

# Further studies on the elution of gold from activated carbon using water as the eluant

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## SYNOPSIS

Some of the parameters affecting the elution of gold from freshly loaded activated carbon using pure water as an eluant were studied. The procedure involved pretreatment of the gold-loaded activated carbon with a strong reagent of sodium cyanide and sodium hydroxide, followed by elution of the gold with water. Gold-loaded carbon obtained from three different sources was studied.

It was shown that the elution temperature was the most critical parameter, and column operation at 110°C (gauge pressure of 50 to 100 kPa) is suggested.

The effects of variations in the concentration of sodium cyanide required for the pretreatment of loaded carbon and of variations in elution flowrate were also investigated. Both these parameters were found to have only a marginal effect on the efficiency of gold elution. The investigation also indicated that gold-elution rates were affected to a considerable degree by the particle size of the carbon concerned. Higher elution flowrates could be used when carbons of finer particle size were eluted. A modified eluate-collection procedure was also developed during the course of the investigation. Oven-drying of the loaded carbon was shown to have little or no effect on the efficiency of the subsequent gold elution.

The calcium and silica contents of the various carbon samples were also determined. It was immediately evident that the calcium content was very considerable in the case of loaded carbons originating from carbon-in-pulp operations. Calcium concentration was particularly high where air agitation had been employed in the carbon-contacting circuit. To some degree, the calcium build-up explains the serious carbon fouling taking place, resulting in a decreased efficiency of gold adsorption. The fouling problem was found to be less severe when mechanical agitation was used. No poisoning by calcium carbonate was observed where the pregnant solution had been acidified before it was contacted with the carbon.

## SAMEVATTING

Sommige van die parameters wat 'n invloed uitoefen op die eluering van goud uit vars gelaaiete geaktiveerde koolstof, deur suiwer water as uitwasmiddel te gebruik, was bestudeer. Die prosedure het die voorbehandeling van goudgelaaiete geaktiveerde koolstof met 'n sterk natriumsianied/natriumhidroksied reagens gevolg deur eluering van die goud met water, behels. Goudgelaaiete koolstof, verkry van drie verskillende bronne, was bestudeer.

Dit was aangetoon dat die elueringstemperatuur die mees kritieke operasionele parameter was en die werking van die kolom teen 110°C (meterdruk van 50 tot 100 kPa) word aanbeveel.

Die effek van variasies in die natriumsianied konsentrasie benodig vir die voorbehandeling van die gelaaiete koolstof sowel as variasies in die eluering vloeitempo was ook ondersoek. Beide hierdie parameters het slegs 'n geringe effek op die doeltreffendheid van die goudeluering gehad. Die ondersoek het ook aangedui dat goudelueringstempo tot 'n noemenswaardige mate geaffekteer is deur die partikelgrootte van die betrokke koolstof. Hoër elueringsvloeitempos kon gebruik word by die eluering van fyner partikelgrootte koolstowwe. 'n Veranderde eluering versamel prosedure was ook ontwikkel gedurende die verloop van die ondersoek. Dit was aangetoon dat oondroging van die gelaaiete koolstof min tot geen effek gehad het op die doeltreffendheid van die daaropvolgende goudeluering nie.

Die kalsium en silika inhoud van die verskillende koolstof monsters was ook bepaal. Dit was onmiddellik duidelik dat die kalsium inhoud aansienlik was in die geval van die gelaaiete koolstowwe afkomstig van die koolstof-in-pulp tipe operasies. Die kalsiumkonsentrasie was besonder hoog in die geval waar lugroering gebruik was in die koolstof-kontakbaan. Tot 'n seker mate verduidelik die opbou van kalsium die ernstige koolstofbesoedeling wat plaasgevind het, met 'n gevolglike afname in goudabsorpsiedoeltreffendheid. Die besoedelingsprobleem was minder ernstig wanneer meganiese-roering gebruik was. Geen kalsiumkarbonaat vergiftiging was waargeneem in die geval waar die dragtige oplossing aangesuur was voor kontak met die koolstof nie.

## Introduction

Because of the recent increase in the price of gold, the treatment of lower-grade ores, as well as waste-rock dump material and slimes-dam residues, is currently receiving considerable world-wide attention. Carbon-in-pulp type operations for the recovery of gold from such materials offer numerous advantages in the form of lower capital and operating costs<sup>1</sup>. Consequently, considerable emphasis, both at the Anglo American Research Laboratories (AARL) and the National Institute for Metallurgy (NIM), has been placed on the optimization of this field of gold technology. Pilot-plant studies and research-and-development efforts have been directed towards improving the carbon-contacting circuits as well as other ancillary aspects. Investigations carried out at AARL have demonstrated more efficient

means of gold elution<sup>2</sup> and gold electrowinning<sup>3,4</sup>, together with relatively inexpensive means of regenerating used carbon thermally<sup>4</sup> and chemically<sup>5</sup>.

A carbon-in-pulp plant is currently being commissioned at Golden Dumps (Pty) Ltd<sup>6</sup>, where crushed waste-rock fines are being treated for the recovery of gold. At the Fairview Gold Mine<sup>7</sup>, flotation concentrates produced from calcined cyanidation residues are being processed. A carbon-in-pulp pilot plant has already been satisfactorily operated at Durban Deep Gold Mine<sup>8</sup> on low-grade run-of-mine material, while a pilot operation using activated carbon in a countercurrent column for the recovery of gold from unclarified gold-plant effluent was successfully run at the Vaal Reefs Gold Mine<sup>4</sup>.

The effectiveness of all the above processes depends to a large degree on the development of an efficient means of stripping the gold from the loaded carbon. Stripping with a hot dilute solution of sodium hydroxide and sodium cyanide at atmospheric pressure, followed

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by electrowinning, has been employed<sup>9</sup>. However, this method has the disadvantage that the procedure involving simultaneous stripping and electrowinning is slow. Elevated temperatures and pressure have also been employed,<sup>10</sup> thereby accelerating the stripping rate, but this technique requires the use of a pressurized reactor, which makes the process more complicated. The use of mixtures consisting of an organic solvent, sodium hydroxide, and water has also been considered<sup>11, 12</sup>. Apart from relatively expensive reagents, the use of such solvents in a gold plant would constitute a considerable fire hazard. Furthermore, investigations carried out at AARL<sup>12</sup> have indicated the inefficient elution of silver when such organic-solvent mixtures are used. A method involving the pretreatment of the loaded carbon with a relatively strong reagent consisting of sodium cyanide and sodium hydroxide and elution with water has also been suggested<sup>2</sup>. This method has many advantages arising from the efficiency, speed, and cost of the gold elution<sup>4</sup>. The recovery and regeneration of cyanide in the subsequent electrowinning operation may also render the process more economically viable.

In view of the likely developments in the use of activated carbon for the recovery of gold and the elution procedure developed at AARL, further elution studies

were undertaken. These studies were designed so that certain operational parameters of an elution plant could be optimized, and so that an assessment could be made of the elution response of loaded carbons from three different sources.

## Materials

### Sample A

A sample of activated type SCII coconut-shell carbon (minus 2380  $\mu\text{m}$  plus 1000  $\mu\text{m}$ , Davy Ashmore S.A. (Pty) Ltd) loaded with gold (16 900 g/t) and silver (300 g/t) was obtained from the Fairview Gold Mine carbon-in-pulp operation.

### Sample B

Two samples of loaded type SCII coconut-shell carbon (minus 2380  $\mu\text{m}$  plus 1000  $\mu\text{m}$ ) from Golden Dumps (Pty) Ltd were obtained during the early stages of plant commissioning. Sample B, taken after the first week of operation, contained 1604 g/t gold and 182 g/t silver. Sample B1, taken after the second week of commissioning, contained 3140 g/t gold and 365 g/t silver.

### Sample C

Pregnant gold-plant solution from the Western Deep Levels Gold Mine, which had been acidified to a pH value between 4 and 5, was pumped through a stainless-

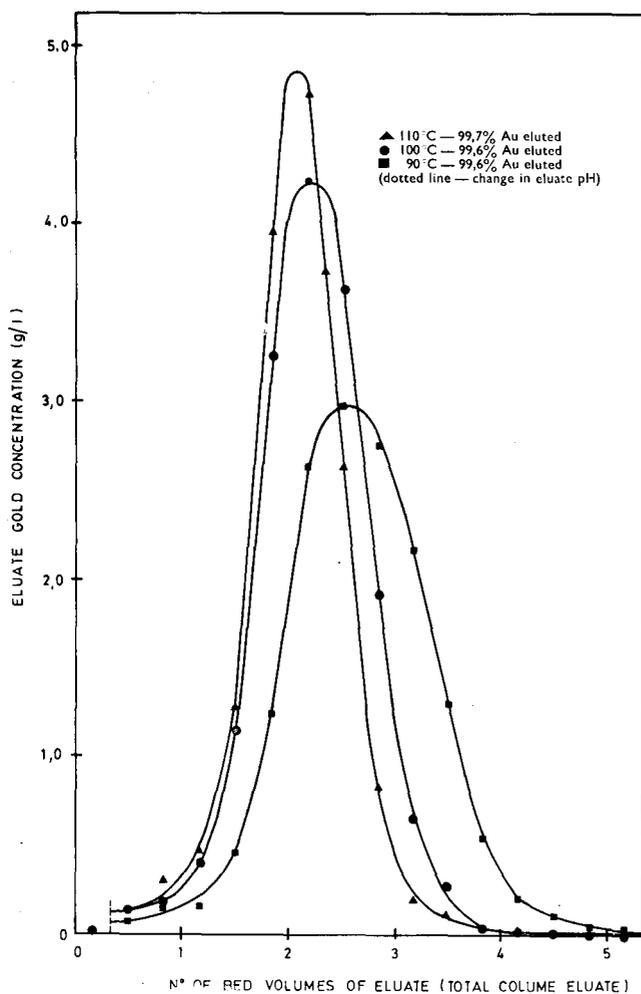


Fig. 1—The effect of temperature on the elution of carbon sample C

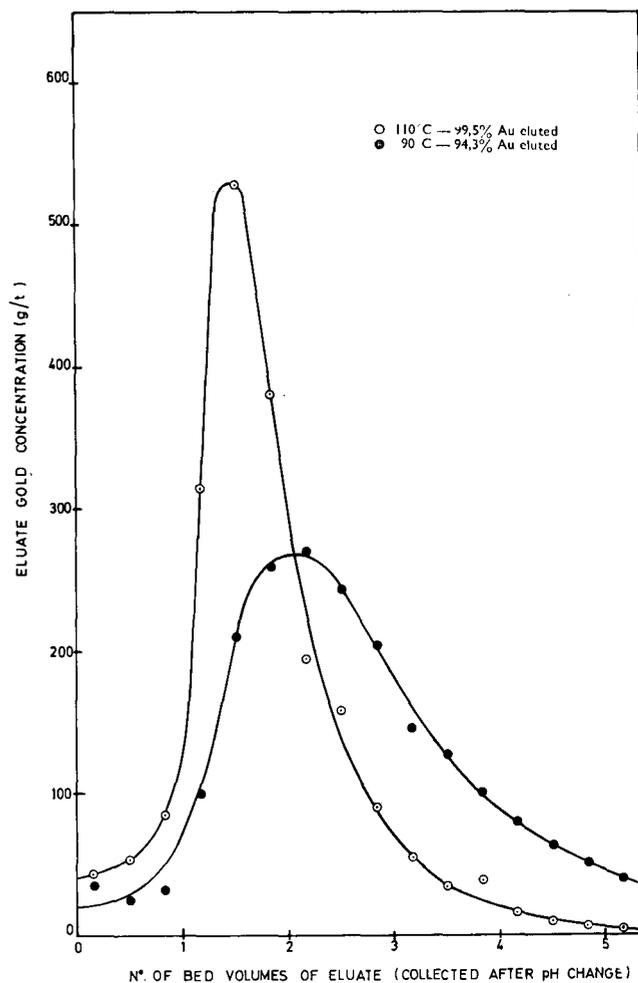


Fig. 2—The effect of temperature on the elution of carbon sample B

steel heat-exchange spiral immersed in a water-bath at 20°C. The spiral was in series with an adsorption column containing granular activated carbon (minus 1190  $\mu\text{m}$  plus 840  $\mu\text{m}$  of type G215 coconut-shell type carbon supplied by Le Carbone (Pty) Ltd). The influent solution was pumped at a constant flowrate by an MPL Monopump metering pump. The adsorption column (16 mm internal diameter and 100 cm long) was packed with up to 100 g of oven-dried granular activated carbon that had previously been equilibrated at a pH value between 4 and 5. The superficial flow velocity in the column was maintained at 0,8 m/min, and pumping continued until a loading of approximately 2 per cent gold on the carbon had been achieved (ca 24 h). Flow through the column was always in a downward direction. The piloting of a similar process using a countercurrent ion-exchange type of column operation is due to commence at Durban Deep Gold Mine in the near future<sup>4</sup>.

### Method

The method of gold elution used in the investigation was as follows: 150 cm<sup>3</sup> of wet-settled gold-loaded carbon was placed in an oil-jacketed stainless-steel elution column of 0,9 cm internal diameter and 75 cm long; oil was heated in a separate vessel and then circulated through the jacket to maintain the contents of the column at the desired elution temperature; before entering the elution column, the eluting solution was heated to elution temperature by being passed through a stainless-steel spiral placed inside the oil-jacket; the elution solution was pumped through the column by an MPL Monopump metering pump. Unless otherwise specified, the elution was carried out at 110°C at a gauge pressure of from 80 to 120 kPa. Pressure within the system was maintained by means of a stainless steel blow-off valve and a manually operated stainless-steel needle valve situated on the effluent line of the column. Column eluate was cooled in a water-cooled glass reflux condenser before being collected in 50 ml volumetric flasks. The elution was stopped after 900 ml of eluate (6 bed volumes) had been collected. When the elution was carried out at 90°C, the system was not pressurized.

The elution procedure used in the present investigation included the pretreatment of the gold-loaded carbon in the column with a reagent consisting of 3 to 10 per cent sodium cyanide and 1 per cent sodium hydroxide. This was followed by the elution of the gold using deionized water<sup>2</sup>. For the A and B samples of carbon (carbon-in-pulp operations), the carbon was first washed at a rate of 5 bed volumes per hour with 1 to 5 per cent hydrochloric acid. No gold or silver was found to be eluted from the carbon during this acid pretreatment. Acid-washing was continued until the column effluent was acid (i.e. a pH value of less than 3), after which 2 bed volumes of tap water at the same flowrate was pumped through the column. This removed excess acid, and the pretreatment of the carbon with the cyanide reagent could then be started. Sample C was not acid-washed since no build-up of calcium carbonate occurred under the particular loading conditions used. After the acid-washing (if used), the loaded carbon was

treated with 1 bed volume of the cyanide reagent and the gold was then eluted with water. Because samples A and B were of different particle size from sample C, the first two carbons were allowed to 'soak' in the cyanide pretreatment reagent for 30 minutes before the elution, whereas sample C was 'soaked' for only 15 minutes. The technique for eluate collection was also modified during the course of the investigation. The procedure for the elution of sample C involved draining of the carbon bed before the cyanide pretreatment, followed by collection of the total column eluate. As already mentioned, no gold or silver was eluted during the initial acid-washing of the column, and the collection of eluate from samples A and B was begun only after the column effluent had become alkaline. A sharp change in the effluent pH defined the alkaline pretreatment front.

## Results

### Effect of Temperature on Gold Elution

Figs. 1 and 2 illustrate graphically the effect of temperature on the elution of gold from carbon samples C and B respectively. The elution was carried out at a rate of three bed volumes per hour in both instances. For sample B, the carbon was pre-washed with approximately 2 bed volumes of 2 per cent hydrochloric acid.

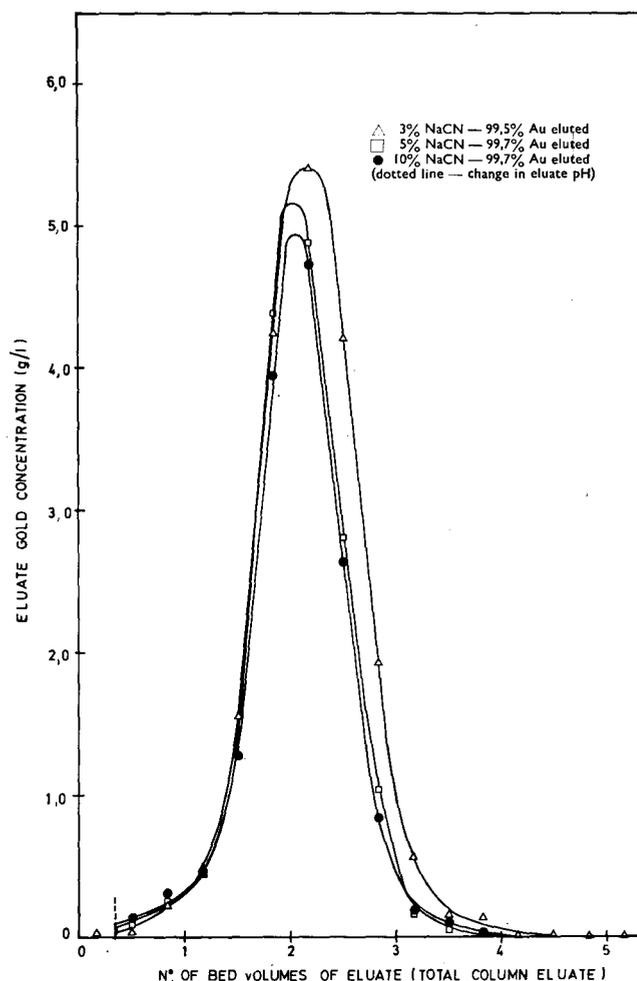


Fig. 3—The effect of cyanide concentration in the pretreatment and elution of carbon sample C at 110°C

In each of these instances there is a significant beneficial effect if the elution temperature is increased from 90 to 110°C. Thus, the elution at 110°C of 97,1 per cent of the gold from carbon C after 3 bed volumes (99,7 per cent after 6 bed volumes) can be compared with the elution at 90°C of 97,3 per cent of the gold after 4 bed volumes (99,6 per cent after 6 bed volumes). Likewise, in the case of carbon B, the elution of 97,4 per cent gold after 4 bed volumes (99,5 per cent after 6 bed volumes) at 110°C can be compared with an 88,8 per cent gold recovery after 4 bed volumes (94,3 per cent after 6 bed volumes) at 90°C. While the elution results from these two carbon samples are not strictly comparable (owing to the different methods of eluate collection used), the more symmetrical elution curve resulting from the treatment of carbon C (minus 1190  $\mu\text{m}$  plus 840  $\mu\text{m}$ ) is noteworthy. It is undoubtedly due to the finer particle size of this carbon when compared with carbon B (minus 2380  $\mu\text{m}$  plus 1000  $\mu\text{m}$ ).

In view of the above findings, unless otherwise specified, further elution testwork in the present investigation was confined to the elution of gold at 110°C.

### Effect of Cyanide Concentration

Figs. 3 and 4 illustrate the elution of gold at 110°C from samples C and A respectively when sodium cyanide

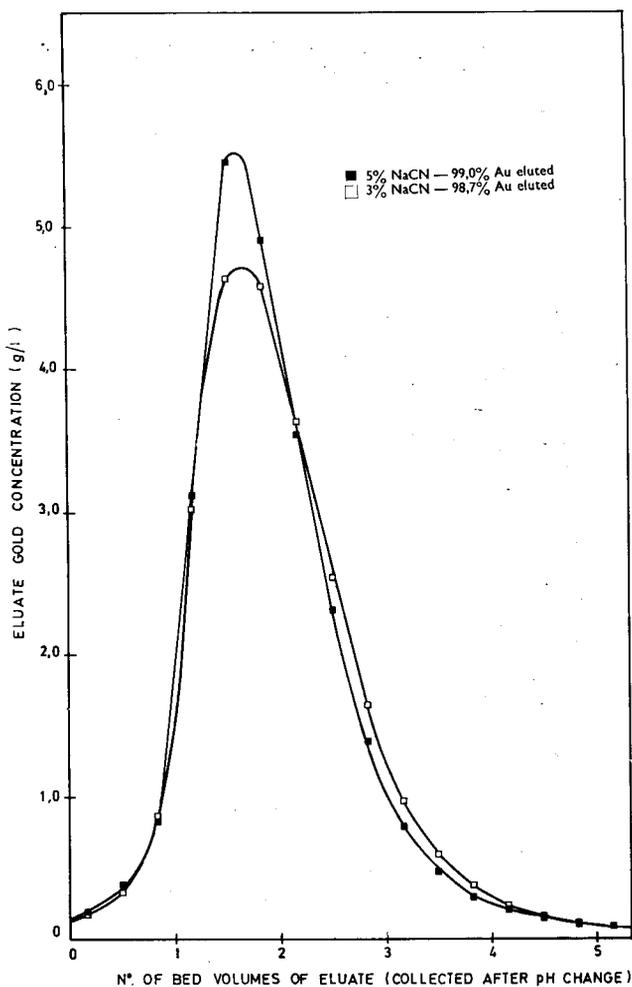


Fig. 4—The effect of cyanide concentration in the pretreatment and elution of carbon sample A at 110°C

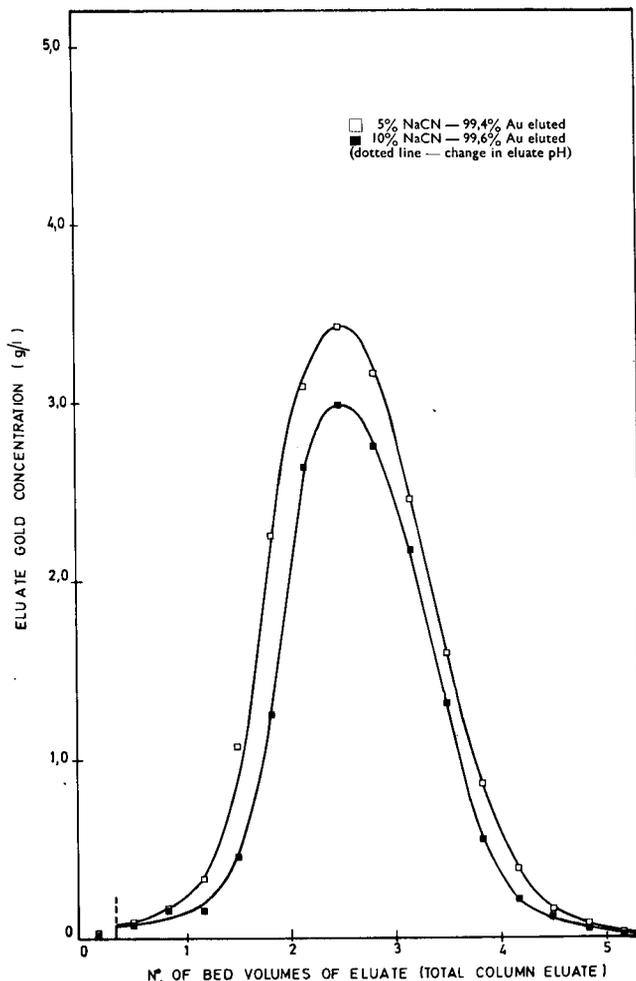


Fig. 5—The effect of cyanide concentration in the pretreatment and elution of carbon sample C at 90°C

of various concentrations was used as a pretreatment reagent. Elution was carried out at a rate of 3 bed volumes per hour in all instances, sample A being pre-washed with approximately 1,6 bed volumes of 3 per cent hydrochloric acid before the elution. The results from the elution of sample C (Fig. 3) would suggest that concentrations of sodium cyanide as low as 3 per cent can be used with little or no adverse effects. The results from the elution of sample A indicate a small decrease in elution efficiency from the use of such a low concentration of cyanide. Similar testwork was carried out on sample C at an elution temperature of 90°C (Fig. 5). Here again it can be noted that the use of a sodium cyanide concentration of 5 per cent was equally as effective as the 10 per cent concentration. Unless otherwise specified, further testwork was therefore confined to the use of a pretreatment reagent consisting of 5 per cent sodium cyanide and 1 per cent sodium hydroxide.

Later experiments showed that the volume of the cyanide pretreatment reagent could be reduced from the 1 bed volume previously used to only 0,5 bed volume without seriously affecting the elution efficiency. Fig. 6 illustrates the use of smaller volumes of reagent (5 per cent sodium cyanide and 1 per cent sodium hydroxide) prior to the elution of gold at 110°C from sample C. A

more concentrated eluate was collected when only 0,5 bed volume of this reagent was used.

### Effect of Eluate Flowrates on Gold Elution

Figs. 7, 8, and 9 illustrate gold elution at 110°C and various elution flowrates from carbon samples A, B, and C respectively. Samples A and B were pre-washed with acid as previously described. The differences in the elution efficiencies at 110°C are in all cases only marginal. However, the results would suggest that the coarser carbons (samples A and B) are best eluted at a flowrate of 3 bed volumes per hour, while a faster rate of 5 bed volumes per hour can be used for the elution of the more finely sized carbon (sample C). Similar testwork carried out on sample C at 90°C (Fig. 10) would indicate that a flowrate of only 3 bed volumes per hour should be used for the more finely sized carbon when operating at the lower elution temperature.

### Effect of Acid-washing

Because of the physical choking of the carbon due to a build-up of calcium carbonate, which is generally observed when conventional plant solutions are treated, the effect of acid washing on the elution of gold from sample A was briefly investigated. Fig. 11 illustrates graphically the considerably improved gold elution at

110°C following acid-washing with 3 per cent hydrochloric acid at 90°C when compared with gold elution carried out on the sample as received. Gold was eluted at a rate of 3 bed volumes per hour in both instances. These findings agree with earlier conclusions<sup>4</sup>.

### Drying of the Carbon

The effect of air-drying or oven-drying of the loaded activated carbon on the subsequent elution of gold had to date always been rather speculative. Fig. 12 illustrates the effect on the gold elution of the oven-drying of sample A (110°C for 17 hours). This can be compared with the elution of the sample as received. Following acid-washing with 3 per cent hydrochloric acid, gold was eluted at 110°C at a flowrate of 3 bed volumes per hour. The elution results presented suggest that oven-drying, or even air-drying, of loaded carbon prior to elution has little or no effect on the subsequent elution of gold.

### Collection of Column Eluate

The draining of the carbon bed following acid-washing and the pretreatment and elution of gold had been previously advocated<sup>4</sup> in order to produce a more concentrated eluate for electrolysis. As it had been established during the course of the present investigation that

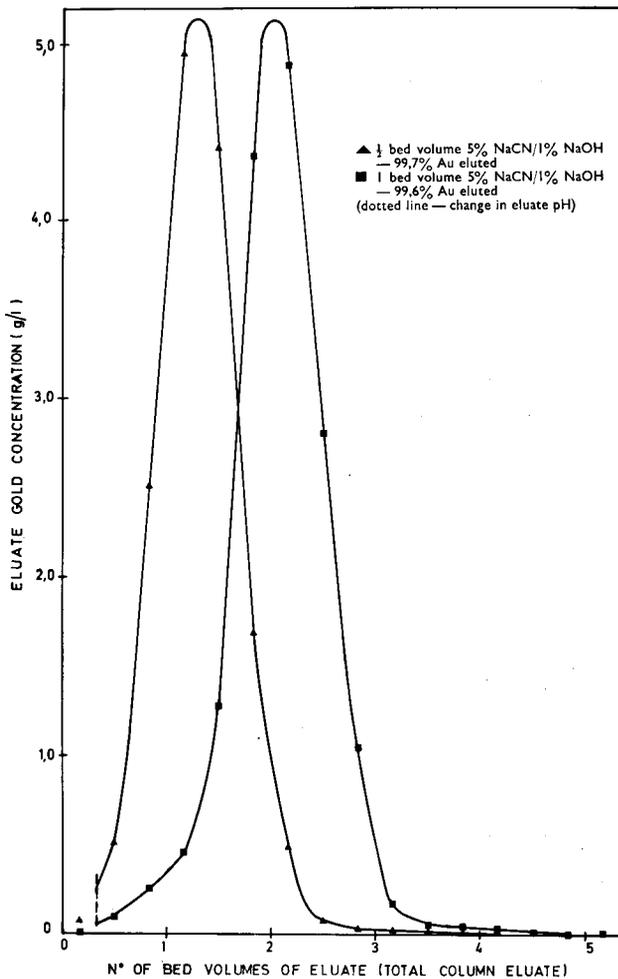


Fig. 6—The use of smaller quantities of pretreatment reagent for the elution of gold from carbon sample C at 110°C

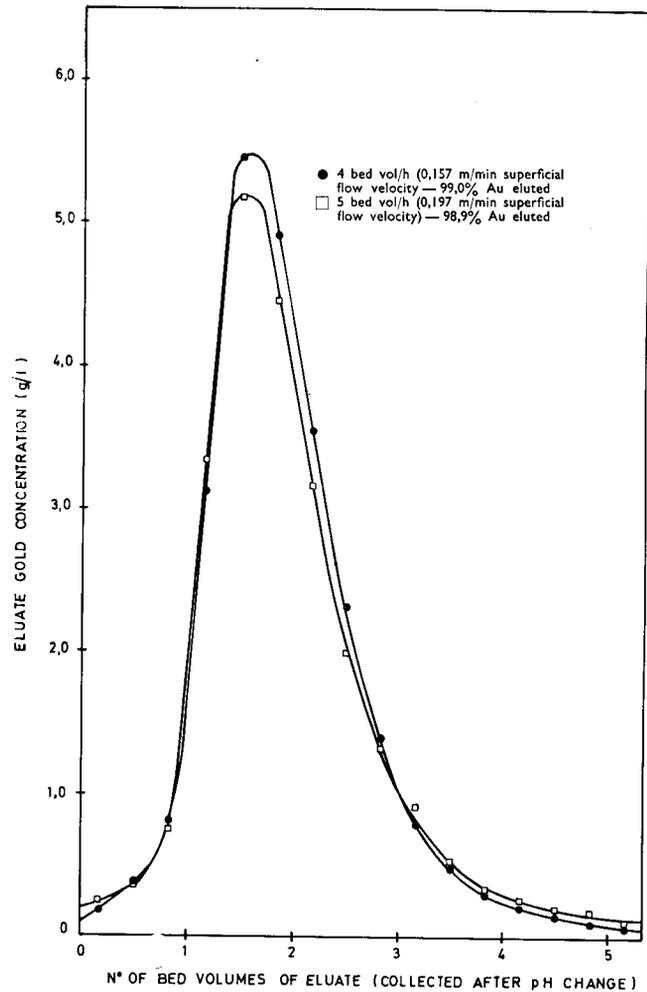


Fig. 7—The effect of eluate flowrates on gold elution from carbon sample A at 110°C

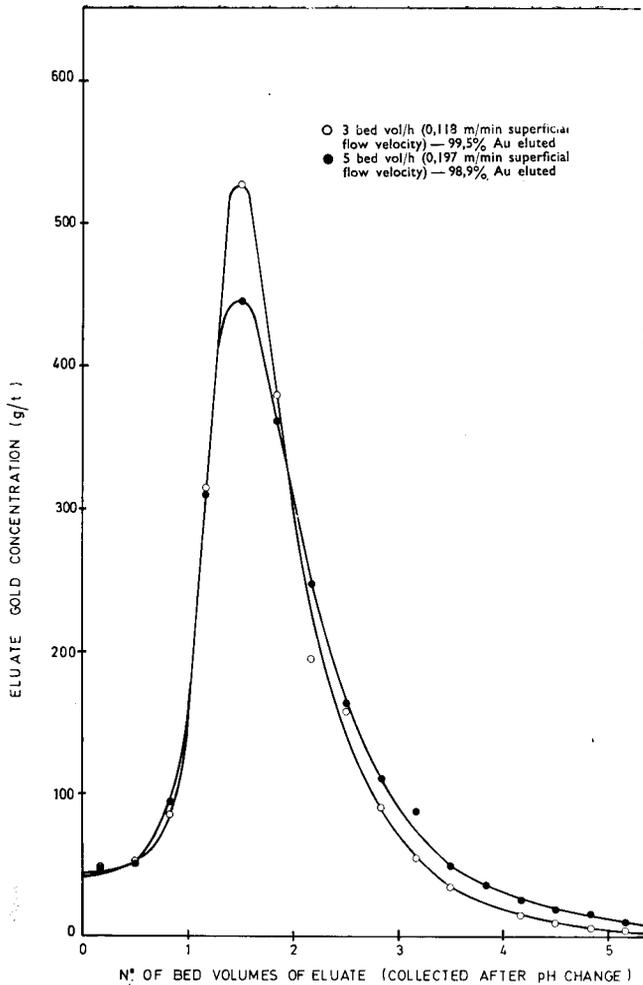


Fig. 8—The effect of eluate flowrates on gold elution from carbon sample B at 110°C

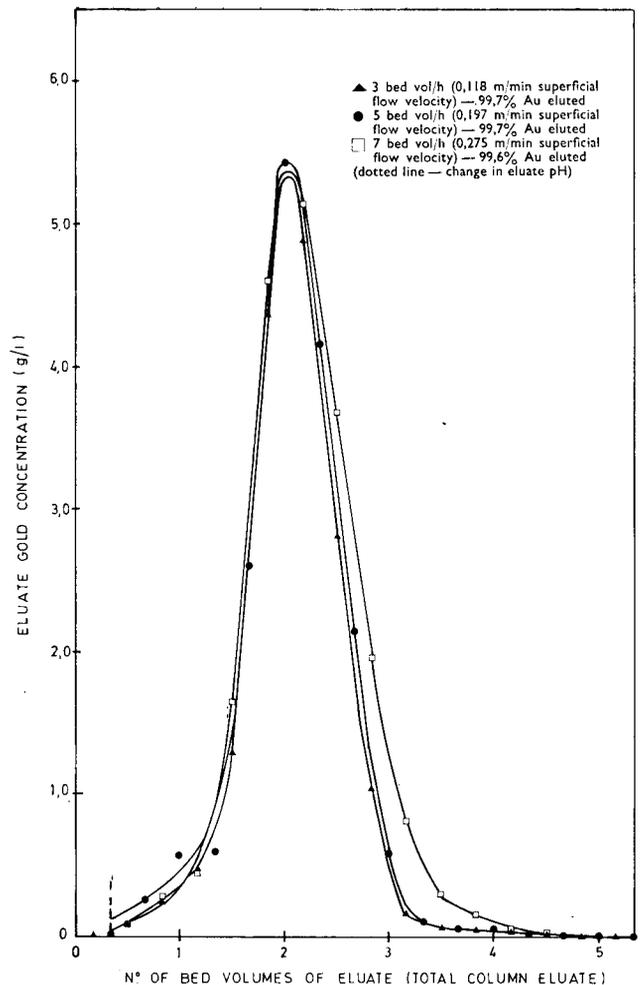


Fig. 9—The effect of eluate flowrates on gold elution from carbon sample C at 110°C

little or no gold was eluted under acid conditions, and that gold commenced eluting only under alkaline conditions, the collection of column eluate following a change in eluate pH afforded a simpler operational procedure. Fig. 13 illustrates the above eluate-collection procedures, indicating little or no change in the resulting gold-elution profiles. Gold was eluted in both instances at a flowrate of 3 bed volumes per hour.

### Elution of Silver

In general, the accurate monitoring of the elution of silver in the present investigation was not satisfactory owing to several reasons.

(a) Silver was found to elute ahead of gold when the prescribed method<sup>2</sup> was used, and the resulting solutions were found to be photosensitive, resulting in the precipitation of silver with time. Visible darkening of the silver-rich eluate fractions was always observed. This phenomenon was undoubtedly due to the instability of the silver cyanide complex at the high pH values of the elution fractions taken at the early stages of gold elution. Either the immediate analysis of eluate fractions (which was not always possible), or the addition of 2 ml of 10 per cent sodium cyanide to each fraction (50 ml), was found to overcome the precipitation problem.

(b) The analysis of carbon residues by conventional fire assay does not yield accurate silver values because of parting difficulties associated with the analysis of such relatively gold-rich material.

In the present investigation, both gold and silver were monitored, but it was found that very poor material balances resulted for silver owing in part to the difficulties outlined above. For this reason, together with the very minor economic role played by silver, the silver results are not presented in any great detail. However, the elution results did in general indicate the elution of 80 to 100 per cent of the contained silver from the carbon. As an example, Fig. 14 illustrates the effect of temperature on the elution of silver from sample C at a flowrate of 3 bed volumes per hour.

### The Removal of Calcium and Silica

The average calcium and silica contents of various carbon samples treated in the investigation are presented in Table I. It is immediately evident that the build-up of calcium is very considerable in the case of the loaded carbon originating from the carbon-in-pulp operations, namely Fairview and Golden Dumps. In the case of the Fairview carbon, a calcium content of 1.5 per cent and a gold loading of 16 900 g/t can be compared with a 3.4 per cent calcium content for the Golden Dumps

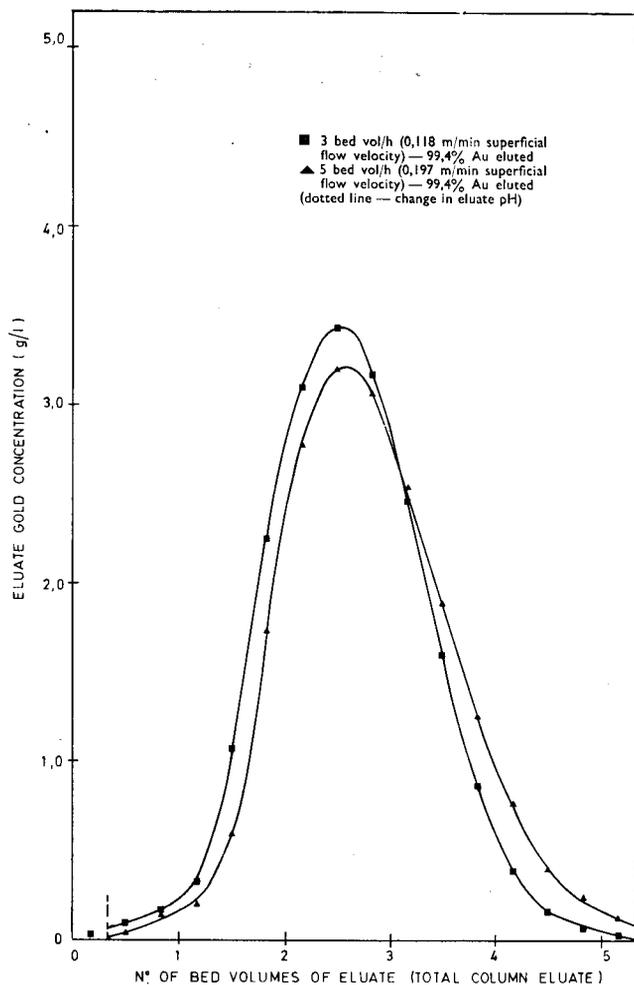
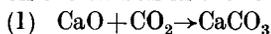


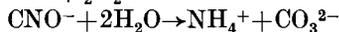
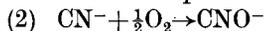
Fig. 10—The effect of eluate flowrates on gold elution from carbon sample C at 90°C

carbon and a gold loading of only 3140 g/t. The use of air agitation in the carbon-contacting circuit at Golden Dumps could to a large degree explain the fouling of the carbon by calcium. Mechanical agitation is used in the carbon contactors of the Fairview Gold Mine.

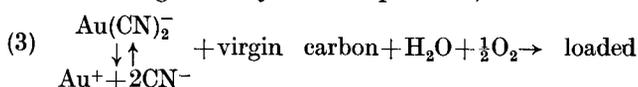
Fouling of the carbon by calcium can be explained on the basis of the following reactions. Clearly, the presence of carbon dioxide is also needed since calcium occurs on the carbon in the form of calcium carbonate.



(This reaction could take place in the carbon contactors, but not necessarily on the carbon surface. The carbon dioxide is derived from the air, where it is present to the extent of 320 p.p.m.)



(The above reactions are catalysed by activated carbon<sup>13</sup>. A strong smell of ammonia was observed in the vicinity of the carbon contactors at Golden Dumps (Pty) Ltd, suggesting that reactions such as those given may occur in practice.)



(This is the reaction mechanism proposed for the adsorption of gold by carbon<sup>14</sup>.)

TABLE I

THE REMOVAL OF CALCIUM AND SILICA FROM VARIOUS LOADED SAMPLES OF ACTIVATED CARBON

Nature of carbon (as received/eluted)	Composition of carbon, g/t			
	Ca	Si	Au	Ag
Sample A as received (ex Fairview)	14 800	1 160	16 900	300
Eluted sample A (average values from 5 different elution tests)	1 794	901	194	47
Sample B as received (ex Golden Dumps after 1st week of operation)	13 900	2 670	1 604	182
Eluted Sample B (average values from 4 different elution tests)	910	1 348	88	41
Sample B1 as received (ex Golden Dumps after 2nd week of operation)	35 250	—	3 140	365
Eluted sample B1 (only 1 elution test)	965	1 750	223	66
Sample C as received (carbon loaded from acidified gold-plant solution)	870	860	18 850	1 750
Eluted sample C (average values from 5 different elution tests)	640	263	97	44

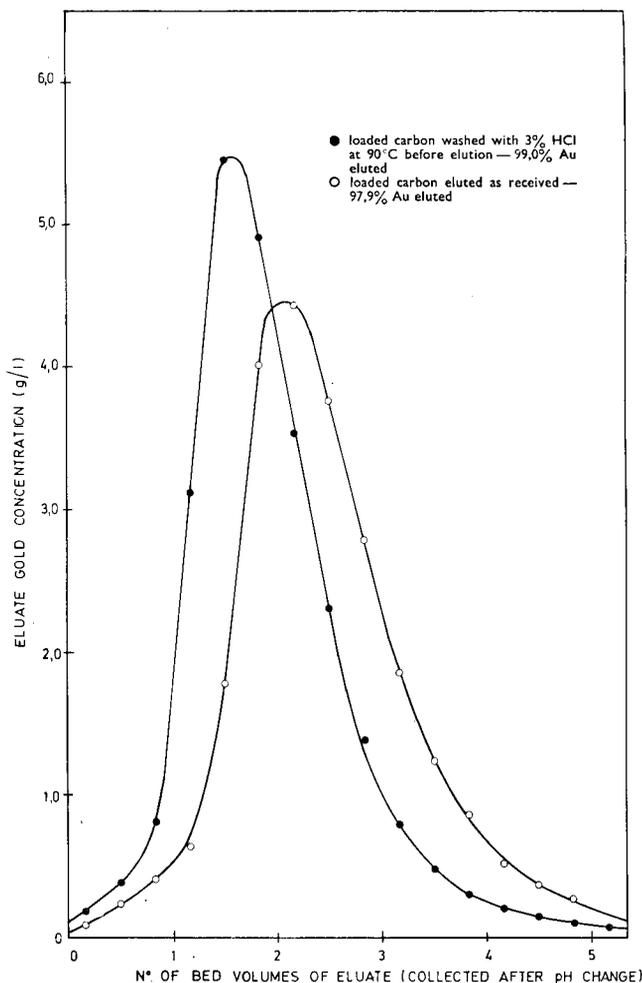


Fig. 11—The effect of acid-washing on gold elution from carbon sample A at 110°C

No poisoning by calcium carbonate was observed in the carbon loaded from acidified pregnant plant solutions. Here a calcium content of only 0,09 per cent was noted (the calcium content of the virgin coconut-shell carbon was 0,1 per cent). While the build-up of silica on the loaded carbon samples is not considered to be excessive, there was nevertheless a substantial increase. Thus, the presence of up to 0,27 per cent silica in Golden Dumps sample B can be compared with 0,09 per cent silica found to be present on sample C (the silica content of the virgin carbon was 0,1 per cent).

The results indicate that the removal of calcium and silica following acid-washing and elution of carbon samples A and B is effective in removing virtually all the calcium and silica. In the case of sample C, where no acid washing was considered necessary, much lower levels of calcium and silica were found to be present following gold elution (0,06 per cent calcium and 0,03 per cent silica).

It should be noted that prussic acid is evolved during acid-washing, and due precautions must be taken.

### Discussion

The most significant factors affecting the elution of gold from activated carbon are temperature and acid-

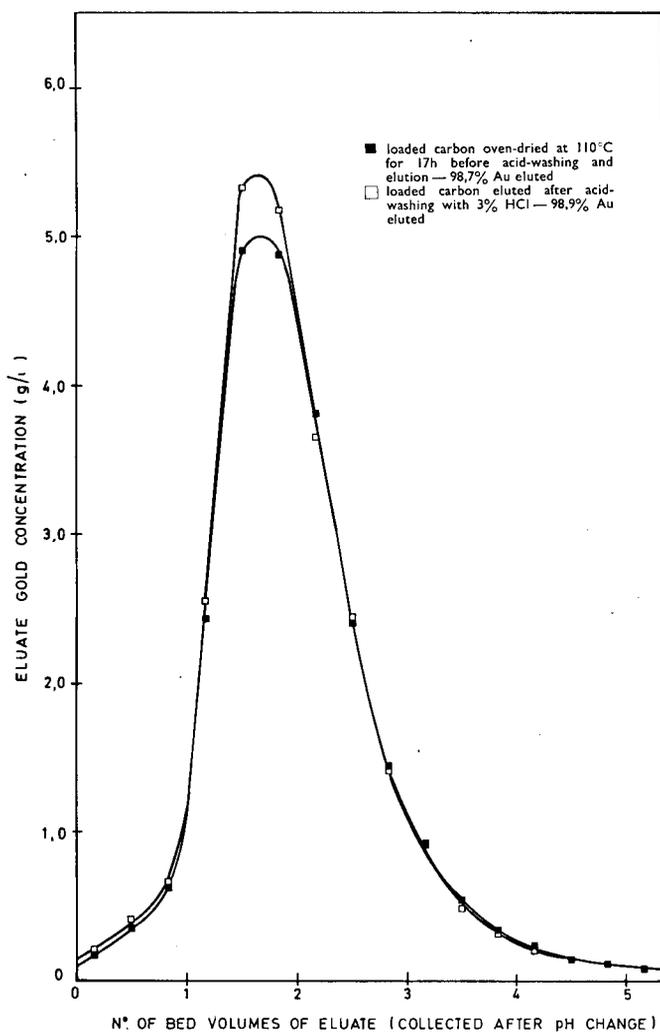


Fig. 12—The effect of oven drying of carbon sample A on gold elution at 110°C

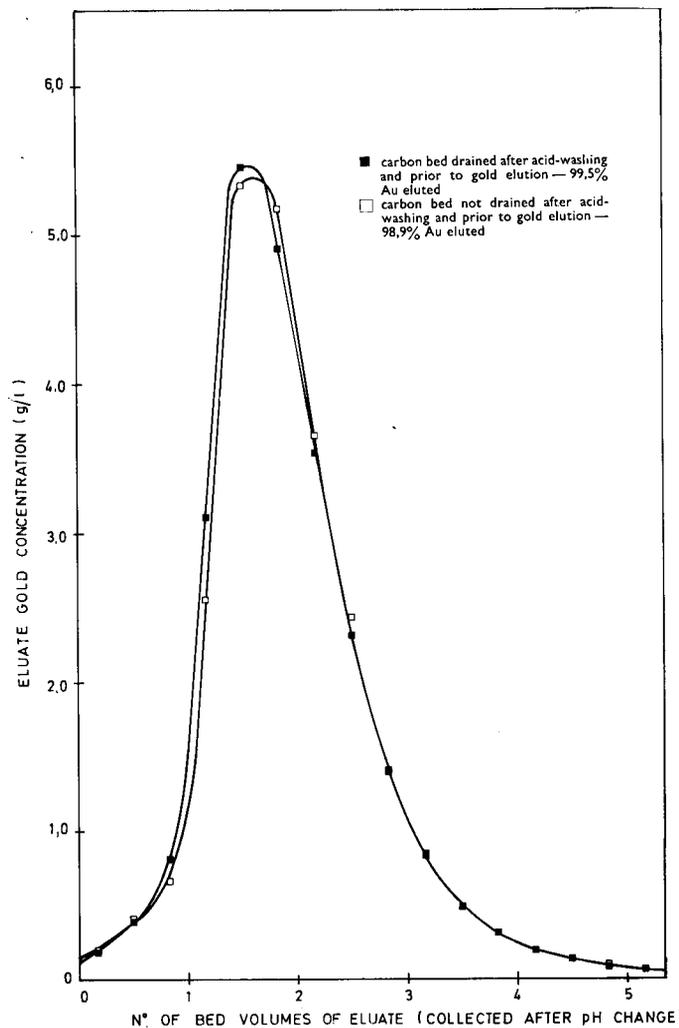


Fig. 13—Two different eluate-collection procedures used in the elution of gold from carbon sample A at 110°C

washing. The other gold-elution parameters studied have only marginal effects on the efficiency of gold elution. Accordingly, elution parameters other than elution temperature and acid-washing can be modified if convenient to do so without adverse effect on the elution procedure. These findings have a direct bearing on the current operations at the carbon recovery plants of both the Fairview Gold Mine<sup>7</sup> and Golden Dumps (Pty) Ltd<sup>6</sup>.

As concluded in the present investigation, as well as in earlier elution studies<sup>2</sup>, temperature is perhaps the most important operational variable in gold elution. Consequently, the elution of gold from carbon at 100 to 110°C (gauge pressure of 50 to 100 kPa) is strongly suggested. Problems associated with possible boiling in the elution column when the process is operated close to the boiling point of water at ambient pressures would support pressurization of the elution column. This problem of boiling was encountered during pilot-plant elution of carbon loaded at the Fairview Gold Mine<sup>7</sup>. Operationally, elution at such low gauge pressure is facilitated simply by the addition of a suitable pressure-relief valve positioned on the eluate line from the elution column. From the safety aspect, any pressurized system must, of course, comply with the provisions of the Factories Act.

Several advantages are gained from operation at the elution temperatures of 100 to 110°C. Not only can elution be carried out in shorter times (2 to 3 h) owing to the use of higher elution flowrates, but more-concentrated gold eluates are produced for the subsequent electrowinning of gold. The use of shorter 'soaking periods' with the sodium cyanide-sodium hydroxide reagent and lower additions of pretreatment cyanide can also be expected. Of course, the particle size of the loaded carbon is to some degree also significant, and must be taken into account in the selection of operating parameters. As can be expected, the choice of a carbon of finer particle size is advocated from an elution point of view. A further operational modification suggested as a result of the findings of this investigation is that

only the alkaline column eluate should be collected so that a more concentrated eluate suitable for subsequent electrolysis can be produced.

With regard to the elution response of the three different carbon samples studied in the present investigation, few problems were encountered. While minor differences in the elution profiles of the respective carbons were obtained following acid-washing if required, such differences were small and undoubtedly related to the particle size of the sample concerned. When this consideration is taken into account, the results presented indicate that the prescribed method for the elution of gold from activated carbon is both reproducible and efficient.

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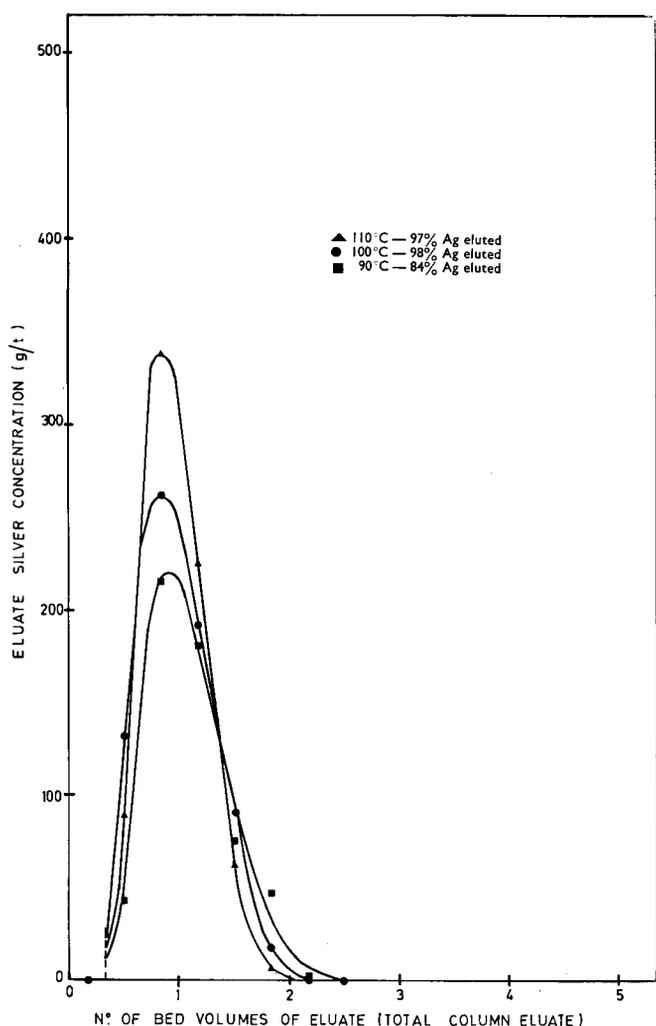


Fig. 14—The effect of temperature on the elution of silver from carbon sample C