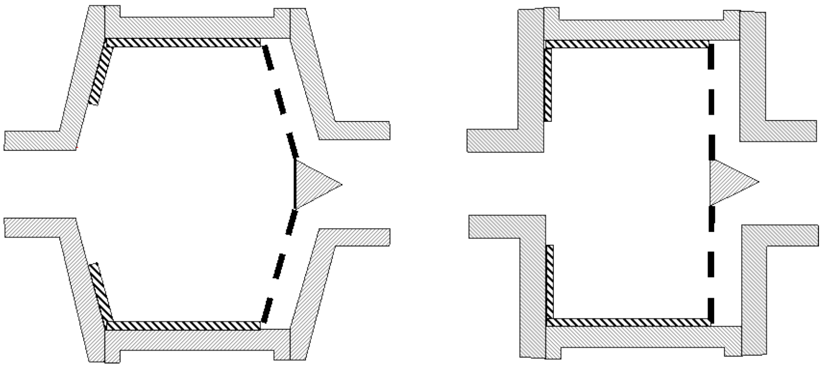


Figure 1 : Schematic of conical and flat ended mills

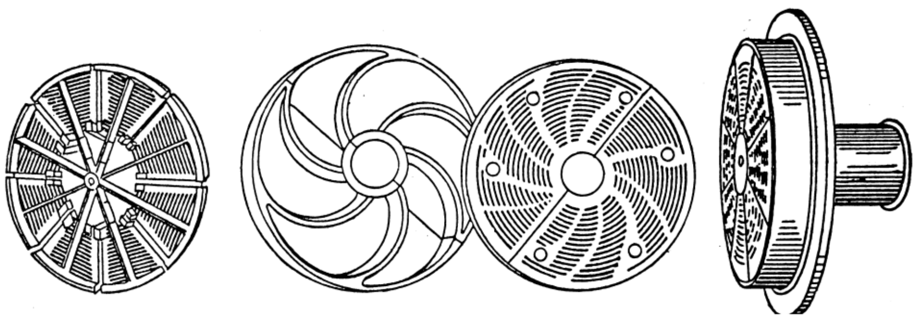


Figure 2: Conventional designs of pan lifters (Taggart, 1945)

Of the above two designs, the radial or straight type is most commonly used in industry. Although pulp lifters are obviously important in determining the ultimate discharge flow capacity, very little work was conducted/reported either on their performance or on their influence on mill efficiency. The exceptions are Mokken et.al., (1975) and Strohmayr (1994). Based on their experience, Mokken et. al., (1975) stated that higher pulp levels would result at higher mill speeds causing reduced pulp gradients. They attributed this to short circuiting. Rowland and Kjos (1975) also stated that the load carrying capacity of pulp lifters is perhaps more important than grate slot area for successful mill operation. A decade later both Bond (1985) and Kjos (1985) reiterated the importance of pulp lifter assembly design and stated that the problem associated with them was yet to be solved.

As with Mokken et al, Strohmayr (1994) observed differences in the actual and theoretical flowrates of pan lifters (based on its physical dimensions) in his tests, which were conducted with radial pulp lifters in a laboratory mill. He also attributed this to short-circuiting.

To provide quantitative data to asess pulp lifter performance, extensive tests were conducted using a wide range of conditions.

EXPERIMENTAL SET-UP

The mill used for the testwork programme was 1m in diameter and 0.5m long. Power was delivered from a 18.5 kW motor via a variable speed gearbox which provided a speed range of 7-42 rpm. Feed to the mill was supplied by a steady-head tank. Flow from the tank to the mill was controlled by two knife gate valves - one just below the feed tank to vary the flowrate, and the other near the feed trunnion to stop the flow into the mill when required. A Warman vertical sump-pump with a discharge capacity up to 12 l/sec was mounted on the sump of 900 litres capacity with a by-pass valve to control the flow into the feed tank. The mill discharge flowed into the sump through a movable launder fixed below the discharge cone (Figure 3).

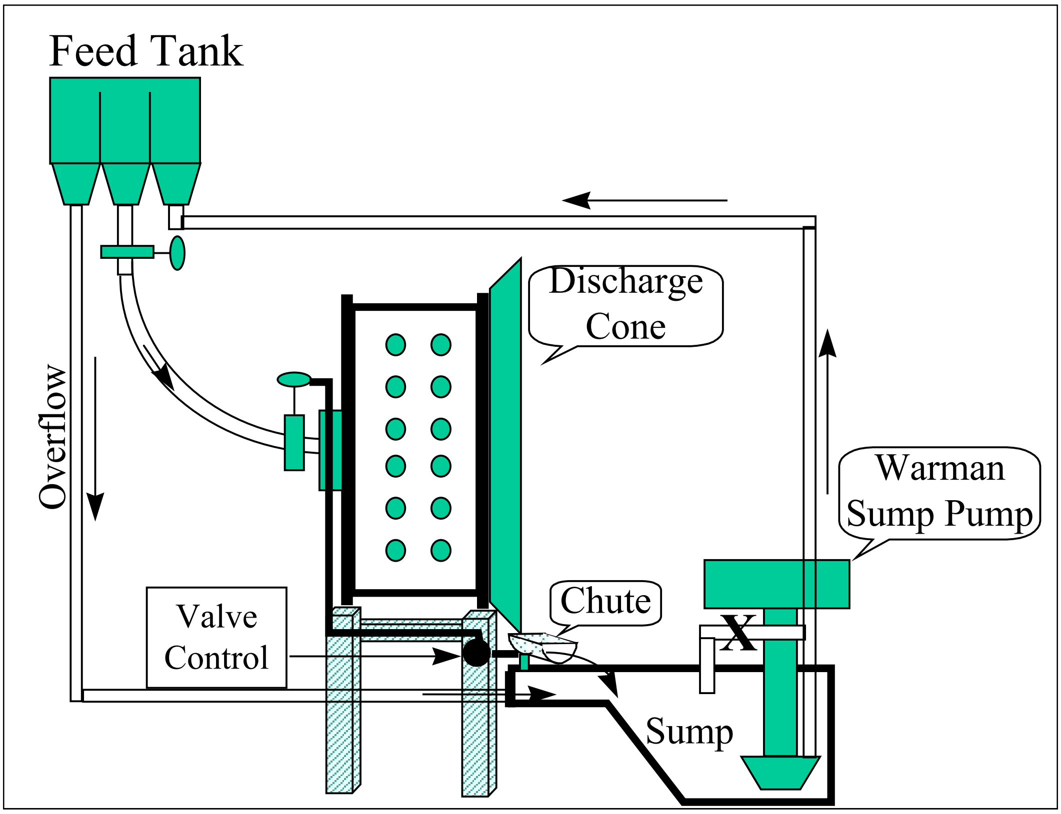


Figure 3 : Schematic of experimental set-up

Both the movable launder and the knife-gate valve near the feed end trunnion were operated pneumatically and controlled by solenoid valves. This arrangement enabled the flow to the mill to be stopped and at the same time the discharge from the mill could be diverted to a measuring container.

Discharge grate and pulp lifters

The grates were made of 6 mm thick steel plate with 3 mm thick rubber lining to reduce the impact of the 25mm balls which were used as grinding media. The number and relative radial position of the holes on the grate are given in Table 1.

Table 1: Position of holes on grate used in pilot mill.

Row No.	Relative Radial Position	No of Holes
1	0.933	80
2	0.867	80
3	0.800	64
4	0.733	64
5	0.667	48
Total		336

A complete pulp lifter assembly consisting of 16 segments was fixed to the grate. Three different pulp lifter depths and two designs were used. A 25 mm thick transparent acrylic sheet was used as the discharge end plate to enable passage of fluid through the pulp lifters to be viewed. Pictures of radial and curved pulp lifters that were used in the test work are shown in Figure 4.

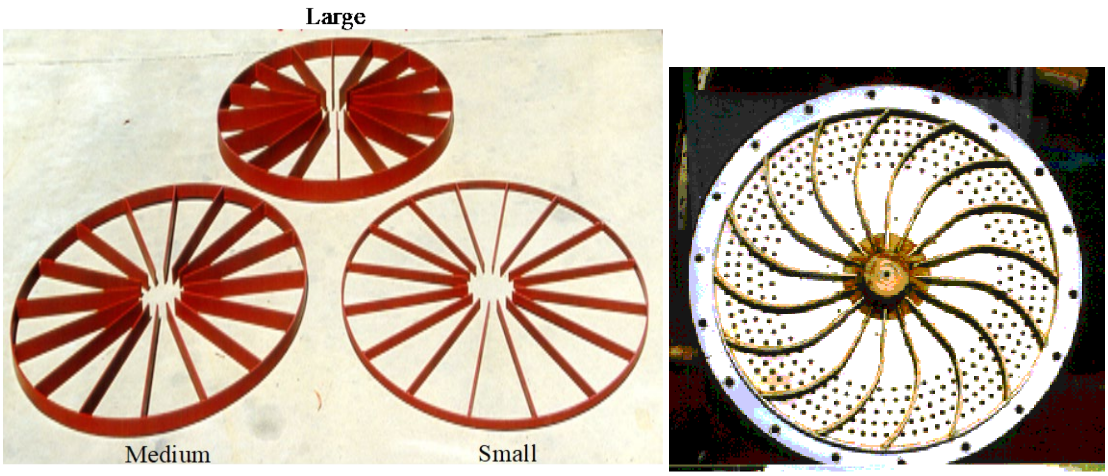


Figure 4: Radial and curved pulp lifters used in pilot mill.

To conduct an experiment the designated grate and pulp lifter were first fixed to the mill discharge end. After filling the mill with the given volume of charge, water was pumped to the feed tank from where it gravitated into the mill. The flow was adjusted using the valve below the feed tank and the flowrate measured using a bucket-and-stop-watch method. The mill was then started at the required speed and allowed to reach steady state. After steady-state conditions were reached the mill was crash stopped and the water inside the mill collected in a drum set on an electronic balance. This was done by closing the knife-gate valve near the feed trunnion and diverting the discharge launder towards the sampling drum at the same time as crash-stopping the mill. The left-over water inside the mill was drained off into the same drum through a drain valve in the mill shell. The mass of the total water is reported as the instantaneous hold-up in side the mill. This procedure was repeated over a range of flowrates for different grate/pulp lifter combinations, charge levels and speeds.

ASSESSING THE PERFORMANCE OF PULP LIFTERS

Since the function of the pulp lifters is to transport the slurry which passes through the grate out of the mill, the maximum flowrate possible with pulp lifters will be equal to that of a mill operating with only a grate (at the same hold-up). Hence to assess the performance of pulp lifters, experiments were conducted with and without pulp lifters over a range of flowrates and the results were analysed with the help of graphical plots as illustrated in Figure 5.

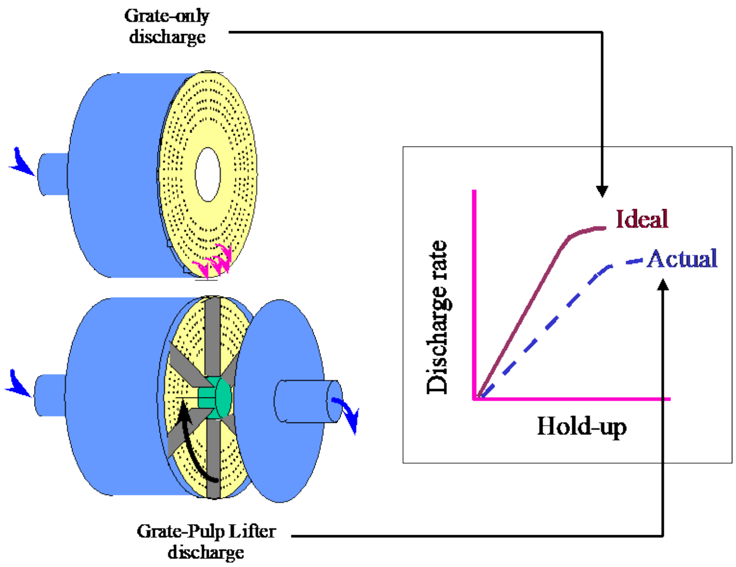
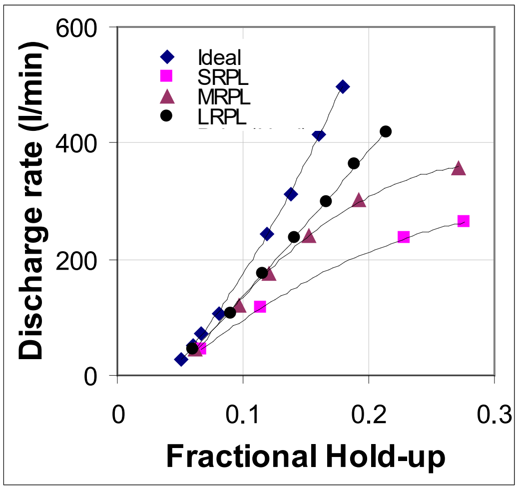


Figure 5 : Concept of assessing the pulp lifter performance

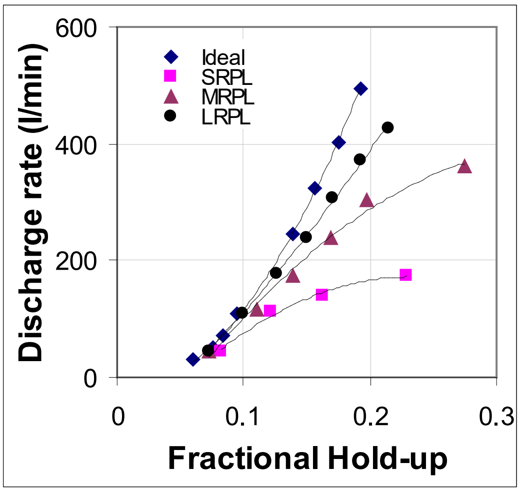
The relationship between hold-up and flowarte (discharge rate) obtained with the grate-only discharge system gives the maximum possible discharge rate that can be obtained at a given hold-up and hence is called the 'ideal' relation. If the pulp lifter has sufficient capacity, the hold-up-discharge rate line of the grate-pulp lifter discharge system will coincide with that of the grate-only discharge line. If not, it will deviate from the grate-only discharge line. The degree of deviation indicates the inefficiency of the pulp lifters in transporting the slurry that passes through the grate. Based on this procedure, the performance of the pulp lifters was assessed and is discussed in the following sections.

PERFORMANCE OF RADIAL PULP LIFTERS (RPL)

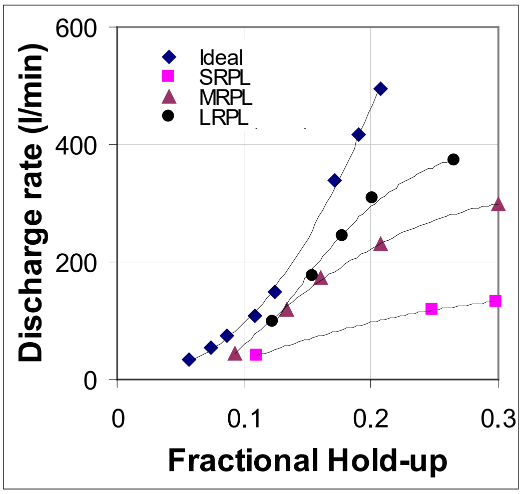
The experimental results obtained with different sizes of radial pulp lifters are plotted together with the results of grate-only discharge system (ideal) as illustrated in Figure 6. At all the operating conditions it was found that the discharge rate with pulp lifters was always significantly lower than the discharge rates under ideal condition i.e., the grate only system.



(a) Mill Speed - 52% critical



(b) Mill Speed - 70% critical



(c) Mill Speed - 89% critical

Figure 6: Comparison of pulp lifter performance with grate-only (Ideal) condition at 30% of charge volume and 7.05% of grate open area

(SRPL-Small Radial Pulp Lifter; MRPL-Medium Radial Pulp Lifter; LRPL-Large Radial Pulp Lifter)

The following three observations can be concluded from Figure 6:

- In none of the conditions does the discharge rates of pulp lifters match with the grate-only discharge rates
- The performance of the pulp lifter improves with increasing size of the pulp lifter
- The performance of the pulp lifter deteriorates with increasing mill speed

The large difference in discharge rates with pulp lifters and the grate-only system can be attributed to 'short-circuiting' as mentioned by Mokken el al (1975). They suggested short-circuiting was due to carry-over. However, visual observation during experimentation showed that carry-over occurs only at higher mill speeds. The significant deviation even at lower mill speeds suggest that there is another important factor responsible for short-circuiting of slurry. This was hypothesized as ***flow-back*** (Latchireddi and Morrell (1997).

The flow-back phenomenon can be illustrated using the picture taken during the test work as shown in Figure 7. Three stages of transportation are evident. They are flow of fluid through grate holes into the pulp lifter chamber, accumulation of fluid within the pulp lifters and flow of fluid from the pulp lifters in to the central discharge cone.

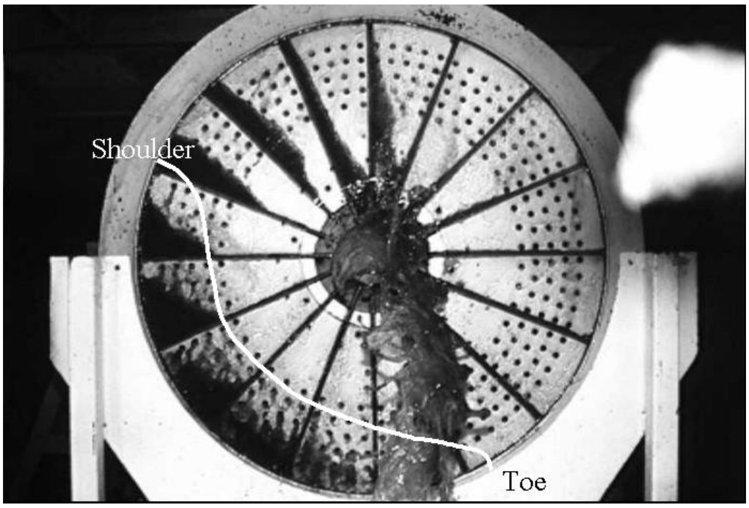


Figure 7 : Process of slurry flow in grate-pulp lifter discharge system

When the mill rotates the grinding media charge typically takes the kidney shape as depicted in Figure 7, whilst the fluid is held in its interstices. Flow of fluid through the grate can be observed from the holes that are exposed to the active charge. Each segment of the pulp lifter, when it first passes through the toe region of the charge, starts receiving which accumulates until it reaches the shoulder position. Once the pulp lifter crosses the shoulder position, the fluid inside the pulp lifter begin to flow down the radial face towards the mill centre due to the dominance of gravitational force.

However, it should be noted that once the grate/pulp lifter segment moves above the shoulder position, the media or charge filled with slurry will be no longer present against the face of the grate inside the mill. This creates a pressure head across the grate from the pulp lifter into the mill, which makes the slurry in the pulp lifter flow back into the mill via the same holes through which it first entered. This phenomenon is called ***flow-back.*** As can be seen from Figure 7, the contents inside the pulp lifter are always in contact with the grate till they get discharged into the trunnion, and hence flow-back becomes inevitable. As the mill speed increases, the gretaer influence of centrifugal force causes discharge to occur later leading to carryover of a fraction of the fluid (Figure 8). This is discussed further in subsequent sections.

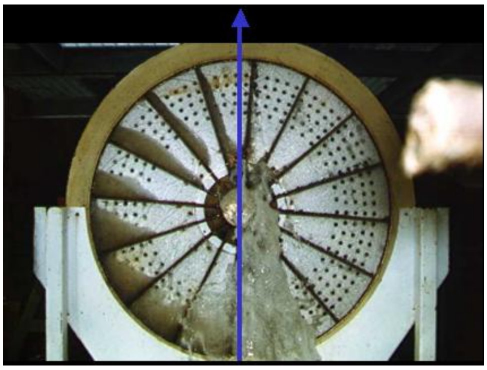
Whether it is flowback or carryover, both lead to inefficient operation of the pulp lifters in transportating of slurry passing through the grate out of the mill. The difference in discharge rates through grate and pulp lifters at any given hold-up can be taken as the total inefficiency of the pulp lifters.

Influence of pulp lifter size on its performance

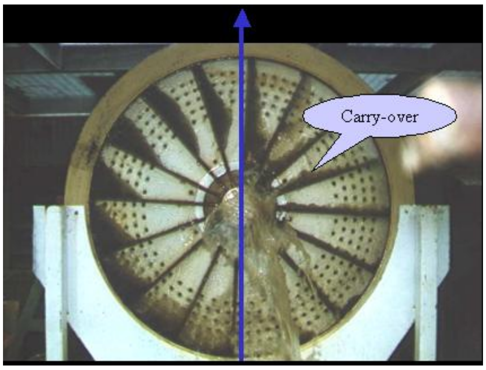
It can be observed from Figure 6 that at a given hold-up the discharge rate increases with increasing size of pulp lifter (ie depth). However, in no case was it found that the pulp lifter discharge capacity matched that of the grate. It can also be observed from Figure 6 that the smaller pulp lifter tended to a limiting capacity beyond which it was not possible to discharge further regardless of the hold-up. The improved performance of the pulp lifters with increasing size can be explained by the fact that at a given flow through the grate the height of the fluid level inside the pulp lifter reduces with increasing lifter depth. This reduced height increases the pressure head across the grate from the mill to the pulp lifters and at the same time reduces the number of holes available for flowback to occur.

Influence of mill speed on performance of pulp lifters

The mill speed plays a significant role in the performance of pulp lifters in discharging the slurry as well as in the grinding process itself. The significant variations with speed of the fluid flow profiles in each pulp lifter section is shown in Figure 8.



(a) 70% of critical speed

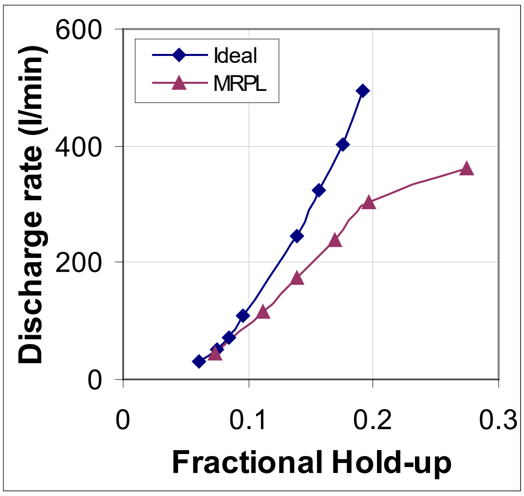


(b) 89% of critical speed

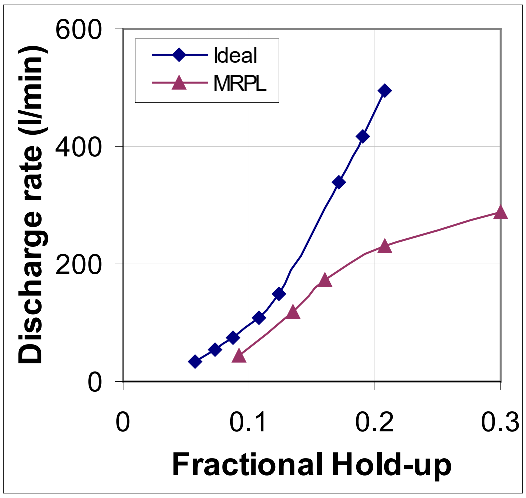
Figure 8 : The influence of mill speed on performance of radial pulp lifter

With radial pulp lifters in use, at 70% of critical speed the contents of the pulp lifter are almost all discharged by the 12 O'clock position (Figure 8a). However at 89% of critical speed, the contents of the pulp lifter only just starts discharging into the central cone after the 12 O'clock position leading to carry-over of a fraction of slurry (Figure 8b). However, the carried over fraction ultimately flows back into the mill.

The quantitative variation in performance of the pulp lifter with increasing mill speed is given in Figure 9. The degree of deviation between the grate-only and grate-pulp lifter lines increases with increasing mill speed is clearly observed.



(a) 70% of critical speed

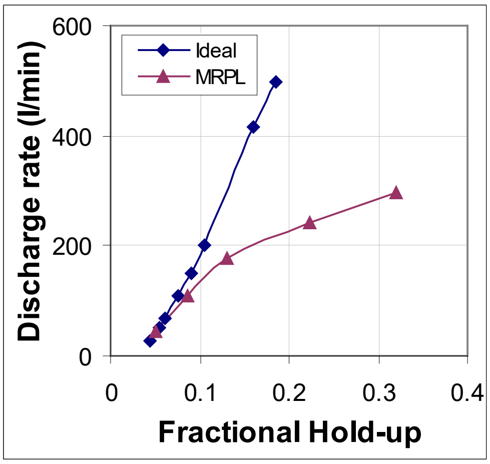


(b) 89% of critical speed

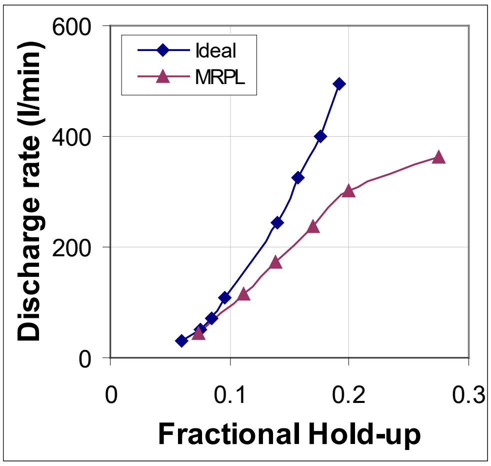
Figure 9 : The inefficiency of radial pulp lifters at different mill speeds (Medium size RPL, 30% charge volume, 7.05% grate open area)

Influence of charge volume on performance of pulp lifters

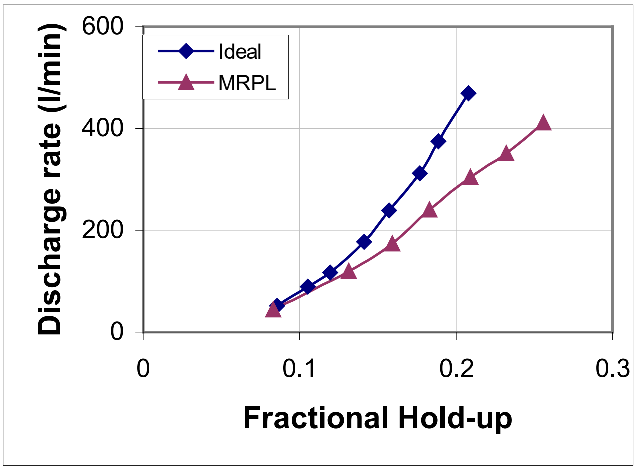
Figure 10 shows the influence of charge volume on the discharge rate. An improvement in performance of the pulp lifter was found when increasing charge volume from 15% to 30%. The increased charge volume increases the cross-sectional area of the grate that will be covered by the charge (and associated fluid), thereby limiting the amount of open area available for flowback. However, with further increase in charge volume to 45%, only a marginal improvement was observed as there were no more grate holes that could be effectively covered to reduce flow-back.



(a) 15% of charge volume



(b) 30% of charge volume



(a) 45% of charge volume

Figure 10 : The influence of charge volume on performance of radial pulp lifter (Medium size RPL, 70% of critical speed, 7.05% grate open area)

This influence of charge volume on the performance of pulp lifters is schematically illustrated in Figure 11 for better understanding.

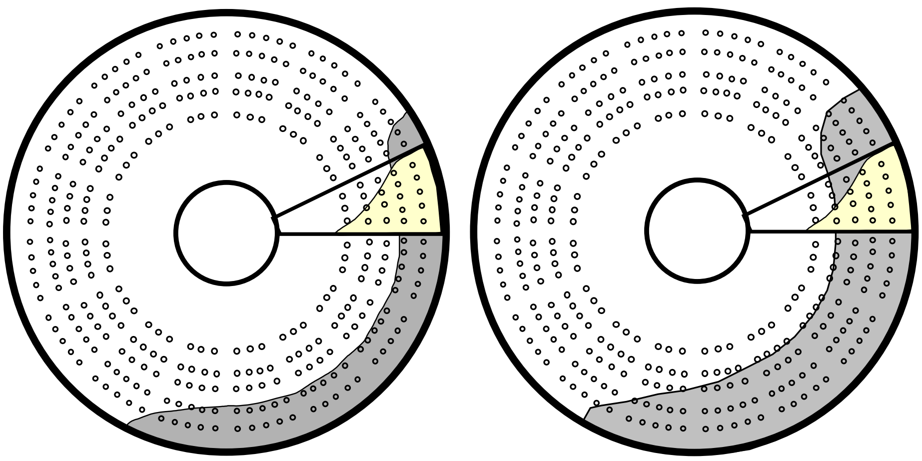
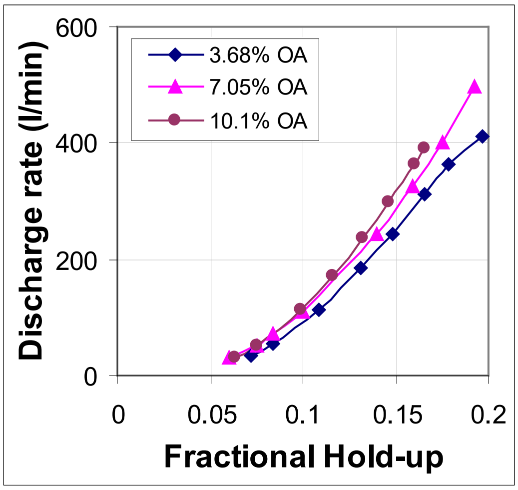


Figure 11 : The schematic of the fluid profile in pulp lifter relative to the charge profile (low and high charge volumes)

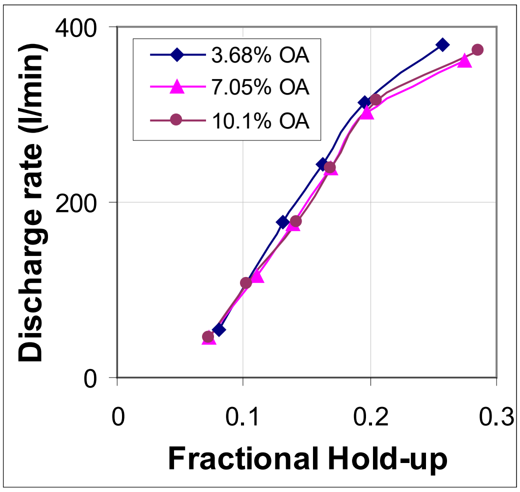
The schematic of the fluid profile in the pulp lifter relative to the charge profile (Figure 11) clearly illustrates that the number of grate holes (outside the charge profile) that are exposed to the fluid in the pulp lifter are far less in the case of a higher charge volume. The amount of flowback is proportional to the number of holes that are exposed to the fluid in the pulp lifter. This is the reason for the increased discharge rates with increase in charge volume.

Influence of grate open area on performance of pulp lifters

In flow through an orifice, the discharge rate is directly proportional to the area of the orifice. Similarly, in case of flow through grate, which is made of many orifices, the discharge rate is expected to increase with increasing grate open area. This has been observed at all conditions with a grate-only discharge system (Figure 12a).



a) grate-only discharge

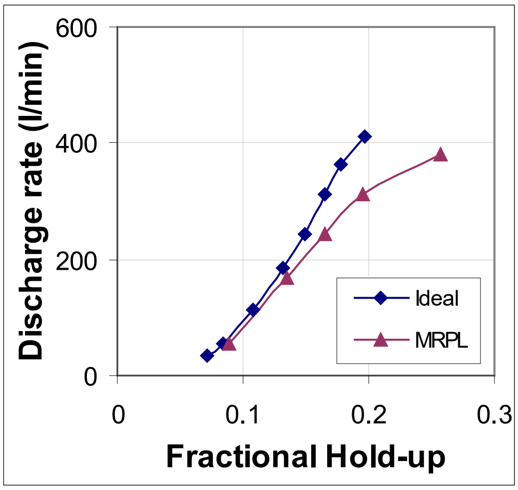


b) grate-pulp lifter discharge

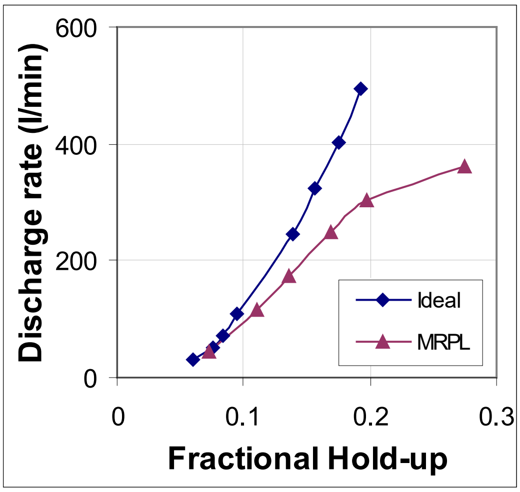
Figure 12 : Influence of open area on discharge rate through the grate-only and grate-pulp lifters with medium size radial pulp lifter (MRPL)

However, with the pulp lifters fitted, the discharge rate was found to marginally decrease up to 7.05% open area and then remained constant with further increase in open area (Figure 12b). This is because of the fact that while the increase in open area helps in providing a higher discharge through the grate, the same open area allows higher flow back of fluid into the mill giving rise to a lack of overall response. As the open area increses the extent of flowback increases at a higher rate than flow from the grate into the pulp lifters. This is seen more pronouncedly from Figure 13, where the hold-up and discharge rate lines are shown independently with the respective grate-only (ideal) line for different open areas. The increased deviation of pulp lifter line (MRPL) from the grate-only (ideal) line indicates the deteriorating performance.

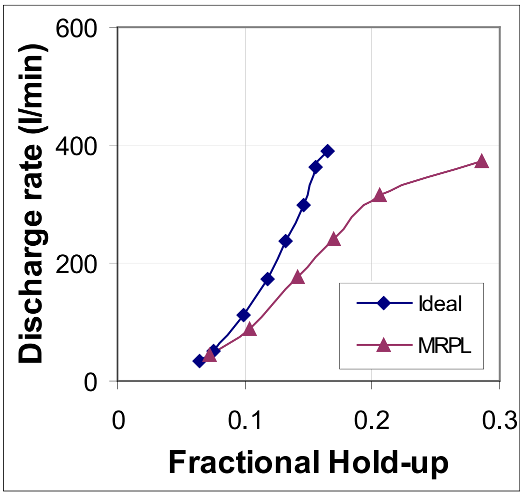
Although similar trends were observed at other operating conditions, the performance of pulp lifters was observed to be better at higher charge volumes and inferior at lower charge volumes. This is once again due to the cross sectional area of charge that covers the grate and helps in reducing flow-back.



(a) 3.68% Open area



(b) 7.05% Open area

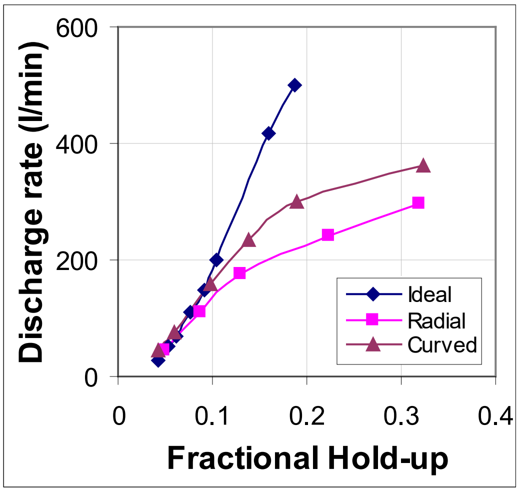


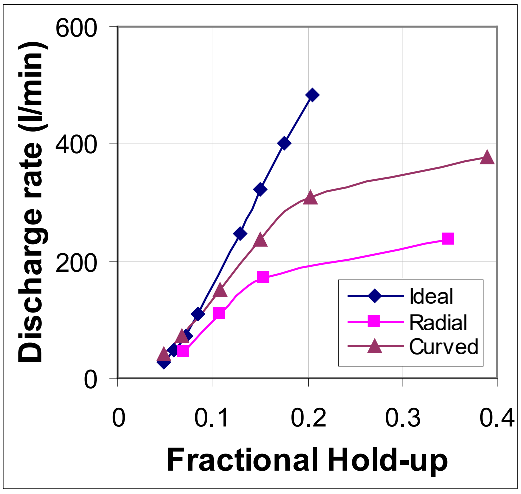
(c) 10.1% Open area

Figure 13 : Influenc eof open area on performnace of medium size radial pulp lifters (MRPL) - 30% charge volume and 70% of critical speed

Performance comparison of radial and curved pulp lifters

To compare the performance of curved pulp lifters with that of radial design, tests were conducted with medium size of curved pulp lifter at different mill speeds and charge volumes. Comparing the results obtained, it was found that, irrespective of the test conditions, the discharge rate of the curved lifters was always higher than that of the radial design. However, the trends between hold-up and discharge rate remained the same in terms of deviation from the ideal line. The hold-up-discharge rate relation at 15% charge volume for both radial and curved pulp lifters are shown in Figure 14.





(a) 70% critical speed (b) 89% critical speed

Figure 14: Performance comparison of radial and curved pulp lifters

The better performance of the curved pulp lifters is due to the faster discharge of the fluid from the pulp lifter towards the trunnion (Burgess, 1989) which is due to its shape. However, the discharge rates of curved pulp lifters were not found to match those of grate only operation.

The above discussion leads to the conclusion that inefficiency due to flow-back is inevitable in either of the conventional pulp lifter designs as the slurry, once passed through the grate holes, always remains in contact with the grate until it is discharged into the trunnion.

SUMMARY AND CONCLUSIONS

The slurry transportation in ag/sag mills is a two-stage process consisting of flow through the grate and the discharge of slurry by pulp lifters into the discharge trunnion. The grate-only discharge condition provides the ideal relation between slurry hold-up and flowrate. By attaching pulp lifters to the grate, the ideal hold-up-flowrate relation is not maintained. The resultant deviation depends on the inefficiency of pulp lifters in transporting the slurry passing through the grate into the discharge trunnion.

The results obtained from the test work clearly demonstrated that even with relatively large pulp lifters the discharge rate through grate-pulp lifter assemblies is considerably lower than that using the grate-only system.

The lower discharge rates in grate-pulp lifter assemblies is due to the inherent drawbacks in both radial and curved pulp lifter design which allow a proportion of the slurry to flow-back into the mill before it is discharged. At higher mill speeds (typically >80% of critical speed) in addition to flow-back, part of the slurry is carried over inside the pulp lifter, which further reduces the discharge rate.

Although curved pulp lifter are found to perform better compared to radial pulp lifters in transporting slurry, their performance did not match the ideal performance as given by the grate-only discharge system.

Since the slurry in pulp lifters is always in contact with the grate, flow-back is unavoidable in both radial and curved pulp lifters leading often to higher hold-up values inside the mill. This may cause a slurry pool which has adverse effects on the grinding performance (Morrell and Kojovic, 1996).

ACKNOWLEDGEMENTS

The authors are grateful to ANI Mineral Processing for providing the pilot sag mill. The fellowship provided by AusAID and the financial support of the sponsors of the AMIRA P9L project are gratefully acknowledged.

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