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The distribution of gold on loaded carbon

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SYNOPSIS
The distribution of gold loaded onto carbon particles from a carbon-in-pulp operation was measured by neutron-activation analysis. The nature of the distribution is examined, and the implications for operating plants and CIP simulators are discussed.

SAMEVATTING
Die verspreiding van die goud wat in 'n koolstof-in-pulpbewerking op koolstofpartikels gelaai is, is deur neutronaktiveringsanalise gemeet. Die aard van die verspreiding word ondersoek en die implikasies vir bedryfsaanlegte en KIP-simuleerders word bespreek.

INTRODUCTION

It has long been known that the gold loadings on individual carbon particles in any contacting stage in a carbon-in-pulp (CIP) process are not the same. Individual particles adsorb gold to different degrees, and this results in a distribution of gold loadings in any given contactor. Although such distributions have been simulated[1], they have not previously been measured. This paper describes a study of the distribution of gold loadings on a loaded carbon taken from one day's production in a South African CIP operation.

The gold loading of carbon particles is distributed among the carbon particles for two primary reasons. In the first place, the rate of adsorption of gold onto carbon is influenced by the size of the carbon particles[2]. If the adsorption kinetics are controlled by film diffusion, the rate is inversely proportional to the particle diameter. If intra-particle diffusion is rate-controlling, the rate is proportional to the inverse of the square of the diameter. In both cases, the relevant mass-transfer coefficients may themselves be dependent on particle size to some degree[3], and this would further modify the influence of particle size on the adsorption rate. In either event, the smaller the particle, the greater the adsorption rate.

The particles of activated carbon used in the CIP process have a range of sizes, as shown in Table I. The lower limit is imposed by the size of the apertures in the retaining screens on the contactor outlets. Typically, this is 600 μm, and the carbon is pre-screened to ensure that all the particles are larger than about 850 μm.The upper limit is less important, but usually the particles are no larger than about 2 mm; otherwise, the adsorption rates are compromised. The size range of the particles used, though relatively small, is nevertheless significant. For the same contact time, the smaller particles will become loaded to higher values than the larger particles, and the gold loadings on individual particles will be distributed as a result.

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The second important factor that is responsible for distributed loadings is the way the carbon is transferred. The mean gold loading on the carbon in the circuit decreases from the first to the last contactor in the adsorption train. During the transfer cycle, carbons from different tanks become mixed to some degree, unless the complete carbon inventory in each tank is instantaneously moved upstream. Only in the carousel arrangement can this ideal transfer be achieved (and this only by moving the feed point, rather than the carbon in each tank). With any other system, carbons from different contactors with different loadings will inevitably become mixed. The influence of the carbon-transfer scheme on the distribution of gold loadings has been simulated by Stange and King[1].

The following specific areas would benefit from a knowledge of how gold loadings are distributed.

(1) Such knowledge would assist the engineer in understanding how the size of the carbon particles and the transfer scheme used might influence the adsorption of gold. The distribution of gold on loaded carbon will certainly influence its elution, and a knowledge of the distribution would obviously be useful.

(2) A favourable comparison between the actual distributions and the predictions of a simulator would help to enhance confidence in that simulator. Confidence in a simulator is particularly important in CIP technology because of the many factors affecting the process and because of the complexity of their influence on performance. It is only through simulation that the effect of these factors on the process can be examined easily.

With these specific objectives in mind, a study was undertaken to measure the distribution of gold loadings on a loaded carbon from a typical CIP operation.

TRANSFER HISTORY OF THE CARBON

The carbon analysed in the present work originated from a fairly typical South African operation. The carbon-transfer scheme used in that operation varies slightly from day to day, but in general is as follows. Transfer takes place daily, and involves the movement of between 57 and 68 per cent of the carbon inventory. In each cycle, the required quantity of loaded carbon is removed from the first contactor, which takes about 2 hours. The carbon is then transferred semi-continuously for a period of between 4 and

8 hours, the transfer being regulated mainly by the requirement to maintain the target carbon concentration in each contactor. Regenerated carbon is added when its preparation is complete—ideally before the loaded carbon has been removed. The addition takes about half an hour.

THE MEASUREMENT OF GOLD LOADINGS

The Method Used

In CIP operations, the gold that has been loaded onto the carbon is determined routinely by one of several analytical techniques. Fire assay is probably still the most reliable method, but the X-ray-fluorescence procedure is widely used because of its convenience[4]. Mossbauer spectroscopy has been used in an investigation of the nature of the adsorbed gold species on activated carbon[5], and the distribution of gold on a single particle of carbon has been investigated by Jones *et al.*[6]. However, these analytical techniques are not practical for the determination of the gold distribution among carbon particles. The determination would involve the individual analysis of a large number of particles, and there is only a small amount of gold on any one particle. For example, a 1,6 mm particle loaded to 4800 g/t would contain about 13 μg of gold. With a 0,9 mm particle at a loading of 175 g/t, the mass of gold would be only 0,8 μg.

Neutron-activation analysis has been used for the measurement of small quantities of gold on individual particles[7]. The technique was adapted and tested at the Schonland Centre of the University of the Witwatersrand. First, the mass of each particle was measured on a microbalance, and the particle was then sealed in a high-density polyethylene irradiation phial. A batch of phials, together with calibration and reference standards, was irradiated for 12 hours in a rotating facility in the 5 MW Oak Ridge type of research reactor of the South African Atomic Energy Corporation. The delayed gamma-emission spectra were recorded after a decay time of 4 days, and the gold content of each carbon particle was then calculated.

Preparation of the Carbon Samples

In the present work, a typical day's production of loaded carbon was sampled. The sample was split into two fractions. One fraction was fire-assayed in the normal way and found to contain 3010 g/t of gold. The second fraction was split by use of a Jones riffler. One half was used in the determination of the size distributions as shown in Table I. The other half was split into eight lots by the use of a spinning riffler. Three of these lots were combined for analysis by fire assay. An independent laboratory reported a gold loading on this combined sample of 2950 g/t, which agrees well with the first analysis. Two further lots were combined, and this sample, consisting of 295 particles and weighing 0,472 g, was used for the neutron-activation determination of the gold distribution. From the neutron-activation analysis, the grade of this sample was calculated as 2582 g/t. This is 13 per cent lower than the grade measured by fire assay but, in view of the small size of the sample, the result is considered to be acceptable.

Table I
Size and mass distributions of carbon particles

Size (*D*) mm	Mass (*m*) mg	Mass fraction smaller than *D* or *m*	Comment
2,360		1,0	Results obtained from laboratory sieving
1,700		0,735	
1,180		0,166	
0,850		0,018	
0,600		0	
(1,836)	4	0,837	Results obtained from the weighing of particles. The sizes in brackets were calculated by use of equation [1] with $s\rho = 1,234$
(1,544)	2,378	0,562	
(1,298)	1,414	0,261	
(1,092)	0,841	0,117	
(0,918)	0,50	0,030	
(0,772)	0,297	0,004	

RESULTS

Mass and Size Distribution

The size distribution of the carbon was determined from laboratory sieving in the usual way. The size and mass distributions are shown in Table I. Equation [1] shows the usual relationship between a particles mass, *m*, and its size, *D*, as determined from laboratory sieving:

$$m = s\rho\frac{\pi D^3}{6}. \qquad [1]$$

The product of the shape factor, *s*, and the carbon density, ρ, was found for the carbon analysed to have a value of 1,234 mg/mm^3. When this value is applied in equation [1], the size of a carbon particle can be estimated from its mass. As can be seen from Figure 1, the agreement between the size distribution that was measured by sieving and that determined from measured masses is very good. The distributions are log-normal, with a geometric standard deviation of 1,28, a mean size of 1,48 mm, and a mean mass of 2,09 mg. The particle masses ranged from 0,126 to 6,219 mg (equivalent to a size range of 0,6 to 2,13 mm).

Distribution of Gold

The wide scatter of the loaded gold on the particles is shown in Figure 2. The loadings varied between 470 and 13911 g/t with a mean of 2582 g/t.

The distribution of particles according to their gold loadings is shown in Figure 3. These data are plotted on log-probability scales to show that the distribution is approximately log-normal. The log mean is 2300 g/t, and the geometric standard deviation 1,85. The distribution of loaded gold may be more clearly appreciated from an examination of the distribution density shown in Figure 4.

Figure 5 shows the effect of particle size on gold loading. The distribution of gold according to particle size is well described by a log-normal distribution function, the log mean being 1,4 mm and the geometric standard deviation 1,28. The distribution is very similar to the size distribution (Figure 1), and has the same standard deviation but shifted to smaller sizes. This confirms the expected trend that smaller particles will become more highly loaded than larger particles.

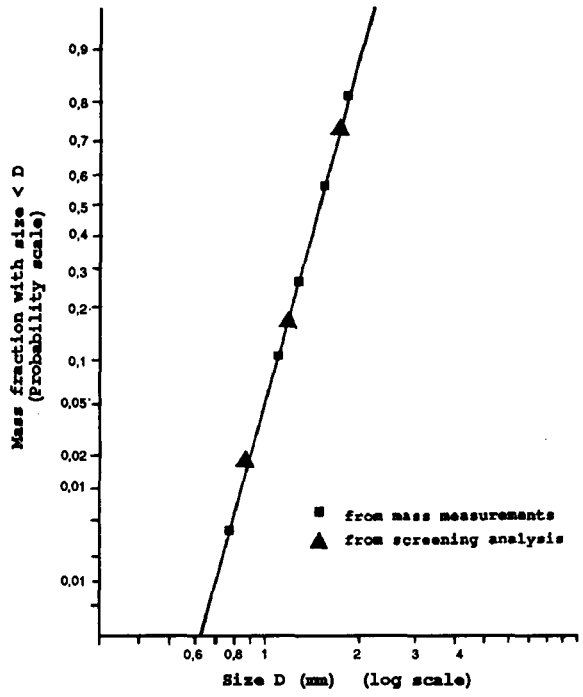

Figure 1—Size distribution of the carbon particles

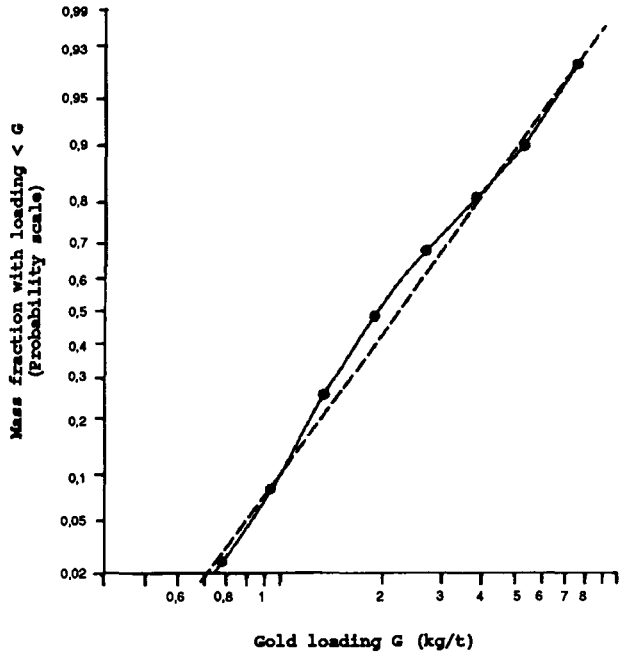

Figure 3—The distribution of carbon particles according to their gold loading

The distribution results are presented in Figure 6 in a way that indicates the proportion of highly loaded particles. The diagram indicates, for example, that about 30 per cent of the gold is found on particles that have a loading greater than 5000 g/t. To complement this information, the distribution of particle mass according to gold loading is also shown in the diagram. From this curve, it can be seen that particles with loadings of more than 5000 g/t constitute about 11 per cent of the mass of the carbon.

SIGNIFICANCE OF THE FINDINGS

Adsorption and Elution

The distribution results are of interest from a practical point of view in that they indicate the proportion of the particles that is highly loaded in a sample of loaded carbon. (Highly loaded particles are any that have a loading greater than twice the mean.) The loading, y, on a particle influences the rate of adsorption, r_a, through expressions with forms similar to that of equation [2]. The rate of elution is the negative of the adsorption rate. Other expressions for adsorption and elution rates are given elsewhere[8-11].

$$r_a = k\,(c - (y/a)^b), \qquad [2]$$

where c is the gold concentration in solution, and a, b and k are constants.

Equation [2] illustrates a common feature of adsorption expressions namely, that the higher the gold loading on the carbon, the slower is the rate of adsorption. However, high

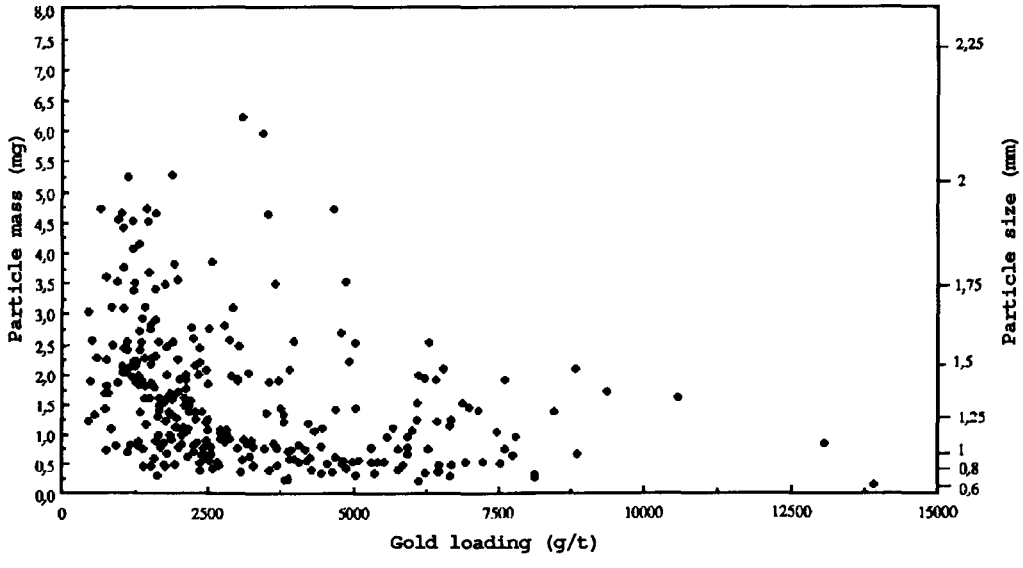

Figure 2—The distribution of gold loadings on the particles of a sample of loaded carbon

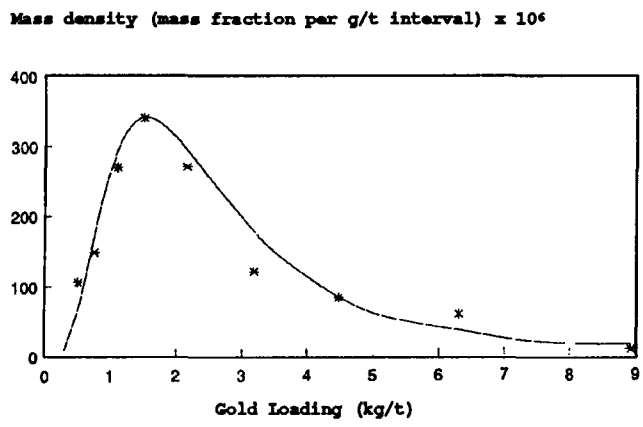

Figure 4—Distribution density of gold loadings on a loaded carbon

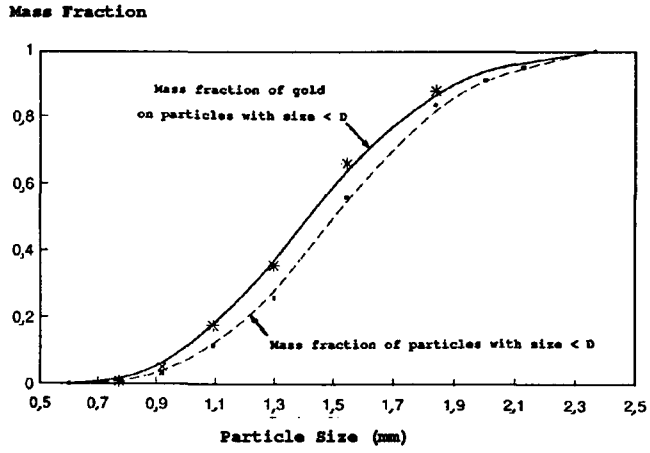

Figure 5—Distribution of gold and carbon particles according to particle size

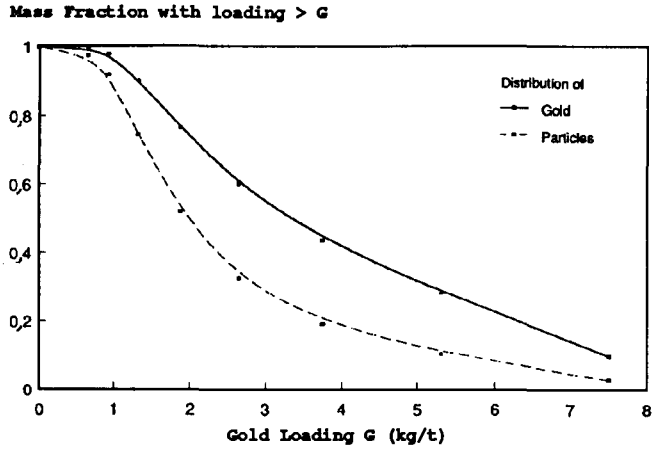

Figure 6—Distribution of gold and carbon particles according to the loading of the particles

loadings favour rapid elution.

A second factor that is important in the influence of gold loading on the rates of adsorption and elution is intra-particle diffusion. The value of the mass-transfer coefficient associated with intra-particle diffusion is likely to decrease as a greater proportion of the loaded gold is found in the more inaccessible pores and adsorption sites within the carbon particles. The greater the gold loading on the particles, the higher is this proportion likely to be. This means that, in adsorption circuits, the adsorption rate on very highly loaded particles is likely to be inhibited both by the magnitude of the gold loading and by a reduced mass-transfer coefficient. In elution circuits, the elution rate from such particles is likely to be inhibited by the reduced mass-transfer coefficient.

The implication of these observations is that the proportion and size of the particles that are highly loaded is likely to have some impact on the adsorption and elution rates. Figure 6 shows that the proportion of highly loaded carbon is significant, and that a considerable proportion of the gold is loaded on such particles. The diagram shows that about 30 per cent of the gold was loaded on 11 per cent of the carbon in particles that were highly loaded; that is, with loadings greater than twice the mean.

Figure 6 also shows that fully 22 per cent of the carbon particles have loadings that are less than half the mean loading. The extent to which these particles are under-utilized can be appreciated when it is seen that they account for only 7 per cent of the gold.

Figure 7 shows the size distributions of carbon particles with high and low loadings. This indicates that all the highly loaded particles were smaller than 1,54 mm, whereas 40 per cent of the particles with low loadings were larger than that. No particles larger than 1,84 mm were highly loaded; 16,3 per cent of the carbon fell into this category and had a mean loading of 1930 g/t.

Influence of Operating Practice on Distribution

Stange and King[1] simulated the effect of the amount of carbon transferred on the distribution of gold loadings in a particular CIP adsorption circuit. Figure 8 shows, for three

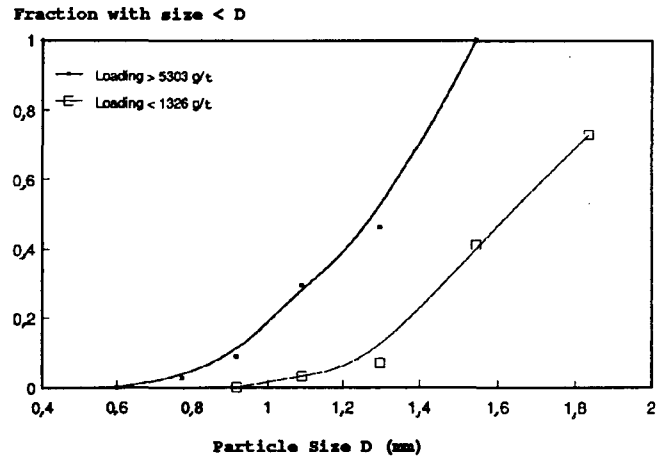

Figure 7—Size distribution of particles with high and low gold loadings

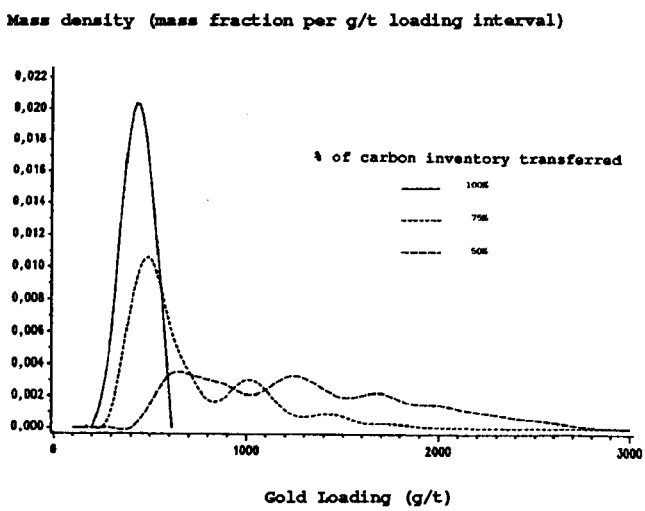

Figure 8—Effect of the amount of carbon transferred on the gold distribution density (after Stange and King[1])

different situations, the distribution densities they predicted in the first contactor. The predictions are based on the assumption that all the carbon in the circuit is of the same size, and that the transferred carbon is transferred instantaneously and at the same time for all the contactors. The predicted gold-loading distribution densities shown give an indication of the nature of the distributions that should be achieved. They suggest, as expected, that the larger the proportion of carbon moved, the smaller will be the fraction of carbon that is very highly loaded, and the narrower the distribution of gold loadings.

An exact quantitative comparison of the distributions predicted by Stange and King with those reported in the present work is not possible. Firstly, the kinetic data used in their simulations do not apply to the carbon analysed in this study. Secondly, the predictions are based on instantaneous transfers. However, some inferences can be drawn from an examination of the shape of the graphs for the predicted and measured distributions.

Accordingly, the measured distribution density for particles in the size range 1,09 to 1,54 mm is shown in Figure 9. (A very similar distribution was obtained for the narrower size range of 1,3 to 1,54 mm.) The measured distribution is essentially uni-modal. There is a suggestion of multi-modality, with one or more secondary peaks in the region of 4000 to 7000 g/t, although the number of particles measured was not sufficient to give strong support to such a proposition.

A qualitative comparison between the measured and the predicted distribution densities shows that the shape of the graph for the measured densities is intermediate between that for the shapes of the simulated distributions for the transfer of 50 and 75 per cent of the inventory. The percentage transfer that applies to the measured densities is between 57 and 68 per cent, which gives qualitative support to the simulation procedure of Stange and King. It must be borne in mind that the measured densities relate to non-instantaneous carbon transfer, and that the impact of this on the predicted distributions should be to smooth them out and widen them to some degree.

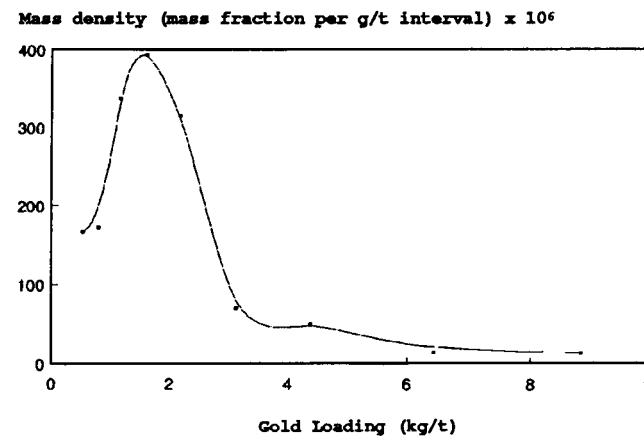

Figure 9—Distribution density of gold loadings on particles in the size range 1,09 to 1,54 mm

Effect of Particle Size

The distribution of gold loadings among particles of the same size is the result primarily of differences in the contact history of those particles. The mean loading on such particles is the result of the averaged effect of their different contact histories. Provided that particle size has no influence on contact history, particles having the mean loading in different size classes should all have the same contact history.

On this basis, the effect of particle size on loading can be examined from a plot of the mean loading, G_m (g/t), in each size class against the associated mean size, D_m (mm), or mean mass, M_m (mg). As can be seen from Figure 10, the relationships are linear on a log-log plot. Equations [3] and [4] are derived from this plot, and quantify the expected inverse relationship between size and loading. No attempt is made here to infer from these equations the influence of size on the relevant mass-transfer coefficient.

$$G_m = 3276\, M_m^{-0,3774} \qquad [3]$$

$$G_m = 3863\, D_m^{-1,132}. \qquad [4]$$

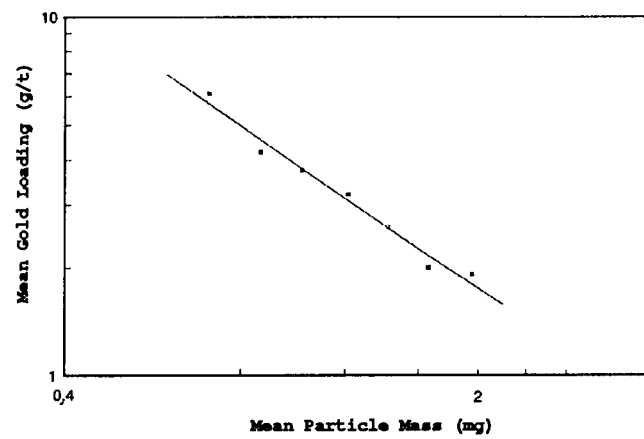

Figure 10—The effect of particle mass on gold loading

CONCLUSIONS

The gold loading on a sample of loaded carbon taken from a typical South African CIP operation, as measured by neutron-activation analysis, was 2582 g/t. The values for individual particles was found to vary by factors of between 0,18 and 5,4 of the mean. The results showed how the gold loading on particles varied from one to another, the distribution being essentially uni-modal and of log-normal form. The expected inverse relationship between loading and particle size was confirmed and quantified. In addition, the way in which the gold was distributed according to particle size was established, as well as the fraction of the loaded gold that is found on particles with given loadings.

From the results it is possible to assess how much of the gold occurs in small highly loaded particles that could impair the oerformance of the adsorption and elution processes. Such particles would have lower than expected adsorption rates before they are removed from the adsorption circuit. In addition, some fraction of the gold in these particles is likely to be found in the smaller pores of the carbon and so may be less accessible to elution. What is revealed is that, for the sample analysed, about 11 per cent of the carbon containing 30 per cent of the gold falls into this category. The adsorption and elution kinetics would be improved if the operating practices were modified so as to reduce the proportion of carbon that is loaded in this way. The influence of the transfer scheme on this proportion and on the distribution of gold loadings is best assessed by simulation. The measured results were not inconsistent with the simulator predictions reported by Stange and King, and lend some qualitative support to their approach. It therefore seems reasonable to use their technique as a means of exploring how a given carbon-transfer scheme can be modified to improve the gold-loading distribution.

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A multi-client proposal to address operating problems in CIP plants worldwide is currently underway, and discussions with consulting metallurgists, plant metallurgists, and mine managers have identified the following areas of concern throughout the industry:

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- recovery of gold from waste materials
- the influence of base metals on gold adsorption
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