ACTIVATED CARBON IN GOLD RECOVERY

TITLE

- What is Activated Carbon?
- Manufacture of Activated Carbon.
- Characteristics of Carbon.
- Adsorption.
- Mechanism of Gold Adsorption.
- Factors influencing Gold Adsorption onto Activated Carbon.
- Desorption (Elution).
- Carbon-In-Pulp / Carbon-In-Leach.
- Circuit and activity profiles.
- Sampling, Sample Preparation and Sample Contamination.
- Carbon-In-Leach (CIL), Carbon-In-Pulp (CIP), Carousel CIP and Process Selection.

Activated Carbon

What is Activated Carbon?

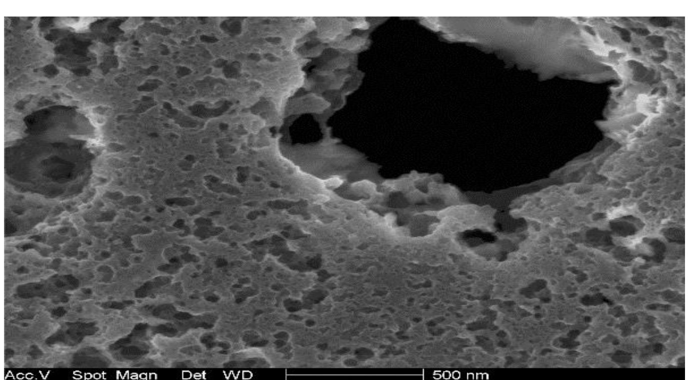
Generic term for a family of highly porous carbonaceous materials, none of which can be characterised by a structural formula or by a chemical analysis.

- Internal Surface 1000 m^2/g
- Pore volume 0,8 ml/g

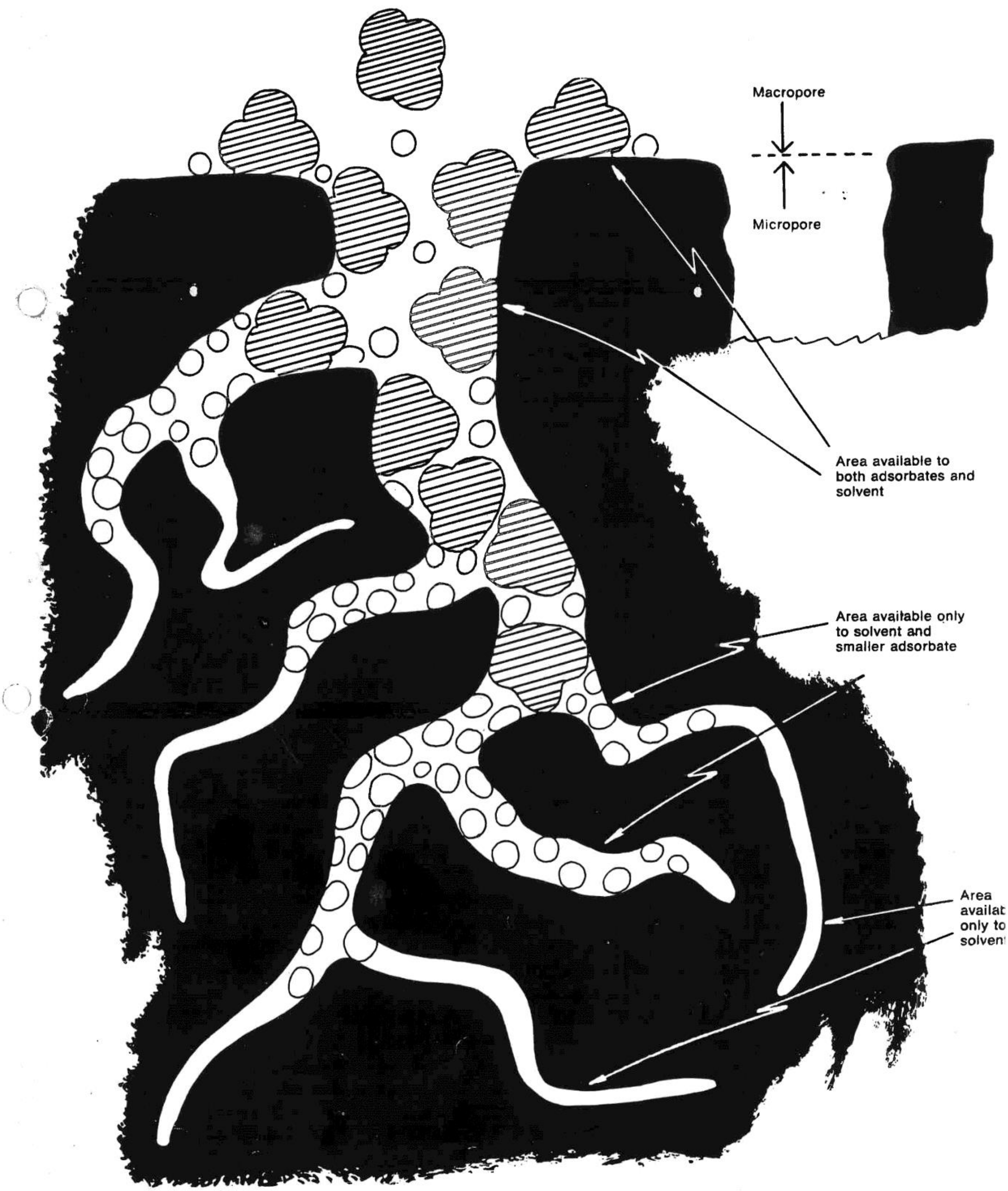
Classification Of Pore Size In Terms of Diameter

- Macropores 500 – 20000 Å
- Transitional (Mesopores) 100 – 500 Å
- Micropores 8 – 100 Å

- Transitional Pores 5% Of Surface Area
- Micropores 95% Of Surface Area



CONCEPT OF MOLECULAR SCREENING IN MICROPORES



How Does Activated Carbon Work?

- Carbon Surface is
  - Neutral
  - Inert
  - High Water Interface

- Attracts Neutral Molecules

Activated carbon is used in many industries:

- Removal of organic species from industrial effluents.
- Purification of potable water.
- Removal of contaminants in gas, in gas masks, in cigarettes.
- Medicinal – removal of certain species from the Human digestive system.
- A carrier for impregnates.
- Recovery of precious metals (gold).
- Very broad field of applications.

Manufacturing of Activated Carbon

Activated carbon is manufactured from carbonaceous raw materials. Examples are:

- Coal: Peat, Lignite, Bituminous coal, Anthracite.
- Nut shells: Coconut, Macadamia.
- Pips: Apricot, Peach, Olive.
- Wood.
- Cellulose.
- Heavy oil.
- Bones.

The carbon content of the raw material will determine the yield of activated carbon.

Material	Carbon Content (%)
Wood	40
Coconut shell	40
Lignite	60
Bituminous coal	75
Anthracite	90

Two types of processes

- Chemical

Raw materials mixed with acid (eg H_2SO_4) dried and heated to 650°C.

- Physical (Thermal)

Raw material is firstly charred in carbonisation step then heated to elevated temperatures in the presence of steam to create activated carbon (activation step).

Physical Manufacture

Preparation of raw material

- Vegetation nuts etc. cleaned of husks etc.
- Coal: milled

↓

Mixed with a binder

↓

Reformed under pressure

Briquetting

Extruding

↓

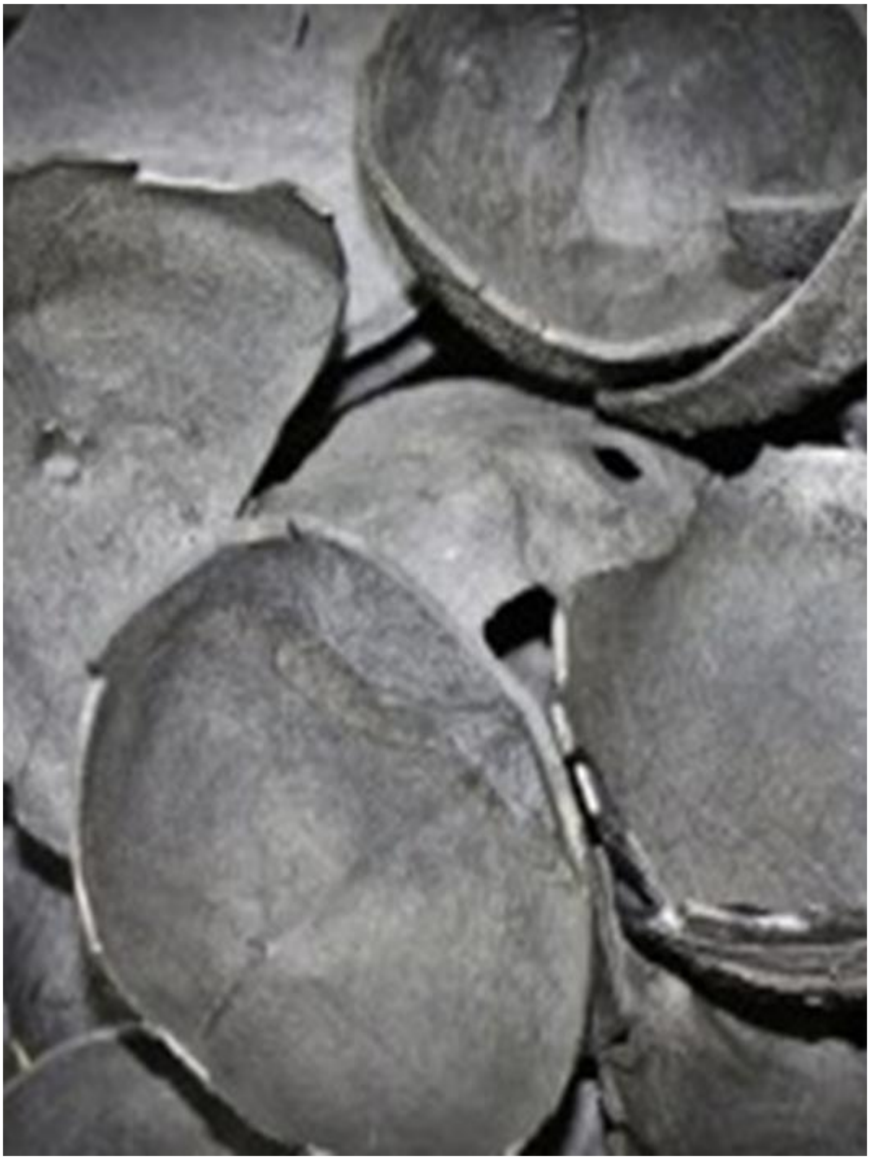
Crushed and sized

Raw coconut shells.

Carbonization

- Indirectly heated at 700°C.
- Volatile organic constituents driven off in an inert atmosphere.
- Dehydrated.

Char has a fixed carbon content of +80% and a surface area of $10m^2/g$.



Carbonized coconut shells

Activation

- Crushed and sized to form the precursor.
- Directly heated using the gas with steam injected, 24 hours with 1 kg steam / 1 kg char / hour.
- Temperature: 800°C to 900°C.

Water gas reaction

$C + HO_2 \rightarrow CO + H_2$

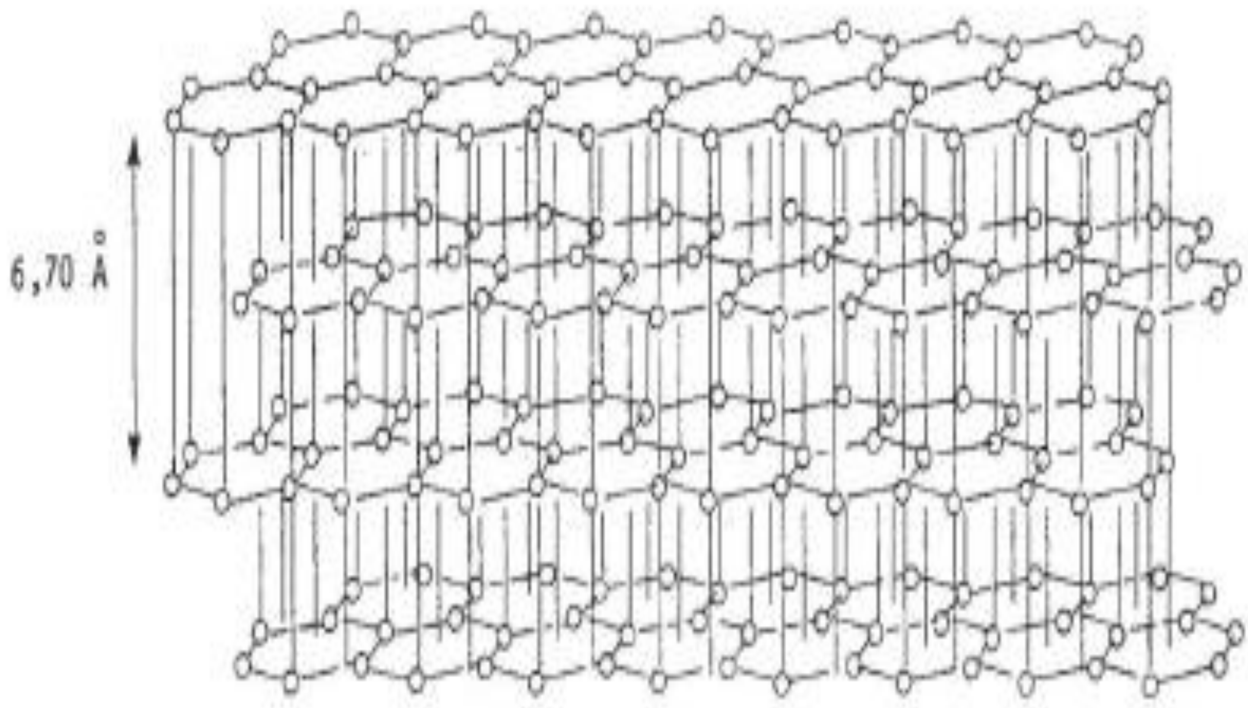
$C + CO_2 \rightarrow 2CO$

- Endothermic reaction.

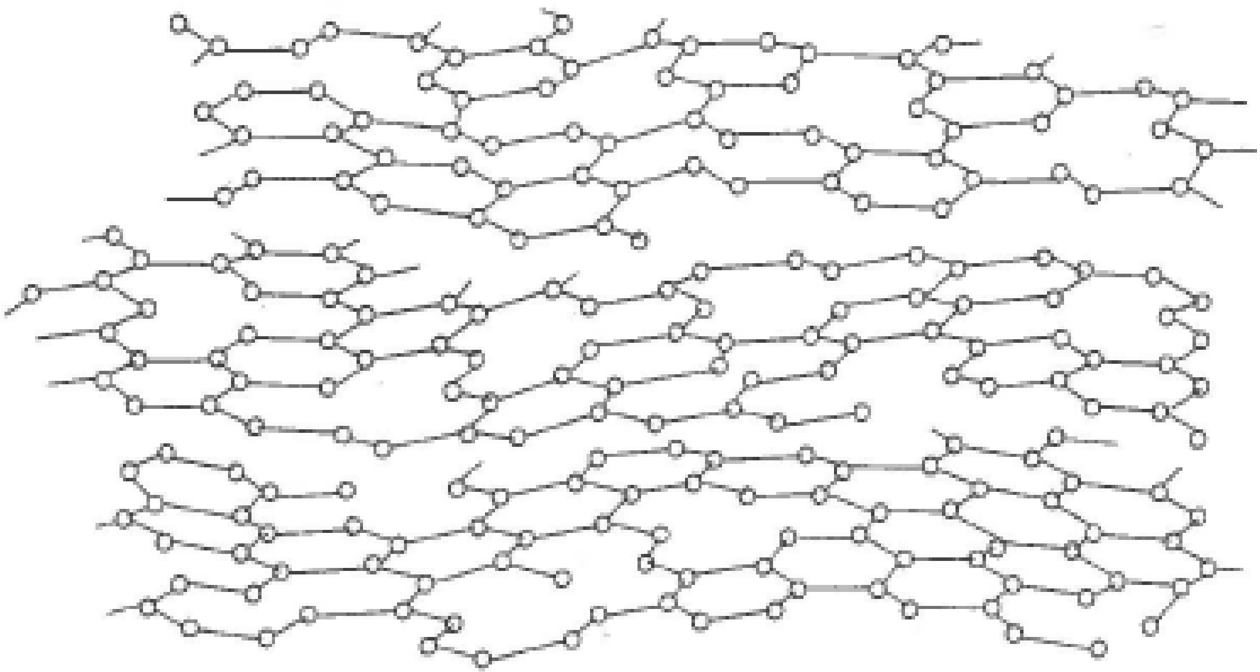
50 % of char is consumed.

Internal surface area 1000m²/g.

Final product: Activated Carbon



Schematic representation of the structure of graphite. The circles denote the positions of carbon atoms, whereas the horizontal lines represent carbon-to-carbon bonds



Schematic representation of the proposed structure of activated carbon. Oxygen-containing organic functional groups are located at the edges of broken graphic ring systems

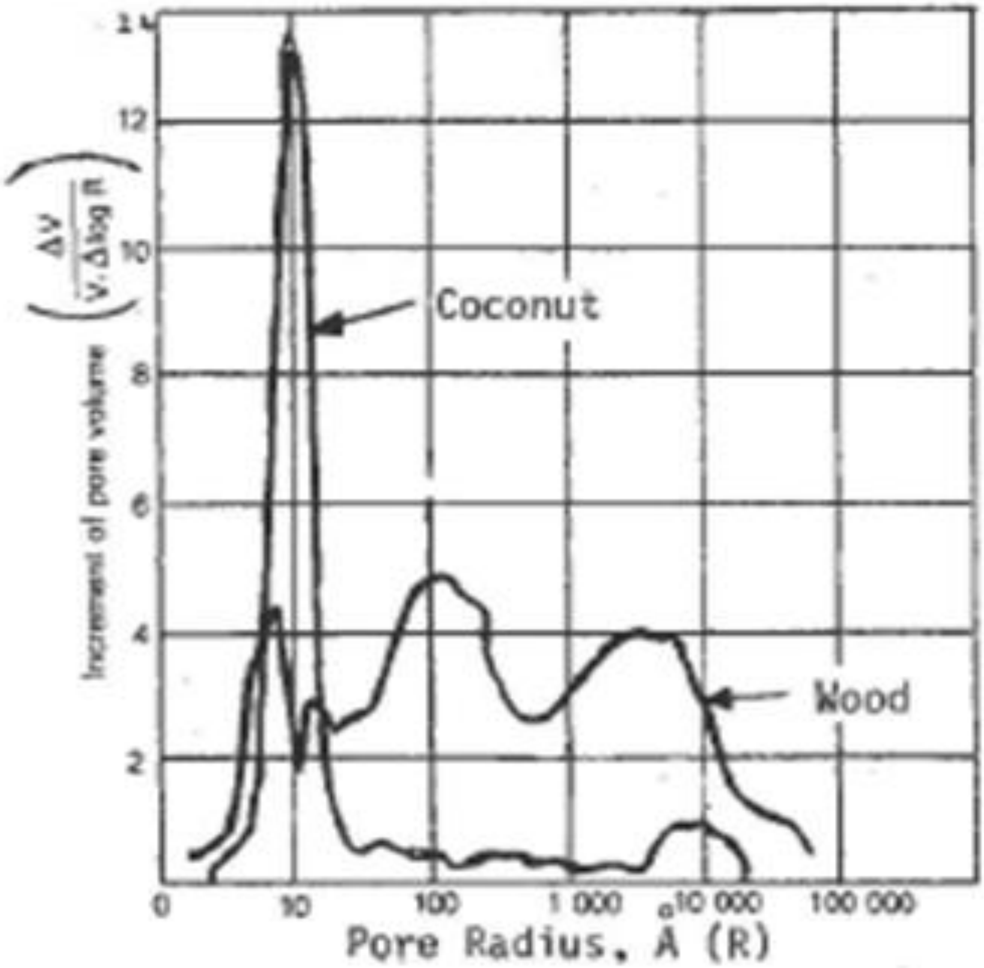
Characteristics of Activated Carbon

Essentially, the raw product defines the activated carbon product.

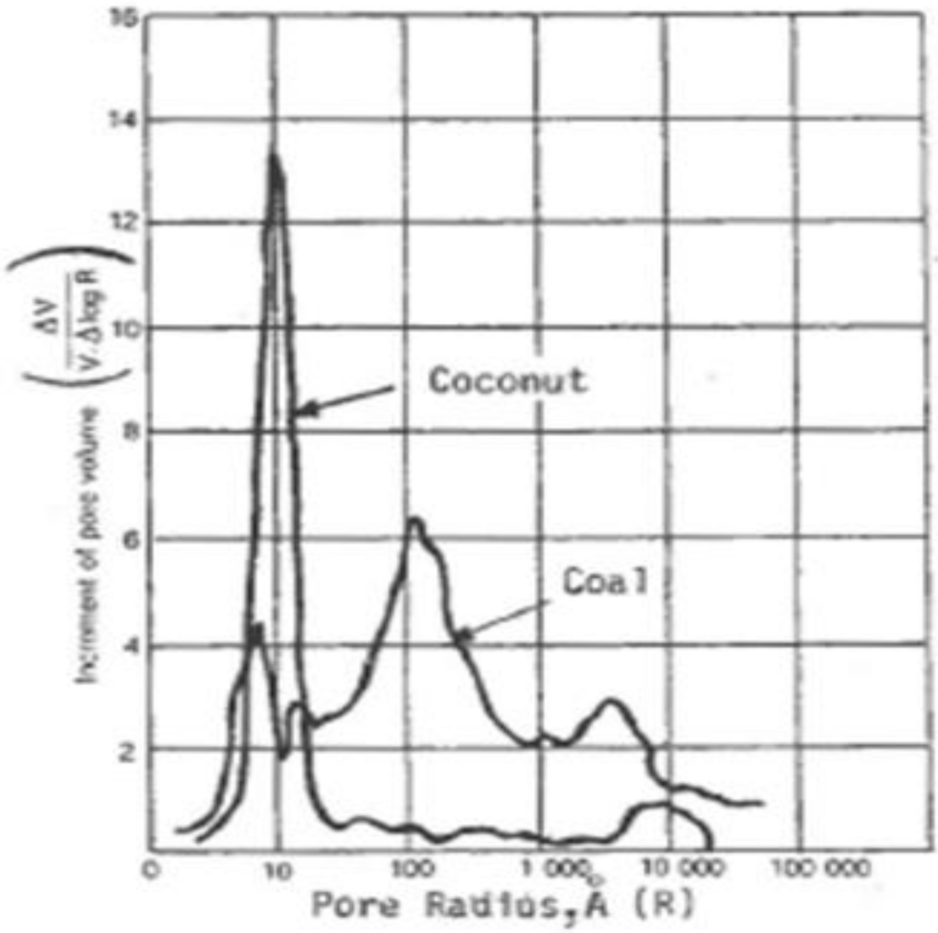
The characteristics of the activated carbon product are thus dependent on raw material.

A hard dense raw material results in a hard dense activated carbon with a micro-pore favouring structure.

A soft, less dense raw material results in a soft light activated carbon with an open pore structure.



Pore-size distribution data for (a) typical thermally activated coconut-shell based activated carbon and (b) a typical chemically activated wood-based product.



Pore-size distribution data for a typical thermally activated coal-based activated carbon and a coconut carbon.

Application based on key characteristics

- Coconut shell based
  Adsorption of smaller molecules from gas and liquids in gas masks, solvent recovery, cigarettes and gold recovery.

- Wood based
  Large organics from industrial streams eg Vodka colorants from liquids.

- Coal based
  Potable water treatment, waste water treatment.

In the gold industry:

- High affinity towards gold.
- Hard, abrasion resistant.
- Density suited to pulp.
- Source material supply not limiting.

Adsorption

Tendency of atoms / molecules in gas / liquids (adsorbate) adhere to a solid surface (adsorbent).

- Chemical adsorption
- Reaction.
- Not reversible.

- Physical adsorption
- No reaction.
- Van der Waals forces between uncharged adsorbates and surface molecules.
- Reversible

Activated carbon adsorbs by physical adsorption.

In physical adsorbtion, adsorbents are characterised by surface area and polarity.

Polarity corresponds to affinity to polar substances like water.

Polar substances are water liking-hydrophilic.

Non-polar substances are water hating – hydrophobic.

Activated carbon is non-polar and has an affinity to hydrophobic species.

Selectivity occurs if multiple species present.

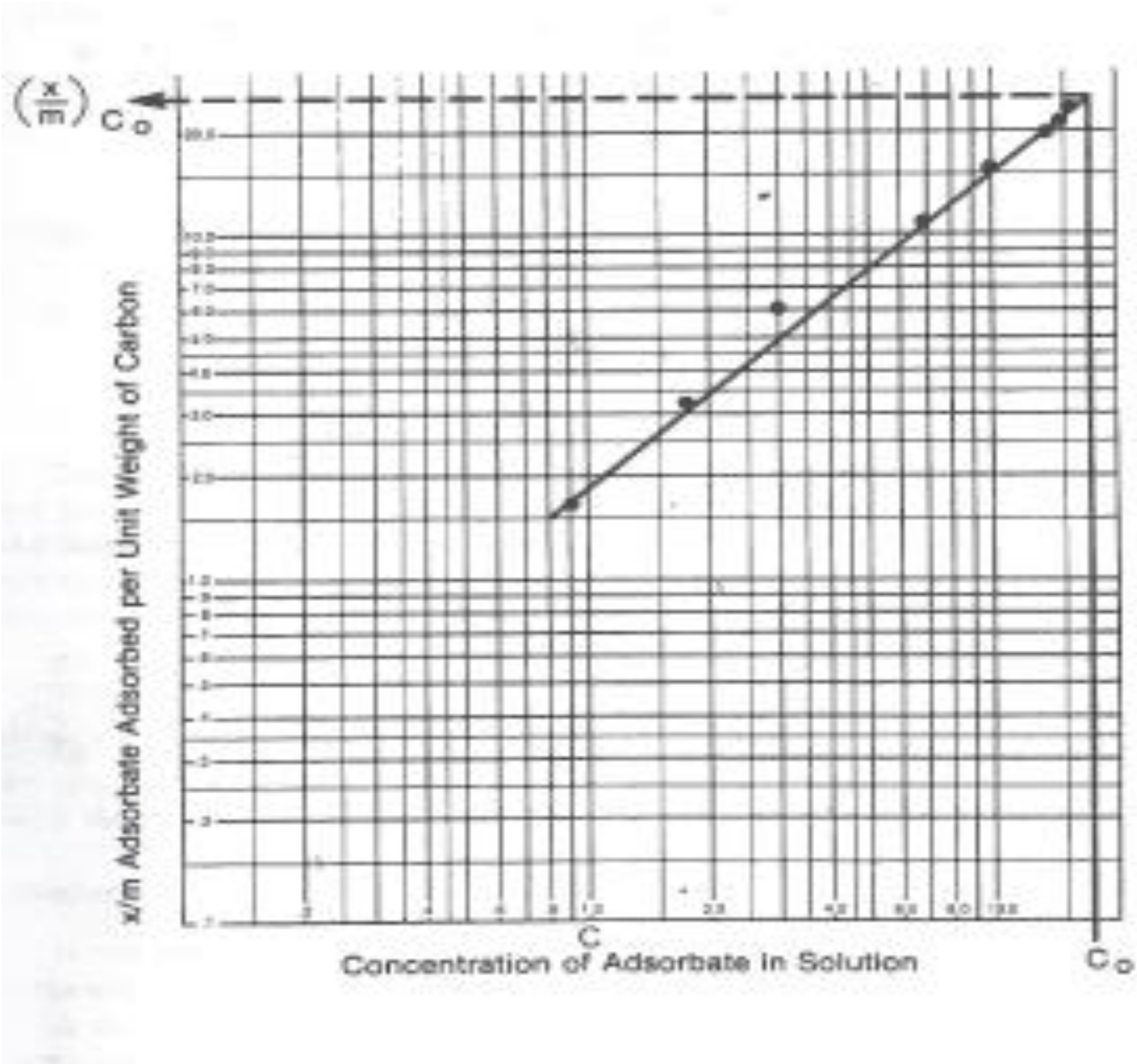
Adsorption is equilibrium and kinetics dependent.

Equilibrium adsorption

At equilibrium there is a defined distribution of adsorbate between liquid and solid surface.

Freundlich Isotherm

$x/m = kc^{1/n}$



Straight-line isotherm plot

Factors that effect equilibrium

- Surface area of the carbon.
- Affinity the carbon surface has for adsorbate.
- Competing adsorbates.
- Concentration of adsorbate.
- Temperature.
- pH.

In applications in which fixed bed columns are used – equilibrium is governing.

The nature of the CIP/CIL process means that gold and other adsorbates load well below equilibrium loading.

Extraction efficiency is governed by kinetics of adsorption.

Adsorption kinetics

Rate of adsorption – three steps:

- Diffusion through the liquid film.
- Diffusion of the adsorbate within pore structure.
- Adsorption.

  Film diffusion is regarded as rate limiting step. It is defined by the expression:

$R = k_f A (C - C^y)$

"R" is the mass transfer rate through film.

" k_f " is the mass coefficient.

"A" is the external area of the carbon particles.

"C" is the concentration of adsorbate in the bulk solution.

"C^y" is the concentration of the adsorbate of the solution carbon interface. This is zero as adsorption is not limiting.

Gold Adsorption via CIP/CIL

WHY DO WE USE THIS PROCESS?

- Gold is a noble metal.
- Gold reserves are low grade.
- Concentrate up gold value.
- Best way: Leach and concentrate in liquid state.

Gold Adsorption Onto Activated Carbon

1. LEACHING (In the presence of O_2)

$Au + 2\,CN^-$	$\longrightarrow$	$Au(CN)_2^-$
Gold + Cyanide	$\longrightarrow$	Gold/Cyanide complex

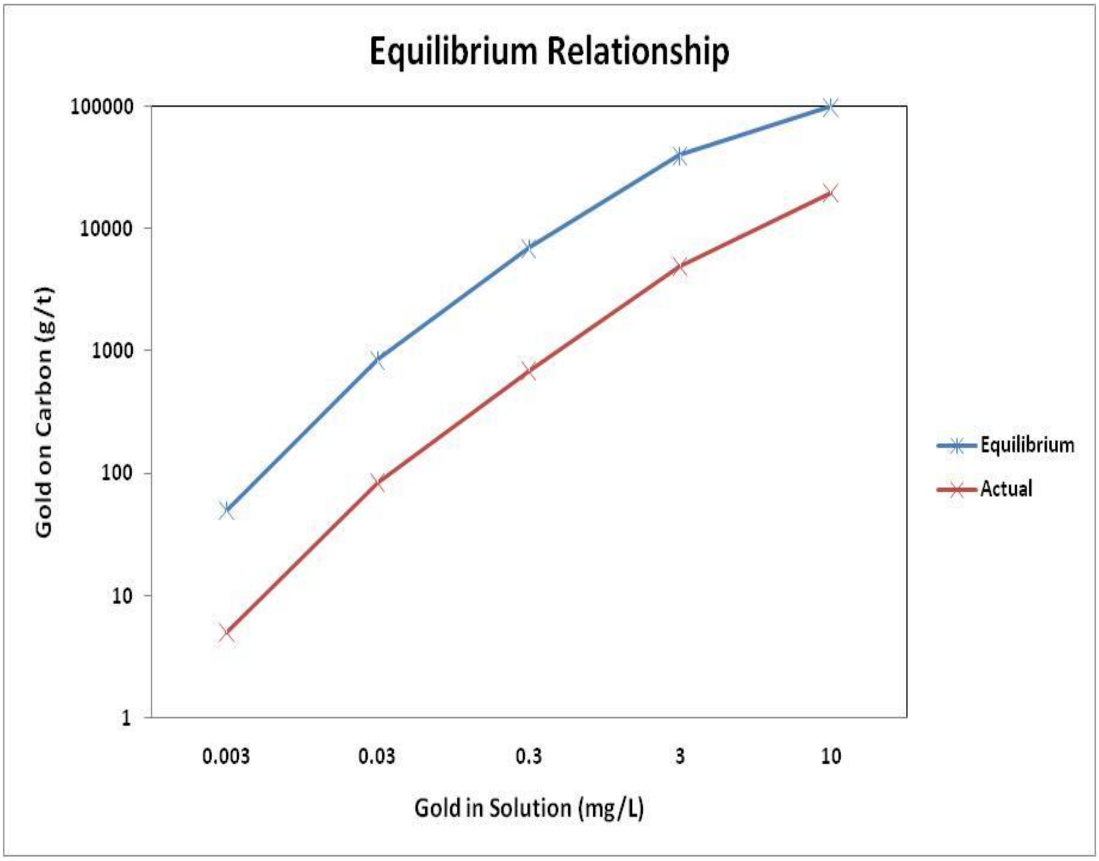
2. ION PAIR FORMATION

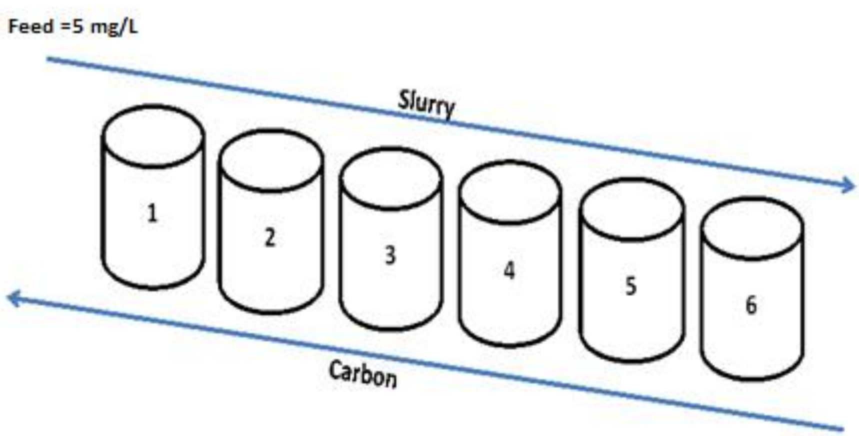
$2Au(CN)^-_2 + Ca^{2+}$	$\rightleftharpoons$	$Ca(Au(CN)_2)$
		Ion Pair

3. ADSORPTION ONTO CARBON

In Solution		On Carbon
$Au(CN)_2^-$	$\not\rightarrow$	
$Ca(Au(CN)_2)_2$	$\rightleftharpoons$	$\overline{Ca(Au(CN)_2)_2}$

Physical adsorption only. No change In the chemical structure of the carbon.





Eluted Carbon =50 g/t

	Stages					
	1	2	3	4	5	6
Tenor (mg/L)	2	0.8	0.32	0.13	0.05	0.02
Loading (g/t)	5000	2500	1200	650	360	205

Factors Influencing Gold Adosrption

- Mixing efficiency
- Pulp density
- Particle size of carbon
- Temperature
- Cyanide concentration
- pH
- Ionic strength
- Gold tenor
- Contact time
- Organic poisons
- Inorganic poisons
- Quality of activated carbon - Carbon activity
- Elution grade
- Quality of carbon regeneration.

Mixing Efficiency / Pulp Density

Activated carbon based on coconut shells has:

- Bulk density of 0.5g/ml
- Porosity of 0.8 ml/g

If porosity filled with water and added to bulk density – wetted density is 1.3 g/ml.

Particle size of Carbon

Balance between size and screening ability.

Size ranges typically used:

8/16 # ASTM (1.18 mm to 2.36 mm)

6/16 # ASTM (1.18 mm to 3.35 mm)

6/12 # ASTM (1.70 mm to 3.35 mm)

Organic Poisons

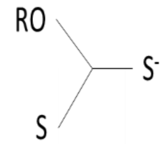
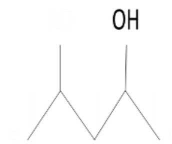
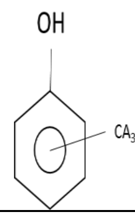
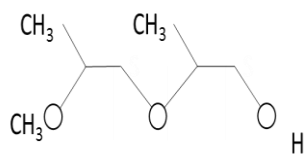
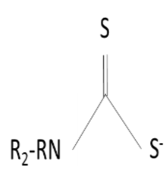
Activated carbon adsorbs a variety of organic species.

Organics arise from:

- Flotation reagents.
- Oils, degreasers.
- Humic and Fulvic acids origination from vegetation / wood.
- Organics prevalent in water utilised.

Organic species depress kinetic gold adsorption.

Activity of Activated carbon in the presence of a suite of organic species
(ACIX procedure, with 100 mg/ℓ organic concentration)

Organic Species	Molecular Structure	% Depressant
Carbon		0
Xanthate (collector) SNBX (Na normal Butyl X) SNPX (Na normal Propyl X)		 61 44
MIBC (frother)		24
Starch Depressant		41
Crysilic Acid (frother)		42
Polypropylene glycol (frother)		41
DTC (Propyl) – Collector		9
Turbine oil		19
Transmission oil		15
Engine oil		30
Hydraulic oil		11
Polyacylamide (magnafloc)		0
CIP Feed water		20 to 30
Return dam water		16 to 32
Domestic water		10 to 15
Sewerage water		16
River water		25

Inorganic Poisons

Two types:

- Adsorbed onto activated carbon.
- Scale formation on activated carbon.

Inorganic species adsorbed

Most common are the base metal cyanides:

$Cu(CN)^-_2$, $Cu(CN)_{3,}^{2-,}$ $Cu(CN)_4^{3-}$

$Ni(CN)_4^{2-}$

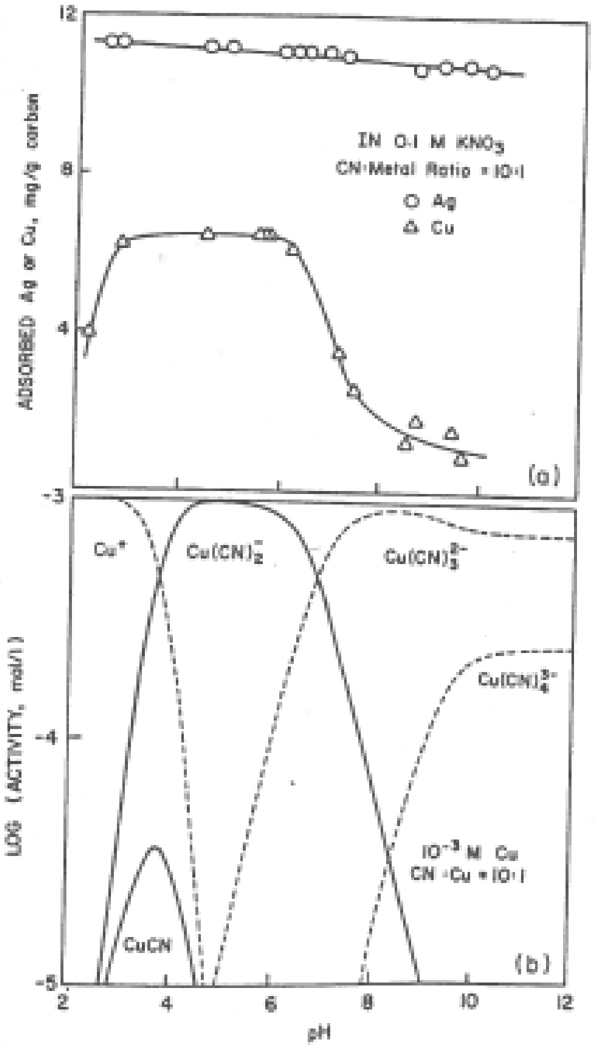
$Hg(CN)_2$

$Co(CN)_4^{2-}$

$Ag(CN)_2^-$

STRONGLY ADSORBED **WEAKLY ADSORBED**

$Cu(CN)^-_2$, $Ag(CN)^-_2$, $HgCN_2$ > $Ni(CN)^{2-}_4$ > $Fe(CN)^{3-}_6$



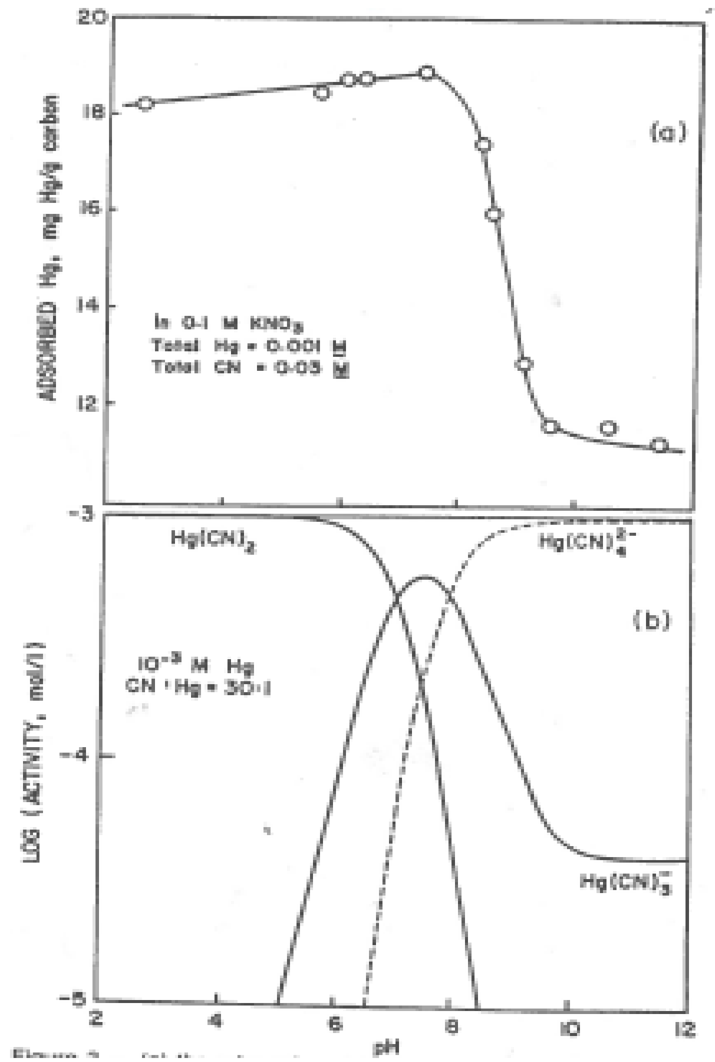
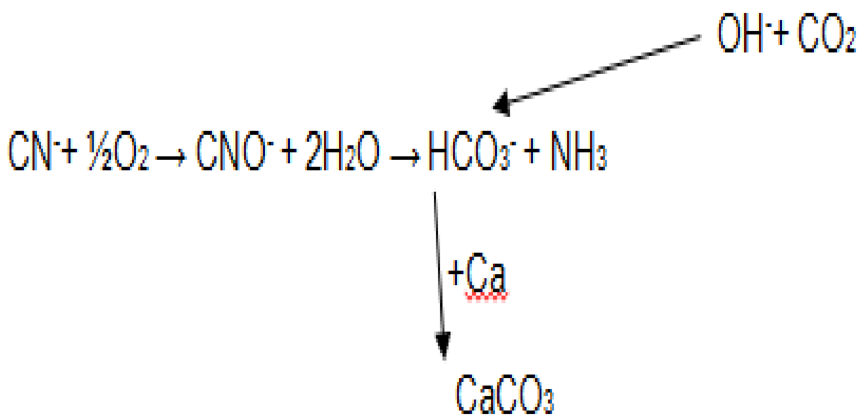


Fig 1 (a) The adsorption of AG(I) and Cu(I) on activated carbon as a function of pH in 0.1 M KNO_3. (b) The distribution of the cyano complexes of Cu(I) as a function of pH.

Fig 2 (a) The adsorption of HG(II) on activated carbon as a function of pH. (b) the distribution of the cyano complexes of Hg(II) as a function of pH.

Scale Formation



Other inorganics

- Silica → Silicates
- Ore Particles
- Prussian Blue

Activated carbon for gold recovery in CIP / CIL

Physical characteristics

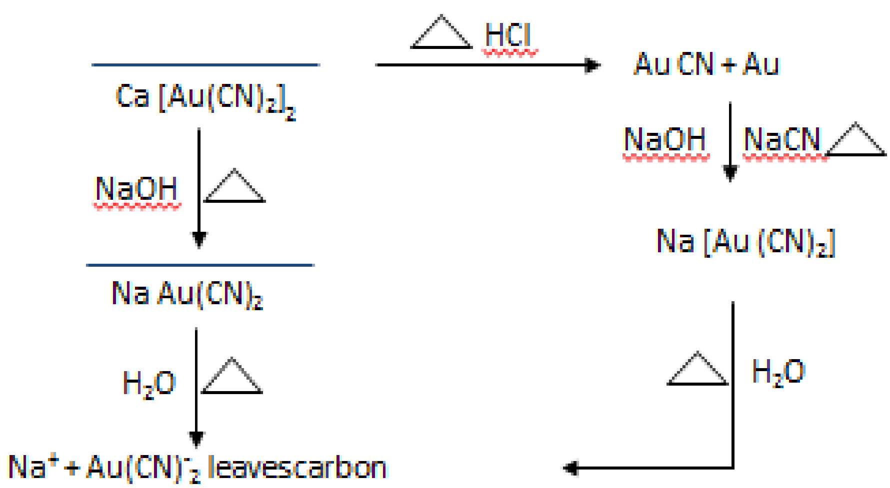
- Hard
- Dense
- Particle size characteristics

Chemical characteristics

- Kinetic activity
- Equilibrium loading
- Elutability

Elution

Reverse of Adsorption

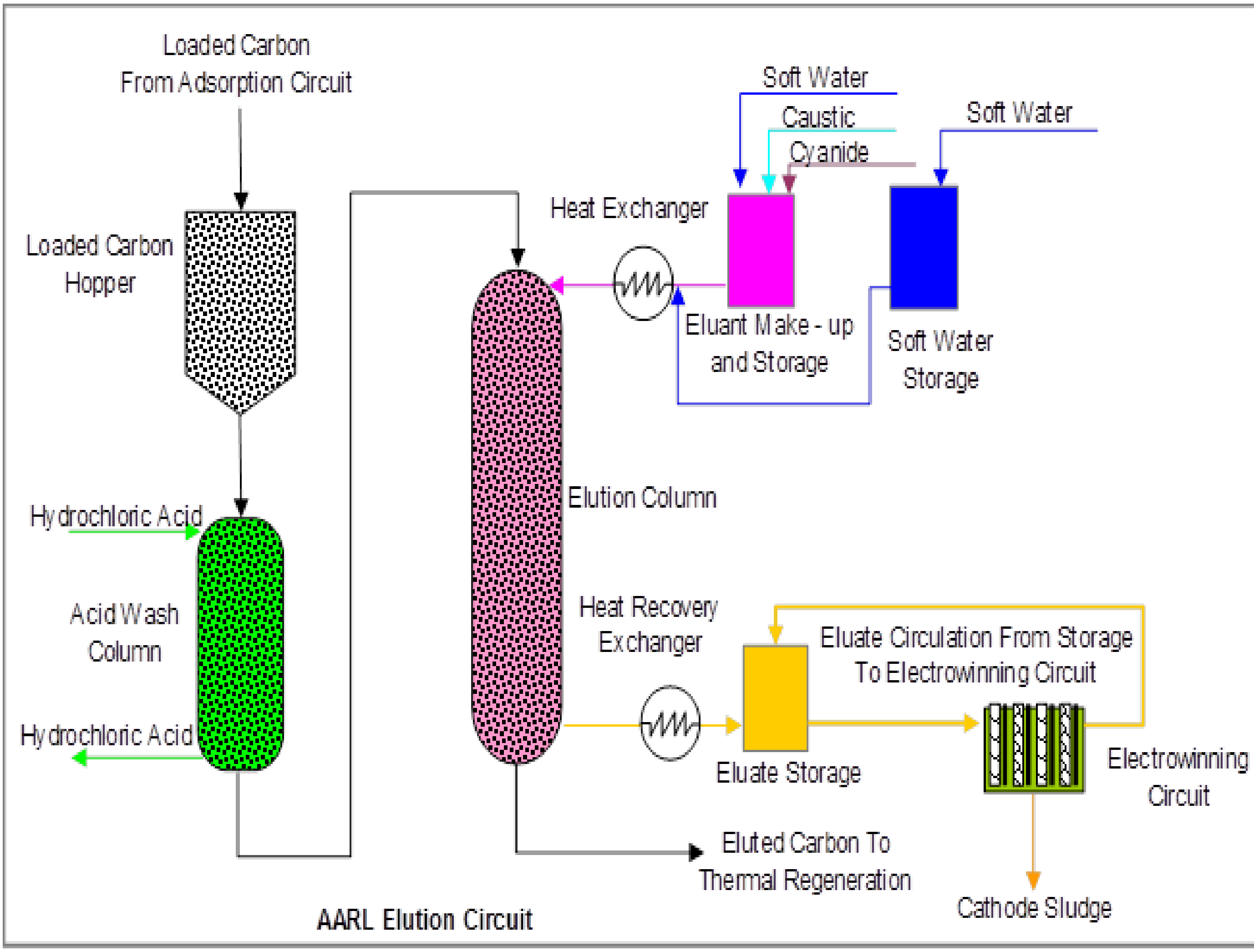


Conditions are reversal of Adsorption

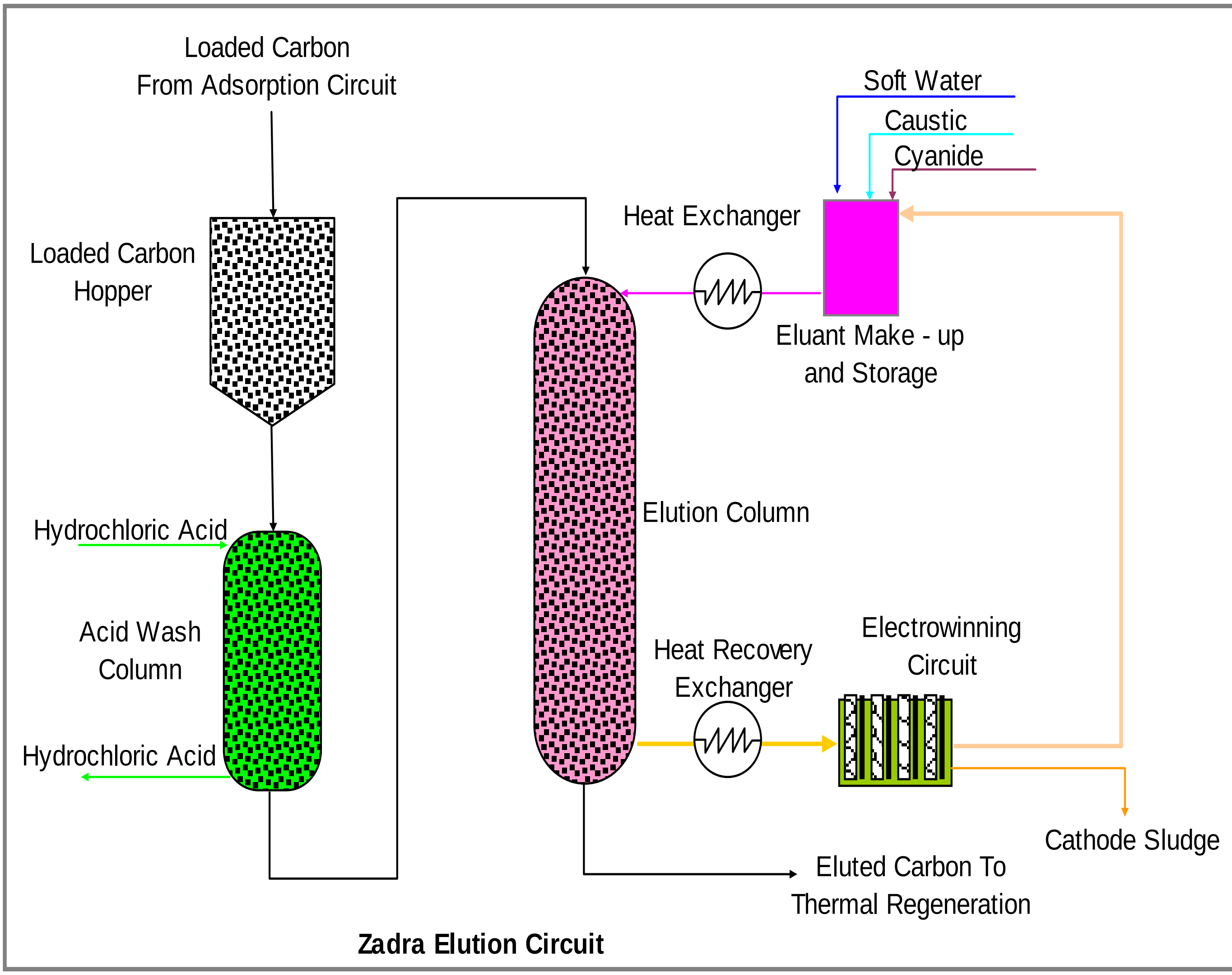
- High Temperature
- Clean Water
- Low Ionic Strength – Little Calcium

Elution – Important Factors

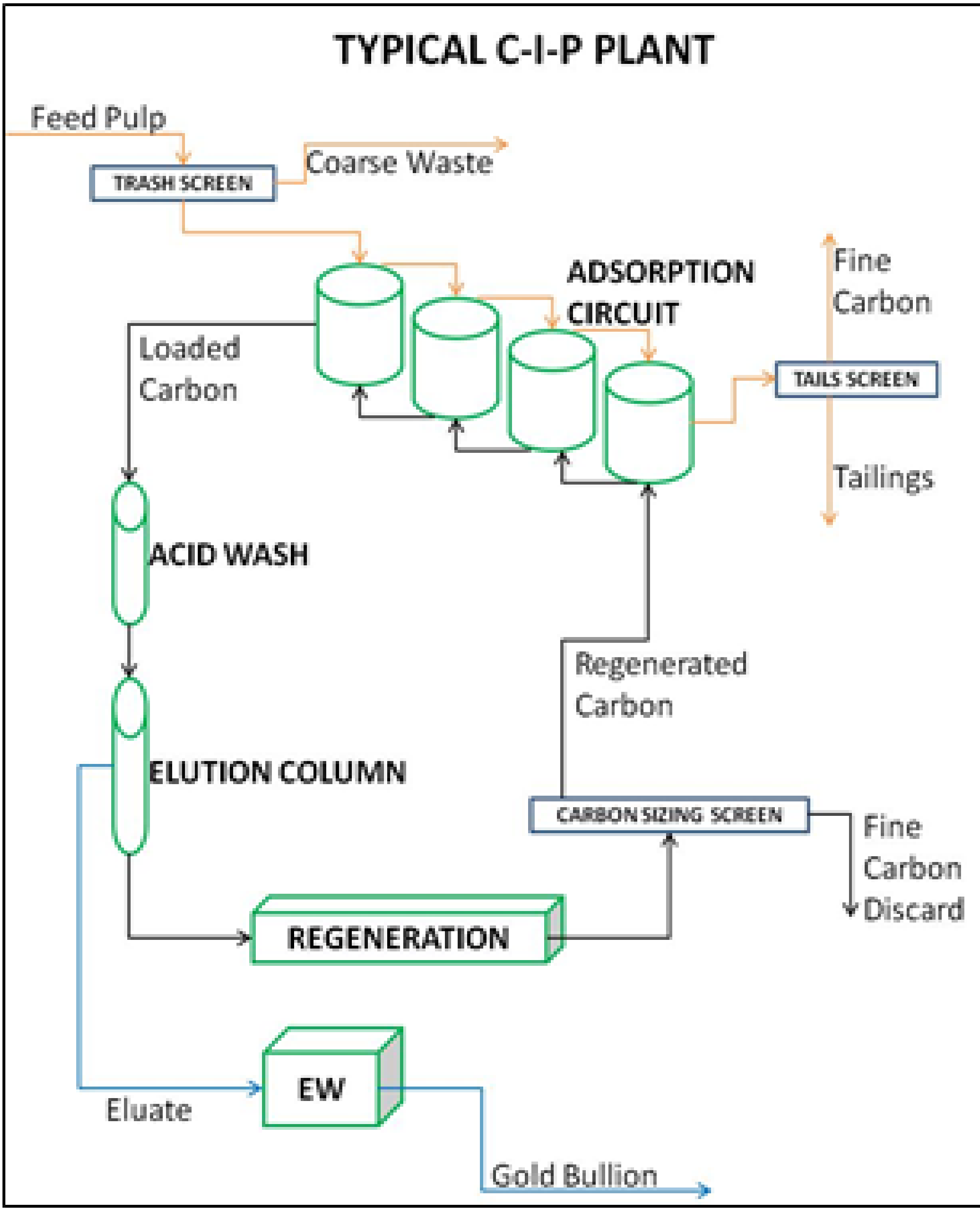
- Scale on carbon has no effect.
- Scale build up in elution – negative effect.
- Water quality important.
- Temperature / rate of elution linked.
- High flow rates 2 to 2.5 BV/hr.



Typical AARL Elution Circuit



Typical Zadra Elution Circuit


TYPICAL C-I-P PLANT
Feed Pulp
TRASH SCREEN
Coarse Waste
ADSORPTION
CIRCUIT
Fine
Carbon
TAILS SCREEN
Tailings
Loaded
Carbon
ACID WASH
Regenerated
Carbon
ELUTION COLUMN
CARBON SIZING SCREEN
Fine
Carbon
Discard
REGENERATION
EW
Eluate
Gold Bullion

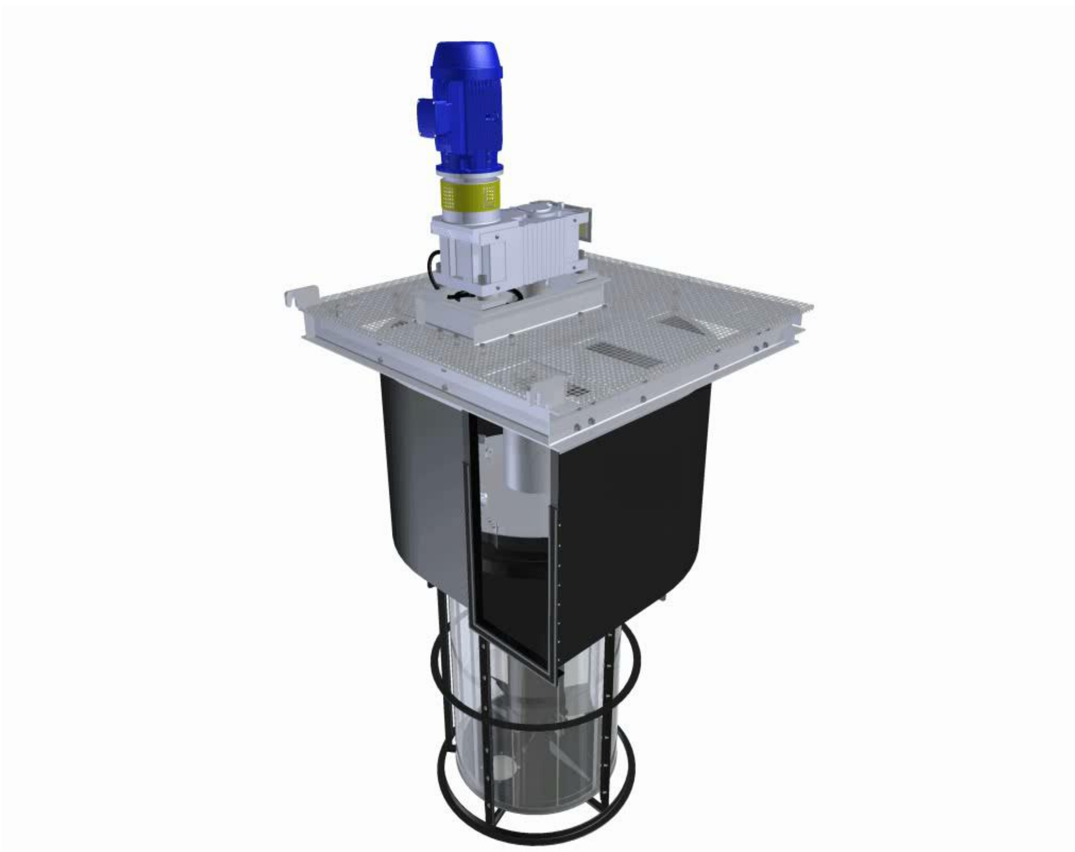
Preparation Of Feed To CIP Circuits

If pre-screening is not effective in removing trash, this will lead to:

- Screen blockages, creating flow problems.
- Grit settling in first tank, reducing retention time.
- Report with carbon, thus occupying volume in the elution, acid washing and regeneration sections.
- Carbon containing wood fibre does not flow, pump or screen as well as clean carbon.
- Wood fibre can "rob" gold – up to 350g/t samples seen.
- Grit causes abrasion, and scale formation in kiln (sintering).

Linear screen

INTERSTAGE SCREEN
MPS SCREENS (Normal Screens)



Interstage screen

MPS-P screens (Pumping Screens)

MPSP pumping Interstage screens

Carbon-in-Pulp circuit with Pumping Interstage screens

Non-pumping MPS Interstage screens, in position.

CIL plant with non-pumping screens. Shows cascade arrangement of tanks.

CIL tanks with pumping screens.

Vibrating screen.

Apertures of Screens

	Option 1	Option 2
Carbon size Mesh ASM	6 x 12 or 8 x 16	6 x 12 or 8 x 16
Trash screen (micron)	600	700
Tails screen (micron)	600	700
Interstage screen (micron)	630 to 700	800
Loaded carbon screen (micron)	600	700
Carbon Sizing Screen (micron)	1200 to 1500	1200 to 1500

Acid Washing

- Cold HCl or $HN0_3$.
- Dilute, 7 to 10%.
- $CaCO_3 \rightarrow CaCl_2$ is rapid.
- One hour contact.
- Base metal cyanides partially removed.

Variation of inorganic species on loaded activated carbon

SPECIES	CONTENT (g/t a.c.)
Nickel	2 250 to 5 000
Iron	100 to 600 (typical) Highs of 3 000 Measured Infrequently
Calcium	2 000 to 4 000
Copper	30 to 4 000 Highs of 20 000 Measured Infrequently

Thermal Regeneration

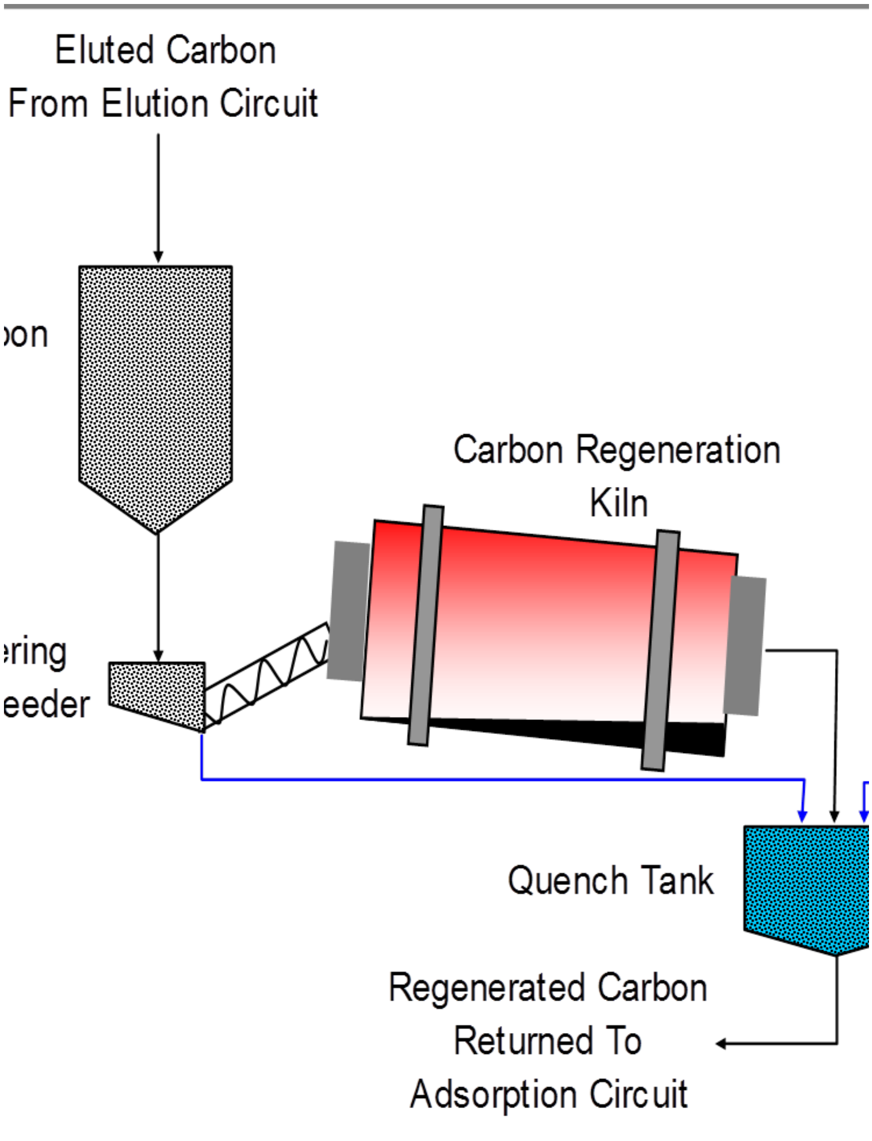
- Drying

  Steam atmosphere $\pm$ 30 seconds.

  Residence time in retort.

- Vaporization – 750 to 800°C.

- Pyrolysis / Selective oxidation – Above 800°C



Carbon regeneration circuit

Important parameters in CIP plant control

- Pulp spends about 1 hour per contactor time available for maximum adsorption is therefore 1 hour.

  Fast adsorption kinetics are required.

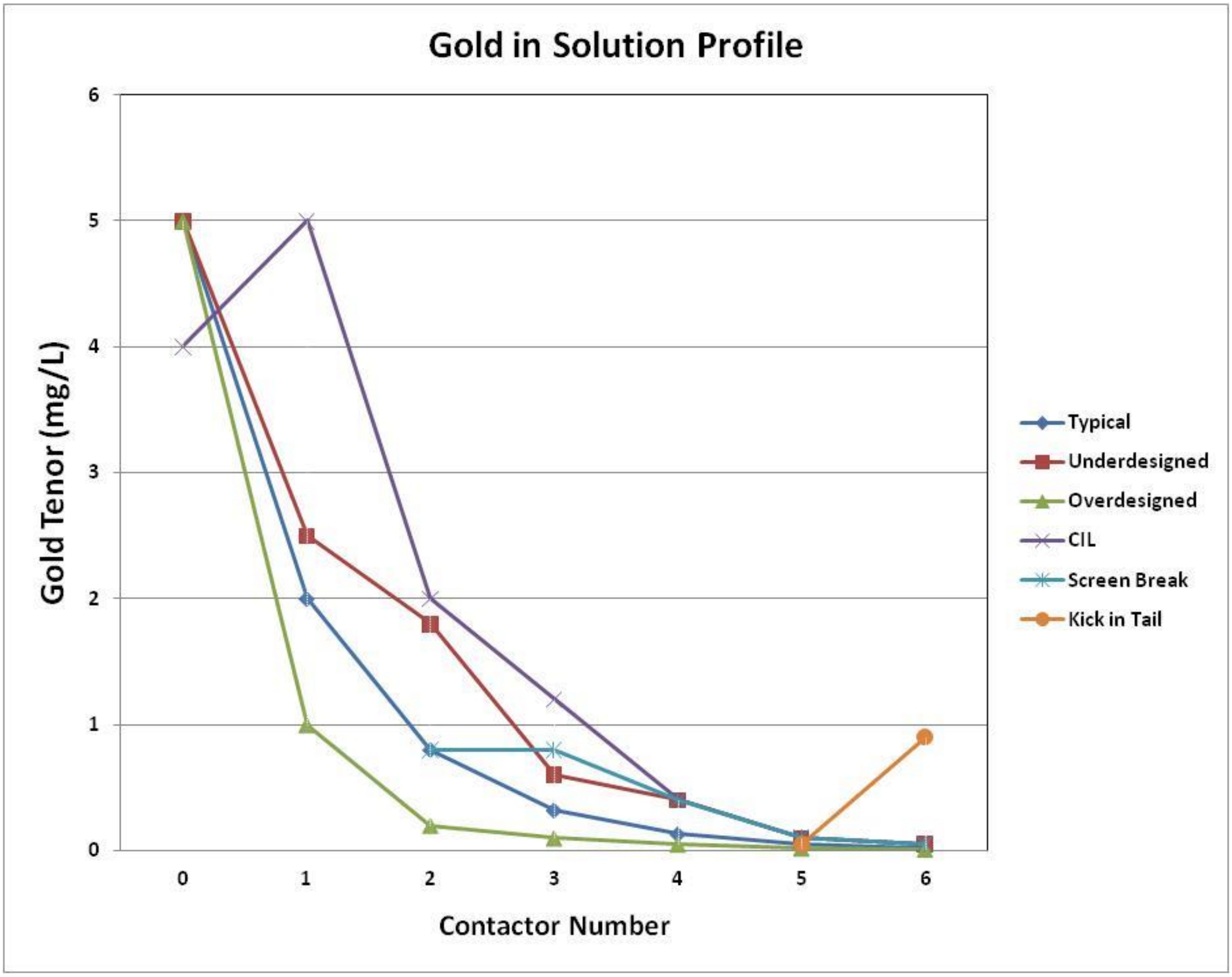
- Carbon spends about one day per contactor therefore, provided tenor remains constant carbon comes into equilibrium with gold.

Profiles: Normal Operation

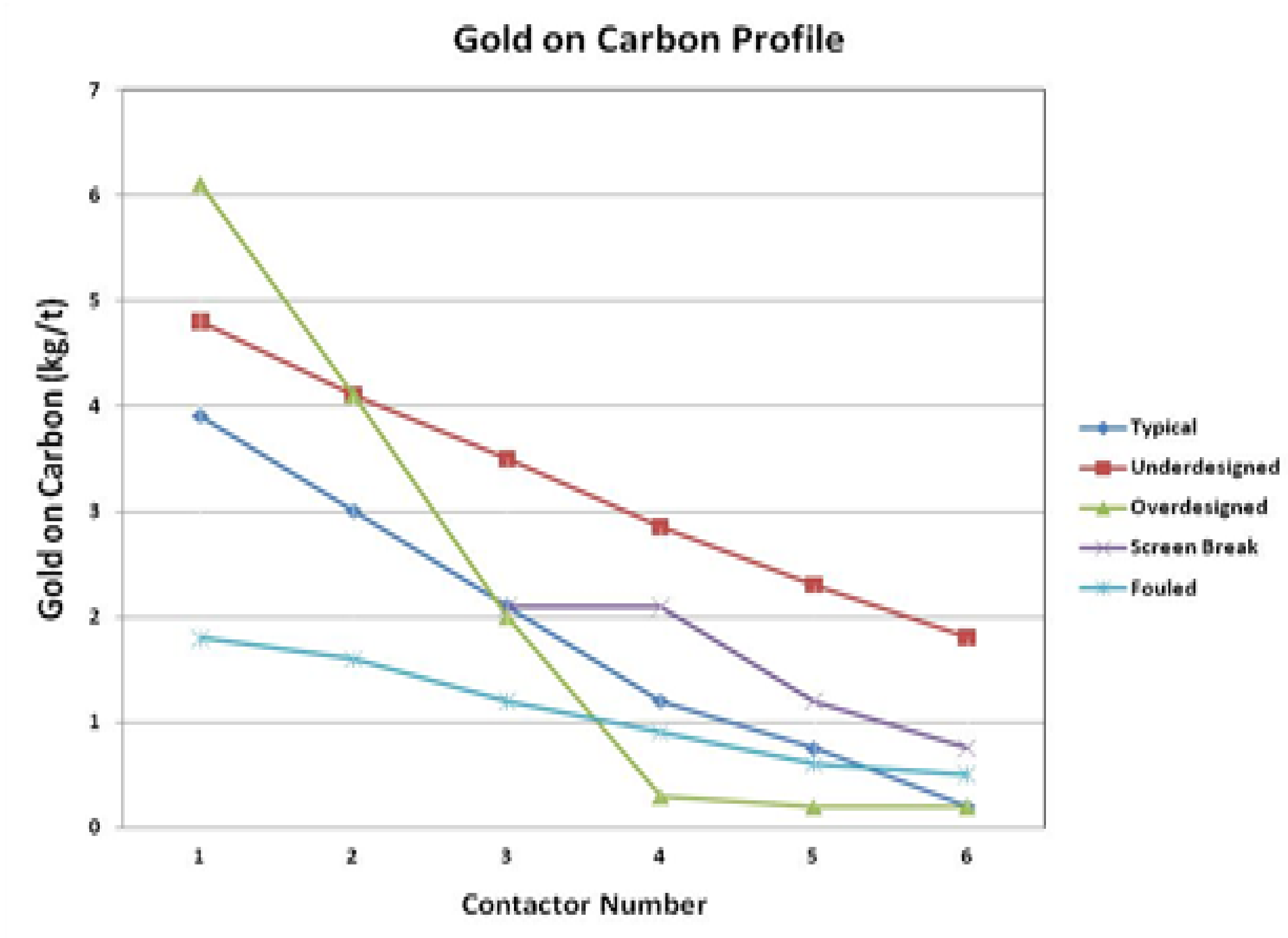
Gold In Solution Profile			Gold in Carbon Profile (g/t)
	Extraction (%)	Value (mg/ℓ)	
Feed		5.000	-
Stage 1	60	2.000	5 000
Stage 2	60	0.800	2 025
Stage 3	60	0.320	835
Stage 4	60	0.128	353
Stage 5	60	0.051	169
Stage 6	60	0.020	93
Stage 7	60	0.008	62
Eluted Carbon	-	-	50

Profiles: Stressed Operation

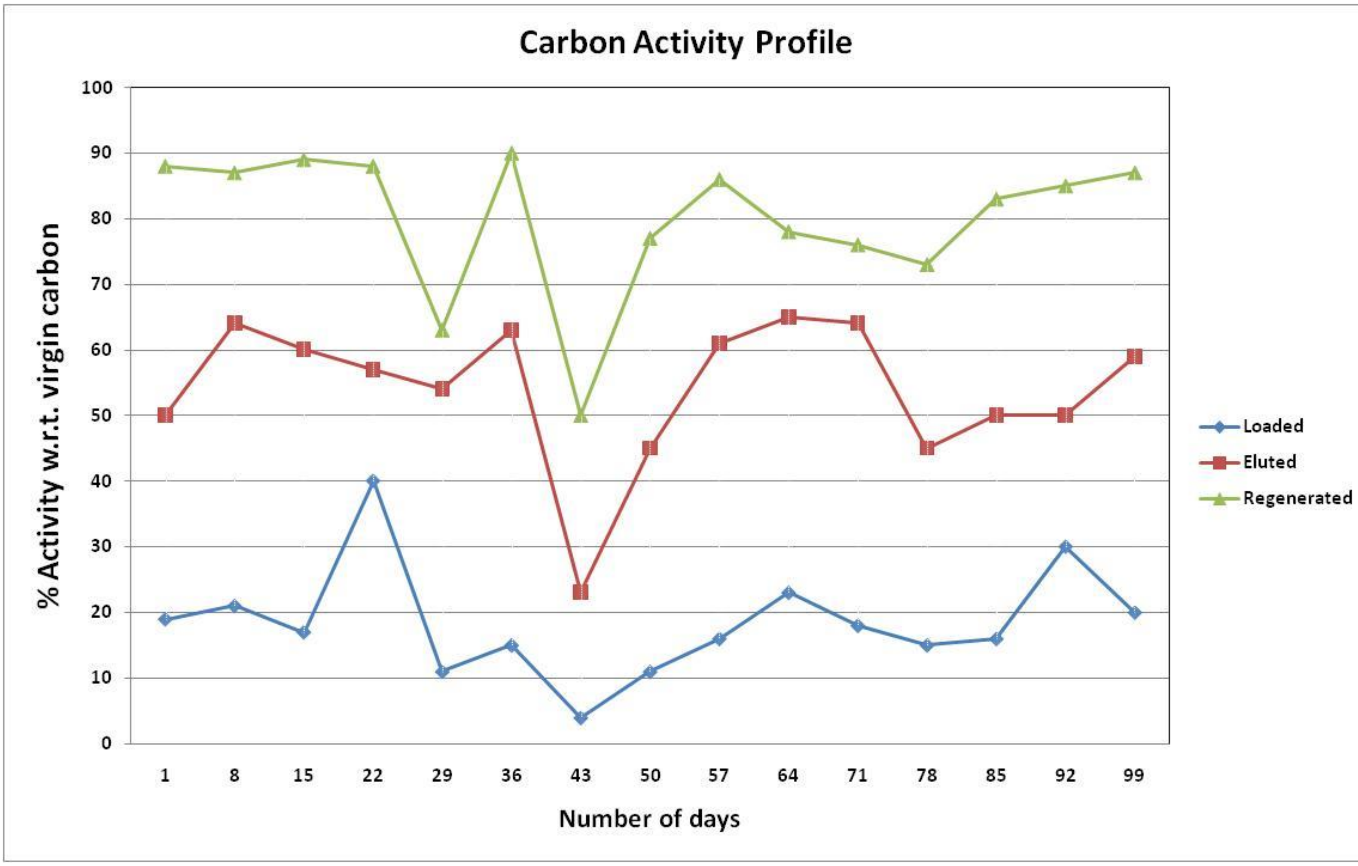
Gold In Solution Profile			Gold in Carbon Profile (g/t)
	Extraction (%)	Value (mg/ℓ)	
Feed		5.000	-
Stage 1	50	2.500	5 000
Stage 2	50	1.250	2 506
Stage 3	50	0.625	1 258
Stage 4	50	0.313	635
Stage 5	50	0.156	323
Stage 6	50	0.078	167
Stage 7	50	0.039	89
Eluted Carbon	-	-	50

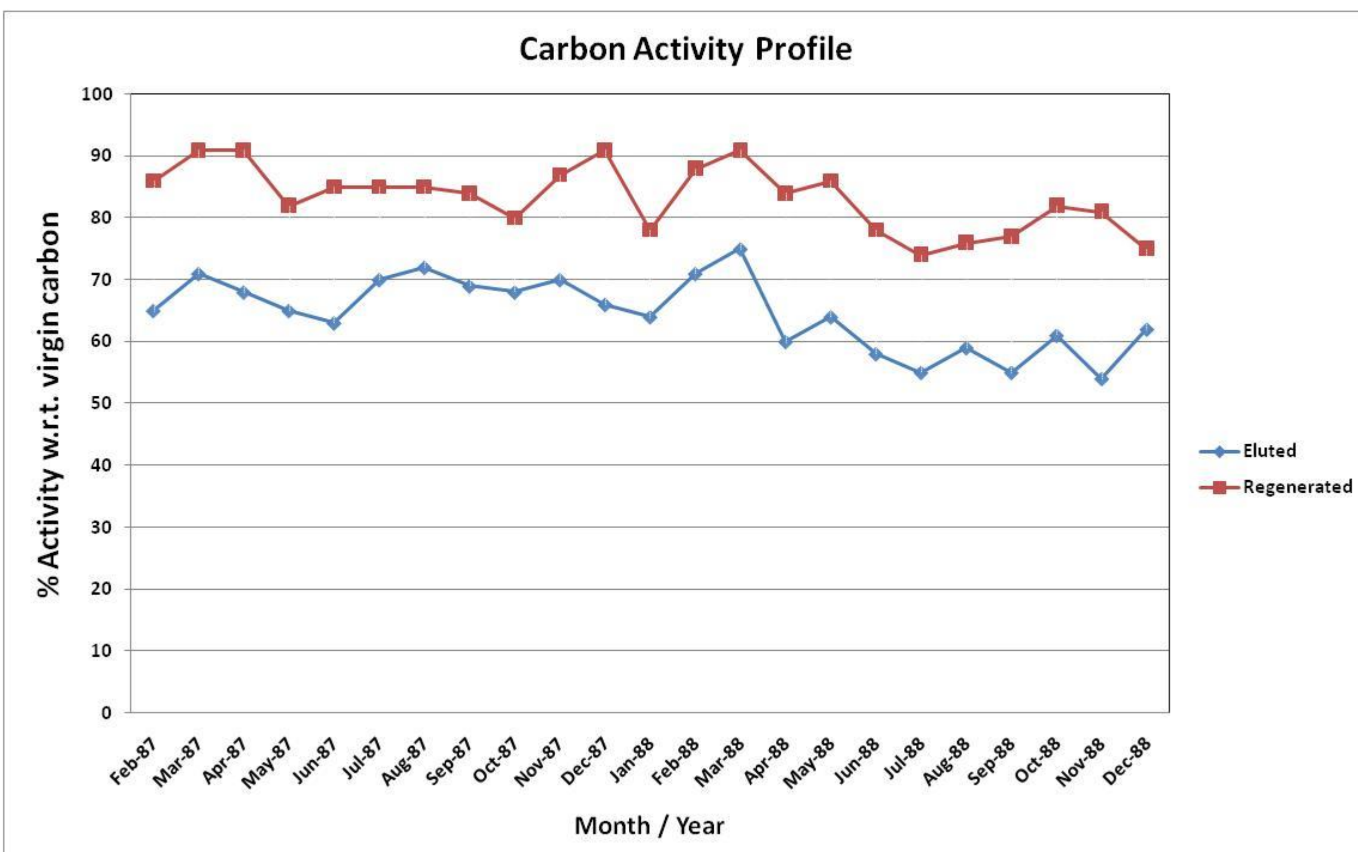


Gold in Solution Profile
Gold Tenor (mg/L)
Contactor Number
0
1
2
3
4
5
6
Typical
Underdesigned
Overdesigned
CIL
Screen Break
Kick in Tail



Gold on Carbon Profile
Gold on Carbon (kg/t)
Contactor Number
Typical
Underdesigned
Overdesigned
Screen Break
Fouled
0
1
2
3
4
5
6
7

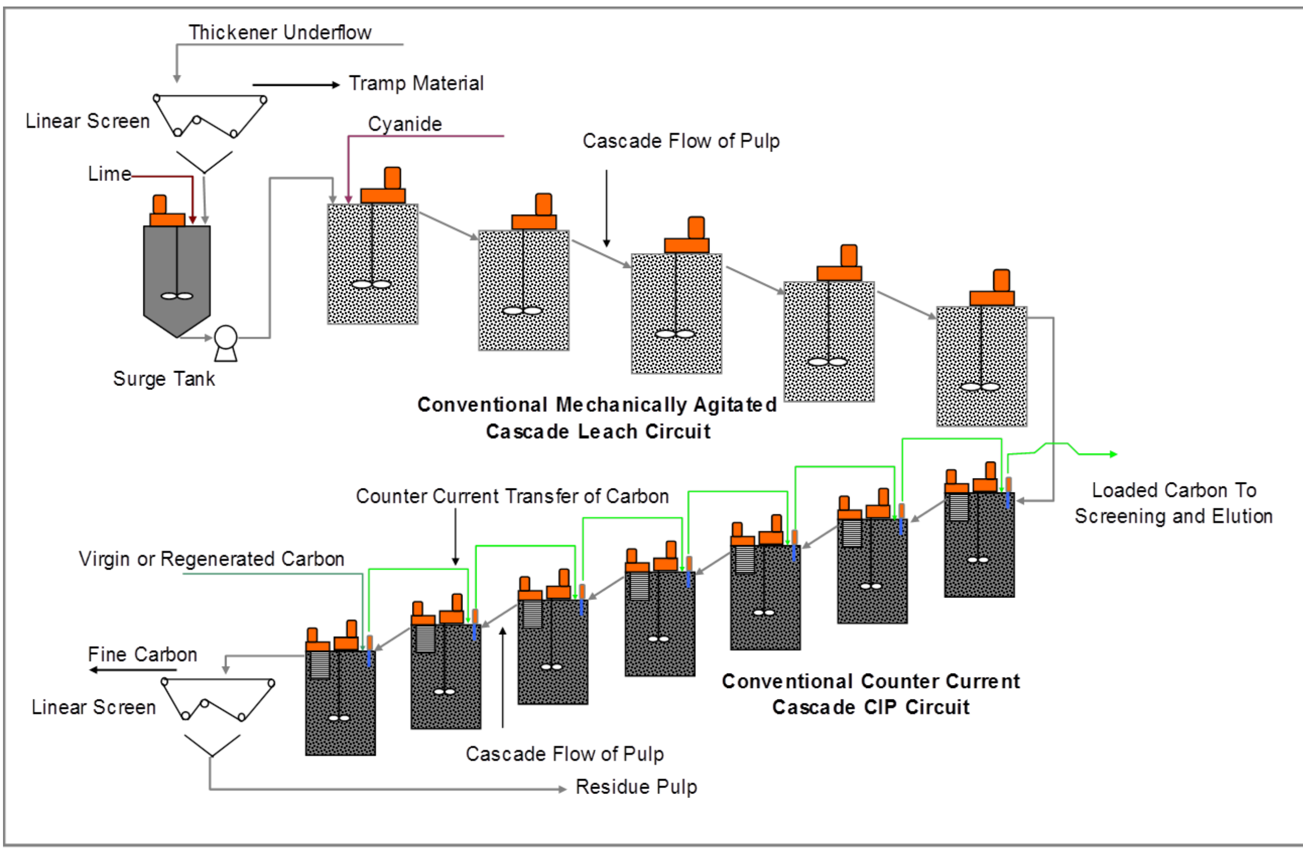

Carbon Activity Profile
% Activity w.r.t. virgin carbon
Number of days
Loaded
Eluted
Regenerated


Carbon Activity Profile
% Activity w.r.t. virgin carbon
Month / Year
Eluted
Regenerated

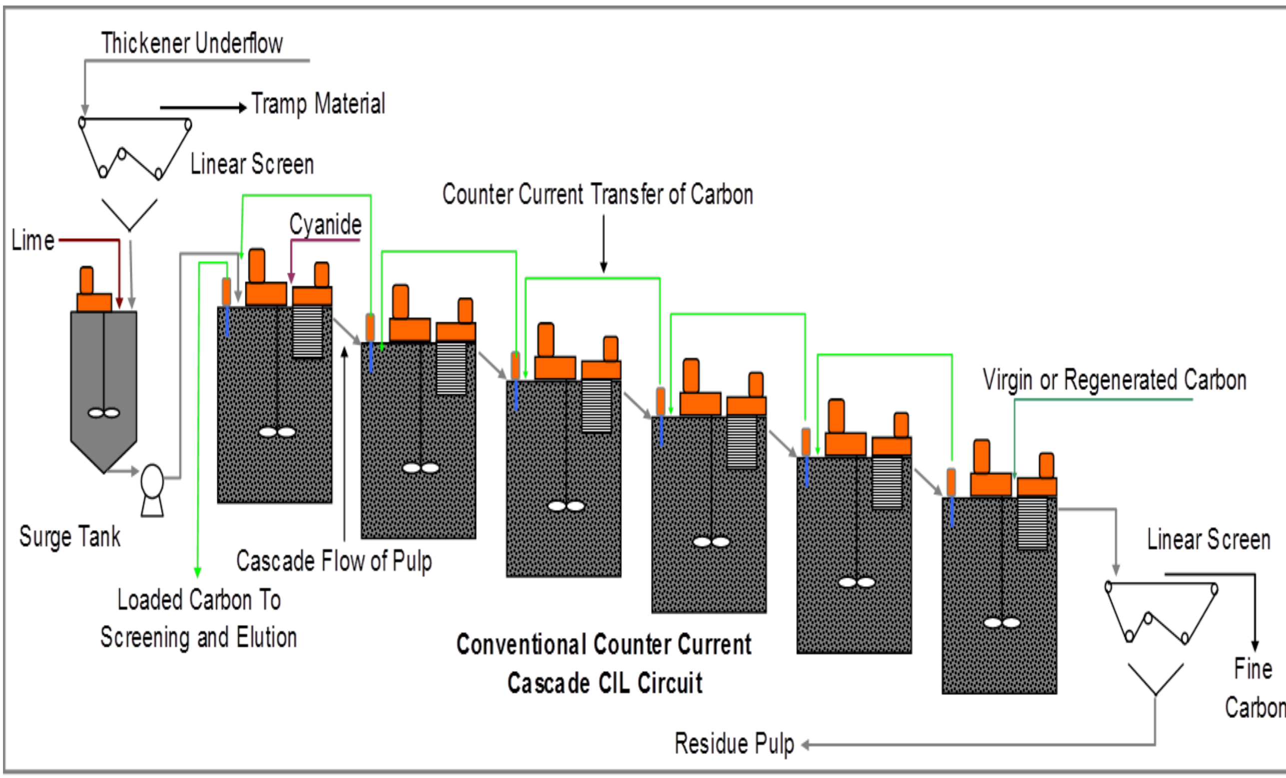
Plant variability and balancing

- Throughput.
- Head Grade.
- Density.
- Carbon Movement Rate / Concentration.
- Eluted Carbon Value.
- Near Size Material.
- Sampling, Sample preparation, Sample contamination.

CONVENTIONAL CIP CIRCUIT

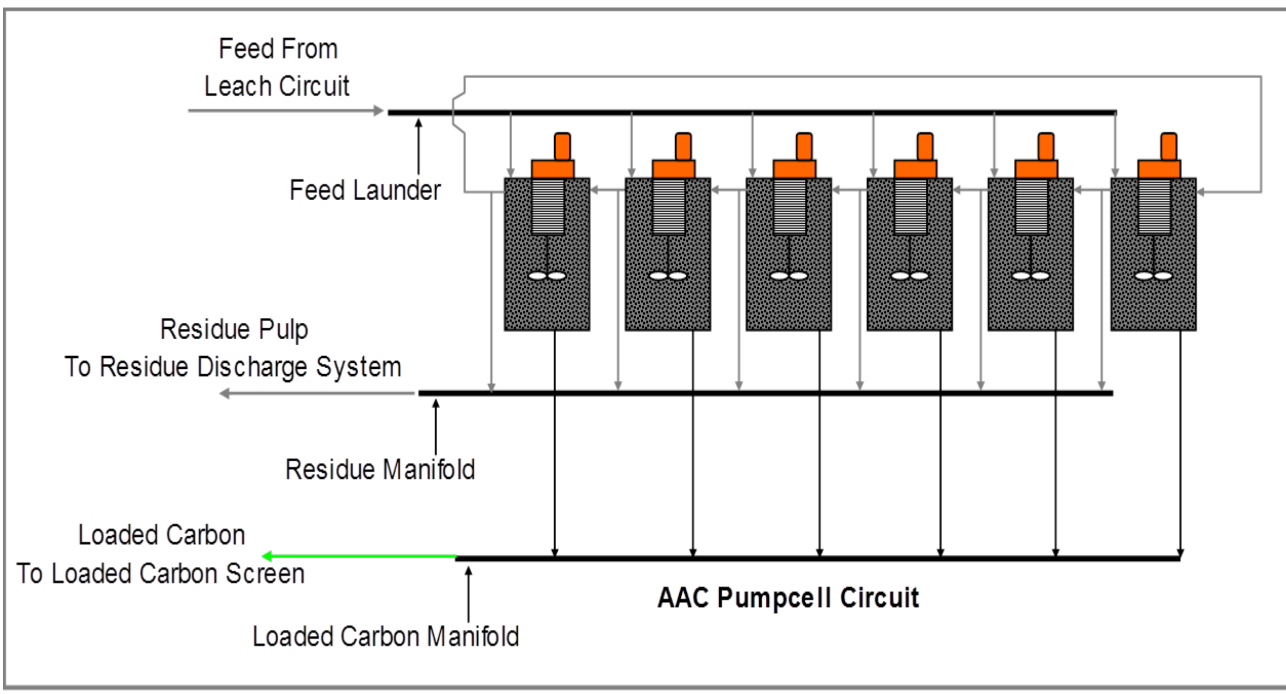


CIL CIRCUIT

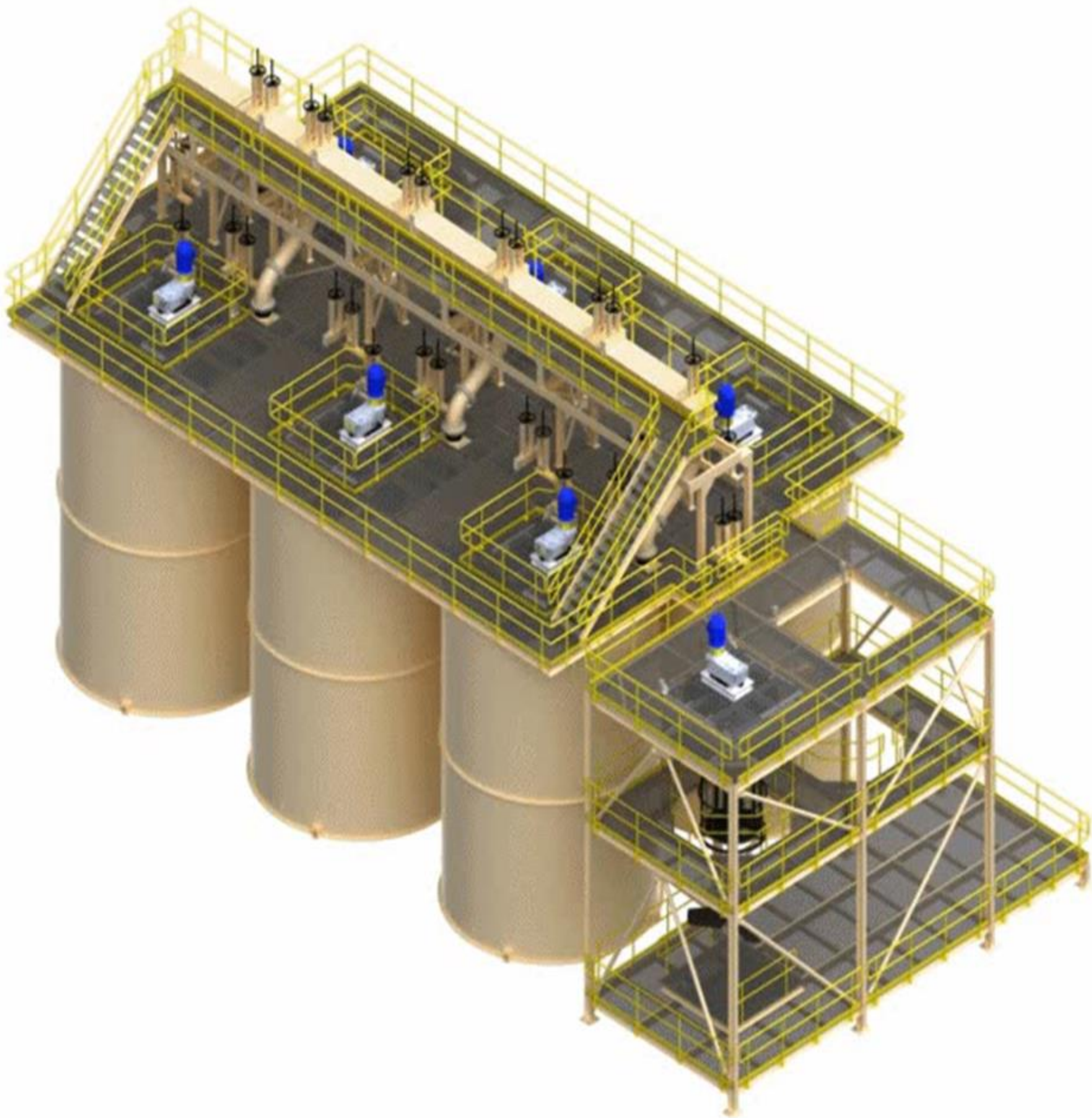


Thickener Underflow
Tramp Material
Linear Screen
Counter Current Transfer of Carbon
Cyanide
Lime
Virgin or Regenerated Carbon
Surge Tank
Cascade Flow of Pulp
Linear Screen
Loaded Carbon To
Screening and Elution
Conventional Counter Current
Cascade CIL Circuit
Fine
Carbon
Residue Pulp

KEMIX PUMPCELL PLANT



PUMPCELL PLANT



THE PUMPCELL PLANT

55 000 tpd Pumpcell CIP plant.

CIL, CIP, PUMPCELL COMPARISON

PARAMETER	Unit	CIL	Leach / CIP	Leach / Pumpcell
Feed Rate	t/month	250,000	250,000	250,000
Percentage Solids	%	45	45	45
Pulp Density	t/m^3	1.41	1.41	1.41
Flow Rate	m^3/h	549	549	549
Head Grade (Au)	g/t	1.52	1.52	1.52
Theoretical Gold Production	kg/month	323	323	323
Theoretical Upgrade Ratio	No.	900	1,100	1,490
Loaded Carbon Grade	g/t	961	1,174	1,591
Loaded Carbon Eluted	t/month	355	287	210
Elution Plant Required	ton	12	10	7
Leach Residence Time	hours	18	18	18
Volume of Leach Tanks	m^3	1,650	1,650	1,650
Volume of Adsorption Tanks	m^3	0	550	150
Carbon Concentration	g/l	10	20	50
Carbon Inventory	ton	99	66	45
Back Mixing	m^3/h	148	60	0
Back Mixing	%	27	11	0
Adsorption Residence Time per Contactor	minutes	0	60	16
Regeneration Kiln Size	kg/h	600	500	350
Number of Electrowinning Cells Required	No.	5	5	4

OPERATING COST COMPARISON

	Unit	CIL	Leach / CIP	Leach / Pumpcell
LEACH - ADSORPTION				
Feed Rate	t/month	250,000	250,000	250,000
Operating Cost (Leach - Adsorption)	ZAR/ton	1.500	1.500	1.500
Operating Cost (Leach - Adsorption)	ZAR/month	375,000	375,000	375,000
ELUTION - REGENERATION				
Carbon Treatment Rate	t/month	355	287	210
Operating Cost (Elution - Regeneration)	ZAR/ton (carbon)	4,500	4,500	4,500
Operating Cost (Elution - Regeneration)	ZAR/month	1,595,682	1,292,657	943,331
OPERATING COST	ZAR/month	1,970,682	1,667,657	1,318,331
OPERATING COST	ZAR/ton	7.88	6.67	5.27