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CENTRIFUGAL CONCENTRATORS IN GOLD RECOVERY AND COAL PROCESSING

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ABSTRACT:

Centrifugal concentrators have been in operation for more than 60 years in the mining industry. Recent developments in "Bowl" type centrifugal concentrators are reviewed in this paper.

The main topics being discussed are:-

- Theory of concentration
- Theory of operation of the concentrators
- Equipment types
- Applications

The current drive in centrifugal concentration is towards improved fine, heavy particle recovery e.g. gold concentration and coal upgrading.

This paper reviews results obtained on plants which are using Superbowl Gold Concentrators in their gravity circuits, thereby achieving improved gold recovery and a reduction in operational costs. Results were obtained on coal fines during a pilot campaign using a continuous discharge Falcon Concentrator to upgrade thickener underflow material by removing high density discard material.

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INTRODUCTION:

THEORY OF GRAVITY CONCENTRATION

Gravity Concentration can be defined as the process whereby particles of various size, shape and density are separated from each other by the force of gravity or centrifugal force. The efficiency of separation can be determined by the use of the "concentration criterion".

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

Where	D_h	-	Density of heavy particles
	D_l	-	Density light particle
	D_f	-	Density of fluid medium

In general terms, when the quotient is greater than 2,5, then gravity concentration is relatively easy. As the value decreases, the efficiency of separation decreases, and below values of 1,25 separation is not commercially feasible (Taggart).

Particle motion in a fluid is dependant on its specific gravity and its particle size; with the larger particles more affected than the smaller ones.

The settling velocity of particles in water poses a basic problem in the application of gravity concentration. As was shown by Stokes the settling velocities for small spheres can be shown to satisfy the following equation:

$$V_m = \frac{d^2 g\,(P_s - P_f)}{18\,\mu}$$

Where	V_m	-	Terminal settling velocity
	P_s	-	Density of solid
	P_f	-	Density of liquid
	d	-	Particle diameter
	g	-	Acceleration due to gravity
	μ	-	Viscosity of the fluid

The above equation highlights the importance of particle size in determining the terminal velocity which occurs when the buoyancy forces and drag forces acting on the particle, balance out gravity.

A fine, dense particle settles at the same rate as a coarse, light particle due to the drag forces which apply at terminal velocity.

To reduce the particle size effect on gravity concentration units, close size control of the feeds to such units is required.

Most gravity concentrators such as Spirals, Sluices, Cones and Drums operate at a gravity field of 1 G, Centrifugal "Bowl" type concentrators operate at gravity fields of up to 300 G's. The increased gravity field using centrifugal forces enhances the terminal velocity of particles, thereby increasing separation of heavy and light particles.

EQUIPMENT:

The bowl type separators discussed in this paper are the continuous discharge Falcon and the batch discharge Superbowl Concentrator.

THEORY OF OPERATION OF THE CONCENTRATORS

The basic theory of operation of the centrifugal concentrators is as follows:- Slurries subjected to a centrifugal field experience large shear rates. Layers of particles moving by each other collide, creating a dispersive pressure at right angles to the shear rate. Large particles are pried apart making it possible for finer particles to percolate through. This is termed "Strain induced Percolation" (Le Plante). This mechanism minimises the problem of terminal settling velocities down to ultra fine particles.

Thus, the "heavier" denser particles move towards the outer section of the spinning bowl whilst displacing the lighter particles.

The diagram below shows the steps:-

FALCON CONCENTRATOR:

The continuous discharge Falcon Concentrator consists of a vertically mounted smooth wall truncated bowl that slopes outwards from bottom to top at an angle of 10° from the vertical.. The purpose of the angled bowl is to use the rotational speed to create movement of the solid bed towards the top of the bowl. The slurry introduced into the bowl via a centralised feed pipe discharges slurry onto an impeller fixed at the bottom of the bowl which accelerates the slurry towards the wall of the bowl. As the particles move up the wall they become stratified due to the differences in densities. The stratified heavy material next to the wall is discharged through a series of equally spaced flow hoppers along the circumference of the bowl. The discharge rate of the heavy particles is controlled via pneumatic valves and fixed orifices in conjunction with the rotational speed of the bowl which can be varied by the motor control system from 0 G's up to 300 G's. The light particles top the stratified material discharge over the top of the bowl.

The automation package controls motor speed via a variable frequency drive allowing the selection of the desired gravitational field for the specific material being treated, as well as pneumatic pinch valve opening and closing times to vary discharge rate and control constant heavy material bed flow, preventing breakthrough of the slurry bed whilst in operation.

SUPERBOWL CONCENTRATOR:

Unlike the Falcon Concentrator the Superbowl unit is a batch machine. The Superbowl consists of a smooth wall vertically mounted bowl similar in design to the Falcon bowl on the lower two thirds of the bowl. On the top third of the bowl a concentrate basket is attached with holes to allow elutriation water to be added at this point for cleaning the concentrate. The slurry enters the bowl via a centralised feed pipe striking an impeller attached to the bowl, which accelerates the slurry to the wall of the bowl. As the slurry travels up the wall the heavy particles stratify next to the wall of the bowl and the light particles move outwards towards the centre of the bowl. The heavy particles are collected in the concentrate basket where water washes out light particles into the tailings stream. The tails discharge over the top of the bowl whilst the elutriated concentrate remains in the concentrate basket. The concentrate is discharged once the concentrating cycle has been completed. The automation control package shuts the feed pinch valve, shows the bowl rotational speed to rinse cycle speed and flush water is introduced into the bowl The concentrate is washed down the bowl and discharges via the false bottom into the concentrate launder. After the rinse cycle has completed, which takes approximately 20 seconds, the bowl speeds up to operational speed, the rinse

Water opens and the feed is introduced by opening the pinch valve. The cycle repeats itself whilst in operation.

GENERAL APPLICATIONS:

FALCON CONCENTRATOR

Uses for the Falcon concentrator have been found in the gold, coal and base mineral industries. Several units, for recovery of alluvial gold are in use in the gold industry throughout the world, and most recent in the recovery of fine tantallum in Canada.

Extensive test work has been conducted by R. Honaker at Southern Illinois University to evaluate the performance of a continious C40 Falcon to upgrade coal fines (-1 mm +0,038 mm) by removing pyritic sulphur. In South Africa, Kleinkopje Colliery has conducted test work on a C20 Falcon to upgrade tailings thickener underflow to acceptable ash levels.

SUPERBOWL CONCENTRATORS

The Superbowl Concentrators are being used extensively in the gold industry for the recovery of liberated "Free" Gold in milling circuits prior to leaching operations, as well as smelthouse slag cleaning.

Some applications can also extend to retreatment of gold leach tailings and PGM metallic recovery. The most common application being used to date is alluvial gold recovery.

CASE STUDY:

Two summarised case studies are presented in this paper, the first being an evaluation of the Falcon Concentrator at Kleinkopje Colliery and the Second using a Superbowl Concentrator at Mazowe Mine in Zimbabwe.

CASE STUDY 1:

FALCON CONCENTRATOR

KLEINKOPJE COLLIERY

Material	:	Tailings thickener underflow.
Objective	:	Upgrade thickener underflow material to 15% ash with a yield of 60% from the Falcon.
Particle size distribution of Falcon Feed	:	-500 micron +45 micron
Machine model	:	C20
Tonnage Rating	:	10 - 15 tons / hr.
Bowl angle	:	10°.

FLOW DIAGRAM OF FALCON TEST CIRCUIT

The test flowsheet as shown above in figure was operated in the following manner. Thickener underflow material was deslimed using a cyclone cutting at approximately 38 microns. The cyclone underflow was collected in the feed preparation tank (approximately 5m^3 of slurry) and the cyclone overflow was discarded.

The density of the material in the feed preparation thank was adjusted and pumped over a 1 mm sievebend to remove tramp material. The screen undersize was then pumped to the Falcon Concentrator via a static 1,6 mm square aperture screen.

The Falcon overflow and underflow streams were dropped into a return tank, which in turn was pumped back to the feed preparation tank.

The following variables were tested on the Falcon: feed rate, g force, discharge rate and nozzle sizes at varying qualities of feed.

Table **(A)** shows the results obtained by varying the g force field on the Falcon.

G. Force	Size	Feed Ash	Product Ash	Discard Ash	Ash Yield
50	+212 µm	17,5	10,6	33,2	69,5
	-212 +45 µm	21,2	12,2	39,1	81,7
	-45 µm	45,4	44,0	61,9	92,2
130	+212 µm	17,5	6,5	25,1	40,9
	-212 +45 µm	21,2	12,8	37,4	65,9
	-45 µm	45,4	49,6	62,0	77,6
170	+212 µm	17,5	5,6	24,0	35,3
	-212 +45 µm	21,2	11,6	28,4	42,9
	-45 µm	45,4	39,5	64,8	76,7
215	+212 µm	17,5	4,9	19,6	14,3
	-212 +45 µm	21,2	9,7	23,5	16,7
	-45 µm	45,4	35,7	60,5	60,9

The above table clearly shows the improvement in the product ash of increasing g force field. The +45 micron material upgrades fairly easily whilst it can be seen that the -45 micron material does not upgrade.

Figure 1 shows the effect of centrifugal field in relation to mass pull to the Falcon underflow the higher the field the more mass of denser particles that can be removed to the underflow of the machine.

Results obtained at SIU on a C40 Falcon by R Honaker shows that the Falcon operated at cut points between 1,5 and 1,7 with an E_p value of 0,12 with feed rates up to 100 t/hr.

Table **(B)** shows the results obtained at SIU on the C40 Falcon at varying feed rates and 200 G Force field.

Feed Mass t/hr	**Size Fraction**	**Feed Ash**	**Product Ash**	**Tailing Ash**	**Ash Yield**
94	-800 +150 µm	14,7	4,21	47,6	85,1
	-150 +38 µm	9,74	5,39	45,2	93,4
	-38 µm	46,5	44,6	54,1	82,8
68	-800 +150 µm	14,7	3,62	35,6	75,2
	-150 +38 µm	9,02	4,20	44,7	92,8
	-38 µm	44,9	44,5	55,4	97,0
46	-800 +150 µm	15,0	3,40	28,9	61,8
	-150 +38 µm	9,2	2,95	40,5	89,0
	-38 µm	44,5	43,6	54,1	93,2

The above table clearly shows the high coal recovery at 94 t/hr feed rate to the C40 continuous discharge Falcon.

The results on the Falcon from both the Kleinkopje and SIU test work demonstrate the ability of the unit to upgrade coal fines to acceptable ash levels in the +38 and +45 micron size fraction. Very little upgrading of the material below 38 micron is effected.

CASE STUDY 2:

SUPERBOWL CONCENTRATOR

MAZOWE MINE - ZIMBABWE

Material	:	Milling circuit.
Objective	:	Replacement of existing gravity circuit with Superbowl Concentrator
Particle size in feed	:	-6 mm screen undersize.
Machine model	:	SB21
Tonnage Rating	:	18 tons / hr.
Operating tonnage	:	40 tons / hr.
Feed percent solids	:	60% solids by mass

FLOW DIAGRAM OF MAZOWE PLANT AFTER INTRODUCTION OF SUPERBOWL CONCENTRATOR

A brief description of the Mazowe Mine gravity circuit:

Ore from the crushed ore bin feeds a primary ball mill, the mill discharge is fed to the secondary ball mill. Both the mill discharges feed a Derrick screen with an aperture of 5 mm. Over 50% of the screen undersize is fed to the 21" Superbowl concentrator (previously three Gallagher belt concentrators), the Superbowl tails and the screen oversize are fed to a primary classification cyclone. The cyclone underflow is in closed circuit with the primary ball mill. The cyclone overflow feeds a secondary cyclone where the overflow is fed to the flotation plant and the underflow is returned to the secondary mill discharge.

Prior to the introduction of the Superbowl concentrator, the overall gravity circuit gold recovery was in the region of 50% from the three Gallagher belts used as roughers and three James tables used as cleaners. Being an old plant the equipment required intensive maintenance as well as operators to run the circuit. The Superbowl was introduced to establish if the unit was able to improve recovery of gold and reduce operating costs due to its automation.

The introduction of the Superbowl Concentrator at Mazowe Mine in Zimbabwe has had the following results:-

- 1 Superbowl Concentrator replaced three Gallagher belt concentrators, carrying out the same tonnage duty and reducing maintenance on the belts.

- One of three shaking tables is used for cleaning of the Superbowl concentrate prior to amalgamation. This table is operated in batches.

- Overall gold plant recovery has improved by 4%.

- Improved gravity circuit recovery of "Free" Gold from 58% to 77%.

- Reduction in gravity circuit tails which relieves the load on the flotation circuit as well as the leach circuit.

- Reduction in power consumption in the plant and extensive maintenance on the Gallagher belts and shaking tables.

- Reduction in plant operators due to the automation.

SUMMARY:

This paper outlines the theory of gravity concentration and the use of centrifugal concentrators in two case studies is discussed namely Coal and Gold.

The results of the Falcon work conducted on coal in both South Africa and USA show that centrifugal concentrators such as the Falcon can be used to effectively upgrade coal down to 38 micron.

The case study of Mazowe Mine in Zimbabwe shows a successful gravity circuit operating to recover gold, using a Superbowl centrifugal concentrator to improve overall plant recovery and reduce operating costs, which is beneficial at the current gold price of around 340 US$.

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S. McAlister :- President Falcon Concentrators Inc. Personal Communication