Metalliferous Mining - Processing

Elution & Carbon Reactivation

Resource Book

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Introduction to Elution and Carbon Reactivation

What is this module about?

This unit is about how we manage and use Elution and Carbon Reactivation within the processing plant

What will you learn in this module?

- Demonstrate an understanding of elution theory fundamentals.

- Demonstrate an understanding of the purpose and action of each stage of the AARL process as applied at SDGM.

- Identify the key elution circuit components.

- Demonstrate an understanding of carbon reactivation theory.

- Demonstrate an understanding of the factors affecting thermal reactivation efficiency.

- Identify and describe the purpose of the HVS screen, VFB screen, Reactivation kiln and carbon eduction vessel.

What do you have to do to complete this unit?

You will need to complete all the training tasks in your workbook, the review exercise and the assessment given to you by your supervisor.

Discuss the competency standards for this unit with the Training Coordinator or your supervisor.

What resources can you use to help?

If you need more information about topics in this unit, then you should approach:

- Your work mates and supervisor

- The training coordinator

- Metallurgists

Introduction

During the CIL process, gold is leached from the ore using an alkaline cyanide solution. The resulting gold cyanide complex ions are then concentrated and separated from the slurry by adsorbing onto activated carbon. Elution is the next step in the process, whereby the adsorption of the gold cyanide complex onto carbon is reversed.

Loaded carbon is removed from the CIL circuit and the gold stripped from the carbon using a number of treatment steps. The result is a solution of high gold concentration (pregnant eluate). The gold can then be removed from the solution by electrowinning onto steel wool cathodes (refer 'Electrowinning and Smelting' module).

As well as stripping the gold from the carbon, the elution process incorporates an acid wash stage, which removes inorganic foulants from the carbon. Foulants reduce the activity, and hence gold adsorbing efficiency and capacity, of carbon. Carbon is only partly reactivated by the removal of inorganic foulants (precipitated salts, mineral matter etc) in the acid washing cycle. Organic foulants such as oil, are unaffected by acid and must be removed by thermal reactivation.

Thermal reactivation (regeneration) simply involves heating the carbon in the presence of steam to 750°C in a gas fired reactivation kiln. The combination of high temperatures and the steam environment vaporises the organic foulants, returning activity to the carbon.

The reactivated carbon is returned to the circuit and the adsorption, elution (desorption) and reactivation cycle starts anew.
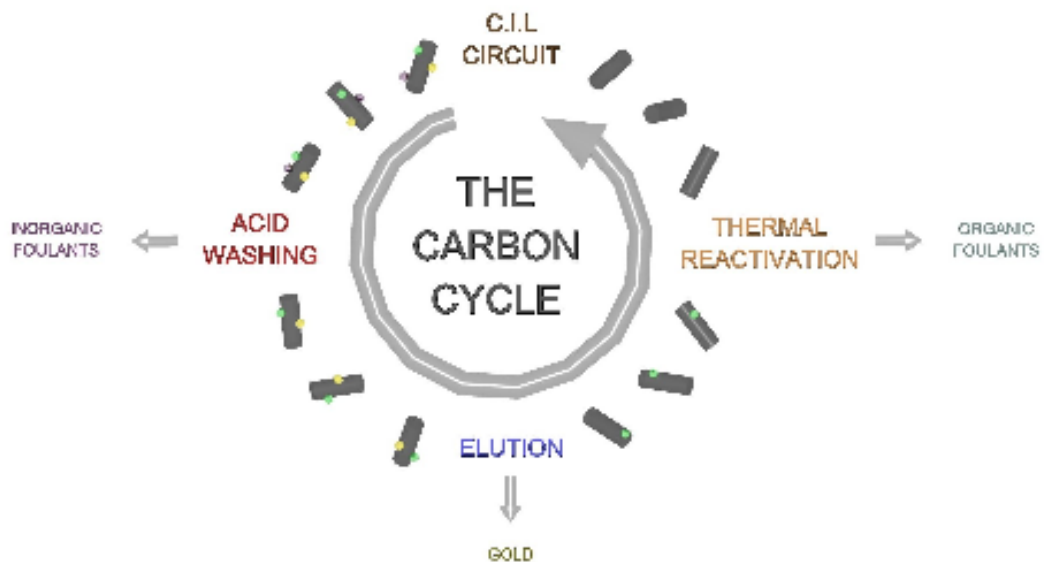
Elution Theory Fundamentals

Elution involves removing the gold from the activated carbon by reversing the adsorption process that occurs in the CIL circuit (refer 'Leach and Adsorption' module). Using high temperatures and pressures and treating the carbon with a concentrated cyanide/caustic solution followed by elution with potable water, the gold cyanide complex can be induced to desorb from the carbon and return to solution. The desorption process is also referred to as 'stripping'.

In the CIL circuit, adsorption of gold onto activated carbon is most effective at low temperatures, low cyanide concentrations, low pH and high gold concentration in solution (although some of these conditions aren't practically achievable). By simply reversing these conditions, elution (desorption) of gold from the carbon occurs.

The main factor that makes desorption or stripping a simple process is the fact that gold will only adsorb onto carbon at low temperatures. If the temperature of a solution and carbon mixture is increased, the gold will readily desorb from the carbon into the solution. Temperature is therefore the most important variable in the elution process and temperatures of 100-120°C are necessary to achieve optimum elution performance.

Other requirements of the elution process are:

- High cyanide concentration

- High caustic concentration

- Low ionic strength of solution (i.e. low level of salts in the water)

- Optimum flowrate of solution through the carbon

- Low gold concentration in the solution

However, these conditions are not all simultaneously achievable and hence the entire elution process occurs as a number of steps.

Split 'Anglo American Research Laboratories' (AARL) Elution Process Stages

Column Loading

Carbon is removed from the circuit from tanks 2 and 102. The slurry is pumped to the loaded carbon screen where the carbon is screened from the slurry, which is returned to the tanks. Spray bars fitted to the screen wash residual slurry from the carbon. The carbon discharges off the end of the screen into the elution column. This is done in a batch process with six tonnes of carbon being treated each strip.

When the elution column is full of carbon, potable water is flushed through the column to remove any remaining entrained slurry.

Acid Washing

Carbon fouling is the buildup of organic and inorganic substances on carbon, which detrimentally affects carbon adsorption by reducing carbon activity. The foulants precipitate or adsorb onto the carbon, taking up active sites which would otherwise be available for gold adsorption and also may block the carbon pores, restricting the flow of solution through the carbon in both the adsorption and desorption processes. The foulants may also adversely affect the eluate composition if they are desorbed in the stripping stage. Acid washing removes inorganic foulants from the carbon.

Acid washing is also critical in the AARL process to ensure elution efficiency. The acid modifies the way in which the gold cyanide ions are adsorbed onto the carbon, in preparation for the following pretreatment stage. Combined, the acid wash and pretreatment steps convert the gold cyanide ions from being strongly adsorbed to the carbon to being weakly adsorbed and hence easily desorbed in the elution stage.

- **Acid Wash Cycle**

A dilute hydrochloric acid solution (3%) is circulated/pumped into the elution column. The acid dissolves inorganic foulants such as calcium carbonate, magnesium and sodium salts, fine ore minerals such as silica, and fine iron particles. Organic foulants such as oils and fats are unaffected by the acid and are removed by thermal reactivation after the elution cycle. The acid wash cycle takes about 20 minutes. A peristaltic pump (PPD 41), feeds concentrated HCl into a water line from the elution water tank. A positive displacement pump (PPC 28) is used to pump water from the elution water tank to the column for both the acid wash and acid rinse cycles.

Hydrochloric Acid Pump

- **Acid Soak Cycle**

The acid soak cycle follows the acid wash cycle and is simply a 40-minute time period where the acid solution sits in the column, allowing time to dissolve the inorganic foulants.

- **Acid Rinse Cycle**

The acid rinse stage involves flushing four bed volumes of water through the column. The water flushes away the mineral impurities that have been freed by the acid wash. The wash also rinses the carbon of acid and raises (neutralises) the pH in the column. If this were not done, the remaining acid would react with the eluate, releasing large quantities of HCN gas.

Cyanide Pretreatment

The next stage involves treating the carbon with a caustic-cyanide solution at high temperature (115°C) and pressure (230 kPa).

The sodium cyanide is required for solubilising the adsorbed gold cyanide complex and the caustic (sodium hydroxide) is added to maintain a high pH to minimise the evolution of HCN gas. Upon the completion of this stage the gold cyanide complex is still adsorbed to the carbon (ie, no gold is removed into solution during this stage) but the attraction between the complex and the carbon is 'weakened', allowing it to be easily desorbed in the following elution stages.

High temperatures are used and hence high pressure is maintained to prevent the solution from boiling (water boils at 100°C at atmospheric pressure, and the solution is mainly water). After it has been through the column, the pretreatment solution reports to either electrolyte tank 38 or 8.

Elution

Elution is the actual gold removal stage. Potable water (low ionic strength) is pumped through the column at high temperature (115°C) and pressure (230 kPa). High temperatures are used as the gold loading capacity of carbon is reduced with increasing temperature.

Low ionic strength water (no dissolved salts) is used to enable the gold to be stripped from the carbon. The loading capacity of activated carbon for gold increases in the presence of ions such as Ca^{2+} (calcium) and Mg^{2+} (magnesium). Hence, desorption of gold from carbon is favoured by conditions of low ionic strength solutions ie; the absence of ions such as Ca^{2+} and Mg^{2+}.

The low gold concentration in the solution also aids the desorption of gold.

Elution Tanks

- **Recycle Elution Stage**

During the recycle stage, a batch of solution (called the recycled eluate or 'split') containing a small amount of gold from the previous elution cycle is flushed through the carbon bed. This solution has a relatively low ionic strength, however, does not have a low gold concentration as it contains gold from the previous strip in the form of gold cyanide complex ions. This is not a problem though, as most of the gold on the carbon will still desorb into this solution, leaving perhaps only 30% of the gold on the carbon. The solution from this stage also reports to the electrolyte tank (tank 8 or 38).

- **Water Elution Stage**

The water elution stage is essentially a repeat of the recycle stage except that fresh potable water is used, and the solution leaving the column reports to the recycle eluate tank, becoming the 'recycle eluate' for the next strip. The potable water has an extremely low ionic strength and has no gold in solution and is therefore able to extract most of the remaining gold, bringing the total gold recovery (for both steps) up to 97%.

A split system is used to achieve the highest possible gold grade in the final solution and also to minimise both electrowinning solution volume and potable water consumption.

Elution Circuit Components

Elution Column

The elution column is a 10m high by 1.2m diameter mild steel rubber lined pressure vessel (rated to 350kPa). Having a high 'length to diameter' ratio enables solution to flow evenly through the bed of carbon without short-circuiting or 'tunnelling'.

The column has a volume of 11.3m^3 (1 'bed' volume) which can hold approximately 6 tonnes of carbon. External lagging (insulation) lines the exterior of the column to prevent heat loss during elution. Various valves are installed at the top and bottom of the column for; filling/eduction, liquid circulation and pressure relief.
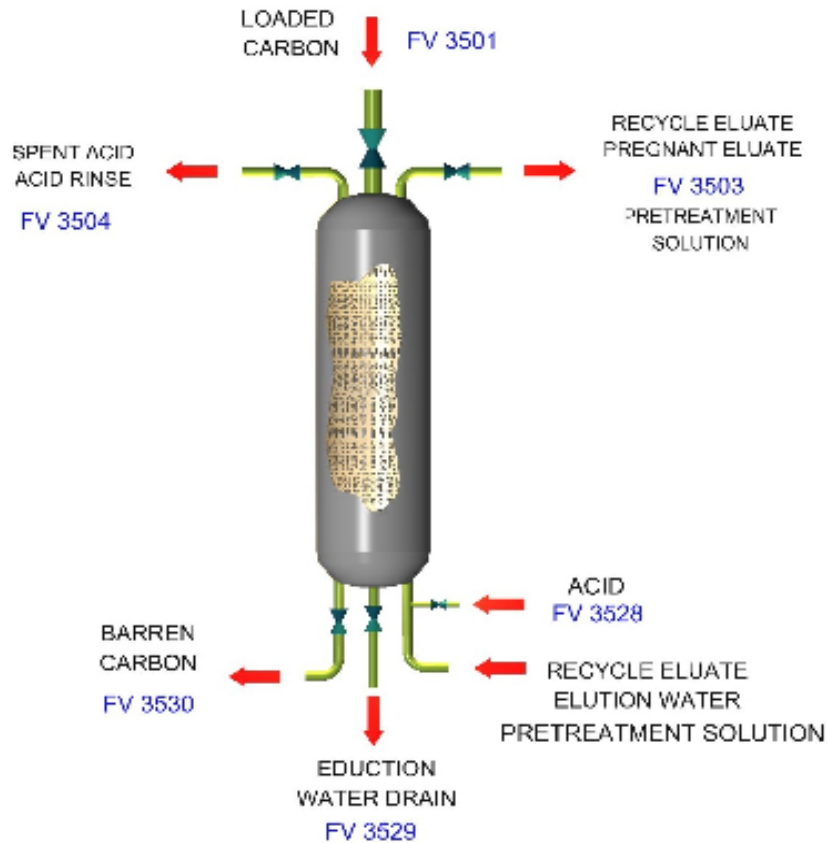
Primary and Reclaim Heat Exchangers

A heat exchanger is a device used to transfer heat from one fluid medium to another via thin metal plates. The fluids never contact each other, they are separated by rubber gaskets. The plates are sandwiched together in a fixed frame between a movable pressure plate and tightened using lateral bolts.Oil is the medium used to transfer heat to the pretreat solution, recycle eluate and elution water via the primary heat exchanger plates. The oil is heated in a reservoir by an LPG fired burner and is circulated to the heat exchangers by a centrifugal pump (PPC 32). An expansion tank above the heater allows for the changes in the oil level in the main tank, due to the expansion or contraction of oil in the system.The reclaim heat exchanger plates allows heat remaining in solutions exiting the elution column to be transferred to the incoming fresh 'cold' solution, prior to the cold solution passing through the primary heat exchanger. Having a reclaim heat exchanger hence reduces the heat input required from the oil in the primary heat exchanger, which in turn reduces LPG costs. Removing the heat from the solution exiting the column prevents it from boiling once it is discharged at atmospheric pressure.

Basket filters (strainers) are installed on the column exit line to prevent foreign particulate material from entering and blocking the heat exchangers.
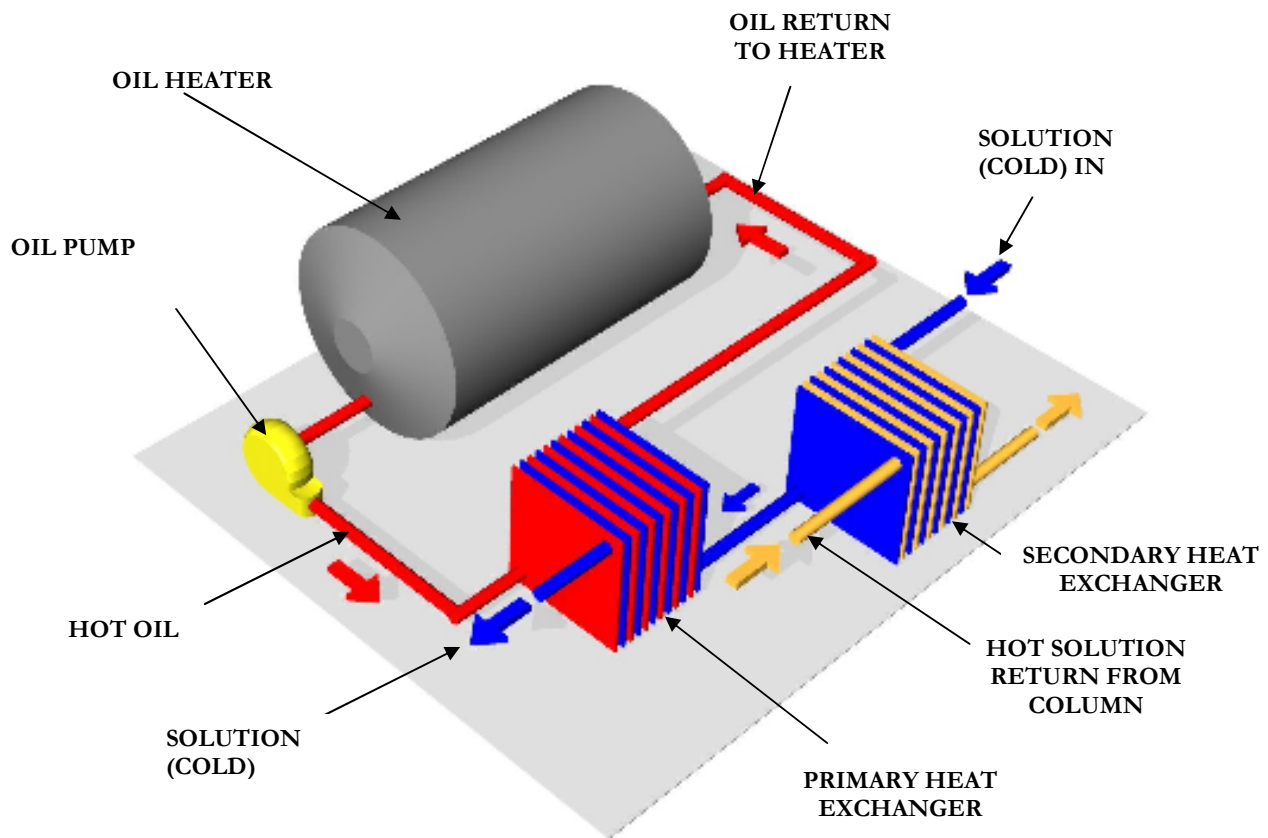
Carbon Reactivation Theory

Carbon Fouling

Carbon fouling is the build-up of organic and inorganic substances on carbon, which detrimentally affects gold adsorption. Fouling results in a decrease in the rate of and loading capacity of gold adsorption onto carbon, and may also adversely affect the efficiency of desorption (elution) processes.

Fouling occurs when:

- Undesirable organic or inorganic species are adsorbed onto the carbon surface, taking up active sites, which would otherwise be available for gold adsorption.

- Inorganic salts are precipitated onto the carbon surface, blocking active sites.

- Solid particles such as fine silica, or precipitates are physically trapped in carbon pores, restricting access to gold-bearing solution.
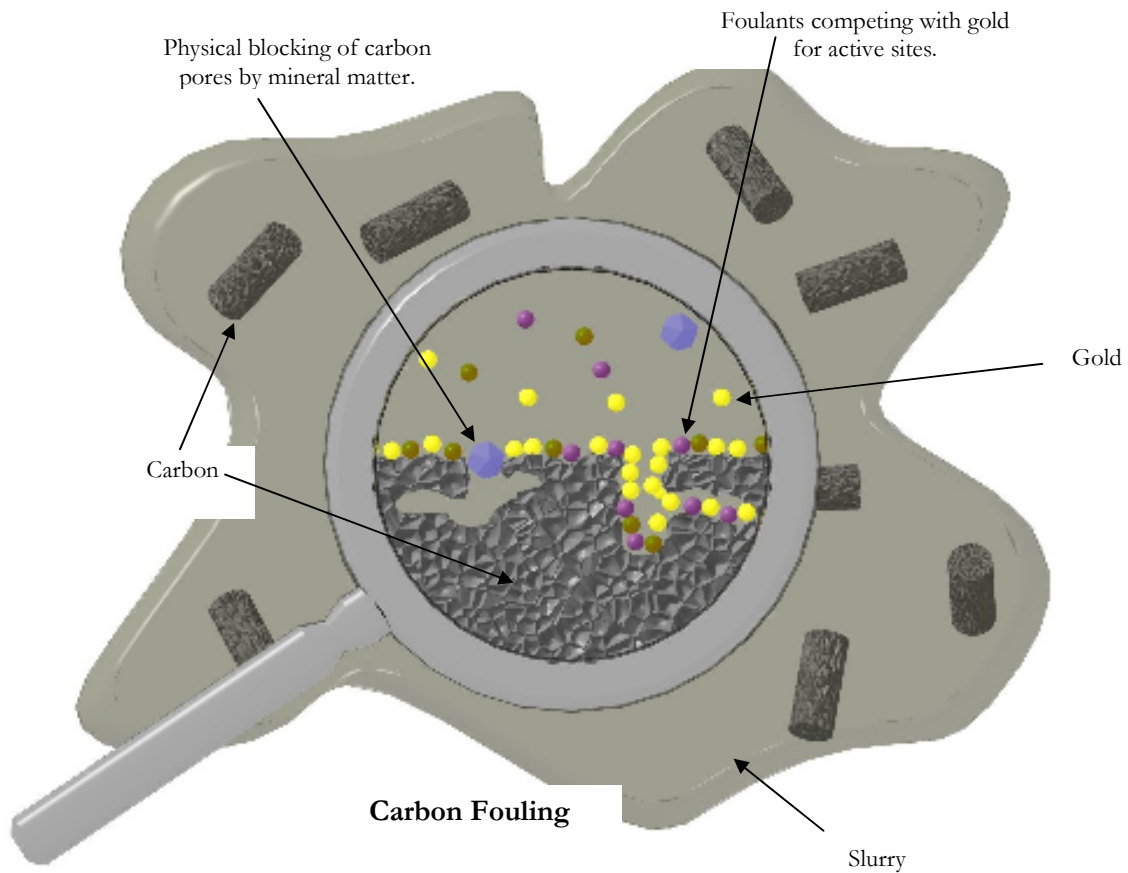
Inorganic foulants are those elements and compounds/molecules other than those composed of carbon. However, inorganic substances include carbon oxides, metal carbonates and hydrogencarbonates, but excludes all organic carbon compounds such as alcohols, esters, hydrocarbons, oils, fats etc.

Examples of inorganic foulants include magnesium hydroxide ($Mg(OH)_2$), calcium carbonate ($CaCO_3$), iron cyanide ($Fe(CN)_6$) and silica (SiO_2).

Conversely, organic foulants are those compounds based on carbon, not including carbon oxides, metal carbonates etc.

Examples of organic foulants include diesel fuel, lubrication oils, grease and fine vegetation/plant matter.

It is not possible to prevent fouling altogether, as salts and organic matter are invariably present in the ore and water supplies. It is, however, possible to minimise the degree of fouling by ensuring no foulants are added to the process unnecessarily (eg oils, grease etc).

Physical blocking of carbon pores by mineral matter.

Foulants competing with gold for active sites.

Gold

Carbon

Carbon Fouling

Slurry

Inorganic Foulant Removal

Most of the inorganic foulants are removed in the acid washing stage of the elution cycle, whereby the precipitated/adsorbed salts are dissolved in hydrochloric acid (HCl) and then rinsed from the carbon. The HCl will readily dissolve most (70-90%) of the inorganic species, but the adsorbed gold complex is unaffected. Silver and copper cyanide complexes are also not removed by HCl.

The acid washing procedure is described earlier in this module.

Organic Foulant Removal

Thermal reactivation is used to remove organic foulants, by subjecting the carbon to temperatures in the order of 650-750°C in a steam environment.

The high temperature burns off some of the organic matter whilst reaction with the steam removes the rest. Steam also serves to keep the reactivation system oxygen free (to prevent the carbon burning) and is involved in the chemical formation of active sites within the carbon.

Thermal Reactivation

Organic Foulant Types

Organic foulants are loosely categorised into three main types:

- **Type I -** Volatile (easily vaporised) organic compounds, which are weakly adsorbed to active adsorption sites.

- **Type II -** Organic compounds not sufficiently volatile for thermal desorption, which require higher temperatures for thermal decomposition (cracking) and/or those compounds which are tenaciously bound to surface sites.

- **Type III -** Carbon residues remaining in the pores from the cracking of type II compounds. These carbonaceous residues are similar (but not entirely the same) to the base activated carbon. These residues are selectively removed from the activated carbon using high temperatures in a steam environment.

In reality, many organic foulants will display combinations of types I,II and III behaviour.

↑ **Organic foulants used in the plant.
Oils, grease, laboratory reagents.**

Thermal Reactivation Stages

The following steps usually occur during thermal reactivation inside the kiln:

- **Drying - < 200°C**

  Carbon enters the kiln tube at approximately 60°C and 25% moisture.

  As initial heating occurs, highly volatile foulants are vaporised. As the carbon temperature passes through 100°C any moisture remaining inside the carbon pores will boil and be released as gas.

- **Vaporisation - 200-500°C**

  As the temperature rises to 200-500°C in about the first metre of the tubes, volatile 'Type I' foulants are vaporised.

- **Pyrolysis - 500-700°C**

  During this stage the cracking or pyrolysis (the decomposition of a substance by the action of heat) of non-volatile (type II) foulants occurs and 'Type III' foulants are deposited.

- **Removal of Pyrolised Residues - ≈ 750°C**

  The last metre of the kiln is operated at 750°C. Water is injected at the base of the kiln and the steam generated selectively oxidises and vaporises the pyrolised (Type III) residues.

  The steam creates an inert (oxygen deficient) atmosphere which prevents the activated carbon from burning. The steam is also thought to be responsible for generating fresh active sites on the carbon.

- **Carbon Cooling and Discharge**

  The water injection at the base of the kiln also serves to cool the carbon to approximately 250°C before exiting the kiln. If the hot (750°C) carbon were to enter the atmosphere the oxygen in the air would react with the carbon causing burning and damage of the carbon surface. The carbon discharges into the high-pressure eduction vessel (sputnik) via a discharge vibrating feeder, and is quenched in water to prevent prolonged exposure to oxygen and loss of activity.

Factors Affecting Thermal Reactivation Efficiency

Temperature

Temperature is one of the most important parameters in the reactivation of carbon for the adsorption of gold. Too low a temperature will not give adequate foulant vaporisation and hence effective reactivation will not occur. On the other hand, if the temperature is too high the carbon may degrade or become weakened.

Residence Time

If the residence time is too low then removal of the organic foulants will be insufficient.

Residence time is an important consideration in the instance that a kiln tube becomes blocked. The rate of kiln throughput is determined by the output vibrating discharge screen, which is set at a fixed speed. If a tube becomes blocked then the carbon will simply travel faster through the remaining tubes to compensate and hence carbon residence time is reduced. Therefore it is important to monitor the tubes to ensure adequate residence times.

A blocked tube, viewed through the furnace observation port, will appear 'red' whilst the others 'black'. A blocked tube should be cleaned prior to the commencement of the next regeneration cycle to prevent damage to the tube and to maintain the appropriate residence time.

Water Addition

Control of water addition is a critical factor in reactivation.

High flowrate – Heat will be consumed in vaporising excess water rather than vaporising foulants.

Low flowrate – Insufficient steam and hence pyrolysed residues remain on carbon.

No water – Leads to an oxygen rich atmosphere, which will damage/consume carbon.

The water injection rate will usually be set by the plant metallurgists.

It is also important that the initial moisture content of the carbon is minimised. This ensures maximum energy input for foulant vaporisation, rather than the heat being consumed in water vaporisation.

Feed Carbon Contaminants

Carbon feed to the kiln must be free from grit, plastic and trash materials for optimum operation. Continued periods of physically dirty feed will cause blockages and malfunctions.

Reactivation Circuit Components and Process Flow

H.V.S Screen - Carbon Dewatering

Carbon is educted from the column and fed to the HVS (Horizontal Vibrating Screen) dewatering screen. Carbon is screened from the eduction water and discharges into the VFB (Vibrating Fluidisised Bed) screen feed hopper. A potable water spray bar on the screen washes residual salts, fine grit and carbon through the screen.

V.F.B Screen - Carbon Predrying/Kiln Feeding

Carbon remains in the VFB screen feed hopper for a 45 minute period to allow water to drain from the carbon. Upon starting the kiln, the carbon moves over the VFB screen and discharges into the kiln top hopper. Hot exhaust gases from the kiln are circulated up through the screen underdeck, drying the carbon to approximately 25% moisture and heating it to 50°C.

The carbon should appear as dry, free flowing individual particles and grey in colour. Wet carbon entering the kiln may result in blocked kiln tubes. Should the carbon discharging from the screen appear black or 'sticky', it is too moist. In this instance the feed rate may be too high, the screen may be pegged or the exhaust gas fan may have malfunctioned.

There are two level probes situated in the VFB discharge/Kiln feed funnel.


V.F.B Screen

When the high-level probe is clear of the carbon the VFB screen exciters are actuated, and once the probe is embedded in carbon the exciters stop, halting the flow of carbon off the screen. This way a constant stream of carbon is fed to the kiln. When the low-level probe is exposed, the kiln discharge vibrating feeder will stop.

Reactivation Kiln

The kiln is a 'Combustion Air' vertical gas fired kiln, comprised of a 1.5m diameter cylinder insulated with a 75mm think high temperature lining.

A cluster of 16, 50mm diameter tubes carry carbon through the kiln (by gravity). Water injection ports at the base of the kiln provide a steam atmosphere, and also serve to quench the carbon prior to discharge.

A vibrating feeder discharges carbon from the kiln to the transfer/eduction vessel. The output of the discharge vibrating feeder is fixed, changing the angle of the feeder alters the rate of carbon throughput though the kiln. The kiln has it's own feed and temperature control system (PLC).

CARBON
FEED

EXHAUST GAS
TO VFB SCREEN

KILN
TUBES

LPG BURNER

WATER
INJECTION
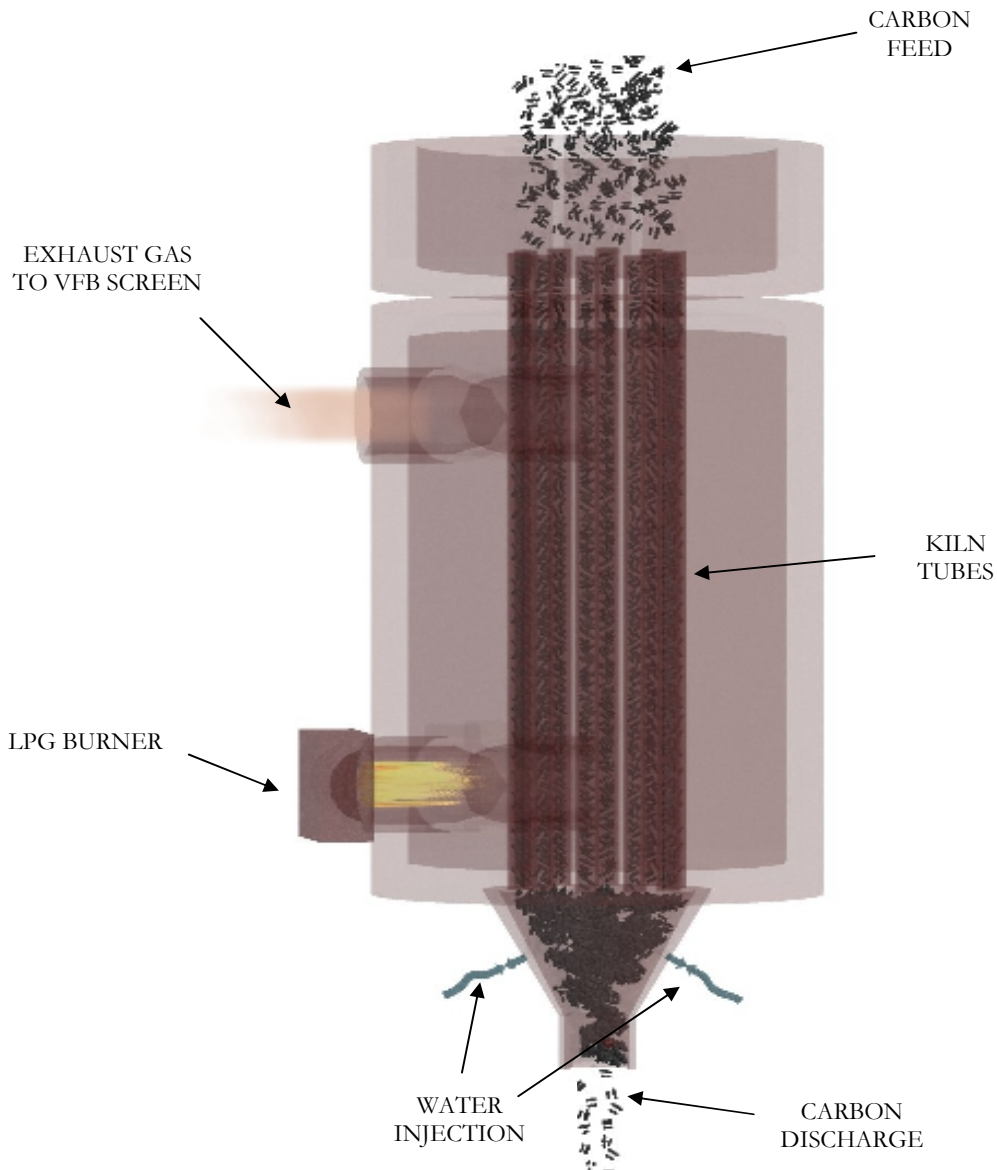
CARBON
DISCHARGE

Carbon Eduction Vessel

A high pressure vessel is used to transfer (educt) the carbon back into the CIL circuit.

Once the reactivation process is complete and the transfer vessel/quench tank full of carbon, the carbon is educted to either tank 7 or 107.

All feed and discharge valves are closed to the vessel and water is pumped in to pressurise the vessel to 250kPa and fluidise the carbon bed. The bottom exit valve is then opened and the fluidised carbon and water flows out under the force of the vessel pressure.