# Hopper clarification of uranium pregnant solution at Western Deep Levels

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**SYNOPSIS**

A method for the clarification of uranium pregnant solutions using a high-rate floc blanket was developed from laboratory scale through pilot-plant testing to full-scale production by the Anglo American Research Laboratories.

A two-stage clarification process (hopper plus leaf) was commissioned at the Western Deep Levels uranium plant in October 1980. The high efficiency of the hopper clarification permitted its use on its own. The leaf clarifiers were therefore taken out of service in September 1981, since when the secondary clarification is achieved by further unaided gravity settling in the semi-clarified and clarified pregnant-solution storage tanks. As a result, a daily 12 000 to 17 000 t of countercurrent-decantation overflow with a suspended-solids concentration of 500 to 600 mg/l is continuously clarified to a suspended-solids concentration of less than 30 mg/l. Secondary gravity settling reduces the suspended-solids concentration to under 20 mg/l.

The cost of the single-stage hopper-clarification process is R0,0020 per ton of liquid treated. The removal of the leaf clarifiers from the circuit resulted in an approximate visible saving of R100 000 per annum.

**SAMEVATTING**

'n Metode van verheldering van uraandraende oplossings deur gebruik te maak van 'n hoë tempo vlokkombers is ontwikkel deur die Anglo American Navorsings-laboratorium vanaf laboratorium proefnemings deur 'n toets aanlegskaal tot in volskaalse produksie.

'n Twee fase verhelderingsproses (tenk en blad) is in gebruik geneem in Oktober 1980 by die Western Deep Levels uraanaanleg van Anglo American Corporation. Die hoë doeltreffendheid van die tenkverheldering het dit moontlik gemaak om die bladverhelderaars se gebruik in September 1981 te staak. Vanaf hierdie datum is sekondêre verheldering verkry deur verdere swaarteafsakking in die halfverhelderde en verhelderde uraandraende oplossing opgaartenks. Gevolglik word daagliks 12 000 tot 17 000 ton van die teenstroomdekantering oorloop, wat 500 tot 600 mg/l deeltjies in suspensie bevat, deurlopend verhelder tot 'n konsentrasie van minder as 30 mg/l deeltjies in suspensie. Sekondêre swaarteafsakking verminder die konsentrasie van deeltjies in suspensie tot minder as 20 mg/l.

Die koste van die enkelstap tenkverhelderingsproses is R0,0020 per ton vloeistof behandel. Die ontrekking van die bladverhelderaars uit die proses het 'n merkbare besparing van R100 000 per jaar meegebring.

## Introduction

The success of hopper clarification for the treatment of gold pregnant solution at Vaal Reefs South (described in an earlier paper[1]) resulted in a laboratory investigation at the Anglo American Research Laboratories on the adaptation of the process to the clarification of uranium pregnant solution.

Floc-blanket clarification of uranium pregnant solutions has, to the best of the authors' knowledge, never been attempted owing to serious doubts about the suitability of inorganic coagulants under the prevailing conditions of low pH (1,0 to 2,1). However, laboratory investigations showed that, if the 'mixing-in' technique was changed, several inorganic coagulants would be capable of producing effective floc-blankets in conjunction with non-ionic polyacrylamide-based flocculants. As a result, the hopper clarifier pilot unit was lined with rubber, and pilot-plant tests started at Western Deep Levels (WDL) in December 1977. At the completion of these tests, the pilot plant was transported to Vaal Reefs West (VRW), where clarification tests were conducted in conjunction with leaf clarifiers during May to June 1978.

The success of the pilot-plant tests proved that the process was suitable and cost-effective for full-scale operation. In the tests, a feed containing 400 mg of solids per litre was clarified to an average of 18,9 mg/l at a pH value between 1,2 and 2,1, and at a rising velocity of $8,5\ m^3/m^2/h$. This had required 20 to 30 mg of sodium chloride coagulant and 0,2 mg of Magnafloc 351 non-ionic polyacrylamide flocculant per litre at a cost of R0,0025 per ton of solution treated. Accordingly, a full-scale plant was designed for the new uranium plant at WDL. The two-stage installation, which included hopper and leaf clarification, was commissioned in October 1980, and single-stage hopper clarification on its own was introduced in September 1981.

This paper describes operating experiences on the full-scale plant between October 1980 and May 1982. The operating costs of hopper clarification in the two-stage and single-stage modes are also given.

## Process Criteria Based on Pilot-plant Experiences

For successful and continuous hopper clarification of uranium pregnant solutions, the following fundamental conditions must be maintained.

(1) The *pH value* of the feed solution should not fall below 1,0 since, at pH values lower than 1,0, the effectiveness of inorganic coagulants diminishes rapidly.

(2) The *rising velocity* should not fall below 5,0 m/h since this results in the loss of the fluidized bed. At velocities higher than 10 m/h, the solids are carried over into the overflow. The optimum rising velocity is between 6,5 and 8,5 m/h.

(3) The *concentration of solids in the feed* should preferably be more than 400 mg/l for a sufficiently dense fluidized bed with good filtration characteristics. However, the concentration should be kept below 2500 mg/l, or the need for high dosages of reagents may cause premature aggregation and segregation

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of the bed.

(4) The *particle size* in the feed should not exceed 147 μm since coarser particles may be too heavy to be kept in the fluidized blanket and may have to be removed by manual desludging of the hopper bottom.

(5) *Air entrainment* is to be avoided at all costs since it results in dirty overflows when some of the solid particles adhere to air bubbles.

(6) *High temperatures* (higher than 40°C) may cause a partial carry-over of solids into the overflow by convection currents.

(7) The *depth of the fluidized bed* should be stabilized at about 2 m below the overflow weir to give optimum filtration efficiencies. The higher the level of the fluidized bed in the cylindrical part of the hopper, the less the likelihood that solids will break through into the hopper overflow.

(8) The *dosage of coagulant* must be just sufficient to create imbalances in the charges on the colloid surfaces, but must not be too low since the coagulant has also to supply part of the bulk of the porous filter medium in the blanket. The porosity of the filter medium in the blanket depends on this dosage, which in turn controls the filtration efficiency of the process.

(9) The *dosage of flocculant* should be just sufficient to keep the fluidized solids inside the bed at the prevailing rising velocities. Small increases in this dosage can control the depth of the blanket very rapidly. However, excessive changes must be avoided since, at high dosages (0,3 mg/l), rapid aggregation may cause channelling in the bed. Very high dosages (0,5 mg/l) may also cause rapid shrinkage of the bed, or even loss of fluidization.

(10) Desludging of the *sludge cone* should be limited to once a shift, or in the case of feeds high in solids to twice a shift, and should not cause an excessive drop in the level of the blanket. Therefore, the surface area of the sludge-collecting cones must not exceed 10 per cent of the total surface area of the hopper.

## Scale-up Design for WDL

The plant process required the continuous clarification of 700 t of uranium pregnant solution per hour from a suspended solids content of 300 to 1000 mg/l to below 30 mg/l.

A single-pipe feed system was chosen and, consequently, the hopper diameter was limited to a maximum of 10 m. Hoppers of larger diameter can be used, but they require elaborate feed-distribution systems, which are liable to suffer from mechanical breakdowns. One 10 m diameter hopper was not large enough to accommodate the volume at the peak flow of 700 t/h within the effective range of rising velocity of 5,5 to 8,5 m/h. The setting of the peak flowrate in the middle of the permissible range of rising velocity (i.e. at 7,0 m/h), and the use of three 6,5 m diameter units as well as a gravity overflow recirculating system, gave a design that was flexible enough to accommodate the expected fluctuations in feed volumes.

The gradual reduction of the rising velocity from approximately 60 m/h at the bottom of the hopper to the desired 7,0 m/h at the widest part of the hopper is achieved through a 60° cone, taking up about 60 per cent of the total height. Steady upflow conditions are established in the cylindrical section of the hopper, which takes up about 40 per cent of the total height. The bed depth is controlled by the removal of sludge through two peripheral half-cones (1 m radius by 1,2 m deep) situated opposite each other at the junction of the conical and cylindrical parts of the hopper. This avoids excessive narrowing of the cross-sectional area in the cylindrical section, which would induce different velocity gradients. The surface area of the cones was set at 10 per cent of the total surface area of the hopper so that, during desludging, the total drop in blanket level—which in this case is only 0,03 m—should not materially interfere with the process. Feed into the hopper bottom is through a simple pipe pointing downwards and set about 1 m above the hopper bottom. The downward thrust of the feed ensures continuous high turbulence and fast reversal of flow.

Chemical design considerations required the consecutive addition of coagulant and of flocculant near to each other under highly turbulent conditions (outside the hoppers) so that the reagents reacted only with fresh feed. The dosages had to be low enough to avoid the break-through of reagent into the overflow, which could have an adverse effect on the solvent-extraction process.

The only totally non-ionic flocculant available on the market that does not interfere with solvent-extraction processes is Polyox, which is based on ethylene oxide. However, it is effective only at a dosage of 20 g/t or higher. At that dosage, it removes all the colloidal silica but is very expensive, at R10 per kilogram. Owing to the high dosage required and the high price, it cannot at present compete with the slightly less efficient hopper process using coagulant with a polyacrylamide flocculant. Details of the process flowsheets and hoppers are shown in Figs. 1 to 3.

## Designs of Hopper Clarifiers

Several hopper-clarifier designs are shown in Fig. 4.

*Design 1* is the pilot-plant hopper, which consists of a cylindrical section 2,44 m in diameter and 2,4 m deep above a 48° shallow cone 1,9 m in depth. Sludge is collected in a 45° sludge cone 0,8 m in width suspended centrally 1,3 m below the overflow launder. This arrangement

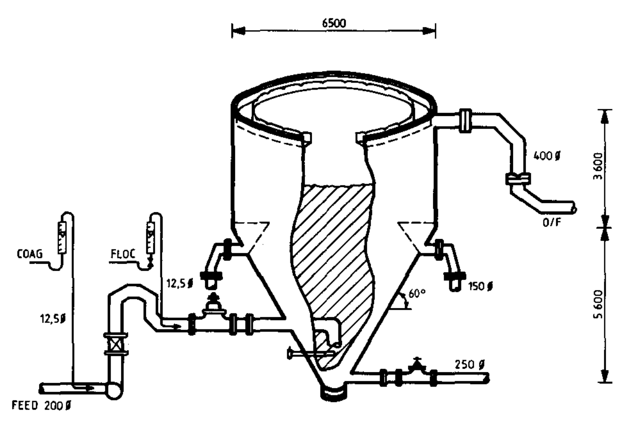


**Fig. 1—Layout of hopper clarifier at Western Deep Levels**

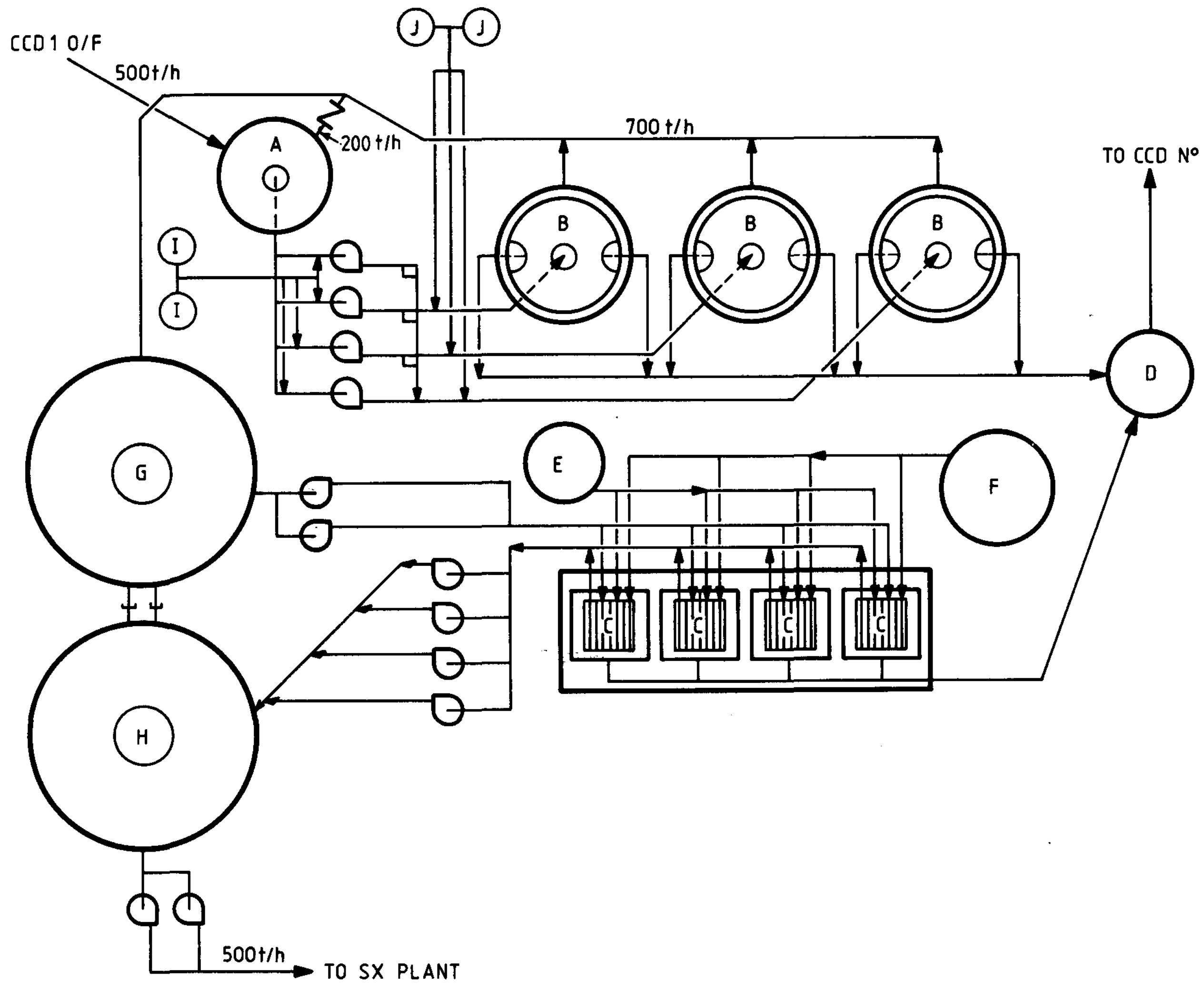


**Fig. 2—Two-stage clarification, 200 kt/m uranium plant at Western Deep Levels:**

A Unclarified surge tank
B Hopper clarifiers
C Leaf clarifiers
D Hopper sludge tank
E Pre-coat tank
F Dilute-caustic tank
G Semi-clarified pregnant storage
H Clarified pregnant storage
I Coagulant
J Flocculant

works very well owing to the pilot unit's small diameter and high height-to-width ratio of 1,76 to 1. Good filtration is obtained in the deep cylindrical section. However, at larger diameters, the height-to-width ratio has to be reduced for economic reasons. This restricts the diameters to 10 m, at which value the total height of about 14,0 m must be catered for since, below a height-to-width ratio of 1,4 to 1, the process equipment may become unsuitable for fluidized-blanket clarification. Operating difficulties may also arise with centrally suspended sludge cones in large units.

*Design 2* is the design of an industrial unit employed in the clarification of gold pregnant solution. The unit is a modified standard plant pachuca 10 m in diameter and 14,5 m deep. To obtain a deep fluidized bed and collection of solids from the top of the bed, the four peripheral sludge-collecting cones were installed only 1,5 m below the overflow weir. This resulted in insufficient collection of solids, and necessitated desludging from the hopper bottom from time to time. The height of the blanket gives efficient filtration, but the four cones, which take up 20 per cent of the total surface area, reduce the cross-sectional area where it matters most and from time to time may induce the carry-over of solids owing to sudden increases in the upflow velocity around the edges of the cones.

In *Design 3* (for uranium pregnant solutions), the sludge cones are placed well below the top of the blanket. Their number was reduced from four to two, taking up only 10 per cent of the total surface area. Increases in upflow velocity were negligible around the edges and were further dampened by the fluidized-bed solids. The reduction in diameter to 6,5 m at a height-to-width ratio of 1,45 to 1 reduced the bed retention time to about 45 minutes. This reduced the likelihood of bed segregation due to 'aged' large aggregates.

*Design 4* is the design that is regarded as the optimum. It includes a central de-aerating pipe and improved overflow-launder collecting system. Single-pipe downflow feed distribution and a maximum diameter of 8 m are considered to be the best combination at present.

*Design 5* shows the introduction of a false cone for use on filtrates from rotary vacuum filtration, which may contain coarse solids. The coarse solids are supposed to collect in the 'dead space' between the false cone and the hopper bottom, from where they are removed by desludging. This solution is less than ideal since the coarse solids collect in the false cone and not in the 'dead space', resulting in double hopper-bottom desludging. Although this may also interfere with the efficiency of distribution of the single-pipe feed system, it may reduce any damage by erosion to the hopper bottom.

## Operation of Hopper Clarifier

Pregnant overflow solution (after countercurrent decantation) from the unclarified surge tank is pumped with 4 Hydroseal pumps (one on stand-by) through pipes of 200 mm diameter to the bottoms of three 60° conical-bottomed hopper clarifiers in parallel at a continuous rate of 700 t/h and at the process pH of between 1,2 and 2,1. The hoppers are 6,5 m in diameter and 9,2 m deep.

Sodium chloride coagulant in the form of a 5 per cent solution is injected by an SH 60 R5 monopump through rotameters into the feed pipes of the hopper at the pump suctions at a dosage of between 15 and 25 g/t.

Magnafloc 351 non-ionic flocculant — made up as a 0,06 per cent solution in an existing flocculant plant — is injected into the feed pipes of the hopper through rotameters by a CD 60 monopump at the pump delivery side at dosage rates of 0,2 g/t.

The required energy (or turbulence) for the completion of the coagulation–flocculation process is supplied by the feed-pump impellers and the flow velocity of approximately 2 m/s in the feed pipes. Coagulation–flocculation is completed outside the hopper in 5 to 8 seconds while floc conditioning is completed by the gradual decrease in velocity inside the hoppers over a period of 40 to 50 minutes. The upflow velocity, which is reduced to 7 m/h at the widest diameter of the hoppers, is sufficient to keep the low-density floc blanket in a fluidized state. Under these conditions, the floc blanket acts as a porous filter and helps to collect and agglomerate any fine particles and most of the colloidal particles. This results in a well-clarified and -filtered overflow. Excess sludge is removed by gravity through two 0,6 $m^3$ capacity sludge-collecting half-cones (per hopper) into the hopper sludge tank once per shift, from where it is pumped back to No. 2 countercurrent-decantation thickener. The overflows gravitate through a common 450 mm diameter pipe to the semi-clarified pregnant-solution storage tank or, when necessary, to the level-controlled unclarified-solution surge tank for recirculation to the hopper. The semi-clarified pregnant-solution tank (19,1 m in diameter and 6,4 m deep) overflows into a clarified pregnant-solution storage tank of similar size

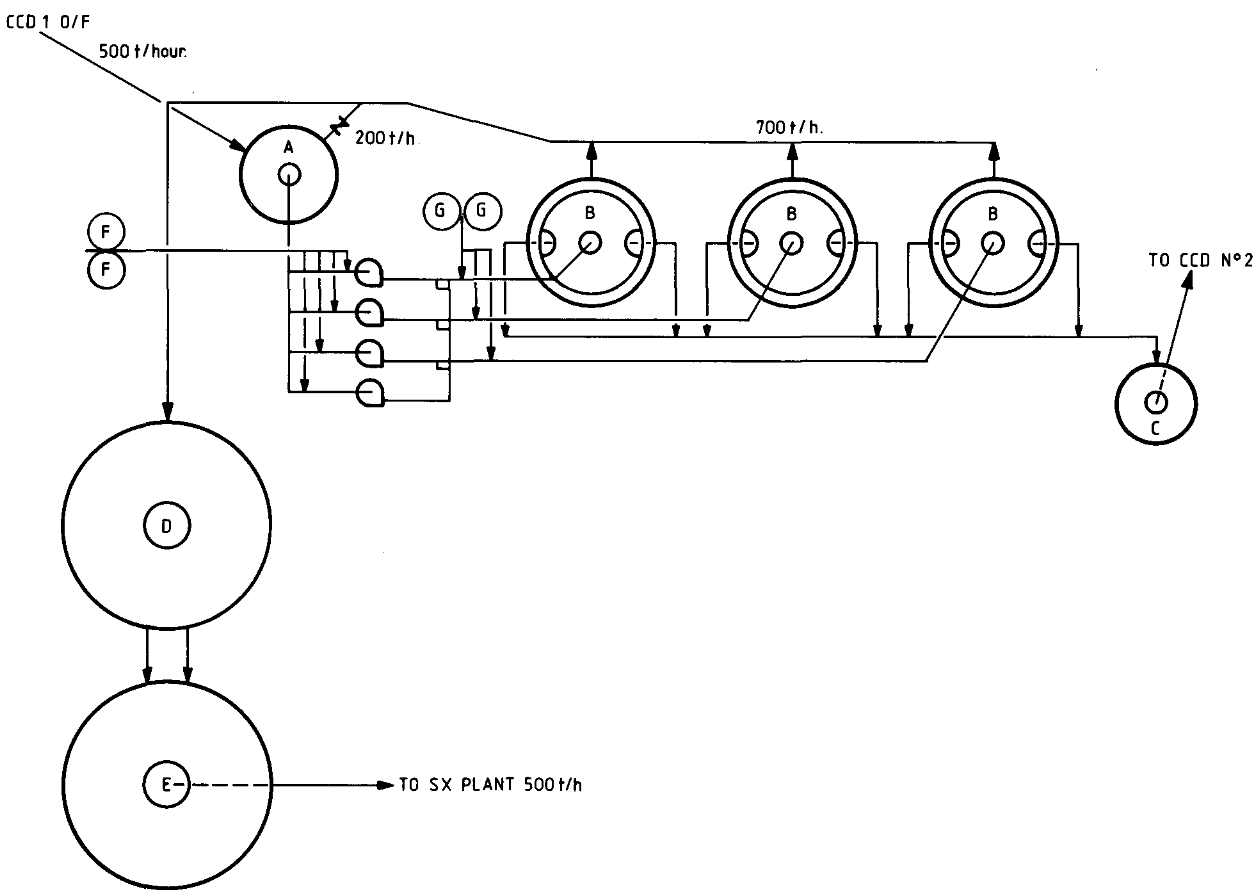


**Fig. 3—Single-stage clarification, 200 kt/m uranium plant at Western Deep Levels:**
**A Unclarified surge tank**
**B Hopper clarifiers**
**C Hopper sludge tank**
**D Semi-clarified pregnant storage**
**E Clarified pregnant storage**
**F Coagulant**
**G Flocculant**

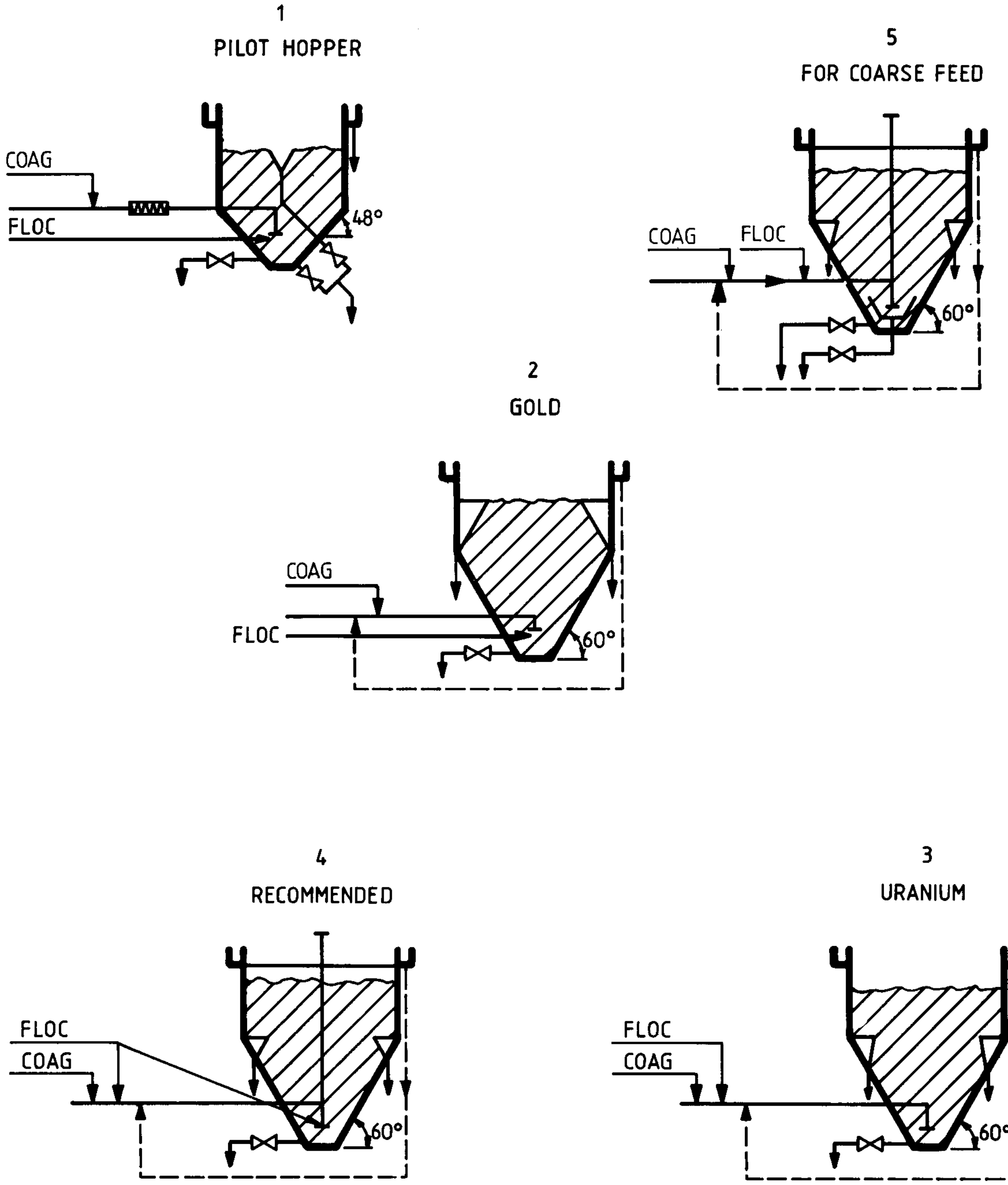


**Fig. 4—Various designs for hopper clarifiers using the combined coagulation–flocculation process**

from where the clarified solution is pumped to the solvent-extraction plant.

Before the removal of the leaf clarifiers from the circuit, the overflow from the hopper, which collected in the semi-clarified solution storage tanks was pumped to the leaf clarifiers, which consisted of 240 kieselguhr-precoated standard Merrill-filter leaves. Filtrate was pumped to the clarified pregnant-solution storage tank and from there to the solvent-extraction plant.

Desludging from the hopper bottom, which is practised infrequently, is carried out manually if and when required.

Monthly averages of operating results are summarized in Tables I and II. These show that, during commissioning and for a time afterwards, hopper operation suffered from too low a solids content in the feed, too high a dosage of coagulant–flocculant, and unsatisfactory process control. The operation of the leaf clarifiers was mostly unsatisfactory owing to frequent leaf blockages and tears in the filter cloth. Leakages of the precoat resulted in the formation of emulsion at the interface in the solvent-extraction plant, while the uncoated leaves were not able to remove the bulk of the fine solids from the hopper overflow.

Since the introduction of tightly controlled hopper clarification on its own, coupled only to free settling in the semi-clarified and clarified pregnant-solution storage tanks, the average concentration of solids in the hopper overflow has been 24 mg/l decreasing to less than 20 mg/l in the feed to the solvent-extraction plant. One reason for the improvement was an increase of solids in the feed to above 500 mg/l, by the running of the overflow from the No. 1 countercurrent-decantation thickener much dirtier than before. This also reduced the overall dosages of flocculant on the countercurrent-decantation plant.

## Operating Costs

At a sodium chloride (coagulant) cost of R64 per ton and a flocculant cost of R3,60 per kilogram, the operating cost of the single-stage hopper-clarification process is R0,0020 per ton of liquid treated at the average dosage rate of 20 g of coagulant and 0,2 g of flocculant per ton.

TABLE I

COMBINED HOPPER AND LEAF CLARIFICATION OF URANIUM PREGNANT SOLUTION AT WDL, 1980 – 1981

| Month and year | Average suspended solids mg/l | | | Average pH | Average $H_2SO_4$ content g/l |
|---|---|---|---|---|---|
| | CCD 1 thickener overflow | Hopper overflow | Leaf-clarifier filtrate | | |
| Oct 1980 | — | 165 | 157 | — | — |
| Nov 1980 | — | 190 | 100 | — | — |
| Dec 1980 | 239 | 154 | 87 | 1,7 | 2,9 |
| Jan 1981 | 150 | 139 | 76 | 1,5 | 2,3 |
| Feb 1981 | 145 | 70 | 30 | 1,7 | 2,5 |
| Mar 1981 | 333 | 97 | 71 | 1,8 | 2,9 |
| Apr 1981 | 250 | 72 | 50 | 1,6 | 3,6 |
| May 1981 | 237 | 75 | 55 | 1,7 | 3,6 |
| Jun 1981 | 258 | 95 | 51 | 1,9 | 2,3 |
| Jul 1981 | 236 | — | 42 | 1,8 | 2,9 |
| Aug 1981 | 225 | 54 | 32 | 1,8 | 2,2 |
| Sep 1981 | 295 | 62 | 45 | 1,8 | 2,2 |

CCD = Countercurrent decantation

TABLE II

HOPPER AND GRAVITY SETTLING OF URANIUM PREGNANT SOLUTION AT WDL, 1981 – 1982

| Month and year | Average suspended solids, | | | Average pH | Average $H_2SO_4$ content g/l |
|---|---|---|---|---|---|
| | CCD 1 thickener overflow mg/l | Hopper clarifier mg/l | Feed to SX plant mg/l | | |
| Oct 1981 | 440 | 32 | 23 | 1,8 | 2,2 |
| Nov 1981 | 530 | 28 | 21 | 1,8 | 2,1 |
| Dec 1981 | 557 | 24 | 15 | 1,7 | 2,6 |
| Jan 1982 | 636 | 23 | 19 | 1,8 | 2,5 |
| Feb 1982 | 683 | 24 | 17 | 1,8 | 2,7 |
| Mar 1982 | 680 | 27 | 21 | 1,8 | 2,7 |
| Apr 1982 | 559 | 23 | 12 | 1,9 | 2,1 |
| May 1982 | 640 | 11 | 9 | 1,7 | 2,0 |
| Jun 1982 | 654 | 18 | 16 | 1,8 | 2,0 |

CCD = Countercurrent decantation

SX = Solvent extraction

The cost of single-stage hopper clarification of 16 800 t of uranium pregnant solution per day is R33,60 in May 1982 money terms. The cost of a two-stage clarification process is R352,50 per day, resulting in a daily cost saving of R318,90. This is equivalent to an annual saving of R100 000 (approximately 90 per cent).

## Summary and Conclusion

Hopper clarification of uranium pregnant solutions was developed on a bench-scale at the Anglo American Research Laboratories and was tested at WDL and VRW on pilot-plant scale. The full-scale process at WDL was operated successfully as the first stage of a two-stage clarification circuit and later as a single-stage process for about 20 months. The process is based on the formation of a floc blanket, which is obtained by the combined use of sodium chloride coagulant and Magnafloc 351 flocculant and the maintenance of a rising velocity of 6,5 to 8,5 m/h in three 60° conical-bottomed hopper clarifiers 6,5 m in diameter and 9,2 m deep. To date, experience shows that the hopper-clarification process, coupled to storage tanks for secondary free-gravity settling, can maintain the concentrations of suspended solids in the feed solution to the solvent-extraction plant below 25 mg/l, thereby ensuring trouble-free operation on the solvent-extraction plant at the low process cost of R0,0020 per ton of liquid treated.

The performance of the solvent-extraction plant was improved by the introduction of hopper clarification, despite fears of the effect of the flocculant on phase separation. It appears not only that the process reduces the suspended solids in the solvent-extraction feed but that the reagents are effectively adsorbed on the bed of solids. The removal of secondary leaf clarifiers from the clarification circuit resulted in a reduction in process costs from R110 000 to R10 000 per annum, which is equivalent to an annual saving of R100 000.

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## Reference

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