

ABSTRACT

Improvements in the InLine Pressure Jig Expands its Applications and Ease of Use for Gold, Silver, Sulphide and Diamond Recovery

Authors: Gray, S., Hughes, T.

The Gekko InLine Pressure Jig (IPJ) was unleashed on the World gravity separation market in 1996 and has since sold over 150 units in applications including tin, diamonds, silver, coal, garnet and gold. During the past twelve years the knowledgebase of the best applications and capabilities of the IPJ has greatly increased. Improvements to the original IPJ design have included engineered ceramic ragging in s.g.'s from 1.6 to 5.0, full automation and improved designs of feed presentation and tailings and concentrate handling systems. The IPJ has been found to be able to handle a wide feed size range and recover mineral at liberation size without significant addition of water to the mass balance. Test work carried out during full-scale operation of the IPJ has shown the IPJ can recover diamonds down to 0.5 mm, sulphides down to 0.3mm and gold down to 0.1mm which greatly expands its application in the mineral processing industry. A significant volume of data now supports the symbiotic benefits of an IPJ and flotation circuit combination to pre-concentrate an ore and minimize downstream processing requirements.

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The Gekko InLine Pressure Jig (IPJ) was unleashed on the World gravity separation market in 1996 and has since sold over 150 units in applications including tin, diamonds, silver, coal, garnet and gold. During the past twelve years the knowledgebase of the best applications and capabilities of the IPJ has greatly increased. Improvements to the original IPJ design have included engineered ceramic ragging in s.g.'s from 1.6 to 5.0, full automation and improved designs of feed presentation and tailings and concentrate handling systems. The IPJ has been found to be able to handle a wide feed size range and recover mineral at liberation size without significant addition of water to the mass balance. Test work carried out during full-scale operation of the IPJ has shown the IPJ can recover diamonds down to 0.5 mm, sulphides down to 0.3mm and gold down to 0.1mm which greatly expands its application in the mineral processing industry. A significant volume of data now supports the symbiotic benefits of an IPJ and flotation circuit combination to pre-concentrate an ore and minimize downstream processing requirements.

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INTRODUCTION

The InLine Pressure Jig (IPJ) was commercialised in 1996 for the purpose of recovery of heavies from a slurry stream into a variable yield of between 0.5 and 50% mass.

The use of the InLine Pressure Jig has been widespread across many mineral types including gold, sulphides, tin, coal and diamonds.

This has included installations across the world in over 20 countries. Many of these installations have suffered from issues such as poor installation, poor operation and variable setup in the initial commissioning phase. In most cases the IPJ itself has had very few operational or maintenance issues. Generally it is the peripheral equipment and installation which has affected the IPJ's performance.

Some of the latest IPJ installations have proven to be exceptional performers and, based on the learning from the last 12 years, have come into their own with regards to installation and operation. This is despite the physical dimensions of the IPJ and design ratios remaining the same.

This paper will seek to show some of the ways in which this learning has been developed into a winning formula and that a properly installed and operated IPJ can produce outstanding results on a range of ores.

THE INLINE PRESSURE JIG (IPJ)

The InLine Pressure Jig has been described in numerous papers (Gray, 1997) and a brief summary is given below.

The IPJ is unique in its design and use of jiggling concepts. The unit combines a circular bed with a moveable sieve action. The screen is pulsed vertically by a hydraulically driven shaft. The length of the stroke and speed of the up and down stroke can be varied to suit the application. Screen aperture, ragging dimension and ragging material can also be altered for the application. An overview is shown in Figure 1 below.

Inside the IPJ, the particles are kept submerged in the slurry thus eliminating any hydrophobic issues which sometime occurs with fine particles at the air/slurry interface of conventional jigs. The submerged slurry also acts as a pseudo heavy media suspension above the jig bed greatly assisting the separation performance of the IPJ.

The IPJ is a compact, low cost continuous process that requires minimal infrastructure or logistical support. In addition to its low capital cost, it has very low operating costs per volume treated and very low power requirements. Hutch water can be supplied from the ocean, river, boreholes, thickener overflow, de-sliming cyclone overflow (up to 5% solids wt/wt) or slimes dam return. The IPJ requires as little as 10% of the water consumption of traditional jigs.

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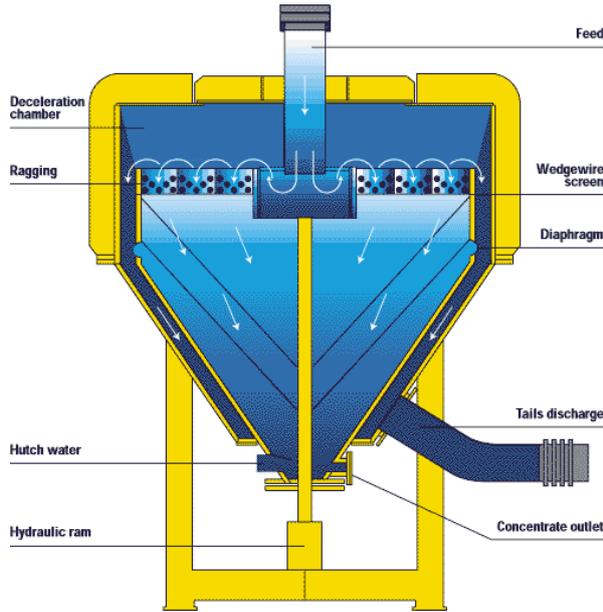


Figure 1: IPJ cross sectional view.

Separation of valuable minerals from gangue particles occurs based on relative density as well as particle size and shape. High specific gravity particles are drawn into the concentrate hutch during the suction stroke of the bed and are continuously discharged. The lighter gangue is continuously discharged over the tailboard to the outer cone.

The IPJ comes in 4 sizes with capacities as shown in Table 1.

Table 1: IPJ specifications.

Specifications	600	1000	1500	2400
Maximum feed rate (tonnes per hour)	1.5 - 3	15 - 25	35 - 50	80 - 100
Maximum particle feed size (mm)	6	20	20	50
Hutch water flow rate (m ³ /hr)	2.0	10 - 20	15 - 35	15 - 50
Typical yield to sinks/concentrate (tonnes per hr)	0.6	1 - 4	5 - 8	5 - 40
Dimensions (all mm)				
Overall Height	1300	2105	2500	3200
Footprint Diameter	800	1350	1800	2500
Screen Diameter	520	1030	1330	2000

THE LEARNING

The key to operating success can be broken into several categories which have been individually resolved by design and training. A combination of site trials, specific observation and customer surveys has helped to highlight the key concern areas. Site trials have been carried out on many sites and in many mineral types. Observation of site operations by the Gekko Technical team has included visiting almost all operating and non-operating sites in order to ascertain the “good” and the “bad” in all installations. Customer surveys were carried out in 2003 and 2006 which highlighted the fact that many IPJ installations were let down by their installation and/or operation. This meant that many installations were not able to reach their maximum potential due to engineering shortfalls or operator training.

Flowsheet Development

Engineering the IPJ into a circuit requires know-how and specific design skills. Historically issues relating to the materials handling of coarse slurries made installation difficult. These included settling, flushing and materials of construction. Early installations were prone to blocking and wear in the pipe work. Ensuring proper physical layout of the unit is critical in the success of the installation. Careful selection of materials and the layout for pipe work will ensure high availability.

There are two main applications of the IPJ:

- Concentrating in mill re-circulating loads
- Pre-concentration
- Rougher/Cleaning/Scavenging

Concentrating in mill re-circulating loads

The critical issue is to engineer a relatively high re-circulating load with a low amount of breakage in a single pass through the crusher or mill, thereby preserving the size of the mineral particles for more efficient recovery. The IPJ will recover well in the range from 5mm down to 100µm. This means that the target is to keep the mineral liberation at or above 100µm. The IPJ is one of the very few devices which will recover across this wide a feed size range. This allows for efficient recovery in the critical size range for most minerals Gekko have tested. Even though unit recovery drops in the finer size range it is important to note that the coarse mineral tends to liberate first and is recovered at a coarse size very easily whereas the fine mineral tends to take longer to liberate and so has an apparent recovery drop-off although it actually re-circulates more in order to achieve liberation and consequently recovery.

Initially the IPJ was marketed as a free gold recovery device installed in gold mill recirculating loads. The emphasis was on the recovery of free gold into a high grade stream which could then be further upgraded by a small centrifugal concentrator - called “super-charging the feed”. The IPJ with its ability to operate under pressure was installed in the cyclone feed line or cyclone underflow line and the pressure provided by the feed pump and/or head height was used to push the products to their final locations eg. Concentrate to a centrifugal concentrator, tailings to the ball mill feed (see Figure 2).

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Figure 2: Installation of an IPJ with the tailings being pushed above the IPJ using the feed pressure.

Whilst this installation was simple to retrofit, it was plagued with numerous operational issues related to the coarseness of the slurry feed and flow interruptions blocking the discharge lines from the IPJ resulting in downtime for the IPJ and/or milling circuit. The feeding of mill discharge slurry which contained significant amounts of steel from worn grinding media caused issues in the bed of the IPJ and further settling issues in the pipelines. Most of these issues were resolved with the invention of the Gekko MagScreen (Gray, 2004) which magnetically separated the steel and screened the slurry before it entered the IPJ.

Also, whilst the IPJ is still installed in the circulating load of a grinding mill or fine crusher, the products are now pumped to their final destination and incorporate automatic dump lines and water addition to keep the product lines clear (see Figure 3).



Figure 3: Two IPJ's installed in a gold and sulphide recovery application with products pumped.

Pre-concentration

In a lot of industries, especially alluvial gold and diamonds, the IPJ has been used to pre-concentrate screened run-of-mine ore to upgrade the ore feeding downstream processes such as Dense Media Separation (DMS) plants (Davidson et al, 2006). Initial installations again used the feed pump pressure to drive the products to their final destinations. This was still a problem as the feed to diamond jigs in particular are generally very coarse, up to 30mm, and the size distributions are truncated with the -2mm screened out resulting in fast settling and hard to fluidise slurries. The feeding systems to these circuits were also very stop/start resulting in over and under feeding of the IPJ's.

These issues have now been overcome by the use of gravity feed systems to remove the feed pumping issues, automation of the IPJ (discussed later) to maintain sufficient flowrate in the product lines and to automatically dump pipe lines in case of impending blockage and built in flushing points to keep the heavy concentrate moving towards its final destination.

Rougher/Cleaning/Scavenging

It has also been found that the IPJ circuit should be treated in a similar fashion to other concentrating devices, eg. Flotation cells, and use the principles of roughing, scavenging and cleaning. This allows high recovery, high grade and low mass concentrates to be produced as well as very high recovery, low grade, high mass concentrates to be produced as the need arises (see Figure 4).

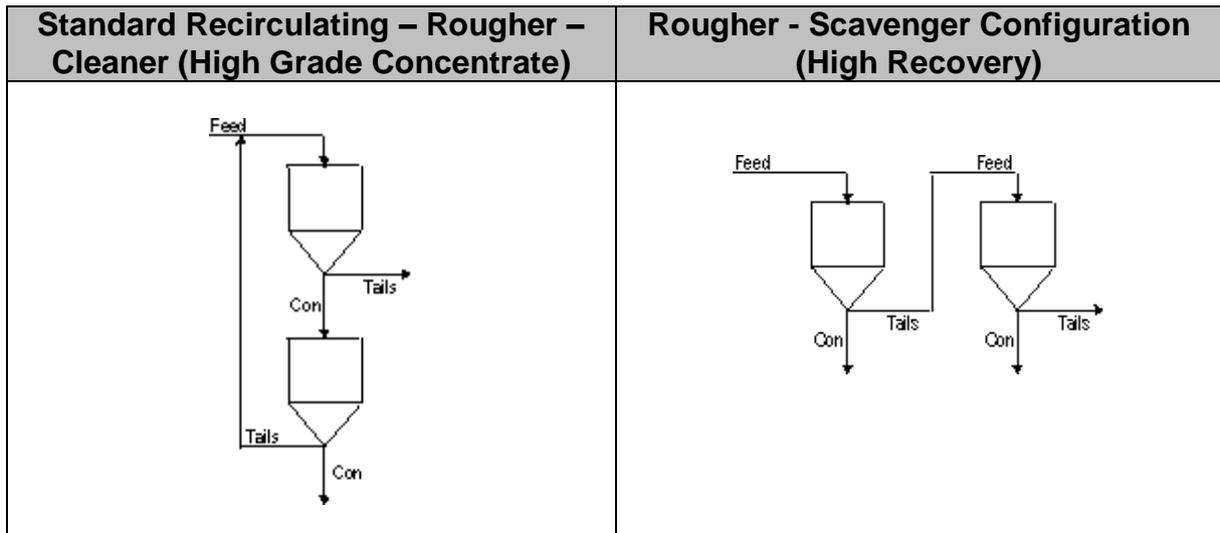


Figure 4: Alternative IPJ flowsheets.

Feed Rate

Depending on the application of the unit, the feed rate and unit capacity of the IPJ will vary significantly. Survey work shows the drop off in unit recovery related to feed rate for any given separation. Site specific variability makes it difficult to quantify and site specific setup is required to optimise the unit.

As feed rate is increased the unit single pass recovery decreases (see Figure 5).

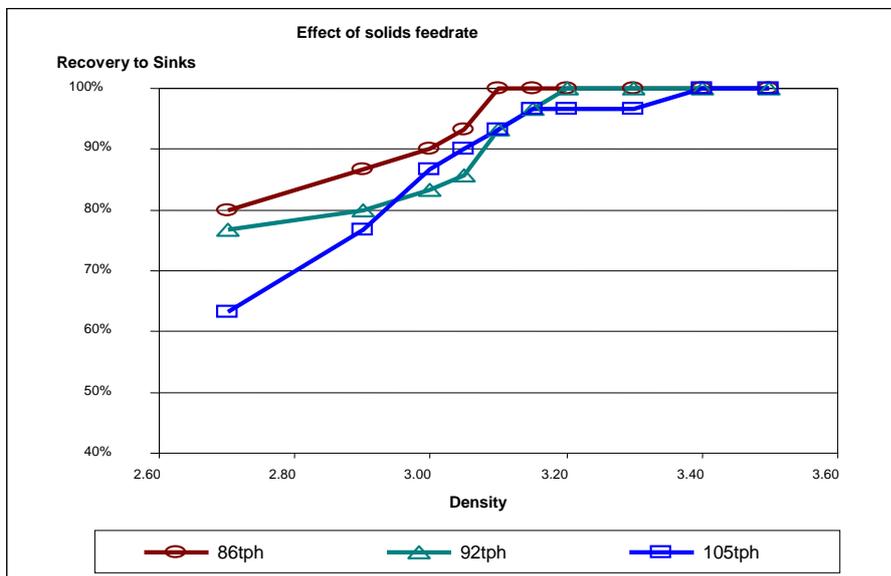


Figure 5: Affect of solids Feedrate on Recovery of tracers to concentrate.

Obviously the rate of decrease depends on many factors but is most affected by density differential of gangue and valuable mineral. In the first installations of the IPJ high throughput and unit recovery

were not required as they were installed in the re-circulating load of a milling circuit to recover free gold with a very high Concentration Criterion (CC):

Concentration Criterion:

- Classically gravity differential ratio greater than 1.25 is required

$$\frac{D_h - D_f}{D_g - D_f}$$

Where D_h is sg of heavy component

D_f is sg of fluid medium

D_g is sg of gangue component

Table 2: Concentration Criteria for a number of different minerals

Mineral	D_h	D_g	D_f	CC
Gold	19.3	2.7	1.0	10.76
Diamond	3.5	2.65	1.0	1.52
Ilmenite	4.7	2.7	1.0	2.18

As the installation base has increased across mineral types and the units have been installed in single-pass pre-concentration applications, the need for greater knowledge of the unit capacity for any given separation was required. This work has led to the reduction of feed rate to the units in those areas where the CC is very low as that for Diamonds shown in Table 2.

Particle shape also plays a key role in CC but in this case tends to be more of an issue in high CC minerals such as gold where the flakiness of the gold is compensated for by its density.

Mass Pull or Yield

The other important parameter for ensuring recovery in a separation with a very low CC is the ability to recover high feed mass to concentrate ratios or Yields.

$$\frac{C_m}{F_m}$$

Where C_m is the concentrate mass

F_m is the feed mass

Where Concentration Criteria is low the yield may need to be increased to maximise recovery.

Work carried out in the diamond recovery systems with a very low CC showed a clear relationship between feed rate, yield and recovery (see Figure 6). In general, as CC decreases then maximum feed rate drops, required mass yield rises and maximum recovery drops.

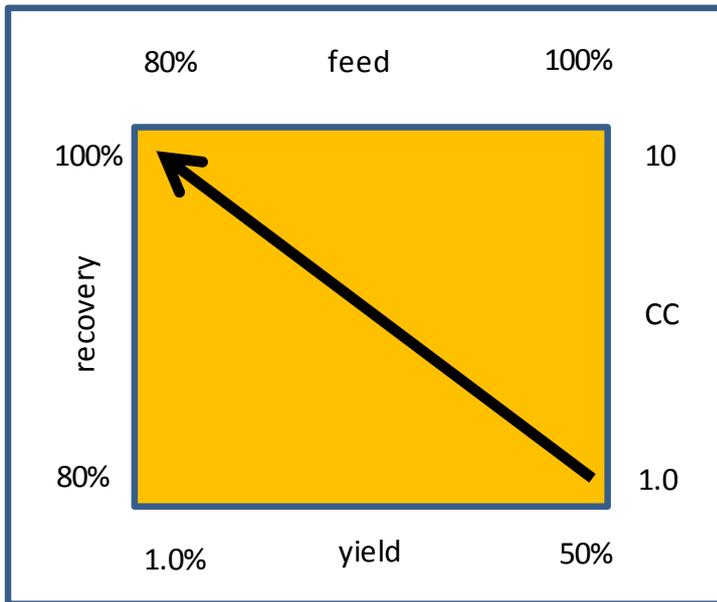


Figure 6: Generalised relationship between Feed Rate, Yield, Concentration Criteria and Recovery

Ragging

Ragging is the media in the IPJ that effects the density of separation. Ragging development has been ongoing for the past 15 years. At first a search was carried out for suitable naturally occurring product with the correct density, hardness and shape (see Figure 7). However it was obvious that there are very limited options in the density ranges required for good separation. Ragging shape, density and volume are critical as well as the ability of the ragging to wear without losing its density.



Figure 7: Naturally occurring Magnetite Ragging.

Consistent ragging is critical to repeatable results. Figure 8 shows how critical the level of ragging is in a diamond jigging application.

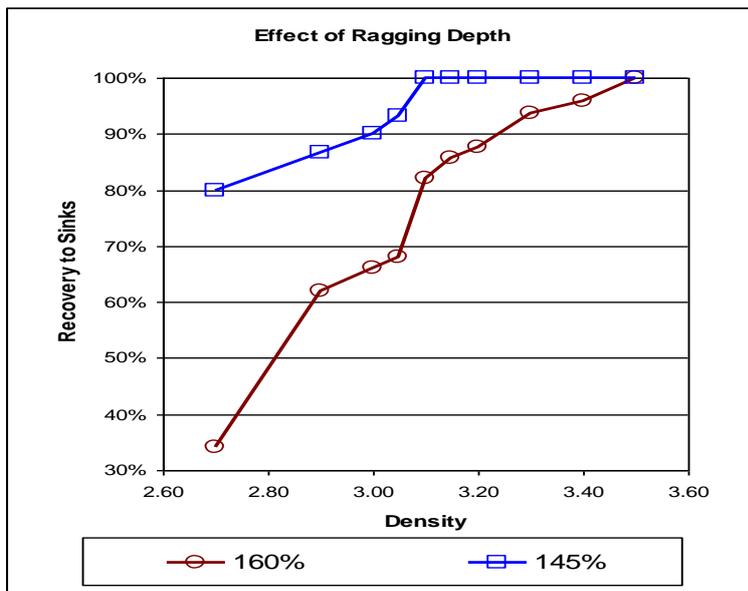


Figure 8: Affect of ragging depth on tracer recovery to concentrate in diamond recovery.

If ragging differs in shape it will “lock in the bed” and can cause loss of yield as beds wear-in and tighten (porosity decreases). The Gekko polymet ragging is spherical which means the porosity and locking factor will never change (see Figure 9). This allows results to be transferred from one operation to the next.

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Figure 9: Gekko Polyurethane (Red) and Ceramic ragging

An issue which arises is when the CC is low it is difficult to choose a ragging material with sufficient density differential to ensure it is not pushed out of the bed. In extreme cases a ragging capture and recycle system would be installed to recover ragging as it leaves the bed (as per Figure 10 for 1.6 sg ragging retainment in a coal application). This in turn can cause issues with distribution whereby the ragging ends up in the wrong bed segments and cannot spread evenly across the screen. Gekko have developed “Bed Drains” (see Figure 11) to ensure the heavies can migrate through the bed to achieve an even distribution. Development in this area is ongoing as we continue to expand the operation of the IPJ into lower density and more difficult separations.



Figure 10: Ragging retaining screen

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Figure 11: Bed drains to stop the build-up of heavies in IPJ beds.

Screens

The ragging size and supporting screen size affect the operation of the unit. In most cases the role of the support screen is to carry the ragging and prevent losing it to the sinks. The ragging size is set relative to the size of the feed and the screen aperture will be set to maximise the life of the ragging on the screen as well as ensuring that all feed particles can pass through the screen (see Table 3). In order to maximise ragging and screen life the following table is used to size the screens.

Table 3: Screen Aperture Calculator

Screen Size Calculator							
Ball Size	Ratio	Aperture	Overlap	Each Side	% of Dia	% Worn Before Loss	Minimum Diameter Before Loss
mm	%	mm	mm	mm	%	%	mm
10	0.75	7.5	2.5	1.25	13%	25%	7.5
10	0.5	5	5	2.5	25%	50%	5
25	0.75	18.75	6.25	3.125	13%	25%	18.75
25	0.5	12.5	12.5	6.25	25%	50%	12.5

It is necessary to choose a screen and ragging combination to achieve the technical aims first and then optimise the wear life of the system second. Typically the ragging size is chosen based on the maximum opening size between balls. With the spherical ragging the ratio never changes and the operation of the ragging is very predictable. A decision between the minimum ragging ball size and the allowable wear must be made. If the screen aperture is smaller it will allow the balls to wear to a smaller size which could be detrimental to the separation.

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Lower yields for gold and sulphides concentration require tighter ragging sizing (smaller openings relative to feed particle sizing) whilst high yields such as in diamond separation will require a higher opening ratio to feed particle sizing (see Table 4).

Table 4: Ragging size calculator

Ragging Size Calculator						
Ball Diameter	Volume	Total Cubic Void	Void of Ball	Hypotenuse of Square	Max Opening	Ratio Ball Dia:Opening
mm	mm ³	mm ³	%	mm	mm	%
10.00	523.80	1000.00	52%	14.14	8.28	83%
15.00	1767.83	3375.00	52%	21.21	12.43	83%
20.00	4190.40	8000.00	52%	28.28	16.57	83%
25.00	8184.38	15625.00	52%	35.36	20.71	83%
30.00	14142.60	27000.00	52%	42.43	24.85	83%
35.00	22457.93	42875.00	52%	49.50	28.99	83%

It is very important that in ores with low CC, the feed particles can all report either to tailings or concentrate. If heavies build up in the bed then the relative density of the bed changes and the operation and recovery will vary. This will continue until the bed fills with the heaviest material in the feed and will almost certainly push the ragging from the bed.

Automation

Several key flows must be maintained in order to keep the IPJ operating within its optimised recovery zone. Whilst the IPJ can tolerate variability in feed and water supply it works better with a constant feed volumetric flowrate and water supply. In order to guarantee the IPJ is working within its optimised recovery zone a control system has been developed to monitor, control and record all water and feed as well as pulse control. The automation system runs on several PID control loops designed to maintain constant flows around the circuit, pulse frequency and stroke length and air bleed rate (see Figure 12).

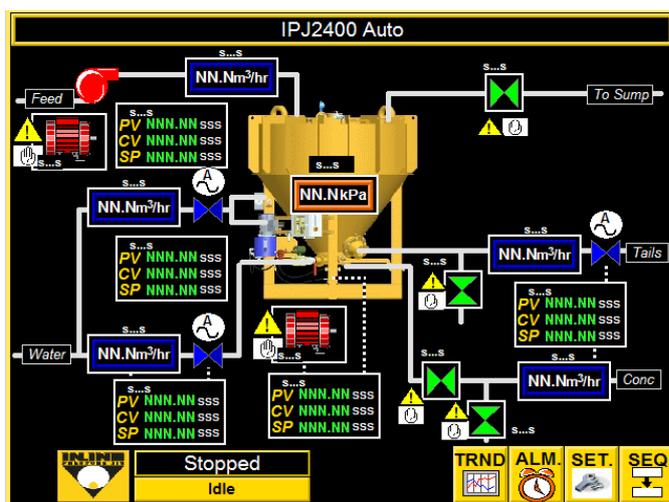


Figure 12: An IPJ Automatic Control Screen

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Mineral Specific Applications (See Table 5)

Sulphides

Perhaps the best example of an IPJ in sulphide recovery is the IPJs at Lihir Gold's Ballarat Goldfields operation. The design of the crushing circuit is such that liberated mineral is recovered as soon as possible in the size reduction process (Gray et al, 2007). A final crush size of 1 mm allows for almost complete liberation of the sulphides and recovery into the IPJ as shown in Figure 13.

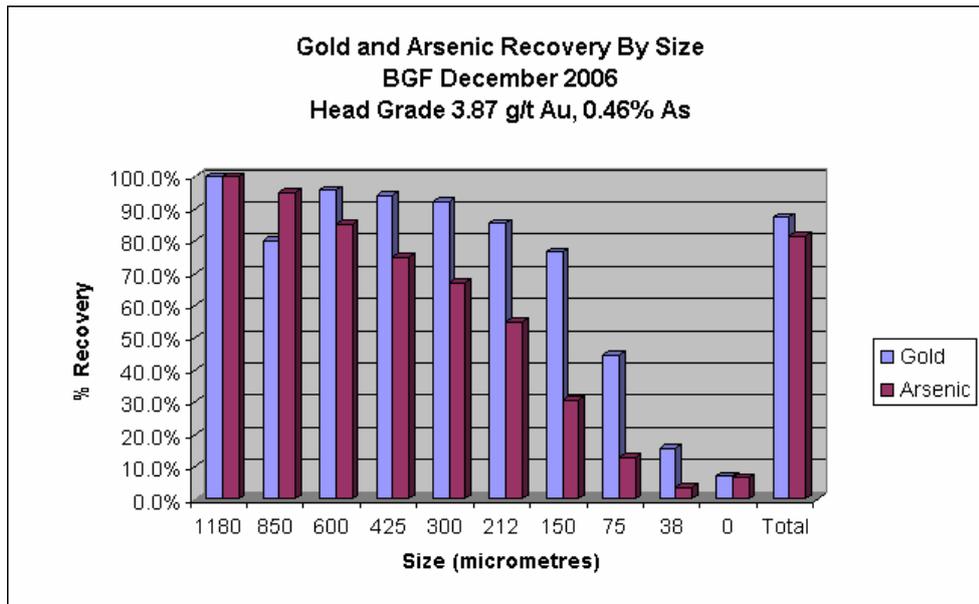


Figure 13: IPJ Gold and Arsenic recovery by size at Lihir Gold's Ballarat operation.

IPJ recovery for the arsenopyrite starts dropping significantly below 300 μm whereas gold recovery is maintained down to 150 μm .

Table 5: Summary of IPJ Mineral Specific Applications and Performance

	Sulphide Recovery IPJ2400		Diamond Recovery IPJ2400		Base Metals Recovery IPJ1500		Coal Recovery IPJ600	
Mineral:	Arsenopyrite	6.0 g/cm ³	Diamond	3.5 g/cm ³	Galena	7.4 g/cm ³	Coal (4% Ash)	1.3 g/cm ³
	Pyrite	5.0 g/cm ³			Sphalerite	4.0 g/cm ³		
Gangue:	Silica	2.65 g/cm ³	Silica	2.65 g/cm ³	Silica	2.65 g/cm ³	Coal (50% Ash)	2.3 g/cm ³
CC:	Arsenopyrite	3.03		1.52	Galena	3.88		4.0
	Pyrite	2.42			Sphalerite	1.82		
Feed Rate	tph	100	tph	80	tph	20	tph	2
	m ³ /h	160	m ³ /h	150	m ³ /h	40	m ³ /h	15
Feed Size	Max. mm	5	mm	1.5 x 25	mm	2 x 19	mm	0.25 x 6
Mass Pull %		5		15		50	(To Sinks = Reject)	20
Recovery %	Arsenopyrite	90	Diamonds	100% +4mm	Galena	94	Ash Rejection	72
	Pyrite	80			Sphalerite	87		
Screen Aperture	mm	8	mm	28	mm	25	mm	8
Ragging Size	mm	16	mm	32	mm	35	mm	22
Ragging sg		3.2		3.2		2.8		1.6

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Diamonds

Diamond recovery has a very low CC factor however this is compensated by the size and shape of the particles which greatly assist the recovery. High typical diamond recovery is achieved in diamond sizes >1.5mm which is a size below which turbulence and surface properties play a major role. The semi-spherical shape of a diamond means it also has a low aspect ratio and a resulting low relative density. Both these factors aid in the recovery of diamonds by gravity. Relatively high mass pull is the other tool used to ensure recovery of diamonds to the sinks fraction. By pulling a high mass pull the flow through the bed is kept consistent and an even bed density distribution is more easily maintained. High mass flow through the bed ensures the bed density does not rise due to a build up of heavies in the Jig Internal Middling (JIM). If there is low mass flow then there is the possibility that a combination of increased bed density and uneven density distribution could cause loss of heavies to the floats fraction.

Raura Base Metals

Pre-concentration of base metals such as sphalerite and galena from quartz is carried out at the Raura base metal mine in Peru (Bermejo Severino et al, 2006). Ore crushed to minus 19mm is fed to the IPJ and a high mass pull is used to recover 94% of the galena and 87% of the sphalerite to the concentrate. The relative CC ratios of galena and sphalerite help explain the difference in recovery with the CC for galena being significantly higher than sphalerite and hence higher recovery.

Coal Upgrade

In recent pilot trials carried out by ACIRL in NSW, a pilot IPJ600 was used to wash Hunter Valley and Bowen Basin coal. This application is an example of reverse jigging where the valuable mineral is the floats (low ash content coal). The trial wasn't optimised but clearly indicated a separation was achievable in the IPJ (see Figure 14) and its performance was similar to spirals though with a much higher top size – 6 mm compared to 2 mm with spirals.

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Figure 14: Floats (top) and Sinks (bottom) from an IPJ600 treating Australian -6mm coal

The large operating size range of the IPJ could greatly increase the throughput of coal handling and preparation plants compared with existing technologies.

CONCLUSIONS

This paper has described some of the knowledge gained from twelve years of operation of InLine Pressure Jigs. This knowledge has shown that the IPJ when correctly installed, with the optimum screen size, ragging size and s.g. can produce outstanding results in a variety of applications including but not limited to gold, sulphides, diamonds and base metals. Recent research also indicates the IPJ has significant potential in coal processing.

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