AACHEN

HIGH SHEAR REACTORS

MAELGWYN

BACKGROUND

AACHEN REACTOR USAGE:

Aachen reactors can be used to **increase the leach kinetics** in gold and silver cyanidation resulting **insignificantly higher gold recoveries.** The Aachen reactors can be used on most gold ore types including:

- REFRACTORY ORES
- OXIDES
- TRANSITIONAL MATERIAL
- GOLD TAILINGS RETREATMENT

The Aachen reactor is a **highly efficient** mass transfer device developed out of the experience with Maelgwyn' s Imhoflot flotation technology. The unit can be used for any application where it is required to **intimately mix gas with a liquid** but has been found to be particularly suitable for gold leaching applications where it is required to **boost the dissolved oxygen levels of slurry** either prior to, or during the leach reaction.

In many operations, this has been done by **various types of lance arrangements** and their derivatives. However:

1. **Lances** by their very nature **tend to be very inefficient resulting in large oxygen bubbles and high oxygen consumptions.**
2. They **fail to address the problem of surface passivation** from oxidised species which **can retard the leach dissolution process.**

The Aachen shear reactor in contrast is able to **produce significantly higher dissolved oxygen levels** whilst also introducing an element of shear to clean up mineral surfaces.

THE NET BENEFITS:

- ✓ **Higher** gold **recoverie**s/**lower residue** grades
- ✓ **Accelerated** leach kinetics
- ✓ **Reduced** cyanide consumption
- ✓ **Improved** oxygen utilisation
- ✓ **Increased** tonnages without compromising recovery

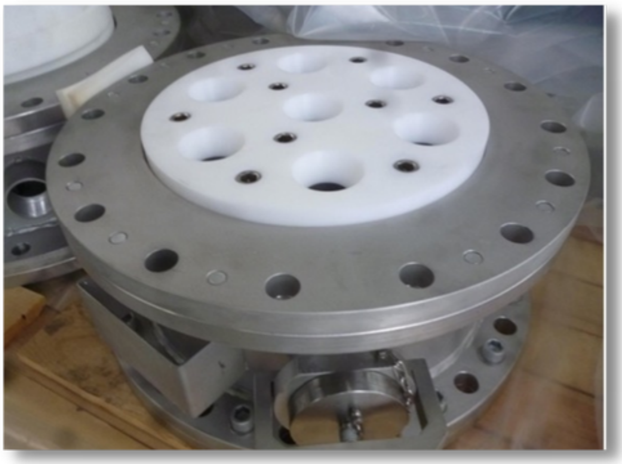


Photo: Current Aachen Reactor Design

The reactors are **particularly suitable** for the treatment of transitional material consisting of a **mixture of oxide and sulphides** where sulphide grades are too low and erratic for flotation but nevertheless compromise leach efficiency and cyanide consumption.

As mentioned above the Aachen reactors can be used on a **variety of ore types** to **increase** gold and silver **recoveries** but the way that the Aachen reactor is used will vary according to the ore type.

CURRENTLY THERE ARE OVER 60 AACHEN REACTORS INSTALLED WITH THE MAJORITY USED FOR PRE-OXYGENATION OR AACHEN ASSISTED LEACHING.

AACHEN REACTOR CONSISTS OF:

The complete **reactor is mounted vertically on a leach or pre-leach tank. Feed** to the Reactor is **pumped via a variable speed pump** into Reactor with the **oxygenated slurry returning to the leach tank**.

Additional turbulence and shear is created within the subsequent **four chambers** which again contain **nozzles** through which the slurry is forced.

Gas is introduced into the slurry **via a slot contained in silicon carbide tubes** contained within the cartridge.

A **cartridge insert** which is used to **introduce gas** under a pressure of approximately **8 bar.**

Slurry is **accelerated through the tubes** to a **speed** of approximately **12-13m/s** at the gas addition point resulting in the **generation of extremely fine gas bubbles.**

Photo: Dissolved Oxygen Impact

WHY AACHEN REACTORS WORK

THE AACHEN REACTOR IS SPECIFICALLY DESIGNED TO MEET ALL THE REQUIREMENTS FOR GOLD CYANIDATION.

1. **Dissolved Oxygen** (DO) is **often the rate limiting factor.**
2. **Additional NaCN will not** dramatically increase recovery. Often leads to **complex cyanide species** and **higher cyanide** in tailings.
3. Oxygen is a **high opex reagent** that ensure that the OUE of the **O2 introduction technology is as high as possible.** Aachen vs Spargers, Lances, In-line bubbling, Cones, Serrated rings.

AACHEN TYPICAL DO IMPACT

Typical DO levels for Aachen Tanks
- 40ppm dO2
- Super-saturated slurry state

Removes the rate limiting step from Elsner's equation
- Increased leach kinetics

WHY AACHEN REACTORS WORK

To determine the **potential suitability** of an oxygen addition device to **improve cyanidation** a basic understanding is needed of the **cyanidation reaction** itself and the factors driving it and importantly the role of oxygen.

Cyanide = one of the **major drivers** of gold dissolution **BUT** cannot be viewed in **isolation** in respect of the relationship between cyanide and oxygen derived from **Elsner's equation.**

ELSNER'S EQUATION:

$$4\ \mathrm{AU} + 8\ \mathrm{NACN} + \mathrm{O_2} + 2\ \mathrm{H_2O} \rightarrow 4\ \mathrm{NA[AU(CN)_2]} + 4\ \mathrm{NAOH}$$

Both cyanide and oxygen are **required** in an aqueous solution to leach gold. For the **leaching of pure gold**, the stoichiometry of Elsner's reaction gives the **required molar ratio of free cyanide to oxygen** as 8:1.

Dissolved Oxygen (DO) is often the **rate limiting factor**. Additional cyanide will **not dramatically increase recovery**, and can:

- Often leads to **complex cyanide species**
- **Higher cyanide** in tailings

Oxygen is a **high opex reagente**:

- Ensure that the OUE of the **oxygen introduction technology** is as high as possible
- Aachen vs Spargers, Lances, In-line bubbling, Cones and Serrated rings

The **rate of dissolution of gold in alkaline cyanide solutions** is controlled by the **rate of dissolution of oxygen from the bulk solution** to the metal surface.This is why the **Aachen Reactors are successful** in boosting leach kinetics and reducing reagent consumption as they are specifically **designed to maximise the phase interface surface area.**

In practice **significantly more oxygen is required** to maintain gold dissolution due to numerous side reactions that also take place consuming oxygen and so potentially "starving" the leach of oxygen. The net effect of this can be to **slow down leach kinetics** or even, potentially **bring the leach to a halt**.

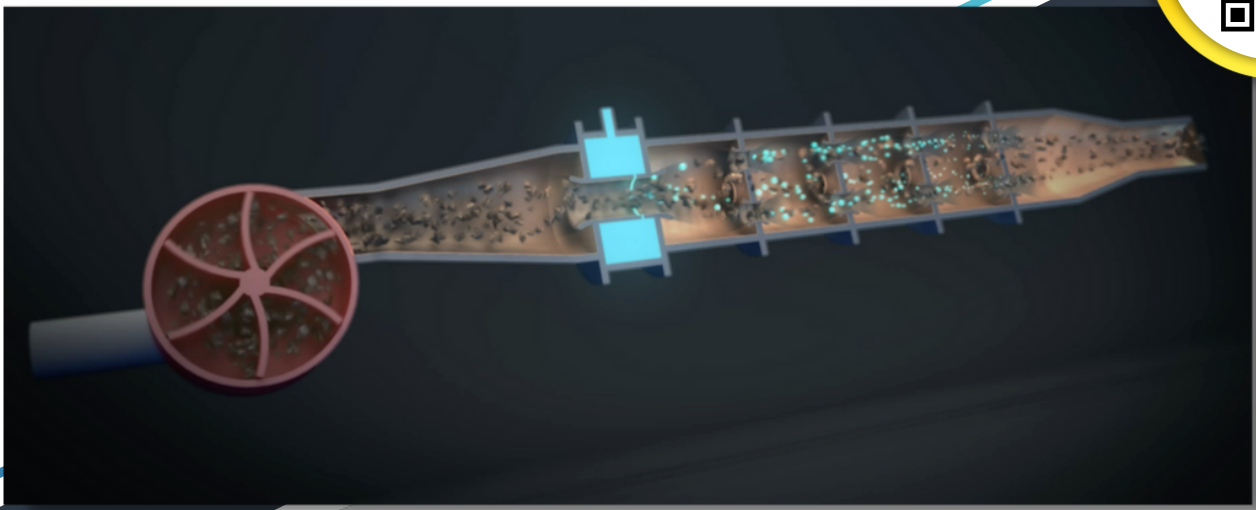
In certain processes it may also be **beneficial for some side reactions to be encouraged** e.g. partial sulphide oxidation of gold bearing minerals such as in the Leachox™ process, depending on the gold deportment within the mineralogical phases.

The **reactions consuming oxygen** (and often cyanide as well) can be categorised in terms of increasing oxygen demand into two basic groupings namely:

1) Solution species
2) Solid species

WATCH THE VIDEO:

AACHEN REACTOR DESIGN



SOLUTION SPECIES OXIDATION

Some of the **mineralogical phases** might dissolve and react in the **comminution circuit** ahead of the main leach circuit and thus **lead to solution species prone to oxidation.** The circuit process water might also contribute to these species. **The more important of these include:**

01

FERROUS IRON

The **oxidation of Ferrous to Ferric** (Fe^{2+} to Fe^{3+}) requires ¼ O_2 for each iron in solution to be oxidised. Hence, **without the further addition of oxygen**, a 50 ppm Fe^{2+} in solution could consume the entire mass of oxygen contained at usualequilibrium values. Therefore, at Fe^{2+} levels exceeding 10-20 ppm, it is **advisable to apply pre-oxidation to reduce the oxygen consumption** during the leach (and also prevent ferro-cyanide formation at the same time). The **mass of oxygen required is relatively low** and addition could be achieved using lances or other low efficiency mass transfer devices.

02

SULPHUR SPECIES

Unstable products of sulphide dissolution may also **consume oxygen to form thiosulphate or poly-thionates.** The oxygen consumption for these species is higher than the iron oxidation, but the kinetics tend to be slower.

Where **fresh meta-stable sulphur compounds** are present in solution, more aggressive pre-oxidation might be advisable to try and **convert them away from thiocyanate forming species**. The oxygen mass requirements are still **relatively moderate.**

SOLID, MINERAL PHASE COMPONENTS

Whilst **solution species oxidation largely prevents the slowdown of gold leach kinetics** due to inadequate oxygen levels as well as **limiting cyanide consumption** due to iron or sulphur, the solid phase oxidation may be **unavoidable, desired and targeted, or best restricted.**

Minerals very **easily oxidised** and would **consume nearly the same mass of oxygen** to be transformed to sulphate and ferric hydroxide **include:**

1. **Pyrrhotite** (Fe_7S_8): For each 1 kg of sulphide oxidised in the leach feed approximately 1 kg of oxygen would be required if the oxidation reaction were to advance to completion. Pyrrhotite may fall into the category of unavoidable oxidations and must be accommodated to a degree whether the mineral is gold barren or not.
2. **Arsenopyrite** (FeAsS) would consume roughly an equivalent of oxygen equating to half the mass of arsenopyrite to be oxidised. The oxidation kinetics of this reaction are reasonably fast.
3. **Pyrite** (FeS_2) would consume the same mass of oxygen for each mass equivalent pyrite transformation to sulphate and ferric hydroxide. The kinetics of this reaction are significantly slower than those of pyrrhotite and pyrite.

Arsenopyrite and pyrite are often associated with gold and hence the dissolution of these matrix minerals might be deliberately targeted through oxidation in order to release encapsulated gold.

FILM BOUNDARY LAYER EFFECTS

Whether it is the dissolution of **relatively coarse free gold**, the **oxidation of gold containing sulphides** or the **diffusion of either oxygen or cyanide** to the solid interface, the reaction kinetics are driven by the **film boundary layers.**

With **less agitation or shear**, the layer will be thicker than under conditions of raised shear.

A REDUCTION IN FILM BOUNDARY LAYERS CAN INCREASE THE GOLD DISSOLUTION REACTION RATES SIGNIFICANTLY. NET BENEFITS CAN INCLUDE:

1. **REDUCED** residence time (allowing for **higher throughput**) if coarse gold is present
2. **INCREASED** gold recovery if the **partial dissolution of sulphides** renders some gold leach amenable (either matrix mineral dissolution or opening up of lixiviant access areas)

THE SIDE EFFECTS TO BE ASSESSED (DEPENDING ON ORE) ARE:

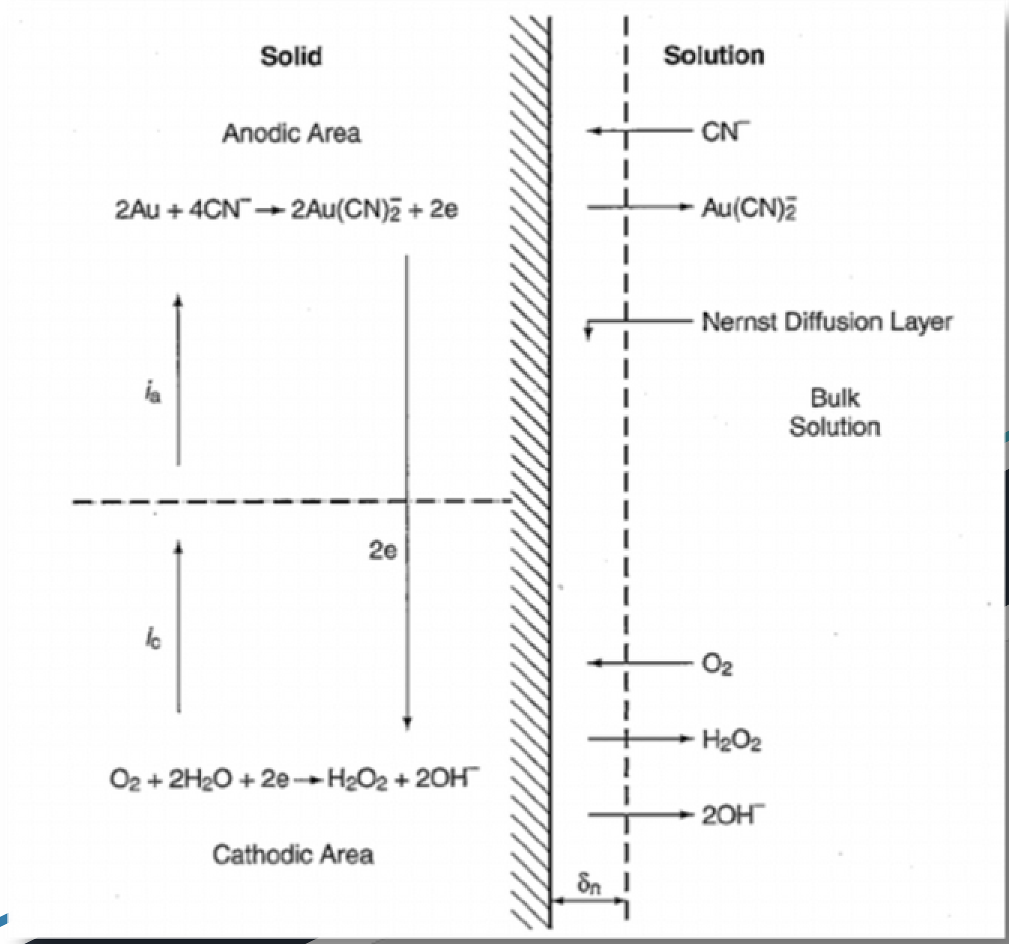
1. **Unwanted oxidation reactions** (barren sulphides with no direct benefit from Au)
2. Where a **high oxygen level induced surface coating** with iron oxide may support passivation and thus slow down reagent consuming side reactions

The **constant polishing of particle surfaces** at high shear in the Aachen Reactor **prevents surface oxide film formation.** Whilst this can be a desirable outcome where a sulphide matrix has to be oxidised; it would be detrimental in the case of barren mineral phases where the surface film inhibits unwarranted sulphide dissolution.

The **degree of shear required therefore requires careful assessment** during laboratory trials.

NERNST DIFFUSION LAYER

Schematic representation of the **local corrosion cell at a gold surface** in contact with an **oxygen-containing solution.**



KEY:

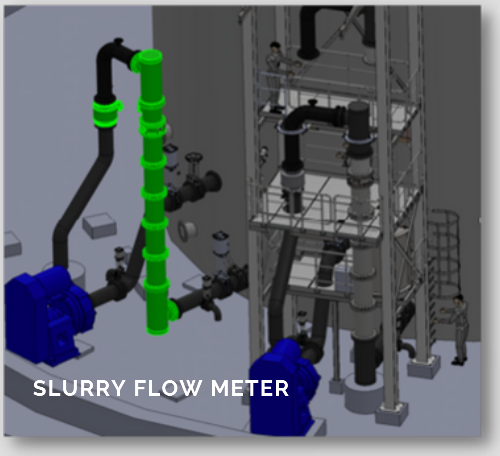
i_a = the anodic current;

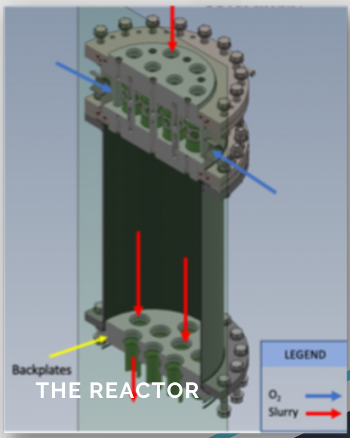
i_c = the cathodic current

AACHEN SIZING AND DESIGN

Aachen reactors are **designed to handle a range of throughputs** the most popular are:

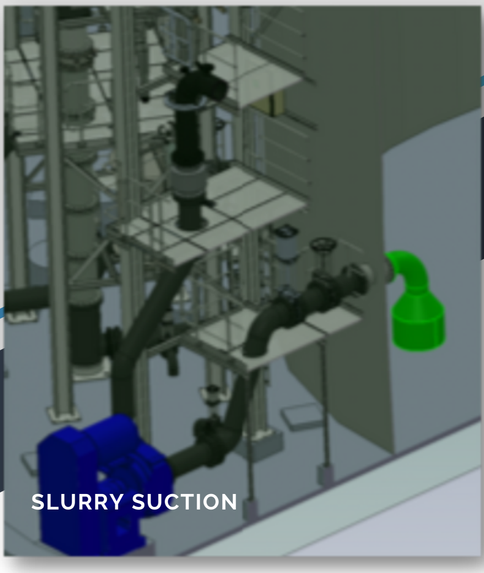
1. The **slurry is accelerated** through the Aachen reactor where it is contacted with the oxygen under a slight **pressure generated by the pump**. This **meets the conditions** required for **optimum gold cyanidation.**
2. The oxygenated **slurry is returned to the same tank**. The acceleration of the slurry and mixing within the **aeration cartridge and subsequent mixing chambers** results in a high degree of shear which **removes passivating films** as they form and thins the boundary layer thus **turbo boosting gold dissolution.**
3. The Aachen reactor requires a screened feed to **prevent tramp material damaging the Aachen internals.** As most gold dissolution plants use **carbon-based technologies (CIL/CIP)** this screening is an inherent part of the process and satisfactory providing it is maintained and operated correctly.


SLURRY FLOW METER

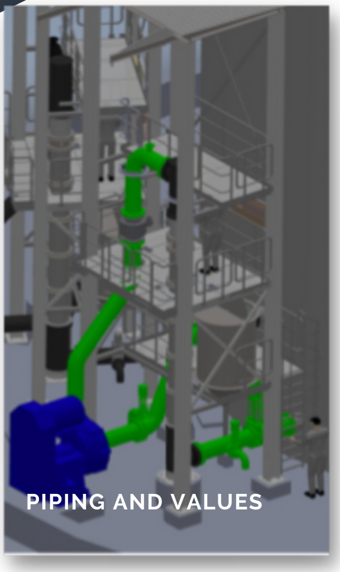


THE REACTOR


WATER SEALING AND FLUSHING SYSTEM


SLURRY SUCTION


FIRST PLATFORM

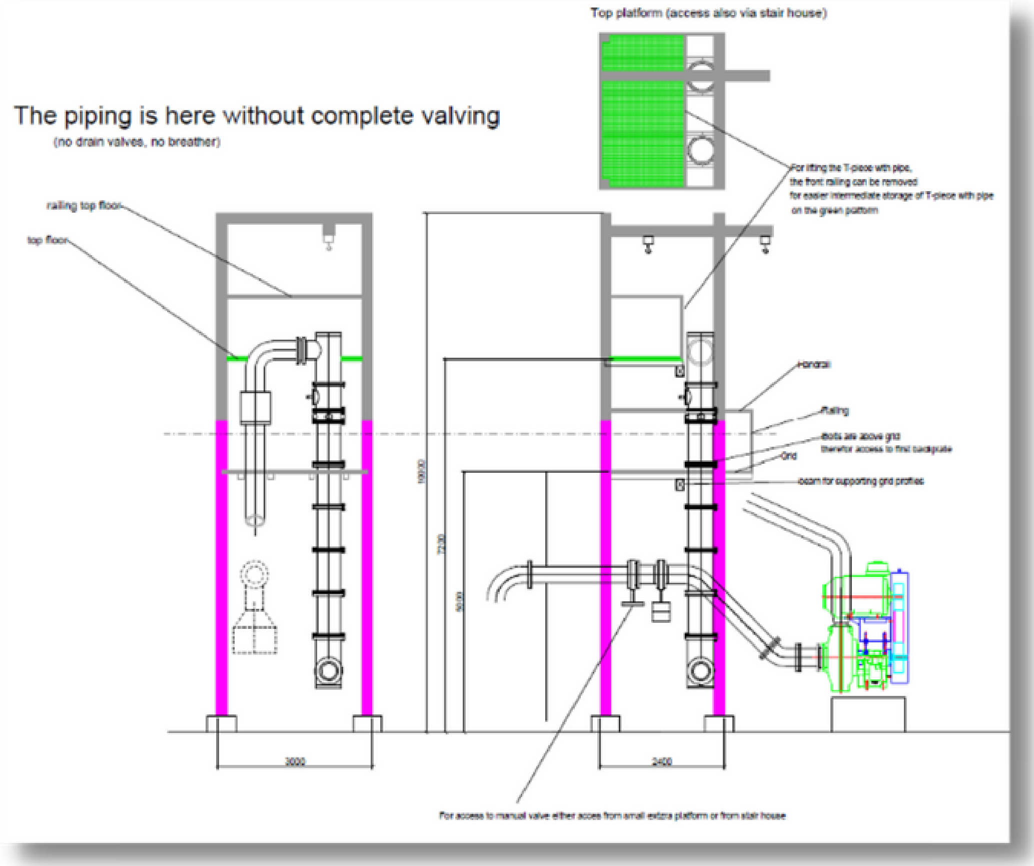

PIPING AND VALUES

REA450 STANDARD MODEL (100,00 T/MONTH, 2 PASS SYSTEM)

AACHEN	SLURRY FLOW, m^3/h	RECOMMENDED PUMP SIZE PER UNIT	TYPICAL MOTOR SIZE REQUIRED kW	O_2 MASS FEED RANGE AROUND OPTIMUM
REA 450	Low - 500 Optimum - 650 High - 750 High High - 850	Warman 10/8 or equivalent	200	Idling - 25 kg/h Shear Optimised - 70 kg/h Initial Commissioning - 130 kg/h dO2 optimised - 190

REA450 AMD SECTION VIEW

SUBJECT TO CONFIRMATION BY MAELGWYN PROJECT EXECUTION TEAM AND CLIENT. SHOWN HERE FOR ILLUSTRATIVE PURPOSES ONLY.

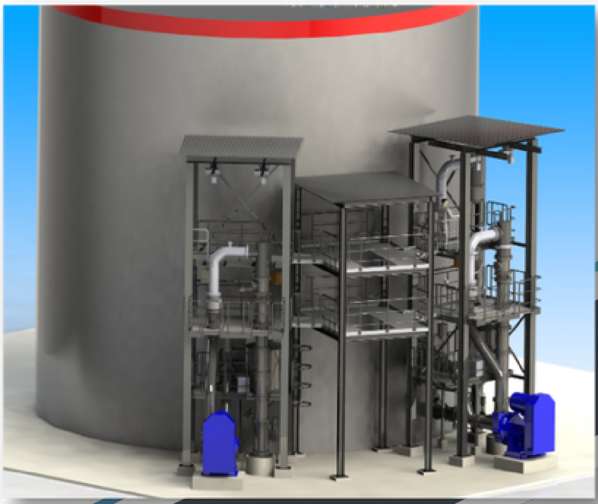


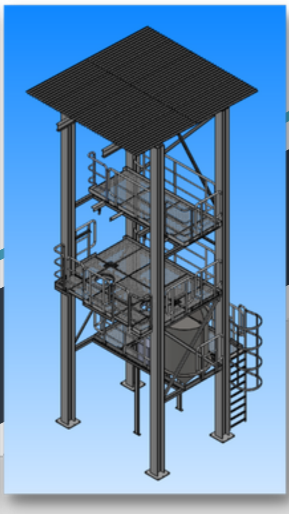
MODULAR DESIGN CONCEPT

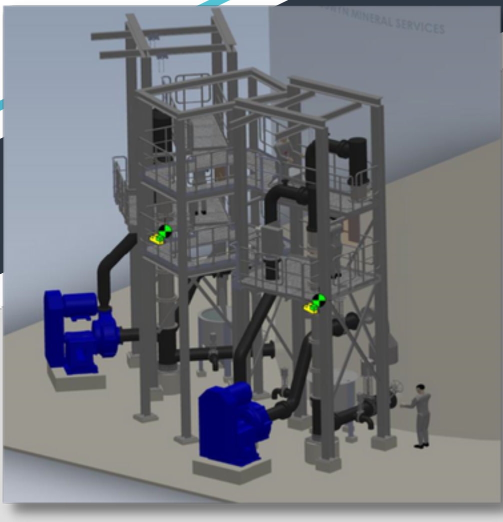
DIMENSIONS
- Height: 9.92 m
- Width: 2.8 – 3.0 m
- Depth: 2.4 – 2.5 m

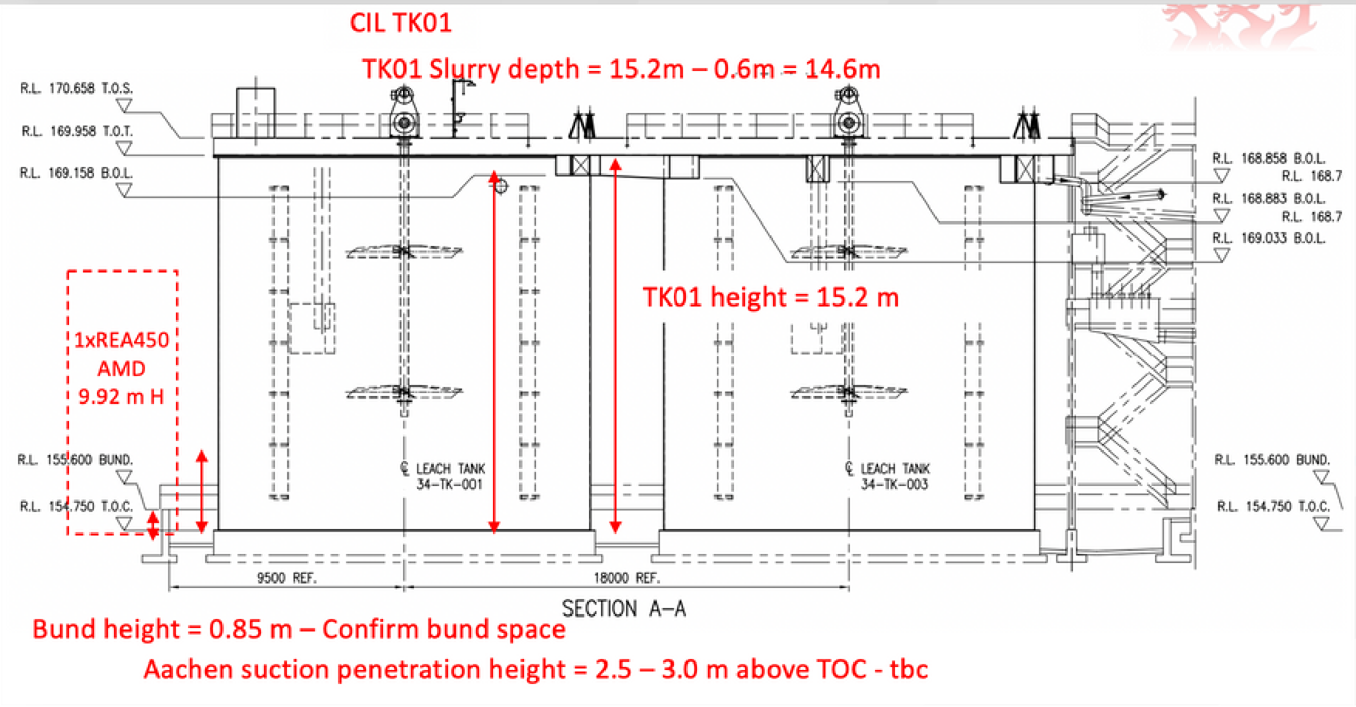
WEIGHT
- Steelwork frame: 7,650 kg
- Stairs -TBC
- REA450 - 928 kg
- PUMP -TBC

PUMP
- Warman 10/8
- 200 kW motor with VSD









CIL TK01

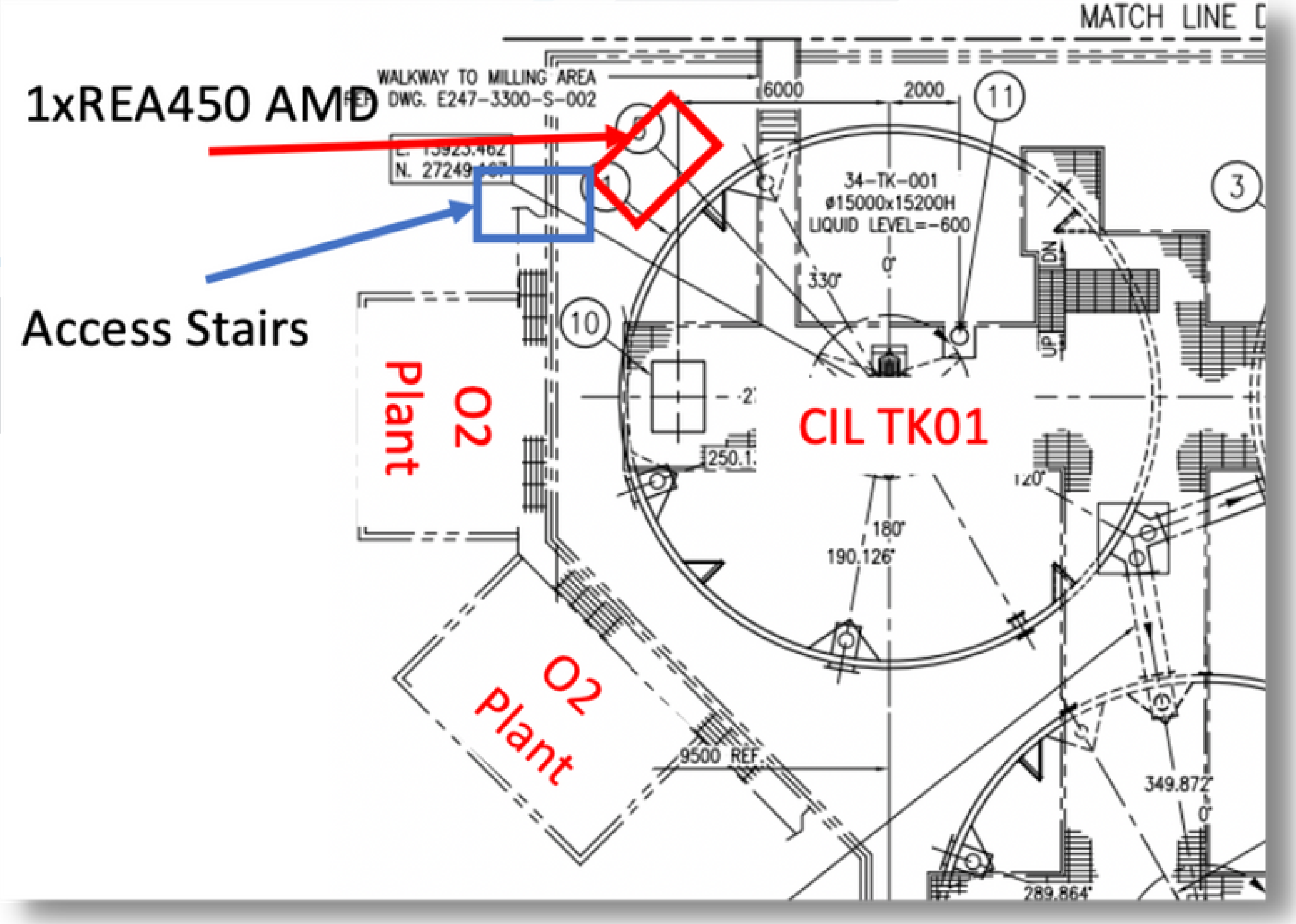
TK01 Slurry depth = 15.2m – 0.6m = 14.6m

TK01 height = 15.2 m

1xREA450 AMD 9.92 m H

Bund height = 0.85 m – Confirm bund space

Aachen suction penetration height = 2.5 – 3.0 m above TOC - tbc

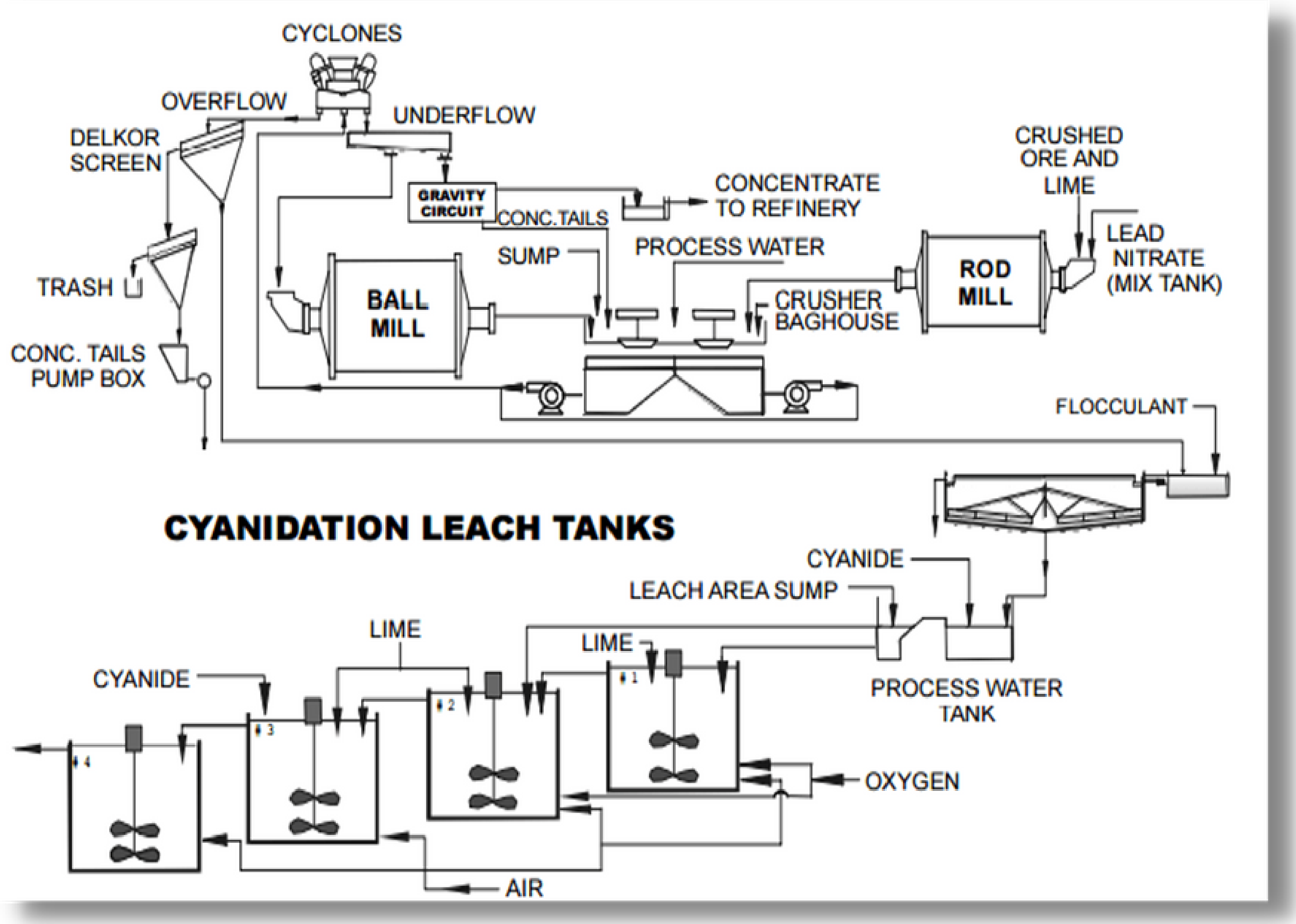


1xREA450 AMD

Access Stairs

CYANIDE LEACH CIRCUIT

POSITION IN A CYANIDE LEACH CIRCUIT (AACHEN RETROFIT)



INSTALLATION

The Aachen reactors would **normally be installed vertically** on the top of the pre-oxygenation/leach tank and are fed by a dedicated variable speed centrifugal pump. **Oxygen is required** to be added to the Aachen reactor. This oxygen would be sourced either from a liquid supply or generated on site for more remote sites using a PSA/VSA unit.

The Aachen reactor should ideally be installed with the aerator cartridge at approximately chest height with a straight length of pipe prior to the Aachen of at least 2m.

TESTING FACILITIES MAP

CERTIFIED TESTING FACILITIES

- UNITED KINGDOM: CORNWALL
- RUSSIA: TOMS
- AFRICA: JOHANNESBURG
- CHILE: SANTIAGO

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CASE STUDIES

WATCH THE VIDEO

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