

Knelson Concentrator – New Gravity Equipment at the Boliden Concentrator

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Abstract

Gravity Recoverable Gold tests at the KNELSON Research & Testing Centre showed a potential for improved gold recovery for the Renström ore. Traditional gravity equipment in one of the grinding circuits at the Boliden concentrator was replaced with a Knelson Concentrator.

After installation of the Knelson Concentrator, the gold grade in the tailing has decreased at the same time as the calculated head grades has increased. The Au-grade in the concentrate has increased more than 2.5 times, and the total Au-recovery to gravity and flotation has increased by more than 4 %-units.

The change to this gravity separation technique has considerably reduced the floor space requirements in the plant. The fewer amount of equipment is expected to lower maintenance costs in the future.

Future plans include installation of one more Knelson Concentrator in the parallel grinding section of the Boliden concentrator.

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1 Introduction

Most of the ores processed at the Boliden concentrator are complex sulphide ores. Valuable minerals contain zinc, copper, lead, gold and silver, in varying proportions. Five different mines feed two parallel sections. The ores are trucked to the concentrator and treated on campaign basis. The Boliden concentrator operates with two-stage fully autogenous grinding circuits, which includes traditional gravity equipment for separation of gold. The fines from the grinding circuit are fed to a copper/lead-flotation circuit. The copper/lead concentrate is pumped to a copper/lead separation, which produces separate copper and lead concentrates. The middling from the copper/lead-flotation are pumped to a zinc-flotation. Figure 1 shows a simplified process flowsheet and typical gold distribution for the Renström ore are presented in Table 1. Revenues increase if more gold is distributed to the gravity and copper concentrates rather than to the lead-concentrate. One way of achieving this technically is to recover the gold before the copper-lead separation that is in the gravity separation circuit.

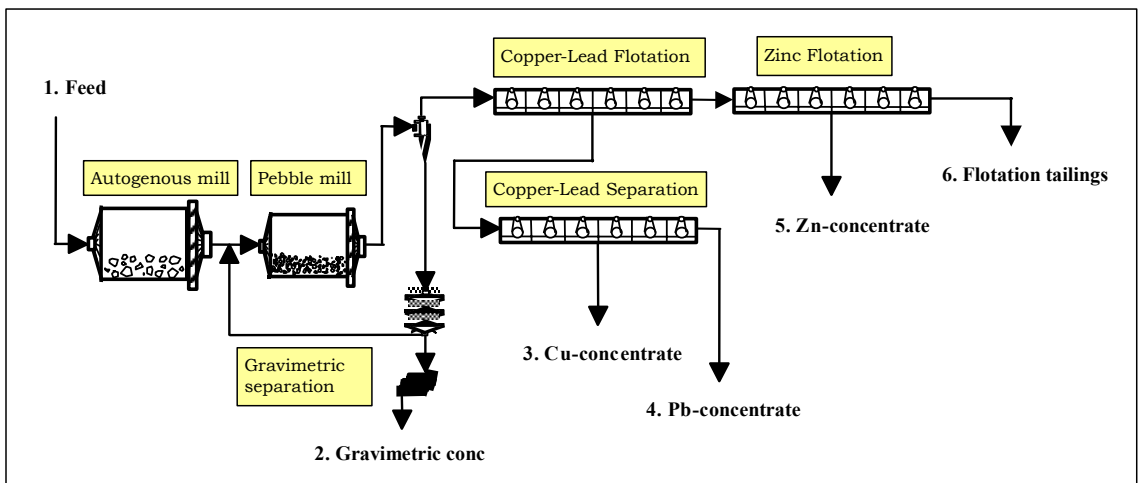


Figure 1 Simplified flowsheet

Table 1 Au-grades and recovery for the Renström ore during the year 2003

	Au-grade (g/tonnes)	Au-distr. (%)
1. Feed	3.95	100
2. Gravimetric conc	1 236	12.7
3. Cu-concentrate	62.0	48.7
4. Pb-concentrate	17.5	7.1
5. Zn-concentrate	2.8	8.6
6. Flotation tailings	1.09	22.9
Total Au-recovery		68.5

In 1985, Reichert cones, spirals and shaking tables were installed at the Boliden concentrator. Gold gravity recoveries for Renström ore, known to hold high amounts of coarse gold, reached 45% the first year, see Figure 2. During the years 1990 and 1991 the concentrator changed from primary rod mills to fully autogenous grinding

circuits. It is likely that the change in grinding technique generates a finer gold size distribution in the feed to the gravity circuit; possibly effecting the gold recovery negatively. Due to ore mixing, it is difficult to investigate the gold recovery for the Renström ore during the year 1992-2002. From the year of 2003 the Renström ore is processed as a single ore again, with low gravity and total gold recoveries, as can be seen in Figure 2. In search for improvements a sample was sent to the Knelson Research & Testing Centre for testing the amount of gravity recoverable gold, GRG-test. Promising results led to full-scale tests with a Knelson concentrator in one of the sections in the Boliden concentrator.

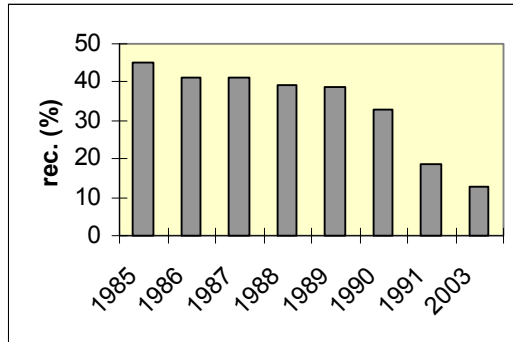


Figure 2 History of the gravity recovery on Renström ore

2 Description of how the Knelson Concentrator Works

The Knelson concentrator is a high-speed centrifuge that sets a centrifugal force to the particles in the slurry against a fluidisation water flow. The conical shape of the concentrating cone incorporates a series of rings, increasing in diameter from bottom to top, Figure 3. Around the circumference of each ring, holes allow the injection of fluidisation water into the concentrating cone. Positioning the concentrating cone inside the rotor housing creates a water cavity. Fluidisation water flows into the cavity through the rotor shaft. Once the cavity fills to capacity, pressure forces water through the fluidization holes and into the concentrating ring. During operation, the entire rotor assembly spins at a pre-determined speed according to the size and model of the unit. This rotational speed creates a centrifugal acceleration of 60 G's.

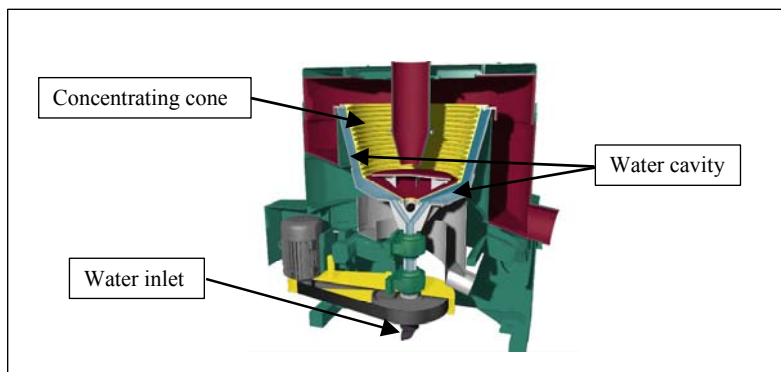


Figure 3 A cross section of the Knelson concentrator. Source: Knelson Manual.

Feed slurry enters the unit through a stationary feed tube. It flows down into the concentrating cone, where centrifugal force drives it outward to the cone wall. As the solids reach the wall, they fill each ring starting from the bottom. Once every ring reaches capacity, a concentrating bed is established. Water injected from the water cavity fluidises this bed, Figure 4. Optimum fluidisation occurs when inward flow of water through the bed balances with outward forces of solids. This enables fine-grained target heavy mineral particles to sink into the bed through interstitial trickling. Provided that the flow of fluidisation water is maintained, the selection and concentration of high specific gravity particles and rejection of low specific gravity particles will continue.

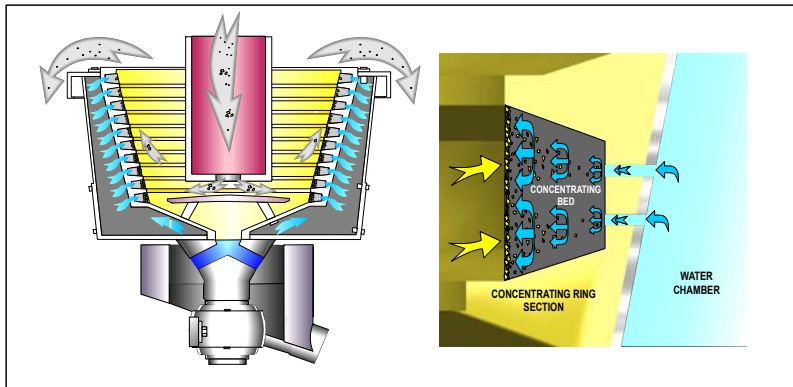


Figure 4 Concentrating cycle. Source: Knelson Manual.

When the concentrating cycle ends, the flush cycle is initiated and the rotor power is shut off. When the rotor comes to a complete stop, the fluidisation water flow valve is opened for several seconds. Opening the valve while the rotor is stationary allows water flow into each ring to wash out the concentrates. Concentrates flush out through the bottom of the concentrating cone and into the concentrate launder, Figure 5.

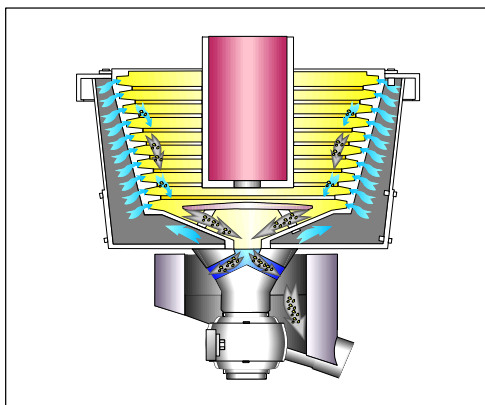


Figure 5 Flush cycle. Source: Knelson Manual.

3 Installation and Test Work Procedures

The results from the GRG-test were very promising, Boliden decided to rent a Knelson concentrator (KC), model KC-XD30, for a test period. Specification data sheet for the KC-XD30 is enclosed in Appendix 1.

The KC was installed during May 2004. To ensure flexibility and enable comparable test work, the concentrator was installed to study different flowsheets. The KC can operate in two alternative positions according to the flowsheet in Figure 6, before the hydrocyclones or at the hydrocyclone underflow. During the test period the old gravity circuit with cone, spiral and table could be utilised if the KC was bypassed.

The first step in the test work was to optimise the operating variables, which for the KC-XD30 with fixed rotation speed are; fluidisation water flow rate, concentrating cycle time and feed flow rate. Optimisation tests were done for two ore types, the Renström ore and the Petiknäs ore (Petiknäs Södra). The test procedures followed the supplier's recommendations. First the addition rate of the fluidisation water was varied at a constant cycle time and then the cycle time was varied at the chosen flush water addition rate. A few tests were also made at different slurry flow rates to the KC. The feed to the KC together with the middling and the concentrate from the KC were sampled and assayed for Au and Ag. Also the feed to the flotation was sampled to calculate total gravity recovery.

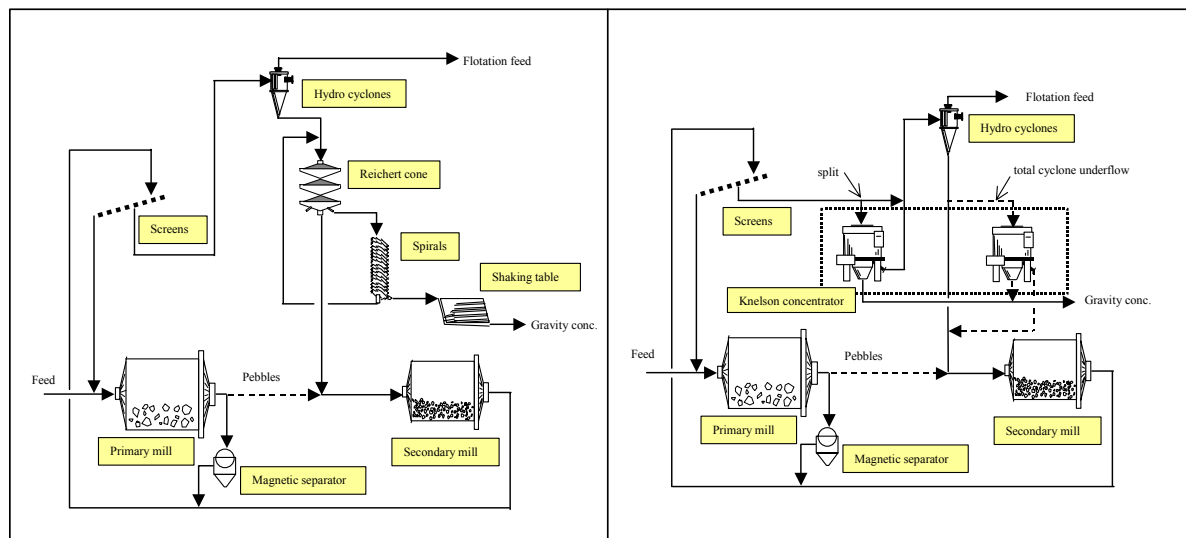


Figure 6 The left flowsheet shows the old gravity circuit, and the right flowsheet show the two alternatives with the Knelson concentrator

After the operating variables were settled, the old gravity circuit was compared with the circuit where the KC was treating the hydrocyclone feed. The objective with this test was to see if the KC could increase the total Au recovery. The tests were carried out during a Renström campaign as the different circuits were turned on and off every second day. The KC could just treat a part of the hydrocyclone feed due to low discharge pump capacity. The split was made through a simple gold trap.

During a following campaign the two circuits with the KC treating the feed to the hydrocyclone and the underflow from the cyclone respectively, were compared in the same way. The objective with this test was to decide the final flowsheet.

4 Results and Discussion

GRG-tests

The GRG value is the theoretical limit of gold that is recoverable by efficient gravity concentration methods within a mill.

The procedure for the GRG-test at the Knelson Research & Testing Centre is to run the sample on a Laboratory Knelson Concentrator (KC) after coarse grinding. The tailings from the KC are reground and processed on the KC again, the second tailing is than reground and processed in the KC a third time. This testing procedure is based on the philosophy that progressive size reduction allows the determination of liberated gold at finer grinds without over-grinding and smearing coarse gold present in the initial sample. Each of the three KC concentrates was hand panned to produce pan concentrate and pan tailings (middling) samples. A number of ore types were sent for GRG-tests; Table 2 presents the results of the test with Renström ore.

Table 2 The results from GRG-tests on Renström ore

Grind size P ₈₀ µm	Product	Mass		Gold	
		(g)	(%)	Assay (g/tonnes)	Dist'n (%)
1215	Pan Conc.	22.6	0.11	14.1	7.5
	Middlings	115.8	0.54	10.5	2.9
	Sample Tails	76.3	0.36	2.26	0.4
412	Pan Conc.	29.2	0.14	250	17.2
	Middlings	69.2	0.32	3.02	0.5
	Sample Tails	201.8	0.95	1.51	0.7
97	Pan Conc.	32.0	0.15	204	15.3
	Middlings	82.4	0.39	28.4	5.5
	Sample Tails	20674.7	97.05	1.03	50.0
Totals (Head)		21304	100.0	2.00	100.0
Knelson Conc. (GRG Value)		351.2	1.65	59.2	48.8

The overall GRG value was 48.8% at a head grade of 2.0 g/tonnes Au. The concentrates produced were easily upgradeable through panning, and coarse gold particles were observed in the second and third panned concentrates. According to Knelson representatives, this ore sample was extremely amenable to gravity separation.

A similar investigation of the Petiknäs Ore gave a GRG-value of 30.2 % at a total head grade of 2.0 g/tonnes Au.

Optimisation of operating variables

The intervals of the tested operating variables, fluidisation water flow rate, concentrating cycle time and feed flow rate is shown in Table 3. The tests were made with the KC treating a part of the hydrocyclone feed.

Table 3 Intervals for optimisation of the operating variables

	Fluidisation water flow rate (m ³ /hour)	Concentrating cycle time (min)	Feed flow rate (tonnes/hour)
High	24.1	180	79
Low	17.3	30	42

For the same ore type, variations of the fluidisation water flow rate did not influence the concentrate grade in the investigated range. Successive tests for both the Renström ore and the Petiknäs ore were made at the medium flush water flow rate.

Figure 7 presents the KC mass load in relation with the concentrate grade. The mass load is the total amount of tonnes that are feed to the KC during a cycle time. The mass load is a calculated value that combines the solids feed rate to the concentrator and the concentrating cycle time. The concentrating cycle time is the active part of the cycle time (time for flushing out the concentrate is not included).

$$L = \lambda * m / 60 \quad \lambda = \text{concentrating cycle time [min]}, m = \text{KC solids feed rate [ton/h]}$$

The cycle time is the single most important parameter for the concentrate grade. By combining cycle time and feed rate, i.e. the mass load, the correlation improves.

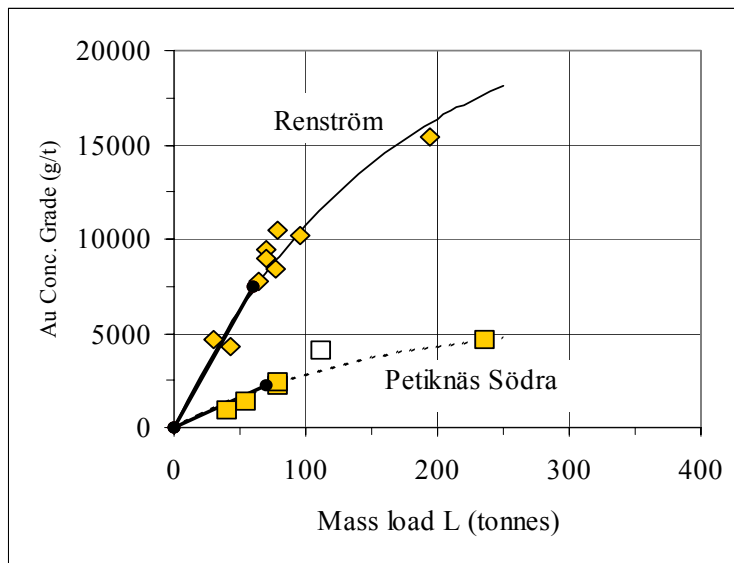


Figure 7 Concentrate grade at different mass loads from optimisation tests for Renström and Petiknäs ore

In the figure a linear correlation between the concentrate grade and the mass load is marked out. At mass loads beyond the correlation interval, the increase rate of the concentrate grade falls. This can be expressed as a loss in separation efficiency.

One of six tests with the Petiknäs ore had a divergent higher calculated head grade than the rest of the tests and is marked in the figure as a non-coloured square, it is not investigated whether this is actually a richer ore, or the result of an error.

The concentrate weight from the KC is fairly constant and the concentrate grade is dependant on the mass load. The total gravity recovery can therefore be expected to be dependent of the KC mass load. One of the components of the mass load is the feed rate. In Figure 8, calculated gravity recoveries from all optimisation tests are plotted against the KC solids feed rate. Linear trends with intercepts at 0 % Au, have been fitted to Renström and Petiknäs test results. The corresponding GRG-values for each ore type are marked in the figure. The trends are indicating weak relationships, the R2-values are low.

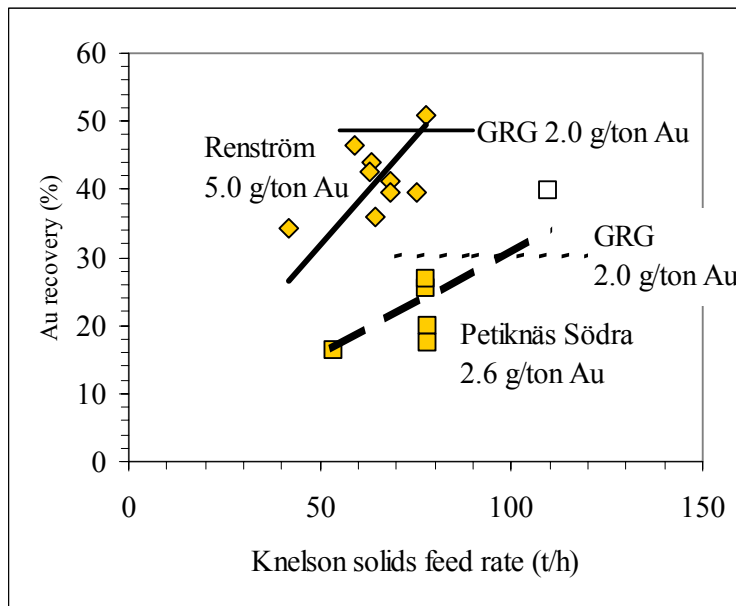


Figure 8 Au-recovery to Knelson concentrate at different Knelson solids feed rates

The GRG-value for Renström was determined at head grade of 2.0 g/tonnes Au, whereas the optimisation tests were made at an average grade of 5.0 g/tonnes Au. The maximum gravity recoverable gold is probably much higher at an ore grade of 5.0 g/tonnes. This indicates that the maximum Au recovery was not reached during the Renström optimisation tests.

Optimisation tests for the Petiknäs ore were made at an average ore head grade of 2.6 g/tonnes Au, the GRG- value was determined on a sample with an Au grade of 2.0 g/tonnes. According to the figure it seems that the maximum Au-recovery was almost reached during the Petiknäs optimisation tests.

Now tendency for overloading was found in the feed ranges investigated. It is advisable to proceed from the maximum KC solids feed rate used in the optimisation tests together with a corresponding concentrating cycle time that gives the optimum mass load. Optimum mass load is the maximum mass load during the correlation period in Figure 7.

Table 4 presents recommended settings for the KC. The concentrate grades at these settings are estimated using the relationships in Figure 7. The gravity Au-recovery is calculated from expected feed rates and head grades. Concentrate weights are average concentrate weights during the optimisation tests.

The calculated maximum gravity Au –recovery especially for the Renström ore is much higher than can be expected. The relationships in Figure 7 are probably not valid for lower ore grades.

Table 4 Variable settings and calculated maximum gravimetric Au-recovery from optimisation tests

Parameters			Ore type		Comments
			Abb	Renström	
Planned section B feed	Ore [tonnes/hour]	M	90	102	
	Head grade Au [g/tonnes]	F	3.1	2.1	
Knelson	Concentrate [kg]	m_k	28	32	
	Fluidisation water [m ³ /hour]		17	15	Min. not investigated
	Feed [t/hour]	m	79	111	Max. not investigated
	Conc cycle time [min]	λ	46	38	
	Mass load [t]	L	60	70	Optimised
Grav conc	Calc grade [Au g/tonnes]	c	7200	2100	
	Calc max gravity Au recovery [%]	U	(94)	49	Se text for comments

On/Off tests

Full-scale on/off tests were carried out in order to compare three different process circuit layouts. The primarily objective was to compare the total Au recovery that was achieved at each layout. The secondary objective was to compare the distribution of recovered gold amongst the different concentrates produced.

The results comparing the old gravity circuit with the Knelson circuit treating the hydrocyclone feed is shown in Table 5. There is a big difference between the calculated head grades in the two test circuits. The on/off tests should give similar head grades if a sufficient number of partial tests are done; similar head grades can therefore be seen as proof that no errors were made during the tests. The big difference in this test can either be explained by nugget problem in the gold sampling, or be the result of an error during the tests. However it is satisfying to see that the gold grade in the gravity concentrate is more than three times higher when using the

Knelson Concentrator (KC). Furthermore the gravity gold recovery and the total gold recovery are increased by 15.4 % and 3.4 % respectively (%-units).

Table 5 Knelson concentrator treating cyclone feed versus old gravity circuit tested on Renström ore

	Ore (tonnes)	Grade Au (g/tonnes)				Recovery (%)		
		Head Grade	Gravity concentrate	Cu/Pb-concentrate	Cu/Pb-middlings	Gravity	Flotation	Total
Knel. CF	9 330	3.45	5 428	33.3	1.20	27.4	39.2	66.7
Old Gravity	9 214	2.86	1 607	36.2	1.09	12.0	51.2	63.3

The Au gravity recovery during the KC tests were about half of the GRG-value, indicating that the operation of the KC was not completely optimised.

The feed to the KC during on/off tests was approximately 70 tonnes/hour, and the cycle time was 120 minutes giving an approximate mass load of 140 tons. The concentrate grade and the recovery are lower in comparison with what was achieved at the same mass load during the optimisation tests; this can partly be explained with a lower head grade.

In the second on/off test, the cycle time was set to 60 minutes. The feed flow rate was 100 tonnes/hour during the periods when the KC was treating the hydrocyclone underflow and 50 tonnes/hour when treating the cyclone feed. Comparing with the optimisation tests for the cyclone feed, a doubled mass load on KC should give a much higher concentrate grade and a higher gold gravity recovery. This can also be noted in Table 6, even though the increase in grade and recovery is not that high as could be expected. The optimisation was made on the KC treating cyclone feed so the correlation differs when treating the cyclone underflow.

Table 6 Knelson concentrator treating cyclone feed versus Knelson concentrator treating cyclone underflow tested on Renström ore

	Ore (tonnes)	Grade Au (g/tonnes)				Recovery		
		Head Grade	Gravity concentrate	Cu/Pb-concentrate	Cu/Pb-middlings	Gravity	Flotation	Total
Knel. CF	12 116	3.32	3280	32.7	1.18	33.1	32.6	65.7
Knel. CU	15 643	3.21	3703	32.4	1.00	35.0	34.9	69.9

One problem when treating the cyclone underflow on the KC is the water balance in the grinding circuit. Without dewatering of the KC middling the total addition of fluidisation water will go to the secondary mill causing low percent solids and poorer grinding results. Before choosing between these two flowsheets, more investigations with higher KC feed rates of cyclone feed will be performed. Also an optimisation of the operating variables for the KC treating cyclone underflow is planned.

Metallurgical results

The KC has now been in continuous production for 6 months. The metallurgical balances for Renström ore from the period before and after installation of the new gravimetric equipment is shown in Table 7. The gold head grade in the two balances differs which in this case does not indicate an error, it is instead a normal variation in the ore feed grades.

The total Au-recovery has increased with the KC. Note that the KC gives a lower tailings grade even with a higher head grade. Furthermore, the Au-distribution to the Zn-concentrate and the Pb-concentrate are reduced.

Table 7 Metallurgical results for the Renström ore, year 2004, January-April with the old gravity circuit and July-December with the Knelson concentrator

	Au grade (g/tonnes)		Au distribution (%)	
	Old gravity	Knelson concentrator	Old gravity	Knelson concentrator
Feed	3.49	3.74	100	100
Gravity conc	1 585	4 257	13.5	35.7
Cu-conc	65.22	51.9	48.8	31.6
Pb-conc	8	7.5	5.1	4.4
Zn-conc	2.9	3	10.8	10.5
Flotation tailings	0.93	0.81	21.8	17.7
Total Au-recovery			67.4	71.7

5 Summary

Traditional gravity equipment in one of the grinding circuits at the Boliden concentrator has been replaced with a Knelson Concentrator (KC). The KC is producing a concentrate with a higher Au-grade comparing to the former shaking table concentrate, and the Au gravity recovery has increased. After installation of the KC, the tailings gold grade from the subsequent flotation circuit has been lowered.

The old gravity circuit consisted of a Reichert cone, three concentrating spirals and a shaking table. The change to the Knelson gravity separation technique has considerably reduced the floor space requirements in the plant.

The daily maintenance is shown to be much less time consuming and the fewer amount of equipment is expected to lower maintenance costs in the future.

A future plan includes installation of a similar KC on the parallel grinding circuit at the Boliden concentrator.