THE USE OF ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE
AS A WEAR RESISTANT SEALING MATERIAL
ON THE CONTACTING SURFACES OF ROTARY FILTER HEADER VALVES
IN THE GOLD MINING INDUSTRY

By A H Mokken Pr Eng
THE USE OF ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE AS A WEAR RESISTANT SEALING MATERIAL ON THE CONTACTING SURFACES OF ROTARY FILTER HEADER VALVES IN THE GOLD MINING INDUSTRY

By A H Mokken Pr Eng

Summary

The leaching of finely milled gold ore in weak cyanide solutions with the object of transferring particulate gold from the solid to the liquid phase and followed by separation of this phase on rotary drum filters, remains an important operating stage in the gold recovery process on South African gold mines.

The driving force effecting the liquid-solid separation is a function of the vacuum level generated in the filter system. This vacuum level is dependent on vacuum pump capacity and efficiency and is adversely influenced by leaks of extraneous air into the vacuum system. These air leaks could originate from improper design, inferior materials, inadequate maintenance and poor operating practice. A drop in vacuum as a result of air leaks constitutes a permanent loss of dissolved gold to residues.

With extraction efficiencies of gold bearing solutions of the order of 99.7 per cent achievable on rotary filters under optimum conditions, a drop in extraction to 99.5 per cent in an Industry filtering in the region of 80 million tons per annum at a gold grade of 5 grams per ton would equate to a permanent loss of gold in 1000 kg or about R33 000 000 per annum.

Based on these considerations, increasing attention is being given to filter header design and to composite materials with optimum wear resistant and frictional properties as lining materials for sliding surfaces to ensure a continuing air tight seal.

Introduction

In order to provide the reader with a background against which to judge the need for superior composite materials in order to minimise the permanent loss of dissolved gold, a short description of the gold extraction process as used by mines in the South African gold mining industry, is given.

Occurrence of gold in the Witwatersrand Conglomerate

It is generally conceded that gold particles occurring in the huge conglomeratic placer known as the Witwatersrand basin were introduced as detrital matter from various distant sources. They are located in the matrix surrounding the rounded quartz pebbles. (Fig 1)

The size of the particles is generally very small ranging in dimension from sub-microscopic to 500 micrometers with the bulk in the 10 - 50 micrometer range.
Exposure of gold particles to cyanide solutions

In order to liberate these fine particles and expose them to the leaching influence of cyanide solutions, the ore has to be milled very fine. This is accomplished in large cylindrical mills using steel rods, steel balls or lumps of ore as grinding medium. As part of the milling circuit hydrocyclones are used to separate the finest fractions of the milled product. This operation is normally carried out at a water:solids ratio of about 6:1. The watery product is thickened to a consistency of about 1:1 and becomes the feed to the gold leaching stage.

Recovery of gold from leach solutions

Three main processes are presently being used to recover gold from leach solutions. These are CIL (Carbon in Leach), CIP (Carbon in Pulp) and solid-liquid separation by filtration. In the CIL and CIP processes dissolved gold is adsorbed on activated carbon whilst in filtration a liquid-solid separation is effected followed by the precipitation of dissolved gold on zinc dust.

Function of the rotary drum filter

The function of the rotary drum filter is to separate, at high efficiency, the slurry received from the leaching stage into a solids residue with minimum dissolved gold in the accompanying moisture and a filtrate representing 99.7 ± per cent of the dissolved gold in the filter feed.

Design of the rotary drum filter (Fig 2)

Four or five types of rotary drum filter are presently operating on mines in the Industry. Because designs differ in certain areas no attempt will be made to describe these. Instead, the main features of a rotary drum filter will be described.

The filter consists of a hollow drum which can vary in diameter from 4.27 m to 7.32 m and in length from 4.88 m to 6.10 m. It is supported on a hollow shaft by spider arms and rests on bearings at either end. Drum ends could be either open or closed.

The shell of the drum is made of redwood staves or fabricated in steel plate. The drum surface is divided longitudinally into shallow troughs or panels by division strips which could number from 24 to 32 depending on the drum diameter. Holes in the panels, equipped with suitable fittings, are connected flexibly to drain pipes that terminate at one end of the filter, in circular mode, in a trunnion journal. Bolted to the trunnion is a wearing plate normally lined with a wear resisting material and equipped with ports to match the pipe ends in the trunnion.
Fitted in the troughs of the drum surface are drainage grids made of wood, rubber or plastic, to conduct filtrate to the collecting pipes. The grids are covered with a synthetic fibre cloth. Cross wires, pressing the cloth into the division strips, ensure air tight joints between panels. The cloth and cross wires are finally held tightly against the surface of the drum by a spirally wound wire.

A trough shaped circular cover or header valve with one or two take-off pipe connections for exhausted air and filtrate fits over the holes in the wearing plate and is supported on a journal centrally attached to the wearing plate. It is held in position by a spiral spring. To prevent rotation of the cover it is anchored to a fixed object. Blanking bridges are fitted in the cover or form part of it. These act as slide valves for the purpose of closing off ports in the wearing plate at predetermined positions of the respective panels on the drum. The drum assembly is supported on bearings placed on the sides of a trough fabricated in steel or cast in concrete. Slurry for filtration is held in the trough at a predetermined level whilst solid particles in the slurry are held in suspension by a slowly oscillating stirrer supported on the main shaft.

The drum drive is designed to permit variation of speed of rotation. Operating speeds vary in the range 8 to 22 revolutions per hour.

Suspended above the drum and running in longitudinal mode are spray pipes. Barren cyanide solution, recirculated after precipitation of the contained gold on zinc dust, is pumped into these pipes to provide the wash water necessary for displacement of residual gold bearing solution in the filter cake.

Operation of the drum filter

The operation of the filter is perhaps best understood by considering the changing conditions experienced by a filter panel as it makes one complete revolution. The diagram in Fig. 3 shows the relationship of a panel on the drum surface and its corresponding port in the trunnion wearing plate of 4.25 m diameter by 4.88 m Oliver filter. Each panel on the drum is served by one longitudinal, inclined drain pipe which terminates in the trunnion. The corresponding port in the wearing plate subtends an angle of 10 degrees 54' at the trunnion centre whilst the angle subtended by the panel is 15 degrees. The leading edge of the panel is in line with the centre of the port.

The position of the blanking bridges in the header valve are shown in Fig. 4. The smaller blanking bridge serves to isolate the ports from vacuum or negative pressure before they are subjected to positive pressure at blow-off. The lower blanking bridge isolates the ports from negative pressure at the lower edge and positive pressure at the upper. Whilst the port moves under the blanking bridge the panel is open to atmosphere and is descending into the slurry pool.
Consideration of the changing conditions to which a filter panel is subjected during one revolution

Commencing at point A (Fig. 4) the panel is covered with a thin cake of fine solids and is being subjected to positive pressure to loosen and discharge the cake over the scraper. Positive pressure continues mainly to clear the cloth and is closed off when the leading edge reaches point B. Positive pressure in the panel dissipates to atmosphere or zero pressure until point C when the panel is subjected to negative pressure. It is important that the panel be completely submerged in slurry at this stage otherwise atmospheric air would be drawn in through the exposed area of the panel. Liquid-solid separation commences at C. Gold bearing filtrate is drawn into the panel whilst the accompanying solids adhere to the filter cloth. The process continues until point D when the panel emerges completely from the slurry and becomes covered with wash solution. The wash solution is drawn into the filter cake and displaces the gold bearing solution retained in the filter cake after loading. Washing continues until position E when the port is isolated from vacuum preparatory to blow-off.

The origin of leaks of extraneous air into the vacuum system

Air leaks could originate in the following areas:-

1. The header valve

Worn or improperly aligned wearing faces would permit atmospheric air or blow-off air to enter the vacuum system. In the twin pipe take-off system on certain makes of filter, improper location of blanking bridges could allow blow-off air to enter vacuum directly. A perforated gasket between wearing plate and trunnion could allow air to cross from one port to another. (Fig 5)

2. Drum and filtrate pipes

An opening in a division strip between two panels could allow compressed air, at blow-off, to enter the panel behind and so enter vacuum. An inadequate wash cover on the cake could allow atmospheric air to filter through the dry cake. Uncontrolled pulp level in the filter pan could partly expose a panel and allow atmospheric air to enter when pulp level is low. Holes in filtrate pipes could allow not only air but slurry also to enter the filtrate system.
Influence of vacuum on dissolved gold loss

At the conclusion of an operational research programme on the now defunct Geduld Gold Mine which was aimed at studying the influence of vacuum (or absolute pressure) in the filtration system on the loss of dissolved gold to residues, the graph in Fig. 6 was obtained. It shows an exponentially increasing loss of dissolved gold with drop in vacuum. The results were confirmed by a carefully conducted plant scale test on the now also defunct Van Dyk Consolidated Mines with the results also shown in Fig. 6.

Improvements in vacuum at Geduld were obtained by modifications to the design of the filter header and using a neoprene covered steel ring, bolted to the valve cover, as wearing surfaces. (Fig. 7). Because diesolene was present in the gold bearing solutions, neoprene instead of rubber was selected.

Quantification of air leaks into the vacuum system

In collaboration with the staff of the South African Atomic Energy Corporation a system was developed for measuring air flow using radioactive Argon gas as a tracer gas. The system was based on a measure of the speed of a pulse of Argon gas injected into an air stream. This was done by having two detectors placed at measured distances down stream from the injection point. From a knowledge of air speed, absolute pressure and temperature in the pipe line and pipe dimensions, air flow was calculated and expressed in m$^3$ per hour at S T P.

To quantify air leaks into the vacuum system of a filter or group of filters the procedure was based on a determination of the volume of air, at S T P, contained in filter panels and service pipes that had to be exhausted by the vacuum pumps per hour and the total volume of air, at S T P, handled by the vacuum pumps per hour. The difference between the two quantities gave a measure of air leaks into the vacuum system. Expressed as a ratio it gave a measure of total volume handled by the vacuum pumps to minimum or ideal volume.

The volume of air at S T P that had to be exhausted from a filter or group of filters was based on a knowledge of filter panel and service pipe volume, number of panels and total filter revolutions per hour. It was found that filter panel and service pipe volume was readily obtained by placing the panel in the 12 o'clock position, plugging the corresponding holes in the wearing plate and filling the panel with water which, on discharge, could be readily measured.
Air flow measurements at West Witwatersrand Gold Mines

In order to test the technique initially, permission was granted by the management of West Witwatersrand Gold Mines to test two filters, one fitted with snap blow-off and one depending on blanking bridges to open and close the blow-off port. In planning the test it was decided to inject the pulse of radioactive Argon into the blow-off air pipe and to measure its rate of flow in the air exhaust pipe connected to the filter header. The arrangement is shown schematically in Fig. 8.

It was anticipated that, after the pulse entered a filter panel, as indicated by the first detector, there would be a delay of about 10 seconds before the pulse would be entering the air exhaust pipe. It was observed however that, after being recorded by the first detector, the pulse was immediately thereafter detected by the two detectors in the air exhaust pipe. It showed that blow-off air shortcircuited directly into vacuum between contacting surfaces in the filter header and pointed to excessive wear on these surfaces. In the absence of the anticipated indications by detectors 2 and 3, no air flow measurements could be made. (Fig 9)

It was concluded from these observations that the low vacuum prevailing in the filtrate system of the filter plant was in great measure due to excessive air that had to be exhausted by the vacuum pumps and that the resulting loss of dissolved gold pointed to urgent action to investigate and improve the sealing arrangements in the filter headers.

Because it was not expedient to examine the wearing surfaces of the two filters tested immediately after the test, examination of a filter header at a later stage explained the phenomenon. It was found that, in addition to excessive wear on the plastic lining a large groove had been cut by the compressed air between the edge of the blanking bridge and the blow-off port causing direct entry of blow-off air into vacuum. (Fig. 10)

It could be mentioned here that the success of the concept was shown on other mines in the Industry where measurements of total air exhausted from the filter plant were carried out. On one plant a ratio of 3.4:1 was measured. In this case it was also found that excessive extraneous air entering the vacuum system was the cause of the low filter vacuum and loss of dissolved gold. Fig. 11 shows the recorded results of air flow measurements on this plant.

Search for improved wear resisting materials for filter headers

A careful search was carried out in an attempt to find acceptable wearing materials for the sliding surfaces of filter headers. In the end the choice was narrowed to two composite materials namely:-
1. Tungsten carbide, in view of its hardness, low coefficient of friction and favourable heat dissipation qualities.

2. Ultra high molecular weight polyethylene (UHMWPE) reinforced with micro glass spheres.

Because of cost considerations the latter compound was selected as a start to the project.

Alignment of wearing surfaces

In fairness to the material to be tested it was appreciated that, unless the wearing faces were properly aligned, the results would be invalidated if, due to misalignment, unknown forces would be transmitted to the lining material. Because the valve cover was supported on a sleeve bearing with unknown wear qualities, it was decided to replace the sleeve bearing with a spherical roller bearing. (Fig 12)

Test results

The newly designed and equipped header was installed on a filter at West Wits Gold Mine on 15 December, 1988 and examined on 29 May, 1989. Very little wear was observed on the UHMWPE linings after 5 months of practically continuous operation. A slight re-planing of the surface would in fact restore them to the "as new" condition. (Fig. 3)

Because the modified header was fitted to one filter in a bank of six filters, all connected to the same vacuum system, it was not possible to measure the improvement obtained from better sealing between vacuum and pressure ports by indications on the vacuum gauge fitted to the header. An Argon test after installation of the new design would have shown the extent to which proper sealing had been achieved. Considerations to place the project on a more scientific basis are presently receiving attention.

Properties of "Ceram P" Port and Face Plate Material

The material used on the header valve port and face plate experiment at the West Witwatersrand Gold Mines is known by the trade name of Solidur "Ceram P" and is essentially a thermoplastic material in the polyethylene family of plastics.

Polyethylenes are thermoplastic members of the polyolefin family and include Low Density Polyethylene (LDPE) High Density Polyethylene (HDPE) High Molecular Weight Polyethylene (HMWPE) and Ultra High Molecular Weight Polyethylene (UHMWPE) (Fig. 14).
All polyethylene materials exhibit good to very good chemical resistance, are light in mass (an average sg of +/- 0.94) and have similar service temperatures. However, as molecular weight increases there are some remarkable changes and improvements in mechanical properties which, from an engineering design and application point of view, can be exploited.

Ultra High Molecular Weight Polyethylene UHMWPE has an average molecular weight lying between 3.5 and 6 million. It exhibits very high wear resistance, has almost the lowest known dynamic co-efficient of friction (of all engineering plastics PTFE is the lowest), absorbs virtually no water and exhibits non stick and self lubricating properties. These characteristics of UHMWPE for example contrast sharply with the more common and better known HDPE which is an extrudable and weldable grade of polyethylene but has a molecular weight less than one tenth that of UHMWPE (viz 400 000 compared with 4 000 000).

UHMWPE because of its very high intrinsic viscosity cannot be extruded or injection moulded by conventional extruders and the conversion process from resin to finished sheets involves a complex compression fusion process at elevated temperatures and pressures using special processing equipment.

Ceram P is a patented grade of UHMWPE (German Patent No. 2756359) and was originally developed as a low coefficient of friction and high abrasion resistant material for dewatering elements in the pulp and paper industries. It fills the gap between polyethylene and sinter ceramics.

This particular grade of UHMWPE material has a molecular weight of between 4.5 million and 6.0 million and is compounded using 5% (by mass) micro glass balls, strengthening fillers and gliding additives. Fig 15 gives the physical and electrical properties of this Ceram P grade of UHMWPE.

The relationship between intrinsic viscosity and molecular weight for various different grades of polyethylenes is depicted in Fig. 16. UHMWPE’s display intrinsic viscosities of 20 or greater.

One of this materials’s major characteristics is its very high abrasion resistance. In sand slurry abrasion tests it has shown an abrasion resistance 84% greater than Grade 304 stainless steel, 70% greater than Grade 316 stainless steel and 83% greater than Grade 3CR12 stainless steel. In this sand slurry abrasion test a specimen of the material to be evaluated is rotated simultaneously with a UHMWPE control specimen in a sand slurry to produce accelerated wear. The resulting wear, or abrasion is measured as weight loss. This measurement is converted to a volumetric loss of material by calculation from the material density.

A further major characteristic which makes this UHMWPE material so eminently suitable for this header valve application is its very low dynamic co-efficient of friction coupled with its inherent self lubricating properties.
The table shown below compares the dynamic co-efficient of friction of UHMWPE on polished steel against five other engineering plastics. It will be noted that only poly-tetra-fluro-ethylene (PTFE) has a lower dynamic co-efficient of friction than UHMWPE.

## COMPARISON OF DYNAMIC COEFFICIENT OF FRICTION ON POLISHED STEEL

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>UHMW</th>
<th>NYLON 6</th>
<th>NYLON 6,6</th>
<th>NYLON</th>
<th>PTFE</th>
<th>ACETAL</th>
<th>MOSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRY</td>
<td>0.11-0.22</td>
<td>0.15-0.40</td>
<td>0.15-0.40</td>
<td>0.12-0.20</td>
<td>0.04-0.25</td>
<td>0.15-0.35</td>
<td></td>
</tr>
<tr>
<td>WATER</td>
<td>0.05-0.10</td>
<td>0.14-0.19</td>
<td>0.14-0.19</td>
<td>0.10-0.12</td>
<td>0.04-0.08</td>
<td>0.10-0.20</td>
<td></td>
</tr>
<tr>
<td>OIL</td>
<td>0.05-0.08</td>
<td>0.02-0.11</td>
<td>0.02-0.11</td>
<td>0.08-0.10</td>
<td>0.04-0.05</td>
<td>0.05-0.10</td>
<td></td>
</tr>
</tbody>
</table>

Plastic header valves fitted with UHMWPE wear/sealing faces have been successfully used in the South African mining industry for the past 8 years but only now are their cost effective benefits being quantified and appreciated.

**Conclusion**

Radioactive Argon, used as a tracer gas in monitoring the performance of rotary filters, has uncovered weaknesses in filter header valve design, adjustments and repairs and in the quality of wear resisting materials used as a lining on sliding surfaces. Vacuum pump inefficiency was also established as a direct result of the use of the gas.

The effect of these weaknesses has been to allow entry of extraneous air, either from the atmosphere or from blow-off, into the vacuum system thereby placing additional burden on the vacuum pumps. This condition has resulted in a lowering of plant vacuum levels and a corresponding increase in dissolved gold loss.

Improvements in filter header repairs and adjustments have resulted, at one mine, in a substantial rise in vacuum and a measurable increase in gold recovery. On another mine, modifications to header bearing design and the use of a carefully chosen composite material, have shown the benefits of this approach in the effective sealing of sliding surfaces. On a third mine vacuum pump inefficiency and its effect on vacuum level was demonstrated.
On the assumption that operating conditions on the first three plants monitored represent average conditions as they exist on filter plants in the South African Gold Mining Industry it is visualized that, by a co-ordinated effort between mines and industry concerned, together with the South African Atomic Energy Corporation as a monitoring authority, means for the development of composite materials of outstanding quality could be achieved which, if properly applied, should make a substantial contribution to recovery of the major portion of dissolved gold that still now reaches the slime dams.
Figure 1  Quartz pebbles with surrounding gold bearing matrix
Figure 2 Section of a rotary drum filter
(By courtesy SAIMM)
Figure 3

Filter panel in relation to its corresponding port in the wearing plate.
Figure 4  Position of blanking bridges in a 4.27m dia by 4.88m Oliver filter and positions of leading edge of a panel at various points of change
Figure 5  Wearing plate and cover of a double pipe take-off system
Figure 6

Filter retention index vs absolute pressure

Filter retention index vs absolute pressure

- GEDULT MINES ANNUAL DATA
- VAN DYK MINES '60 TEST

1958
1959
1960
1961

ABSOLUTE PRESSURE (kPa)

0 5 10 15 20 25 30

4 3.5 3 2.5 2 1.5 1 0.5 0

Filter retention index
Figure 7  Neoprene covered metal ring used as a wearing plate
Figure 8  Injection point of radioactive Argon and position of two detectors
Figure 9  Detector responses
Figure 10
Section of valve cover showing damage done by air blast

Metal base and plastic lining worn way by air blast
Blow-off port
Niche cut into outer rim by air blast
Figure 11  Detector responses during air flow measurements
Figure 13  Ceram P lining after 5 months continuous operation
### Solidur Ceram P Ultrahigh Molecular Weight Polymer

#### Physical Properties (a)

<table>
<thead>
<tr>
<th>Property</th>
<th>Solidur Ceram P Polymer</th>
<th>Test Method (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/cm³</td>
<td>0.98</td>
<td>ASTM D 702</td>
</tr>
<tr>
<td>Izod impact strength at 23°C, ft-lbs/in. (J/m)</td>
<td>25-28</td>
<td>ASTM D 256A</td>
</tr>
<tr>
<td>Hardness, Durometer (D/15)</td>
<td>70</td>
<td>ASTM D 2240</td>
</tr>
<tr>
<td>Double-notched</td>
<td>65</td>
<td>Internal %</td>
</tr>
<tr>
<td>Abrasion Test</td>
<td>3190</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Tensile properties @ yield</td>
<td>6400</td>
<td>2 in/min</td>
</tr>
<tr>
<td>Tensile properties @ break</td>
<td>260</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Elongation @ break</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 15a

#### Coefficient of friction against Cr-plated steel at 23°C

<table>
<thead>
<tr>
<th>FR</th>
<th>Solidur Ceram P Polymer</th>
<th>Test Method (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.08-.10</td>
<td></td>
<td>ASTM D 1894</td>
</tr>
</tbody>
</table>

Figure 15b

#### Electrical Properties (a)

<table>
<thead>
<tr>
<th>Property</th>
<th>Solidur Ceram P Polymer</th>
<th>Test Method (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Resistivity  cm</td>
<td>&gt;10⁻¹⁵</td>
<td>ASTM D 257</td>
</tr>
<tr>
<td>Surface Resistivity cm</td>
<td>&gt;10⁻¹⁹</td>
<td>ASTM D 257</td>
</tr>
<tr>
<td>Dielectric Strength KV/cm</td>
<td>900</td>
<td>ASTM D 149</td>
</tr>
<tr>
<td>Conductivity</td>
<td>non con</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15c

---

**Solidur P Virgin UHMW-PE, I.V. 28-30, 5-6 million molecular weight, inorganic fillers improve wear resistance, manufactured in accordance with U.S. Patent, not FDA/USDA accepted. The best wear resistant UHMW filled product available. Used in many high wear areas.**
Solidur UHMW Polymer

Relationship of Intrinsic Viscosity to Molecular Weight

6,000,000
Ultrahigh Molecular Weight Polymer
UHMW Range

3,500,000
Very High Molecular Weight Range

2,000,000
HDPE

500,000
High Molecular Weight Range
HDPE

100,000
Standard Molecular Weight Range
HDPE

5
High Molecular Weight
HDPE
IV Range

14
Very High Molecular Weight
HDPE
IV Range

20
Ultrahigh Molecular Weight Polymer
IV Range

Intrinsic Viscosity (IV)

Weight-Average Molecular Weight (MW)