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## Technical data
The story of metal mining

Today, more than 2500 mines produce metals (uranium mines not included) on a worldwide basis, and every year new mines are developed. Metal mines play a crucial role in producing and supplying raw materials for the manufacturing, construction and chemical industries.

Copper was the first metal extracted by humans from an ore around 5000 BC in Turkey. Later on bronze was discovered. By extracting tin from tin oxide ores and melting tin and copper together it was now possible to manufacture alloys, which were harder than unalloyed copper. The last discovery in ancient times (around 1000 BC) was how to smelt iron ores to make iron.

Today, metals like gold, silver, nickel, chromium, molybdenum, aluminium etc. are mined and extracted for industrial use.

Apart from Antarctica (which has a treaty in place preventing short to medium term exploitation and exploration of minerals), mining takes place in all of the world’s continents. Traditional mining countries such as the USA, Canada, Australia, South Africa and Chile dominate the global mining scene.

The largest amount of uranium mining takes place in countries like Canada and Australia followed by Kazakhstan and South Africa.

A few definitions

Metal mining is the process of digging into the earth to extract naturally occurring metallic minerals. There are many techniques for extracting metallic minerals from ores. Depending on its properties, each kind of ore is separated by different techniques.

Minerals are solid elements or compounds found naturally in very old rocks (in the Earth’s crust). The oldest known rocks date back nearly four billion years. Those minerals that contain sufficient metal to be of practical and economic use are called ores. Most metals found in the Earth’s crust exist as oxide and sulfide minerals.

Pumps in mining?

Pumps are used for multiple purposes in mining:

- Raw water supply
- Leach solutions
- Chemicals
- Dewatering
- Acid mine drainage
- Process water in metal recovery plant

Centrifugal pump used for conc. sulphuric acid in uranium mining.
Basics on extraction processes

There are three basic ways of treating metallic ores in order to extract their metal content: Pyrometallurgy, electrometallurgy and hydrometallurgy.

**Pyrometallurgy**, is a process that uses high temperature to transform metals and their ores.

**Electrometallurgy**, is a process of separation of metals from ore through an electrical process, or the purification of metals through an electrical process.

**Hydrometallurgy**, is a process that uses aqueous chemistry to separate metals from their ore (leaching, precipitation, cementation, solvent extraction, and ion exchange).

As the concentration of desired metal becomes less in the ores mined, the wet processing of the more valuable metal ores becomes more feasible. This extraction method most often involves the use of acid, typically diluted sulphuric acid in order to dissolve metal from the ore. Depending on the ore composition other agents will be dissolved as well, including silicates, sulphates, carbonates, oxides and chlorides.

In this paper we primarily deal with the hydrometallurgy extraction process.

**In situ leaching process (ISL)**

The in situ leaching process (ISL) is normally used to extract uranium. First a dilute sulphuric acid solution together with an oxidizing agent (e.g. oxygen) is pumped down an injection well, where it flows through the deposit and dissolves the uranium.

Then, the uranium-bearing solution is pumped back to the surface through extraction wells, leaving the underground rock formation intact. Uranium is subsequently extracted at a central processing facility and the raffinate recycled. Before the raffinate is reinjected, it is oxygenated and if necessary recharged with sulphuric acid. This mining technique produces no waste rocks (tailings).
Acid heap leaching

The acid heap leach process is the most simple extraction method and is used to extract low-grade mineral deposits. First a large heap of crushed ore is built (e.g. copper oxide) and the surface of the heap is irrigated with a dilute solution of sulphuric acid. As acid permeates through the heap, it dissolves the metal in the ore and forms an ionic solution (leaching solution).

Then the leaching solution is collected at the bottom of the heap, usually on an polymer liner. Subsequently, the saturated leach solution (Pregnant Leach Solution - PLS), is pumped away for further treatment. Depending on the metal being recovered and the chemical constituents of the ore, the treatment process is carried out using various chemical processes.

The development of effective heap leaching techniques has allowed large low-grade mineral deposits to be effectively and economically treated.

Bio heap leaching

Bio heap leaching is used commercially and covers certain natural bacteria’s ability to leach metals from sulphide minerals.

The bioleaching extraction method is used to extract, e.g. copper, gold and nickel, and involves several steps.

First a large heap of crushed ore is built, (e.g. copper or nickel sulphides). Then, like it is the case with acid heap leaching, the heap is irrigated with a diluted sulphuric acid, in this case containing bacteria and nutrients. In addition, the heap is aerated to stimulate bacterial growth.

The bacteria convert sparingly soluble metal compounds into water-soluble metal sulphates.

The fact that it is possible to leach sulphide minerals is what distinguishes bioleaching from conventional acid leaching where only oxidized minerals are leached.

General considerations for acid and bioleaching

Metal mines may generate highly acidic mine discharges (acid mine drainage) where the ore is a sulphide because bioleaching also occurs naturally when sulfides are exposed to air and water.

This means that mining activities has to be planned and conducted to prevent accumulation of water in the pit and in tailings (waste rock).

All groundwater or surface run-off must be collected and pumped to an appropriate treatment facility. Discharges that do not meet the water quality criteria established in the permit must be treated.

Although heap leaching is a low-cost process, only some 60-90% can be recovered. Therefore it is normally only used in connection with low-grade ores. Higher-grade ores are usually subject to more complex milling processes. The actual process depends on the metallurgical properties of the ore.
The impact of mine water on pump choice

Aggressive mine water and chemicals used in mining may lead to corrosion, erosion and incrustation problems on pipes, well screens, ponds, bridges, water intakes and pumps.

Corrosion attacks on pumps is a critical issue in mining and mineral processing industries. The most common form of corrosion is uniform attack caused by sulphuric acid and localized corrosion (pitting and crevice corrosion) caused by presence of chloride.

Corrosion caused by concentrated sulphuric acid

Corrosion attack on metals due to sulphuric acid is a very complex problem. The reason is that sulphuric acid both has oxidising and reducing properties depending on the concentration. Therefore, different materials have to be used depending on these conditions.

In mining concentrated sulphuric acid is used for preparing the leach solutions.

Concentrated sulphuric acid (above 90 wt. %) is a so to speak weak acid. Therefore, pump components made of cast iron, stainless steel EN 1.4301 (AISI 304) and EN 1.4401 (AISI 316) can be used in concentrated sulphuric acid applications. Titanium on the other hand, is not a suitable pump material for concentrated sulphuric acid.

In order to get a long service life when pumping concentrated sulphuric acid, it is important to keep water (incl. humid atmosphere) from diluting the concentrated sulphuric acid, due to its hygroscopic abilities. Dilution with water renders the solution more corrosive.

Corrosion caused by diluted sulphuric acid

Often, the acid leaching solution consists of highly diluted sulphuric acid plus an oxidizing agent (such as oxygen). The leach solution normally has a pH-value of 1.5-2.5 though in some cases, it can be lower.

Sufficiently high concentrations of oxidizing agents such as Iron (III)-sulphate and Copper (II)-sulphate will render common types of stainless steel like EN 1.4301 (AISI 304) practically resistant. If the water is very acidic with a low content of these oxidizing components it is practical to employ the molybdenum-containing EN 1.4401 (AISI 316). Grundfos recommends this type of stainless steel when it is not clear whether the acidic water is sufficiently oxidized or when the water composition varies a lot. However, if the chloride content is very high, Grundfos recommends the use of stainless steel EN 1.4539 (AISI 904L) rather than EN 1.4401 (AISI 316).

Cast iron is not suitable for any solution with a pH-value lower than 6.5. Titanium, on the other hand, is superior to stainless steel when the chloride content is so high that it causes corrosion problems with stainless steel EN 1.4401 (AISI 316) and EN 1.4539 (AISI 904L).

The pH-value of dewatering solutions from pit and waste rocks is normally higher (3-7) than that of a leach solution and the corrosivity is therefore generally lower.
Corrosion caused by chloride

Depending on the geology of the mine sites the ore or groundwater contains more or less chloride. Presence of chloride in leach solutions increases the corrosivity of water. Selecting the right pump materials is thus very important.

Put in another way, material selection is the most important method of corrosion prevention. Choosing the right materials based on the water composition (pH-value, chloride, oxidizing species and temperature) reduces the risk of corrosion and prolongs the life span of the equipment.

Atmospheric corrosion

Atmospheric corrosion attacks is another important issue when dealing with pumps in mining applications. If concentrated sulphuric acid leaks from the pumps it will absorb water from the environment and form a more corrosive acid. Consequently, it will attack the pump materials from the outside. Use of stainless steel components instead of cast iron or carbon steel reduces corrosion.

Erosion

Erosion is another critical issue. Particulates are often carried in a corrosive medium through pipes, tanks, and pumps. The presence of these particulates erodes and removes the protective film of the metal and exposes the reactive metal to high flow velocity, thus accelerating the corrosion process.

Incrustation

Incrustation results from the deposit of minerals in and outside the pumps. Acidic mine water typically contains elevated concentrations of sulphate (SO₄), iron (Fe), manganese (Mn), aluminium (Al) and other ions. Under certain circumstances (such as pressure, pH- and temperature changes) these metals can precipitate from the solution.

Toxic water

Toxic water due to the presence of cyanide, arsenic, uranium etc.
Pump use and maintenance

In general, it is important to inspect and maintain pumps in mining applications on a regular basis.

Maintenance of the pump implies replacing the rotating parts such as impellers, shaft and shaft seal. A combination of factors e.g. corrosion, erosion, wear and incrustations may also cause damage to the pump.

For example in uranium mines in Kazakhstan, submersible motors are fitted with staybolts instead of standard bolts because the staybolt solution are less sensitive to galling during the frequent disassembly and assembly.

**Concentrated sulphuric acid (concentrations above 90 wt. %)**

Pump parts made of stainless steel EN 1.4401 are suitable for handling concentrated sulphuric acid. However, in certain parts of the pump (such as the shaft seal) water/humidity is present, and corrosion is consequently likely to occur.

The density of concentrated sulphuric acid is about 1,830 kg/m$^3$ and the viscosity is about 25-30 cPs. Therefore, we recommend an oversized motor and that the pump curve is corrected if necessary.

Submersible pumps are normally not used for this type of concentrated sulphuric acid.

**Leach solution**

As mentioned before the composition of leach solutions varies a lot. Basically it is a dilute sulphuric acid with a pH-value of about 1.5-2.5. However, the concentration varies and the content of other substances varies as well.

In order to get the best possible Grundfos pump solution for handling leach solutions it is crucial that the material and pump choice is based on detailed information about the liquid composition.

Mines normally have their own laboratory making frequent analysis of the leach solution possible. Getting access to the relevant data to estimate the corrosivity of the leach solution, is thus quite simple.

When submersible pumps are used for handling leach solution, it is important to be aware of the risk of ingress of leach solution into the motor.

Corrosion attack on shaft from submersible pump used for dewatering of open pit.
Dewatering, acid mine drainage

Basically, these kinds of solutions are leach solutions. However they may differ in composition. Typically, the pH-value of acid mine drainage is higher than that of leach solution. But as stated above detailed information on the solution's composition is required.

When submersible pumps are used in connection with dewatering or drainage, it is important to be aware of the risk of ingress of leach solution into the motor.

Erosion

Erosion due to sand, silicates or precipitated minerals (particulates) can be difficult to avoid. In order to avoid pump breakdown due to erosion, critical components should be replaced on a regular basis in connection with maintenance.

Incrustations

Incrustations in the mining process are normally regarded as a critical issue if it occurs. Again, in order to avoid pump breakdown due to incrustations maintenance at regular basis is crucial.

Installing pumps with small clearances increases the risk of blockage.
Where Grundfos pumps are used in mining

Grundfos pumps are used in a wide range of mining applications around the World. What follows are a few examples of where, in these types of application, Grundfos pumps are used.

Uranium mining, Australia, in situ leaching with sulphuric acid

For leach solutions with a high chloride content, Grundfos has supplied submersible pumps in high grade stainless steel EN 1.4539/ AISI 904 L.

Typical composition of leach solution (injection, recirculation):

- **pH**: approx. 1.5
- **Temperature**: approx 30°C
- **Chloride (Cl**⁻**)** content: between 5,000-10,000 ppm
- **Iron (Fe**³⁺**)**: low

Frequent maintenance is required due to exposure to corrosive solutions.
Uranium mining, Central Asia, in situ leaching with sulphuric acid

Depending on the composition of the in situ leaching solution Grundfos has supplied the following pumps for the extraction and processing of uranium:

- Vertical multistage pump (with or without electropolishing) in EN 1.4401 (AISI 316) with shaft seal type PQQV is used for dosing of concentrated sulphuric acid to adjust the pH value of the leach solution.
- Vertical multistage pump with a HQQV shaft seal for process liquids (leach solution and other sulphuric based liquids).
- Submersible pump in stainless steel (EN 1.4401/AISI 316)
- Staybolt fitted motor.
- Norm pumps in stainless steel (EN 1.4408/CF 8-M) with double shaft seal for recirculation of leach solution for well injection.

**Typical composition of leach solution (well injection, recirculation):**

- **pH:** approx. 1.5-2
- **Temperature:** 30 - 50°C
- **Chloride (Cl⁻) content:** between 1.000-1.500 ppm
- **Iron (Fe³⁺):** high
Copper mining, Chile, open pit, dewatering

Grundfos supplied submersible pumps in EN 1.4401 (AISI 316) and EN 1.4539 (AISI 904L).

Typical composition of dewatering solution:

- **pH**: between 3-7
- **Temperature**: between 10 – 20°C
- **Chloride (Cl⁻)**: between 5.000-10.000 ppm
- **Iron (Fe³⁺)**: low

To minimise the risk of corrosion, regular maintenance is conducted.
Nickel mining, Finland, (pilot project), bio heap leaching

Grundfos supplied vertical multistage pumps for irrigation of heap and for recirculation of leach solution.

Typical composition of leach solution (injection, recirculation):

- **pH**: between 1.5-2.5
- **Temperature**: between 30 – 50°C.
- **Chloride (Cl⁻)**: below 50 ppm

References

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<thead>
<tr>
<th>Country</th>
<th>Type of mining:</th>
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<tbody>
<tr>
<td>USA</td>
<td>Copper</td>
</tr>
<tr>
<td>Finland</td>
<td>Nickel / Copper</td>
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<tr>
<td>Chile</td>
<td>Copper / Gold</td>
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<tr>
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<td>Uranium</td>
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<td>Uzbekistan</td>
<td>Uranium</td>
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Technical data

Grundfos supplies a wide range of pumps for different purposes in mining applications.

DMX/DMH
Motor-driven diaphragm dosing pumps

CRN
Multistage centrifugal pumps

DME, DMS
Compact diaphragm dosing pumps

CRNE
Multistage centrifugal pumps - electronically controlled

CRN high pressure
Multistage centrifugal pumps

Technical data
Capacity, \(Q\): max. 150 l/h
Pressure, \(p\): max. 18 bar
Liquid temp.: max. +50°C

Features and benefits
• Precise capacity setting in ml or l
• Full diaphragm control - always full stroke length
• Operation panel with display and one-touch buttons
• Analog control
• Pulse-/timer-based batch control
• Easy calibration function

Technical data
Flow, \(Q\): max. 120 m³/h
Head, \(H\): max. 330 m
Liquid temp.: –40°C to +180°C
Operat. pres.: max. 50 bar

Features and benefits
• Reliability
• High pressures
• Service-friendly
• Space-saving
• Suitable for slightly aggressive liquids

Technical data
Flow, \(Q\): max. 120 m³/h
Head, \(H\): max. 250 m
Liquid temp.: –40°C to +180°C
Operat. pres.: max. 33 bar

Features and benefits
• Reliability
• High efficiency
• Service-friendly
• Space-saving
• Suitable for slightly aggressive liquids

Technical data
Flow, \(Q\): max. 120 m³/h
Head, \(H\): max. 480 m
Liquid temp.: –30°C to +120°C
Operat. pres.: max. 50 bar

Features and benefits
• Reliability
• High pressures
• Service-friendly
• Space-saving
• Suitable for slightly aggressive liquids
• Single pump solution enabling high pressure
### CRT
**Multistage centrifugal pumps**

**Technical data**
- Flow, Q: max. 22 m³/h
- Head, H: max. 250 m
- Liquid temp.: –20°C to +120°C
- Operat. pres.: max. 25 bar

**Features and benefits**
- High corrosion resistance
- All wetted parts in titanium
- Reliability
- High efficiency
- Service-friendly

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### MAXA and MAXANA
**End-suction process pumps**

**Technical data**
- Flow, Q: up to max. 800 m³/h
- Head, H: up to max. 97 m
- Operat. temp.: +95°C (+150°C on request)
- Operat. pres.: max. 10 bar

**Features and benefits**
- Optimised hydraulics
- Gentle product handling
- Materials: AISI 316 (DIN EN 1.4404)
- Service and repair friendly.

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### SP A, SP, SP-G
**4", 6", 8", 10", 12" submersible pumps**

**Technical data**
- Flow, Q: max. 470 m³/h
- Head, H: max. 670 m
- Liquid temp.: 0°C to +60°C
- Installation depth: max. 600 m

**Features and benefits**
- High efficiency
- Long service life as all components are stainless steel
- Motor protection via MP 204

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### SEN
**Submersible stainless steel pumps**

**Technical data**
- Flow, Q: max. 215 l/s (774 m³/h)
- Head, H: max. 50 m
- Liquid temp.: 0°C to +40°C
- Discharge diameter: DN 80 to DN 250

**Features and benefits**
- Flexible installation length
- Wide range
- Reliability
- Service-friendly