Influence of operating parameters of centrifugal concentrators on flaky gold recovery

A. Schiffers, H. Wotruba
RWTH Aachen University

ABSTRACT: The technical and economical feasibility of by-production of gold from German sand and gravel operations has been investigated by the Department of Mineral Processing of RWTH Aachen University. The by-production can be an interesting option even at low grades as no additional cost occurs for mining or classifying. As the gold contents especially in the German alluvial deposits tend to be very low it is essential to reach high concentration ratios at a high recovery. A further obstacle in recovering gold from sand and gravel is the extreme flakiness of the gold. Only centrifugal concentrators were able to reach a reasonable recovery at high concentration ratios for this type of flaky gold. Extensive test work has been conducted in laboratory as well as in pilot scale to determine the influence of the relevant operating parameters (G-force, water pressure) on the recovery.

1 INTRODUCTION

At present, the European Union only accounts for 0.5 percent of the world mine production of gold with no production in Germany at all (British Geological Survey, 2005).
Nevertheless, recent press releases have increased interest in the potential of by-producing gold from sand and gravel operations. Spanish geologist Viladevall estimates the annual production potential to be 4.4 tons of gold (Nimtz-Köster, 2004), obviously calculating with the average crustal abundance of gold of 4 ppb and 1.1 Bt of sand and gravel, that are currently produced within the European Union.
If the gold recovery for a specific plant is an option at all and what effort can be justified for gold processing depends on the gold grade in the respective deposit.
Extensive work has been conducted to examine economic efficiency of gold recovery for German sand and gravel operations, focusing on the complex interaction of deposit properties, technical and economic feasibility and the Germany-specific legal consequences of the gold production.
This paper gives a short outline of the complete results and mainly concentrates on the examination of recovery of flaky gold by centrifugal concentrators and the effect of their operating parameters on size-by-size recovery.

2 DEPOSIT PROPERTIES

2.1 *Site of examinations*

Traces of gold can be found in many German rivers and old streambeds. This paper is based on tests with sand from a typical sand and gravel operation (500,000 t/a) located in the river Rhine area in Southern Germany. Gold from the Rhine area occurs in the form of small flakes of low thickness and rounded shape. The grades are generally low. Apart from small lenses of gold concentrations of up to several grams per ton, the grade of larger volumes usually tends to be below 0.1 g/t (Kirchheimer, 1965).
Tests were carried out partly in a continuous pilot plant treating part of the –1 mm fraction in the plant as well as under controlled conditions in laboratory scale.

2.2 *Sand properties*

The examined sand has been analyzed regarding its mineralogical composition, particles size distribution and, in the case of the gold the particle shape.
Next to quartz and feldspar, the sand contained a total of ± 0.25 percent of typical heavy minerals, such as garnet, ilmenite, zircon, rutile, magnetite and traces of many others. About 70 to 80 percent of the total heavy minerals show at least a low magnetic susceptibility (determined by a Frantz Magnetic Laboratory Separator) - a property that can be exploited for upgrading pre-concentrates.

The sand is de-slimed at a nominal cut size of 63 µm on the dredger using a hydrocyclone. Consequently, certain gold losses can be expected in the fine size fractions, although the high density of gold should cause at least part of the fine gold particles to report to cyclone underflow.
Figure 1 shows the particle size distribution of the gold bearing sand after desliming and screening at 1 mm.

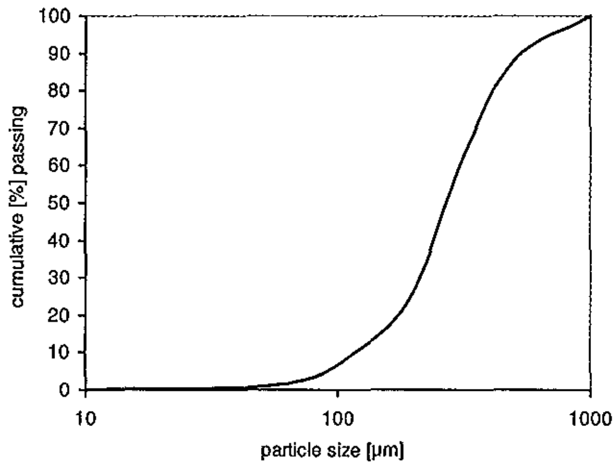

Figure 1. Particle Size distribution of the sand

2.3 *Gold properties*

Gold particles from the evaluated deposit generally show low thickness, as can be seen in the exemplary cross section in Figure 2.

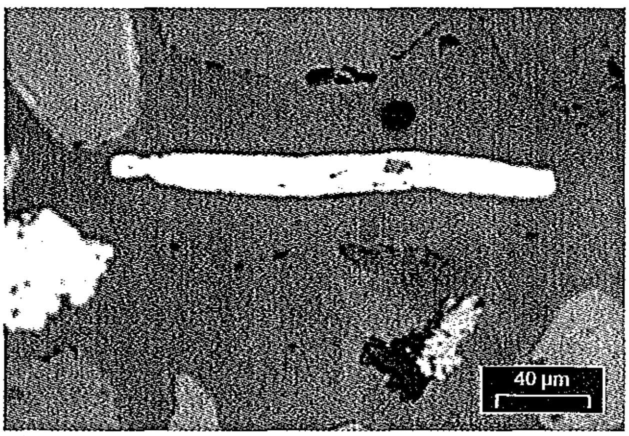

Figure 2. Cross section of a 225 x 17 µm gold flake (reflected light photomicrograph)

A statistical evaluation of more than 1000 particles per size fraction showed that the dimensions of the particles do not affect the average thickness of about 17.5 µm essentially (Fig. 3).
To determine the average thickness, gold flakes have been screened at 20, 40, 63, 100, 125, 160, 200, 250 and 315 µm. The total surface area of samples of the fractions has been determined by automatic picture analysis. The average thickness could then be calculated knowing the weight of the samples and the average density of 18.4 g/cm³. Because the ratio of length and width of the gold flakes varies in a wide range, the average diameter of the particles for simplicity reasons has been calculated assuming the particles are circular. The values for diameters depicted in Figure 3 refer to the calculated average diameters for the particles of the screen size fractions. All calculated average diameters are about 20 percent above the nominal upper fraction limit. This can be traced back to the fact that the flat particles are able to pass the square holes of the screen diagonally, allowing particles with a shortest axis of $\sqrt{2}$ times the nominal screen cut size to pass the screen.
As the thickness of the particles stays nearly the same for all size fractions, the "flakiness", expressed as ratio of diameter and thickness (aspect ratio), is decreasing in the finer fractions. In fact, particles below 40 µm have a different geometrical appearance. They have the shape of irregular needles and wires compared to the rounded gold plates in the coarser fractions.

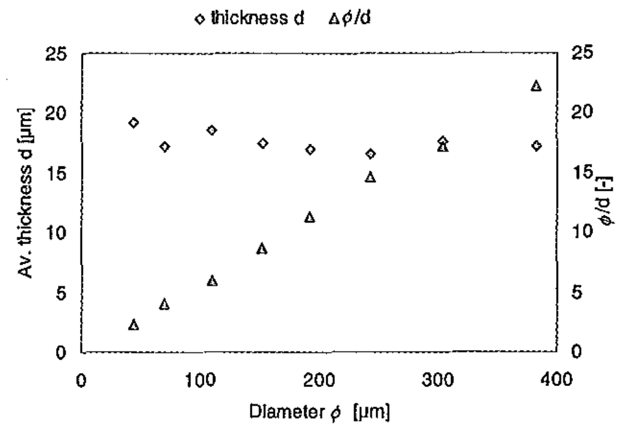

Figure 3. Gold flake thickness for various size fractions

Statements on the typical particle size distribution of the gold and average gold grades can only be made to a limited extend. As the gold grades in all fractions are very low and additionally fluctuate to a great extend, samples are always affected by the nugget effect (e.g.: one 200 µm particle accounts for 0.1 g/t of gold in 100 g of sample). Therefore, analyses could only be conducted after pre-concentrating larger amounts of samples, risking to lose part of the gold to the tailings. Judged from this, more than 80 percent of the gold is in the size range between 100 and 300 µm, an observation corresponding with the examinations of Kirchheimer (1965). Only a small part of the gold is made up of coarser gold flakes of up to 700 µm

diameter, the rest can be found in the -100 µm fraction.
The gold grades in the -1 mm fraction vary between values of 0.01 and 0.1 g/t. An average value can only be estimated from the recovery tests and tends to be around 0.05 g/t.

3 RESULTS OF RECOVERY TESTS (SUMMARY)

Under German legislation, only chemical-free methods of gold recovery can be applied. Therefore, different methods of gravity concentration have been compared regarding their ability of flaky gold recovery: sluice boxes, spiral concentrators and centrifugal concentrators.
All of the methods have their benefits that can be summarized as follows:
Sluice boxes reach the lowest recoveries at high concentration ratios. Due to their ease of operation and low costs, it is a simple option to install sluice boxes in the plant and just remove a small part of the gold. This option could be applied for very low gold grades. Another application for sluice boxes would be the scavenging of tailings from centrifugal concentrators.
Spiral concentrators exceed the recovery of the sluice boxes, but fail to reach an enrichment ratio necessary to concentrate the gold to a sufficient grade for downstream processing (at least without chemicals). They are only a useful option if other heavy minerals are to be recovered. This is not of interest for most of the German sand and gravel deposits.
The best results for recovery and enrichment ratios were achieved by centrifugal concentrators. Recoveries of more than 80 percent were achieved even below 0.1 percent of mass pull. Due to the - compared to sluice boxes - high capital and operation costs a minimum gold grade, depending on the total throughput of the plant as well as on the proportion of the -1 mm fraction, has to be present to justify the installation. In Germany, the profitability of the installation of a gold recovery plant is additionally affected by the fact, that sand and gravel operations producing gold are treated according to mining law (in contrast to a mere sand and gravel plant). To give a figure, gold grades of at least 0.05 g/t in the -1 mm fraction are necessary to make the by-production of gold profitable.
By centrifugal concentrators, pre-concentrates with grades of several hundred to thousand g/t (depending on the grade of the sand) can be produced. To reach a grade sufficient for melting the concentrates, additional processing has to be applied.
Tests for wet tabling have been conducted at the laboratory of Holman-Wilfley Ltd, UK. A pre-concentrate grading only at 44.5 g/t (concentrate of higher grades was not available in a sufficient amount) was tabled on a Holman table in two stages in rougher-cleaner constellation. The results of the tests are shown in Figure 4 (acc. to MacDonald et al., 2004).
The rougher concentrate contained 99 percent of the gold in 12 percent of the initial mass. In the cleaner stage, a concentrate grading at 0.85 percent could be extracted at a gold recovery of 70 percent. By magnetic separation, another 80 percent of the concentrate could be removed with nearly no gold losses. Assuming that in operation the gold content of the table feed usually would be higher, a sufficient gold grade for smelting can be achieved by the described procedure.
To minimize gold losses, the cleaner table tailings are to be re-circulated to the rougher table or centrifugal concentrator.

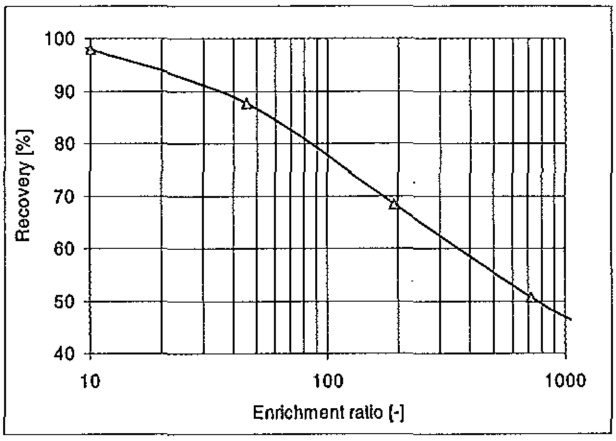

Figure 4. Grade-recovery diagram for the concentration of pre-concentrates using a Holman table

4 FLAKY GOLD RECOVERY BY CENTRIFUGAL CONCENTRATORS

Many papers have been published dealing with gold recovery by centrifugal concentrators from grinding circuits, whereas the effect of operating parameters mostly only appears as a side note.
McAlister et al. (1998) found out that centrifugal concentrators readily recover flaky gold in contrast to 1G-concentrators - not knowing the mechanisms.
Knipe et al. (2004) discussed the problem of the recovery of flaky gold particles by gravity concentration and flotation in detail. Especially coarse gold flakes have a high surface area compared to the mass and tend to behave "like a sail in the wind". Stoke´s law, implying that gravity separation becomes easier for equivalent particles with increasing particle size and density, consequently does not fit for these particles. In laboratory tests with an 3,5" Knelson Concentrator under optimized conditions gold recoveries of about 45 to 82 percent for different -100 µm fractions up to 95 percent for + 300 µm were

achieved out of an artificial mixture . Another result was that in the finer fractions (-40 µm), flaky gold is preferentially recovered compared to equivalent particles while in the coarse fractions the effect is vice versa.
Laplante (2000) developed a standard procedure to determine the proportion of gold that is amenable to gravity recovery (GRG) by centrifugal concentrators. He found out that the amount of GRG can be correlated with the d80 particle size of the gold, limited by other mineralogical factors. In the test procedure, the influence of different operating parameters is not taken into account.
Laplante (1995) did a comparison of a Knelson and a Falcon concentrator, two centrifugal concentrator types that were by the time of testing running at different centrifugal forces. While the Falcon (rotating at higher speed) was working better for particles below 37 µm, the Knelson achieved better results in the coarser fractions. This effect was explained with the compression of the fluidized bed at higher G-forces and the resulting difficulty for coarser particles to percolate through the bed. The link between G-force and fluidization water flow was identified as the main influence factor for the concentrator performance.
The aim of the tests described in the next chapters was to learn in detail, how the operating parameters affect the concentrator performance for the recovery of flaky gold.

5 EXPERIMENTAL

Tests were carried out using a Falcon SB40 laboratory centrifugal concentrator. The function of centrifugal concentrators in general is described for example by McAlister (1998) and Knelson et al. (1990).
To determine the gold content of the original sample and concentrates, a picture analysis method taking into account the thickness and density of the gold was developed to be able to use the same material for each test. This way, inaccuracies in the determination of the recoveries resulting from feed measurements biased by nugget effect could be excluded. The analysis method as such was calibrated by comparing fire assay measurements for concentrates. For particle geometry reasons, the method was not accurate for the -100 µm fraction. Therefore, additional tests have been carried out with artificial mixtures of sand and pure gold for these fractions using fire assay analyses.
The original sample used for all tests consisted of 23 kg of original sand -1 mm from the above mentioned plant. The gold content was determined to be 0.083 g/t - hence higher than the average in the deposit.
The performance of the SB40 was evaluated for five different rotating speeds, resulting into centrifugal accelerations of 45G, 60G, 120G, 180G and 240G and for three fluidization water pressures: 1 psi, 2 psi and 3 psi.
The dry feed material was fed at a constant rate of 30 kg/h to the SB40 and mixed with water in the SB40's feed funnel to a solids content of 25 wt.-%.
After each test the complete tailings and concentrates (about 80-100 g in each test) were collected and dried. After analysing the concentrates, they were mixed with the tailings again and could be used for the next test.
Due to the high effort for evaluating each single test, only three random tests were repeated to check the reproducibility of the results. In all three tests the results could be repeated with ±1 percent deviation in recovery.

6 RESULTS AND DISCUSSION

Figure 5 depicts the overall recoveries for all tests. A high overall recovery of more than 90% can be achieved under optimised laboratory conditions at lower rotating speeds.

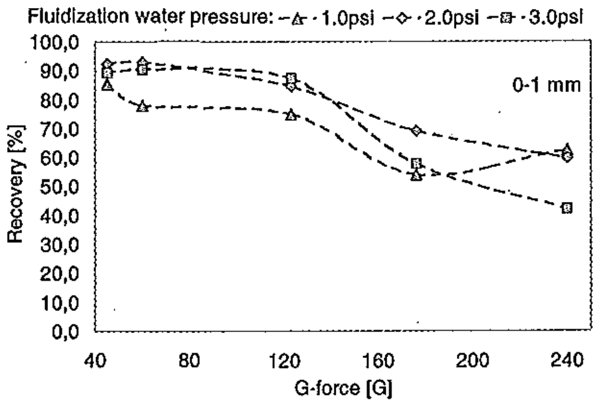

Figure 5. Overall recoveries of Falcon SB40 tests

Figures 6-11 show the size-by-size recoveries for all tests. The results of the tests with a fluidization water pressure of 3 psi for the -100 µm fractions were still missing at the time of submitting this paper.
The results of the size-by-size recoveries allow a more detailed view on the separation mechanisms in the concentrator:

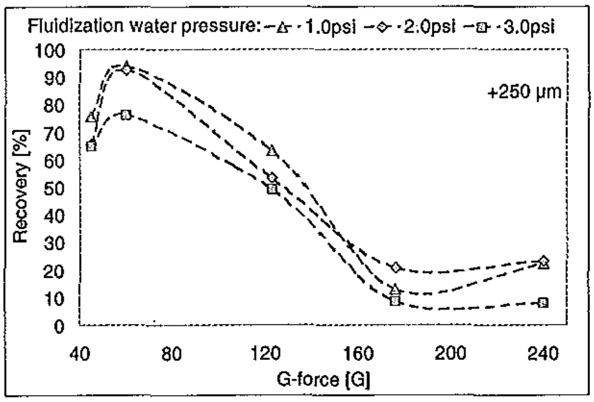

Figure 6. Recoveries in the +250 µm fraction

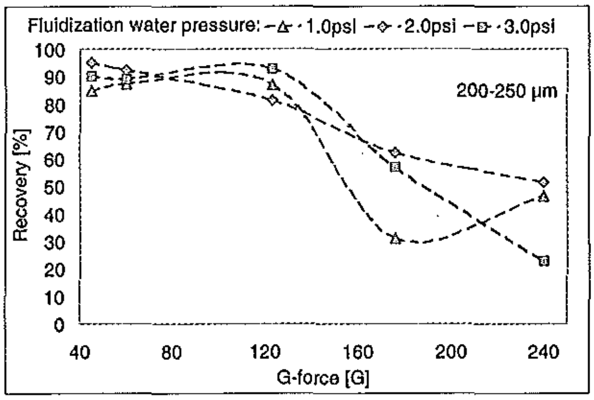

Figure 7. Recoveries in the 200-250 µm fraction

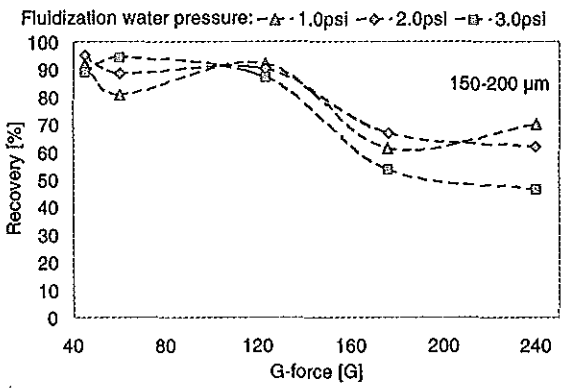

Figure 8. Recoveries in the 150-200 µm fraction

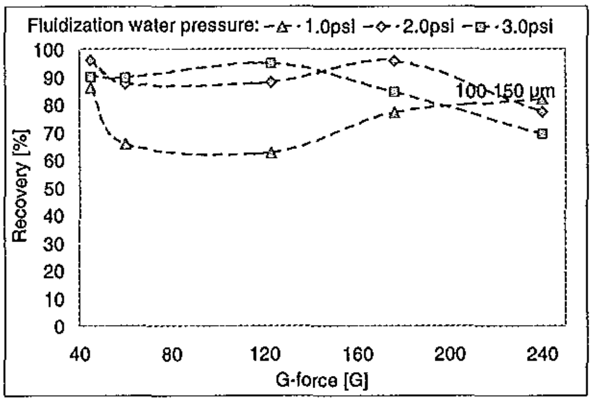

Figure 9. Recoveries in the 100-150 µm fraction

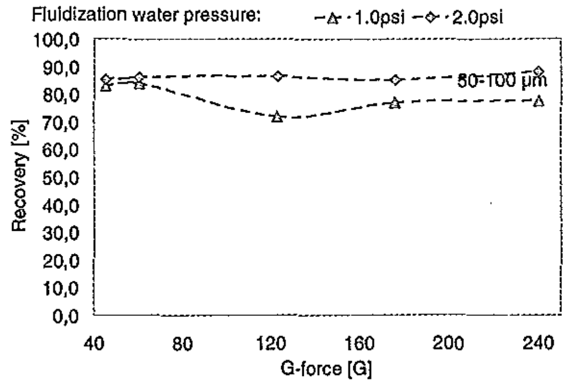

Figure 10. Recoveries in the 50-100 µm fraction

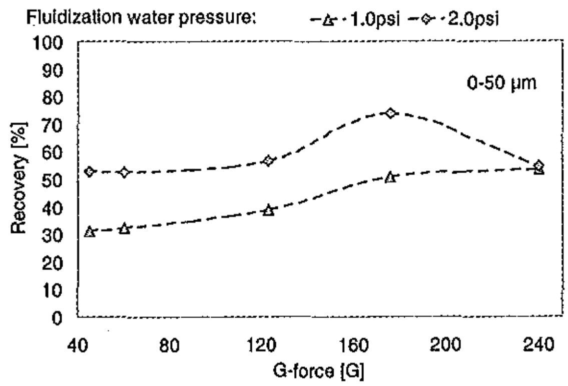

Figure 11. Recoveries in the -50 µm fraction

The following statements can be made based on the results:

- Even gold flakes with high "flakiness", i.e. high aspect ratios are readily recovered by centrifugal concentrators at proper settings
- Maximum recoveries of more than 90% were achievable for all +100 µm fractions
- Recoveries are dropping in the -100 µm fractions
- The coarser the gold flakes, the lower the optimum rotating speed
- The coarser the gold flakes, the higher the sensitivity to varying centrifugal forces
- Fluidization water pressure has only a strong influence on the concentrator performance in the -50 µm fraction
- Optimum fluidization water pressure of 2 psi for all fractions

Obviously, there is not one setting able to reach optimum recoveries for all size fractions. The main factor affecting the concentrator's performance is the rotating speed corresponding to the G-force- at least for the examined type of gold flakes.

The results confirm the statement by Laplante (1995), that at high rotating speeds the fluidized bed is too compact to allow coarser particles to trickle through the bed and thus get recovered, as the losses at high speeds increase with increasing particle size. On the other hand, finer particles seem to be influenced rather by other than the centrifugal forces at low speeds, possibly the drag force of pulp flow passing the machine, and therefore are preferentially kept back at higher speeds. Because many factors and forces influence the separation results, no exact explanation can be given for the mechanisms leading to the received results.

7 CONCLUSIONS

On testing and commissioning of centrifugal concentrators a special focus has to be put onto the operating parameters, as they can severely affect the concentrator's performance.

An optimum testing and commissioning procedure would focus on different rotating speeds, fluidization water pressures and size-by-size recoveries for different settings.

The settings for optimum overall recovery can then be derived knowing the size distribution of the gold.

Knowing the results from this paper it may be useful to implement two or even more machines running parallel or in line at different settings in certain applications, e.g. when using centrifugal concentrators for the scavenging of flotation tailings, where predominantly very fine and coarse gold particles are present, whereas flotation achieves good recoveries for intermediate particles.

8 REFERENCES

British Geological Survey, *European mineral statistics 1999-2003.* 2005, Keyworth, Nottingham: British Geological Survey

Kirchheimer, F., *Über das Rheingold.* Jahreshefte des Geologischen Landesamtes Baden-Württemberg, 7, 55-85 (1965).

Knelson, B., Edwards, R., *Development and economic application of Knelson concentrators in low grade alluvial gold deposits.* AusIMM Annual Conference, New Zealand (1990)

Knipe, S.W., Chryssoulis, S.L. and Clements, B., *Flaky Gold: Problems with Recovery and Mineralogical Quantification.* JOM, Vol. 56, Nr. 7, pp. 58-62 (2004).

Laplante, A., *An Investigation of the Super-Bowl at Mineral Hill and Knelson at Casa Beradi Mines.* Report on the first year of the NSERC-CRD Project 661-148-95 (1995)

Laplante, A., *A standardized test to determine gravity recoverable gold.* Technical paper, McGill University, Canada (2000).

MacDonald, N., Hallewell, M.P., *Internal test report*, not published (2004).

McAlister, S., Armstrong, K.C., *Development of the Falcon concentrators.* Presentation at the SME Annual Meeting, Orlando, Florida (1998).

Nimtz-Köster, R., *Der Traum vom Rheingold.* Der Spiegel, 12, 184-185 (2004).