Recovery plant practice at De Beers Consolidated Mines, Kimberley, with particular reference to improvements made for the sorting of final concentrates

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Discussion

I. R. M. Cheston (Visitor): I should like to congratulate the authors on this interesting paper which graphically illustrates the overall effects of the gradual developments in diamond concentrating processes which have taken place over the past few years. These final stages of diamond concentration represent only a minor factor in the cost of diamond production but because of the shortage of highly trained people for this work, any easing of the burden on the sorting staff has an importance far beyond the immediate economic sphere.

The search for the solution of problems posed by the economic and social conditions of industry is never-ending. The Diamond Research Laboratory is, even now, carrying out further work to improve still more the operation of general diamond recovery processes as described in the paper.

Before looking at some of the latest developments in this field of final recovery, there are a few points arising from the paper on which I would like to comment. On page 321, reference is made to the X-ray sorters originally developed by the DRL. The paper gives a figure of 100 per cent recovery of diamonds from +7 mesh concentrates in two passes through the prototype machine. Not wishing to claim miraculous powers for our group, I would prefer to see this given as *virtually* 100 per cent recovery of all *fluorescing* diamonds. Firstly however much care is taken, there is bound to be an occasional operating loss. In the test work, 100 per cent recovery was made on many occasions but this was not always so. Secondly, although *most* diamonds fluoresce strongly under X-rays, *some* diamonds only fluoresce weakly. Type IIB diamonds, in fact hardly fluoresce at all, but the incidence of this special type of diamond is very low in most deposits. However, in operating the commercial X-ray machines, there is a certain background level of reflected radiation from other feed particles. Unless the diamond fluorescence is several times greater than this, it is not possible to achieve sufficient sensitivity in ejection. A certain small but variable proportion of diamonds from each deposit is always found to fluoresce too weakly to be recovered by the X-ray machine. Tests have shown, that for the De Beers mines, this proportion is considerably less than 1 per cent. These diamonds are nearly all dark brown or black in colour and therefore of low value. The degree of fluorescence does not, however, depend entirely on the colour or quality of the diamond and some of the brightest fluorescence comes from the lowest quality of boart diamonds. Investigations into the property of the diamond which causes this low fluorescence are being carried out.

On page 322 it is suggested that zircon fluoresces in the same colour spectrum as the diamond. This is not quite accurate. The total light given out by zircon under X-rays is of the same order as that of diamond. However the zircon radiation has a much wider spectrum band than the diamond fluorescence.

Reference is also made on page 322 to the effect of selective milling in small laboratory mills on diamonds. Perfect diamonds are very hard and very strong and are extremely difficult to break. Imperfect diamonds, which form the majority of diamonds recovered from most deposits, although hard, can be very brittle. Even under slight impact some of these diamonds may shatter to powder. Milling conditions must therefore be extremely closely controlled to minimize breakage, and even so, some breakage will always occur. As suggested in the paper, the necessary conditions are: the use of small balls, slow speed mills and very limited water addition. Tests elsewhere have suggested that the water content of the pulp in such a mill must be less than 25 per cent by weight of pulp to prevent diamond breakage reaching significant proportions.

The skin flotation techniques described on page 323 operate on a very small scale. It is of interest to note that in West Africa a large-scale continuous skin flotation machine is used to recover the fine diamonds. In this operation the feed is dried and, after standing, is mixed with water and fed in a single layer onto a woven phosphor-bronze conveyor belt. This belt runs at a shallow angle into a water bath and as the particles are carried through the air-water-interface, the diamonds float off and over a weir into a collecting box. The bulk of the particles, being wettable, sink to the bottom of the tank and are continuously removed.

If treated without prior drying, the diamond recovery is poor. If material is treated immediately after drying, a lot of the gangue particles also float. During standing, in the hot and humid atmosphere of West Africa, it is found that the gangue particles recover their wettability much faster than the diamond particles. Optimum selectivity is obtained after standing for approximately 24 hours.

At the DRL we have been experimenting with optical filters to differentiate between the fluorescence of diamonds and zircon. By limiting the light transmission to the fairly narrow range emitted by diamonds, it is found that a useful distinction can be made between diamonds and zircon. Within the normal size ranges treated by the machines, it is found possible to eliminate a large part of the zircon without loss of diamonds.

By making gravity separation at a density of over 3.6 it is possible to remove zircon and other heavy minerals such as ilmenite from the diamond concentrates. This operation is successfully carried out in the Belgian Congo using lead sulphamate solutions. To maintain fluidity at these high densities it is necessary to operate the lead sulphamate baths at temperatures of up to 125°C. Lead sulphamate is expensive and the fumes are toxic. Very successful tests have been carried out at the DRL using atomized ferrosilicon mixtures giving pulp densities up to 3.8. These separations are being carried out in a 20 in. cone at feed rates of up to 500 lb/hr of clean concentrates. Excellent separations are made in sizes down to 10 mesh. It may be pointed out that this mechanism fails to safety since in the event of medium contamination the resulting increase in viscosity only serves to increase the proportion of float material and cannot lead to diamond loss.

A. K. Chant (Visitor): I would like to congratulate the authors on their most interesting paper describing improvements made in the final recovery sections of the plants at Finsch and Kimberley and their effect on quantity of concentrate reporting for final hand sorting. The impetus for the development of X-ray separators and vibrating grease belts was largely brought about by the highly refractory nature of the diamonds at the Finsch mine. Apart from the high recovery efficiencies of these machines, their ease of operation and the reduction in labour, they have also brought about greatly improved security and in the diamond industry this aspect is most important.

It could be said that the introduction of X-ray separators has revolutionized recovery plant practice and in spite of their relatively recent development, apart from their introduction at Kimberley and Finsch mine, they have already been introduced into the recovery sections of the plants at Consolidated Diamond Mines in South West Africa, Williamson Diamonds in Tanzania, Diamang in Angola, and Yengema in Sierra Leone. They will also be used in the new plants at Orapa in Botswana, Koffiefontein in the Free State and Koingnaas in Namaqualand.

The vibrating grease belt has now been introduced at Finsch, Kimberley and Williamson Diamonds and will also be used at Orapa and Koffiefontein. At present the X-ray separators are being used on production generally on concentrate sizes down to 3 mm, but sometimes down to 1.6 mm, with vibrating grease belts being used for the lower sizes, but testwork is at present being carried out in an effort to develop a high capacity machine using an X-ray technique for recovering diamonds in the −3 mm range thereby eliminating grease completely.

The authors have quoted the Gunson Sortex XR-21 machine as handling up to 300 lb/hour of −6 +3 mm concentrate, but further testwork elsewhere at Williamson Diamonds and Diamang has shown that higher tonnages can be handled. These tonnages, together with those for the Gunson Sortex XR-11 machine and the Gunson Sortex XR-112 machine which is at present under test at Kimberley, are given below although sometimes a very high diamond incidence can reduce these figures:

	XR 21	XR-11	XR-112
−32 +19 mm	—	7 tph	40 tph
−19 +10 mm	—	5 tph	30 tph
−10 + 5 mm	—	3.5 tph	20 tph
− 5 + 3 mm	800 lb/hr	2 tph	10 tph
− 3 + 2 mm	275 lb/hr		
− 2 + 1 mm	110 lb/hr		

The capacity of the vibrating grease belt depends upon the refractory nature of the diamonds. The 3.5 ft wide by 17 ft long belts at Finsch treating refractory concentrate are capable of handling 1 tph of −3 +0.5 mm material after attrition milling with a recovery efficiency in two passes of +98 per cent whereas with non-refractory diamonds 2 tph could be handled with only one pass needed. The 5 ft wide by 30 ft long belt at Kimberley is handling up to 5 tph of −3 +0.5 mm concentrate in one pass with a recovery efficiency in excess of 99 per cent and indications are that this tonnage could be increased. The tendency is now to standardize the width of these belts at 5 ft and to vary the length according to the tonnage to be treated.

Fortunately most diamonds fluoresce under X-rays and the loss, particularly in the case of the high value gemstones, is practically negligible. In the case of industrial stones, however, there is a certain quality which gives erratic response to this recovery technique. In the testing of industrial stones at Williamson Diamonds it was found that 4 per cent would consistently not fluoresce and that this 4 per cent was diamond 'boart'. This 'boart' constitutes only a minor proportion of Williamson and South African production but constitutes 83 per cent of the production at Bakwanga in the Congo in the size range 38-0.5 mm. The testing of Congo boart under X-ray fluorescence gave only 60 per cent recovery. Furthermore, although the vibrating grease belt has not yet been tested on Bakwanga concentrate all previous attempts at diamond recovery by grease have been largely unsuccessful. These latest developments, therefore, appear to offer no immediate benefits to Bakwanga where the final recovery process consists of attrition milling followed by wet and dry stage magnetic separation followed by hand picking of +5 mm diamonds and electrostatic separation and lead sulphamate separation of −5 mm diamonds.

The authors trace the evolution of the four stage concentration process at Kimberley which is primarily a 'puddle' pan plant. In order to obtain this puddle the kimberlite 'fines' must form a suspension which is thixotropic. The kimberlite from many areas does not have this property and in many diamond areas no kimberlite is available and so puddle pans are then not used as a method of concentration. Generalizing, therefore, primary concentration and secondary concentration is by puddle pans, clear water pans, jigs, and heavy media cones, cyclones and Wedag drums, with a tendency now in secondary concentration to use heavy media cyclones covering the whole size range of 38-0.5 mm and in primary concentration, even in kimberlite areas, to use heavy media cyclones covering the whole range or at least the range down to 3 mm with pans or jigs covering the lower range. Ferrosilicon is the media used generally of grade Amcor 65D or 100D or the equivalent Knapsack grade with the cyclone feed density, spigot density and feed pressure generally of the order of 2.6-2.7, 2.9 and 20-30 lb/in^2 respectively, and with the feed density automatically controlled. It is possible that the 40 tph XR-112 machine could eventually become a serious rival to heavy media processes for concentration down to about 5 mm.

Final concentration is then carried out by a combination of attrition milling, grease recovery (using belts, vibrating belts, vibrating tables, side shaking tables and vanners), conditioning using fish acid oil, maize oil or Cyanamid Reagent 801, X-ray separation, optical separation, magnetic separation, electrostatic separation, heavy liquid and lead sulphamate separation, skin flotation, and caustic soda fusion followed by hand sorting and acidizing. The modern trend is wherever possible to use X-rays down to 3 mm and sometimes to 1.6 mm and vibrating grease belts below this size. The XR-21 separator having served its purpose in the development of the higher tonnage machines has now been largely superceded by these machines and in the newer plants it will probably only be used for the reconcentrating of grease and X-ray concentrates. It is still however being used as a full production machine at Finsch and at Williamson Diamonds.

The forerunner of the XR-21 machine was the Gunson Sortex 621 optical separator and although this machine together with other optical separators can now be considered obsolete in the diamond recovery industry, these machines are still being used very effectively at the Annexe Kleinzee plant in Namaqualand where with the particular type of gemstone in this area very high recoveries are being obtained in the -10 $+2$ mm range. Electrostatic separation having served a useful purpose in the recovery of fine diamonds is now slowly disappearing although it is still used at Diamang in Angola, Bakwanga in the Congo and at State Alluvial Diggings in Namaqualand. Skin flotation and caustic soda fusion is being used very extensively at Akwatia in Ghana and heavy liquid and lead sulphamate separation is still used, particularly at Bakwanga. With this in mind the heavy media high density cone being tested at the Diamond Research Laboratory is of great interest. Magnetic separation is used at Finsch, Diamang, Bakwanga and Akwatia. Various of the above processes on a laboratory scale such as skin flotation, magnetic separation and electrostatic separation, heavy liquid separation and attrition milling are used in most final recovery sections.

Attrition milling on a large scale is used in the recovery sections of most of the plants mentioned, notable exceptions being Premier Mine, Kimberley main plant, and Jagersfontein in the Free State. It is also used at Dreyers Pan and Langhoogte in Namaqualand, at Helam Mine in the Transvaal and on the barges of Marine Diamonds off the coast of South West Africa. It is in many cases used to reduce the amount of concentrate to be treated but with the development of the higher capacity recovery machines its use will probably eventually be limited to cleaning up the surface of refractory diamonds prior to grease belt and possibly electrostatic recovery and to release any diamonds locked in concentrate. With heavy attritioning for grease belt recovery, conditioning of the diamond surface will also sometimes be unnecessary. In both of these cases where attrition milling is necessary it is felt that it should only be used after all non-refractory diamonds have been recovered since in attrition milling there is always the possibility of some diamond breakage and particularly with high quality non-refractory gemstones, this is very undesirable. Carefully controlled conditions are essential to obtain minimum diamond breakage and generally these conditions are smooth liners, mill speed at a maximum of 50 per cent critical, per cent solids at a minimum of 75-80 per cent, ball size as small as possible in line with effective milling and a short residence time in the mill. The introduction of rubber liners into ball mills is very interesting with this breakage aspect in mind. Finally, attrition milling is also used in a number of plants such as those at Akwatia, Bakwanga, and Williamson Diamonds to grind all recovery plant tailings to -0.5 mm prior to leaving the recovery plant circuit.

J. Levin (Fellow): Because South Africa is the world's largest producer of diamonds, it is appropriate that the *Journal* of the S.A. Institute of Mining and Metallurgy should contain the most comprehensive and up-to-date literature on the technology of diamond mining and recovery. That this is so is due to the efforts of those experts in the industry who have taken the trouble to record their experiences and knowledge in the form of papers presented to the Institute. They earn the gratitude not only of all those directly concerned with diamond recovery but also of those who have a general interest in ore-dressing procedures.

The paper by Messrs Loftus, Simpson, and King is of special interest because, not only does it describe the most recent and very important innovations that have taken place, but it also provides a concise yet still comprehensive review of the development of diamond concentration from the beginnings of diamond recovery in South Africa to the present time. In accordance with the pattern of development observed in most industries, recent years have seen the greatest number of innovations, and these innovations have been so radically different from previous practice and so successful that the innovators can be very proud of their ingenuity and skill.

As indicated in the paper, there are now a variety of sophisticated methods for the recovery of diamonds. It is therefore interesting to be reminded that when diamond mining began in South Africa, the workers had no technology of their own and had to borrow their technique from the gold miners, who, it appears, were only able to offer devices like rockers, cradles and riddles. But from then on the diamond workers began to develop the equipment specially suited to their own needs. Some of this equipment, such as jigs and electrostatic separators, was conventional in other industries but had to be extensively modified for diamond concentration. Other equipment was developed by the diamond workers themselves for their own special needs. This category of equipment comprises the rotary pan and the grease table, and although one is tempted to include attrition grinding, optical sorting, and sorting by X-rays because they have been applied so conspicuously in diamond recovery, these procedures strictly belong to the category of techniques that have been developed for general application and then adapted to the special requirements of diamond concentration.

The rotary pan is of special interest because, while being cheap to operate, it can be applied to large or small operations and is fairly efficient, having an efficiency less than that of heavy-medium separation but comparable with that of jigs. In addition, as we were told, it was developed as a concentrator that uses little water. Such characteristics should ensure a wide field of application, but as far as I am aware it is used on a negligibly small scale outside the field of diamond recovery. I know that it was used in the concentration of chromite in the Rustenburg district, for the 'washing' of andalusite in the Western Transvaal and, many years ago, for the concentration of corundum from eluvial deposits. In its application to chromite concentration it has to compete with the shaking table, which is the more general method for the concentration of chromite, and in its application to corundum recovery it has to be compared with jigging as the alternative procedure. It is more difficult to suggest how its application to andalusite concentration should be compared, because andalusite from the Western Transvaal requires a considerable amount of attrition for conversion to a low-grade concentrate and of heavy-medium separation for conversion from a low-grade to a high-grade product; the rotary pan cannot completely take over the two functions of a scrubber and a concentrator, although it does so to some extent. It is not known or, at least it is not recorded, how the rotary pan compares with the alternative methods of treatment, but the examples mentioned of the use of the rotary pan give some justification for my belief that its potentialities have not been fully exploited outside the diamond industry. It would be a great help in an assessment of its potentialities if more were known of its efficiency and its principles of operation, and I suggest that it would be very worth while for those in the diamond industry to give us more information on these matters.

The other device of which the diamond industry can claim to be the sole progenitor is the grease table and its variations. The grease table is exclusive to diamond concentration, and it is difficult to think of other possible applications. The action of the grease table depends on the hydrophobicity of the diamond, and it can therefore be regarded as the application of flotation principles to particles as large as 20 mm. In other mineral industries attempts have often been made to apply the froth flotation process to coarse particles, and we know about agglomerate tabling and modifications of conventional mechanical and pneumatic flotation machines that permit the flotation of particles up to 2 mm in size, but obviously these machines would not be suitable for sizes in the neighbourhood of 20 mm. On the other hand, where else do we find a mineral that is to be floated at sizes as large as 20 mm?

The use of grease tabling for material between 7 and 28 mesh posed difficulties which, it appears, have now been overcome by the introduction of the vibrating grease belt. I wonder if the oil-agglomeration process could not provide an alternative solution? This process has recently been under consideration in Canada, where it has been referred to as spherical agglomeration and has been tested for the concentration of cassiterite, iron ores, and coals. It uses a collector to coat the desired mineral and to transfer it to an oil phase, which is easily separated from the aqueous gangue-bearing phase. Although the testwork carried out used fine grinding, this does not seem to be an essential part of the process, and the application to particles coarser than 28 mesh may be possible. If this is so, the process would bridge the gap between grease-tabling for coarse particles and froth flotation for fine particles.

It is incidentally of interest to observe the similarity between the oil-agglomeration process and the skin flotation used for the concentration of diamonds, especially when the latter is used after the addition of oil, as described in the paper.

Another suggestion, which I offer only hesitatingly as a contribution to the problems of diamond concentration but which may elicit interesting comment, is related to the development of sorting machines such as optical and X-ray sorters. These sorters make use of some of the very characteristic properties of the diamond, namely colour, refractive index, and visible fluorescence under X-rays. Another and quite exceptional property of the diamond is its very high thermal conductivity. The development of a sorter based on this property should not be impossible because at least two sorters have been described that could make use of the thermal properties of minerals. A sorter that separates halite from sylvite uses the difference in thermal transmission of these minerals to soften a resin belt under one of the minerals sufficiently for the mineral to adhere to the belt. Another sorter which has been proposed for the concentration of asbestos makes use of differences in thermal absorptivity and uses an infra-red detector to observe differences in the temperature of the heated minerals. In principle there should be no difficulty in translating a difference in thermal conductivity into a difference in temperature between the diamond and its accompanying minerals, and the development of a sorter based on differences in thermal conductivity should therefore be possible.

One of the main objects of the paper by Messrs Loftus, Simpson and King is to draw attention to the way in which the final visual-manual sorting of diamonds has been facilitated by the recently developed concentrators described in their paper. However, there is no suggestion that the final sorting could be entirely dispensed with. Such a suggestion would probably be regarded as heresay in the diamond world and, in fact, would not be a very useful one seeing that in using diamonds each diamond is handled and inspected separately. I should nevertheless be interested to know why the use of heavy-liquid separation in the final stages of diamond recovery has not been found advisable. Liquids or pseudo-liquids of specific gravity slightly above and slightly below the specific gravity of diamonds can be obtained, for example by the use of Clerici's solution or a dispersion of mercury in bromoform. The efficient sorting of diamonds by heavy liquids should be possible at a reasonable cost, and the degree of elimination of unwanted minerals by such a separation would be extremely high, although admittedly not complete. It seems to me that heavy-liquids could at least be used as a substitute for the trial-by-pressure that is applied to doubtful diamonds, even if other uses are found to be not feasible.

In conclusion, I should like to add that the novelty of the methods described to us should serve as a stimulus to workers searching for improved methods of concentration in other fields, and this is another reason for our gratitude to the authors for their valuable and interesting paper.