Comparison of the Knelson and Falcon centrifugal separators

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Abstract

The performances of two lab-scale centrifuge concentrators - the 3'' Knelson and the 4'' SuperBowl - have been investigated. Synthetic ores consisting in mixtures of quartz/tungsten, quartz/ilmenite/tungsten and quartz/galena have been used. Concentration tests with quartz/galena suggest that the concentration of the dense mineral can proceed by different ways according to the water flow: by infiltration or by plating of the dense mineral (low flow), by substitution between the light and the dense minerals (intermediate flow) and by elutriation of the light mineral (high flow). Tests carried out on the two concentrators show that the Falcon achieves, on a wide range of particle sizes of the tungsten and on a wide range of water pressure, a better recovery of the tungsten (used to simulated gold) than the Knelson. The Knelson and the Falcon have been used to concentrate less dense mineral than tungsten (galena). In both concentrators, the recovery is less than with the tungsten. Again, a better recovery is obtained with the Falcon.

Introduction

Among the separation processes, gravimetry is probably the cheapest one. Thus, it has to be considered first, of course if the liberation of the constituents is obtained by enough fragmentation and if the difference in specific gravity is high enough (Taggart's criterium[1]). However, the efficiency of gravimetric separation become very poor when the particle size become very fine, around 100 µm. To overcome these limitation, new apparatus utilizing centrifugal force and fluidization have been recently designed and are used more and more in gold recovery. These apparatus, Knelson and Falcon Superbowl, provide good recoveries for very fine particles up to 38 µm and finer. These apparatus and their uses have been described in many papers.[2, 3, 4 & 5]

The fundamental approach of the behaviour of mineral particles in these apparatus has not been studied until now. In our Department, we carried out some fundamental researches on fluidization and centrifugation with well-defined mineral particles in order to describe the laws governing their behaviour.

If the present application of Knelson and Superbowl are the recovery of gold, a good understanding of their working could open the way for other applications such as the dressing of disseminated and/or low grade ores, the retreatment of tailings or residues, the waste beneficiation, or the cleaning of polluted soils. Moreover, the use of the Knelson or Falcon is generally of low cost and has no or very low environmental impact.

The aim of this paper is to compare the use and the recoveries obtained with these two devices. This study has been carried out for the purpose of their application to other materials than the gold ores.

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Equipment and materials

The concentrators used in the study are both the laboratory model: the 3'' Laboratory Knelson and the Falcon 4'' Laboratory SuperBowl (SB4). The table 1 gives for the two concentrators the water flow rate as a function of the water counter-pressure (CP).

CP (kPa)	Flow in the Knelson (l/min).	Flow in the Falcon (l/min).
10	6.15	9.84
20	7.66	11.05
30	9.17	12.26
40	10.68	13.47
50	12.18	14.68
60	13.69	15.89
70	15.20	17.10
80	16.71	18.31
90	18.21	19.52
100	19.75	20.73

Table 1: Water flow rate (liter/minute) as a function of the water counter-pressure (CP, kPa) for the 3'' Knelson and the 4'' Falcon (values do <u>not</u> include the water contained in the slurry).

In order to obtain good and precise comparison, the experiments have been carried out with well-defined and pure mineral particles. The minerals used are described in Table 2. We choose the quartz as an example of the gangue behaviour, ilmenite as a mineral of intermediate density, galena as a dense material to be recovered and metallic tungsten which has almost the same density than the gold (19.1 instead of 19.3).

	Density	Particle size (μm)			
Quartz	2.7	38-53	74-104	147-208	1168-1651
Ilmenite	4.5	43-104	104-208		
Galena	7.5	38-80	80-200		
Tungsten	19.1	<38	38-53	45-250	

Table 2: Nature, density and particle size of the pure mineral samples used in the study.

Experimental procedure

The mixtures studied were:

quartz-tungsten	(100/10g)
quartz-ilmenite-tungsten	(100/10/10g)
quartz-galena	(100/10g)

For each test, a bed of quartz particles is first built in the bowl, until the excess of quartz is ejected out, in order to simulate the steady-state conditions. Then the mixture (110g or 120 g if 2 or 3 components) is fed as a pulp into the bowl. At the end of the test, the "concentrate" remaining in the bowl and the tailings are collected, dryed, weighed and their composition is determined by separation with heavy liquid (bromoform) or by using a Mozley shaking table.

Comparison of the feeding into the fluidization zone

According to differences in the design of the two concentrators, the feeding of the ore in the fluidization zone is very different in the Knelson than in the Falcon.

In the Knelson, the ore is directly fed in the fluidization zone. In the Falcon, the material is first fed in a "segregation zone" along the cone wall where the dense particles percolate through the bed of gangue to reach the wall of the bowl. At the end of this part of the bowl, the bed of materials is roughly composed of a lower layer containing most of the dense particles and an upper layer of gangue. Then, this segregated material enters in the fluidization zone. This way of feeding can have a strong influence on the recovery of heavy particles.

In the Knelson the particles are directly subjected to the water flow. So the smallest gold particles can remain in the feed flow of pulp and do not enter in the inter-riffles spaces (IRS). By this way, some of the gold particles can by-pass the IRS and be lost.

In the Falcon, the gold particles are at the bottom of the segregated bed. According to hydraulic behaviour, the speed of the fluid in contact with the wall is lower. Then, the gold particles can slip on the wall of the riffle whereas the gangue particles, situated in the upper part of the layer, keep their trajectory and are ejected from the IRS. So, the risk that gold particles by-pass the IRS seems to be very low in the Falcon and is only limited to the particles which were not segregated in the first portion of the bowl. With an adequate feed rate it is possible to obtain a complete segregation and a full recovery of gold.

Concentration modes

Depending on the flow rate of the fluid accross them, the light particles can be fixed (low speed), fluidized (higher speed) or elutriated (very high speed). The fluid velocity to get each of these states depends on the size and the specific gravity of the particles.

The results of our experiments showed that the kind of states obtained in Knelson and Falcon depends on the CP water values and leads to different modes of concentration, which can also depend on the relative particle sizes of gangue and heavy materials.

<u>At low CP values</u>, the gangue is blocked into the IRS and gives a porous fixed bed. If the heavy particles are smaller than the voids of this fixed bed, they can percolate through the bed and reach its bottom where they are concentrated. This mode of concentration can be called <u>"concentration by infiltration"</u>. If the heavy particles are larger than the voids, they cannot infiltrate through the gangue bed. However, due to the centrifugal force, they can be accumulated on the top of the bed. This mode of concentration can be called <u>"concentration by plating"</u>.

The figure 1 shows the recovery, with the Knelson, of galena of different particle sizes in mixture with quartz of a given size (1168-1651 microns). The CP used (20 kPa) has been chosen to obtain the packing of the gangue whereas all sizes of galena are fluidized. It can be observed that best results are obtained with finer and coarser particles and that intermediate particle sizes give lower recoveries. This behaviour confirms the existence of concentration by plating (coarse particles) and by infiltration (fine particles), the intermediate particles are too big to infiltrate the bed and too small to remain fixed on the top of the bed.

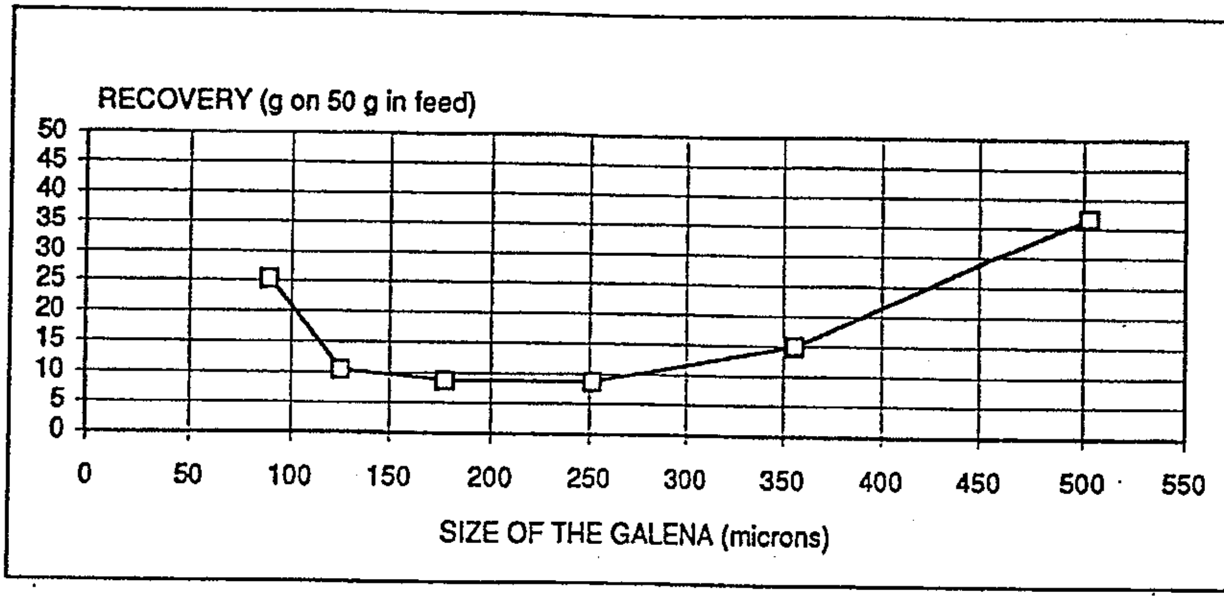

Figure 1: Influence of the particle size of galena on its recovery in the Knelson from a mixture of 50 g galena with 1168-1651 µm quartz. Galena particle sizes are 74-104 µm; 104-147µm; 147-208 µm; 208-295 µm; 295-417 µm and 417-589 µm.

At higher CP values, the gangue bed is partially or fully fluidized and the heavy particles settle through the bed and reach the bottom of the IRS. The accumulation of heavy particles reduces the place for the light ones which are ejected from the IRS. This mode can be called "concentration by substitution".

When the CP is high enough, the gangue is directly elutriated out of the IRS and the heavy material is then recovered by what can be called "concentration by elutriation of the gangue".

With concentration by infiltration the recovery of heavy minerals ceases when all the voids of the fixed bed are filled by the heavy particles. Any additional feeding of heavy mineral will be lost in the tailings.

With concentration by plating the recovery depends on the hydrodynamic drag force of the pulp flow which can remove the heavy particles fixed at the top of the bed.

In the concentrations by substitution and by elutriation of the gangue, the heavy minerals recovery depends on the relative particle size of light and heavy minerals. As an example, the CP needed to fluidize or elutriate the coarse particles of gangue can be higher than the CP giving the same effect on smaller gold particles which are then lost in the tailings.

It should be noted that in the treatment of an actual gold ore the different modes of concentration occur simultaneously according to the wide range of gangue particle sizes.

In the Falcon, due to the presence of a segregation zone, it is probable that the concentrations by infiltration and by plating do not occur because the heavy particles are already almost completely segregated when they enter the fluidization zone.

Recovery of tungsten from binary mixtures with quartz

Figures 2, 3 and 4 show the recovery of tungsten in function of the CP for different particle sizes of quartz and of tungsten. On each figure the results obtained with Knelson and Falcon are presented. It clearly appears that the Falcon achieves recoveries very close to 100 % in the full range of CP. With Knelson, the recovery is 100 % for the 45-250 microns tungsten at low CP values and drops dramatically when CP is increased. It is particularly important with the finer tungsten (0-38 microns). Although the gangue is fluidized at CP values as low as 5-15 kPa depending on its particle size, operating at higher CP values yields higher grade concentrates because the gangue is elutriated.

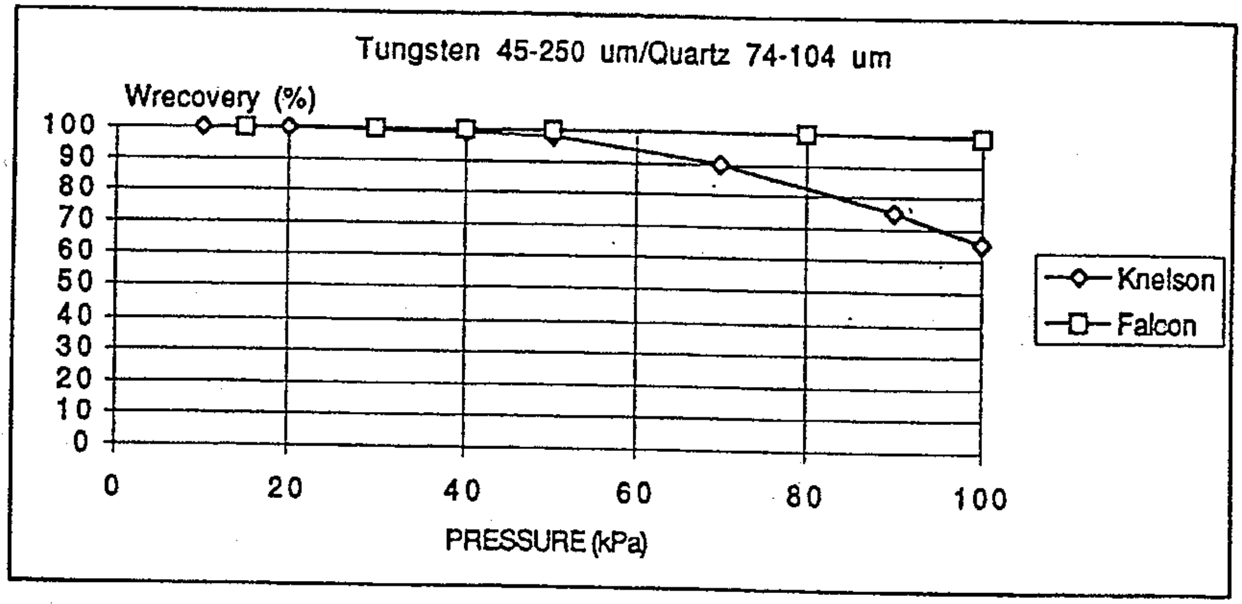

Figure 2: Comparison of the recovery, with the Knelson and the Falcon, of 45-250 µm tungsten from a mixture with 74-104 µm quartz.

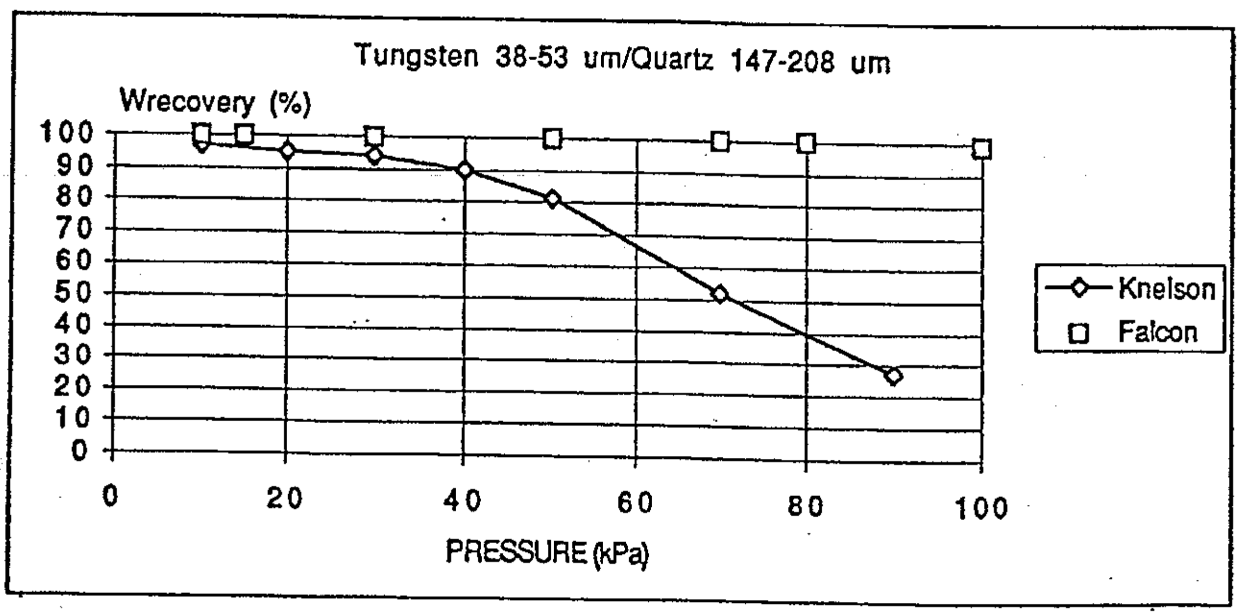

Figure 3: Comparison of the recovery, with the Knelson and the Falcon, of 38-53 µm tungsten from a mixture with 147-208 µm quartz.

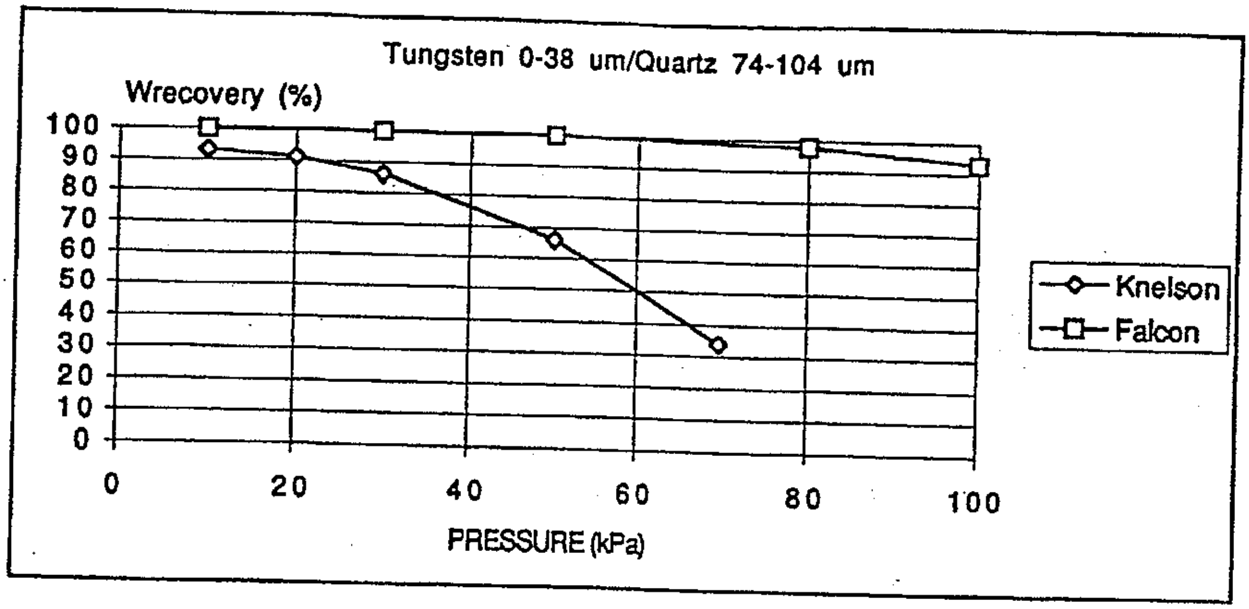

Figure 4: Comparison of the recovery, with the Knelson and the Falcon, of < 38 µm tungsten from a mixture with 74-104 µm quartz.

Figure 5 shows clearly the influence of the particles size of tungsten on its recovery with the Knelson, the corresponding experiments with the Falcon yield recoveries of 100 %.

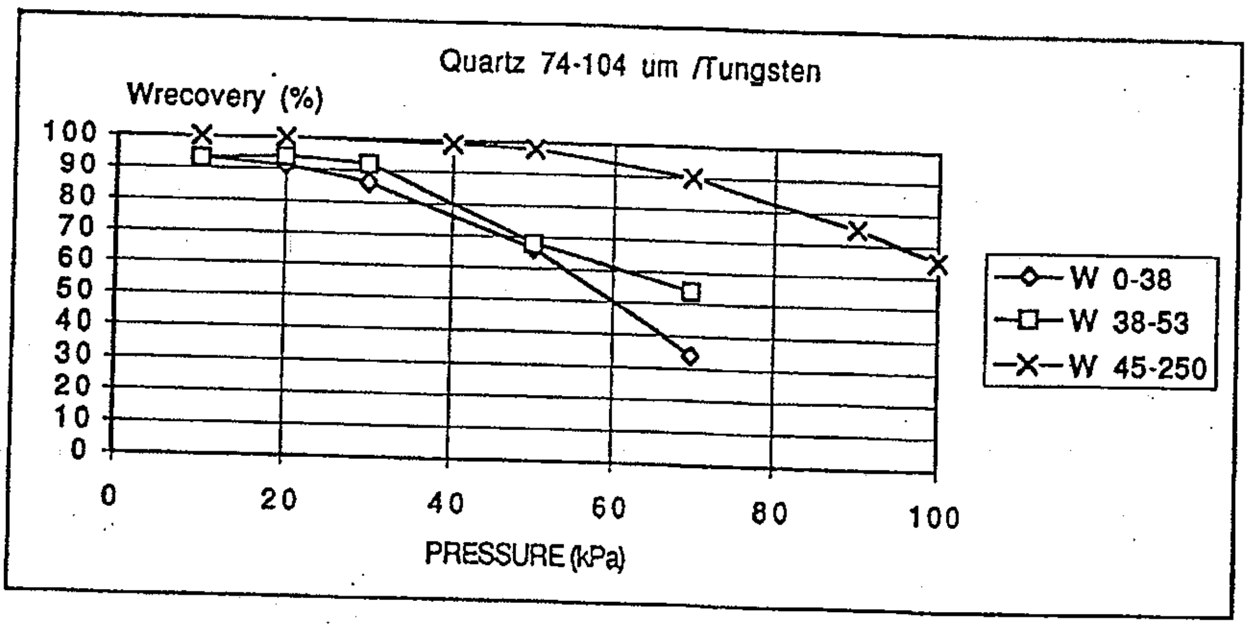

Figure 5: Influence of the particle size of the tungsten on its recovery as a function of the water pressure. The given curves are for the Knelson. The Falcon achieves almost a 100 % recovery for all tungsten particle sizes and on the whole range of water pressure.

Figure 6 shows that for a given particle size of tungsten, a modification of the particle size of the gangue has no influence on the tungsten recovery. This result is coherent with the previous observations of the different modes of concentration because in the present tests, the gangue material is well fluidized at low CP values.

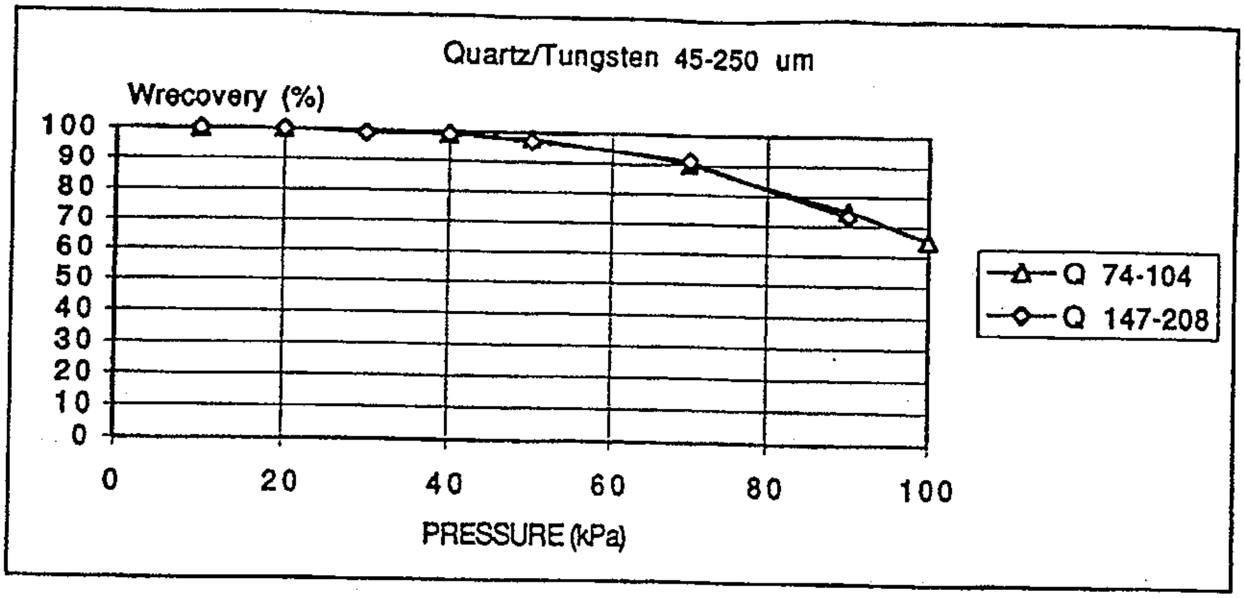

Figure 6: Influence of the particle size of the gangue on the recovery with the Knelson of the 45-250 µm tungsten. The Falcon achieves almost a 100% recovery for all tungsten particle sizes and on the whole range of water pressure.

Recovery of tungsten from ternary mixtures with quartz and ilmenite

By comparing with similar experiments carried out on binary mixtures it can be observed that the presence of a mineral of intermediate specific gravity does not modify the recovery of tungsten, both in Knelson and in Falcon. Results for the Knelson are shown in figure 7. However, the presence of ilmenite can modify the concentration ratio obtained and the working time of the concentrators before cleaning, if according to their particle size, ilmenite particles are not fluidized in the working conditions.

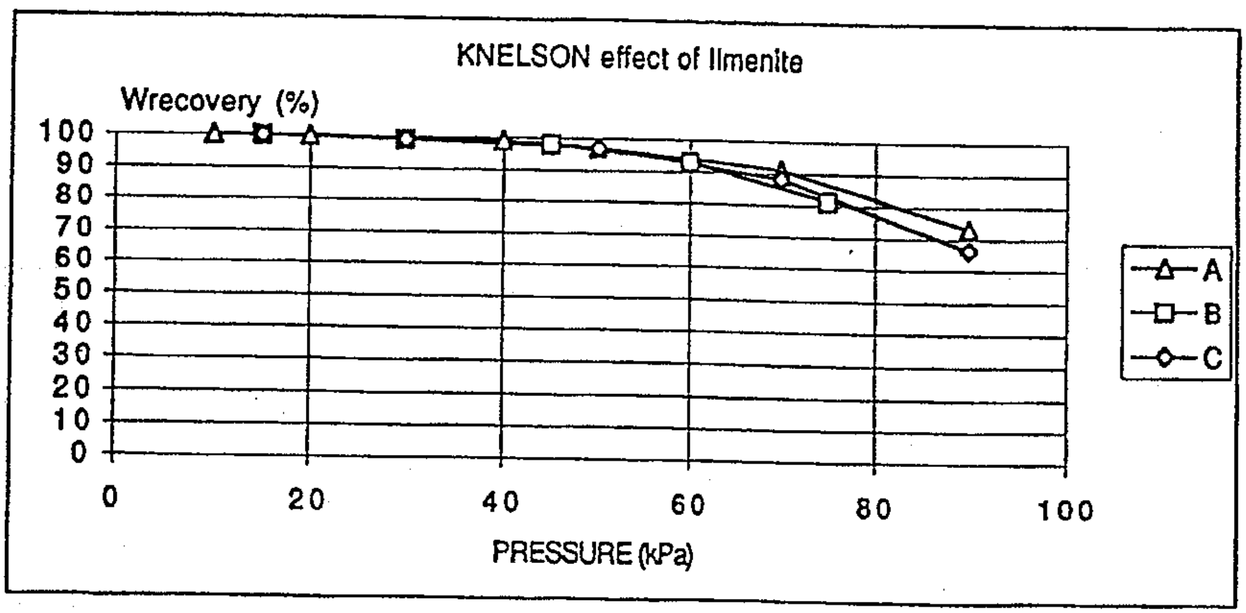

Figure 7: Effect of the presence and the particle size of ilmenite on the recovery with the Knelson of the 45-25µm tungsten (147-208 µm gangue). The Falcon achieves almost a 100% recovery for all tungsten particle sizes and on the whole water pressure range.
A. without ilmenite B. with 43-104 µm ilmenite C. with 104-208 µm ilmenite

Recovery of less dense minerals

The Knelson and the Falcon have been designed for the recovery of the gold. Nevertheless, both can be used to concentrate materials ligther than gold for example for the retreatment of tailings of base metals ores or for the benefication of wastes of small size. The figure 8 shows the results obtained with a mixture of galena and quartz. galena shows a similar behaviour than the tungsten but the recovery is clearly lower in both concentrators.

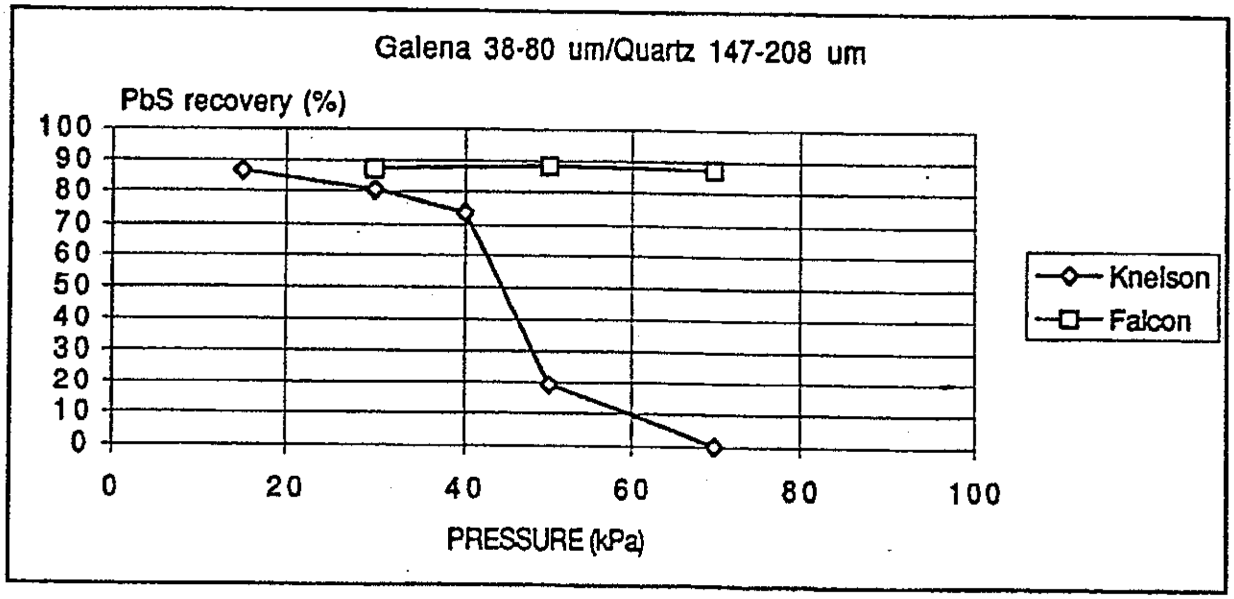

Figure 8: Influence of the water pressure on the recovery of the 38-80 µm galena with the Knelson and the Falcon.

Conclusions

A fundamental study on the behaviour of two gravity concentrators - the 3'' Knelson and the 4'' Falcon "Superbowl" - has been carried out. These two relatively new concentrators use a centrifuge force and a fluidized bed to achieve the recovery of the dense mineral.

The main difference between Knelson and Falcon is the intensity of the centrifugal force (60 g versus 300 g). Moreover, in the Falcon, a segregation of the heavier particles occurs in the bowl before the concentration step itself by fluidization of the light particles. These two differences can be explained the better recoveries obtained in Falcon (100 %) vs 90-95 % in Knelson. The influence of the centrifugal force is obvious. In the Knelson, heavy particles are disseminated in the gangue when they enter in the fluidization zone. Due to the opposite flow of the counter-pressure (CP) water and of the light materials, it is possible that some heavy particles are unable to enter in the inter-riffles spaces (IRS) and are lost in the tailings. In the Falcon, heavy particles are already segregated when they arrive in the fluidization zone and slip along the wall of the IRS to enter in the fluidization zone. In this manner, they are not introduced directly in the main CP water flow. This can prevent the ejection of the heavy particles, especially the finest ones.

From our observations, we can suggest different modes of concentration depending both on the state of the bed of light particles (function of CP water value) and on the difference in particle size between heavy minerals and gangue particles.

- at low CP values, the material remains in a fixed bed. Heavy minerals can be concentrated by infiltration through this bed if their particle size is small enough to allow them to enter in the bed porosity. If they are too coarse to percolate through the porosity, heavy particles can be concentrated by plating i.e. by accumulation on the top of the fixed bed.

- at higher CP values, the materials (mainly the gangue) is fluidized and the concentration of heavy particles is achieved by substitution. The heavy particles settle through the bed and their accumulation causes the ejection of the gangue particles.

- at still higher CP values, the light particles are transported and heavy minerals are concentrated by elutriation of the gangue, i.e. the gangue particles are ejected from the IRS independently of the accumulation of heavy minerals which remain in the IRS.

Of course, in these two last modes of concentration, the values of CP water must remain lower than the corresponding values of elutriation of the smaller heavy particles. If not, these particles will be lost.

In experiments we carried out with tungsten (to simulate gold), it has been observed that the Falcon gives a higher recovery which does not depend on the CP value, as opposite with the Knelson. It is important because with Falcon, it is possible to get concentration by elutriation of the gangue, which gives a higher grade concentration.

The recoveries in the Knelson will vary with the tungsten particle sizes. That is not the case with the Falcon in which the recovery remains around 100 %.

On materials with relative large range of particle sizes we studied, the size of the gangue particles has only few influence on the tungsten recovery. That would remain true in an industrial application.

The presence of minerals which have intermediate specific gravity, at any particle size, does not modify the recovery of tungsten.

The concentration of materials less dense than tungsten can be achieved both with Knelson and Falcon, but again, the Falcon gives better recoveries.

References

1 A. F. TAGGART, Handbook of Mineral Dressing, 1947, Sec. 11, p. 02.

2 B. KNELSON, "Centrifugal concentration and separation of precious metals", in 2nd International Conference on Gold Mining, Vancouver, B.C. Canada, November 1988

3 B. KNELSON, "The Knelson concentrator. Metamorphosis from crude beginning to sophisticated world wide acceptance", Camborne School of Mines, Minerals Engineering Journal, Vancouver, B.C. Canada, 1992

4 B. KNELSON and R. JONES, "A new generation of Knelson concentrators", in Symposium on Environmental Aspects of Minerals Engineering, Cape Town, South Africa, August 1993

5 A.R. LAPLANTE, "A comparative study of two centrifugal concentrators", 24th Annual Meeting of the Canadian Mineral Processors, Ottawa, Canada, 1993

6 Ph. DANDOIS, "Influence de la granularité et de la structure de l'or en concentration gravimétrique". Thesis, University of Liège, Belgium 1992

7 D. GOFFAUX and Ph. JOLY, "Transferencia de nuevas tecnologias de concentracion gravitacional de oro, a la pequena mineria artesanal de la region de Atacama", Informe FNDR, University of Atacama, Copiapo, Chile, 1993

8 G. CACERES, Ph. JOLY, D. GOFFAUX and J. FRENAY, "Application of the Knelson concentrator to small scale mining in the Atacama region, Chile" in Clean Technology for the Mining Industry, Ed. M. SANCHEZ, F. VERGARA and S. CASTRO, University of Conception, Chile, 1996

9 Ph. ANCIA, Ph. DANDOIS and J. FRENAY, "Fluidisation des matières granulaires et nouvelles techniques de séparation gravimétrique. Application au développement durable dans les pays en voie de développement - Study made with funding of the Walloon Region, Belgium 1997