Design Report
Saline Water Treatment Plant

6515-E-132-013-105-REP-035

In Accordance with Water Licence 2AM-MEL1631

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DOCUMENT CONTROL

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1 INTRODUCTION

1.1 SITE LOCATION AND ACCESS

Agnico Eagle Mines Limited (Agnico Eagle) is developing the Meliadine Project (the Project), a gold mine located approximately 25 km north of Rankin Inlet, and 80 km southwest from Chesterfield Inlet in the Kivalliq Region of Nunavut. The project site is located on the peninsula between the East, South, and West basins of Meliadine Lake (63°01'23.8"N, 92°13'6.42"W). The area is accessible from the all-weather gravel road linking the Meliadine mine site with Rankin Inlet.

A general location plan for the project is shown in Figure 1.

1.2 SITE FACILITIES

The current mine plan focuses on the development of the Tiriganiaq gold deposit which will be mined using both conventional open-pit and underground mining operations. Current or proposed mining facilities to support this development include a plant site and accommodations, tailings storage facility and water management infrastructures.

Several infrastructures such as water retention dikes, berms, culverts, channels, collection ponds, pumping stations, fresh water intake and water treatment plants are required to manage water during pre-production, operation, and interim mine closure.

Facilities that are planned to be constructed for the operation of the future Meliadine Mine include a process plant, power plant, maintenance facilities, tank farms for fuel storage, water treatment plant, sewage treatment plant, saline water treatment plant (SWTP), accommodations, and kitchen facilities for 520 people.

The Nunavut Water Board (NWB) has issued Type “A” Water License No. 2AM-MEL1631 (Water license “A”) to Agnico Eagle Mines Limited (Agnico Eagle) for the Meliadine Gold Project site authorizing the use of water and the disposal of waste required by mining and milling and associated uses.

Figure 2 shows the location of the future SWTP including the pipeline between the Saline Water Pond pumping station and the SWTP, then to the final discharge into the collection pond named CP1.

1.3 PURPOSE OF DOCUMENT

This report includes the final design and construction drawings for the SWTP, including the feed pump and discharge pump to CP1. The water treated at the SWTP will be sourced from the Saline Water Pond. The effluent water from the SWTP will be pumped back through a pipeline in CP1.

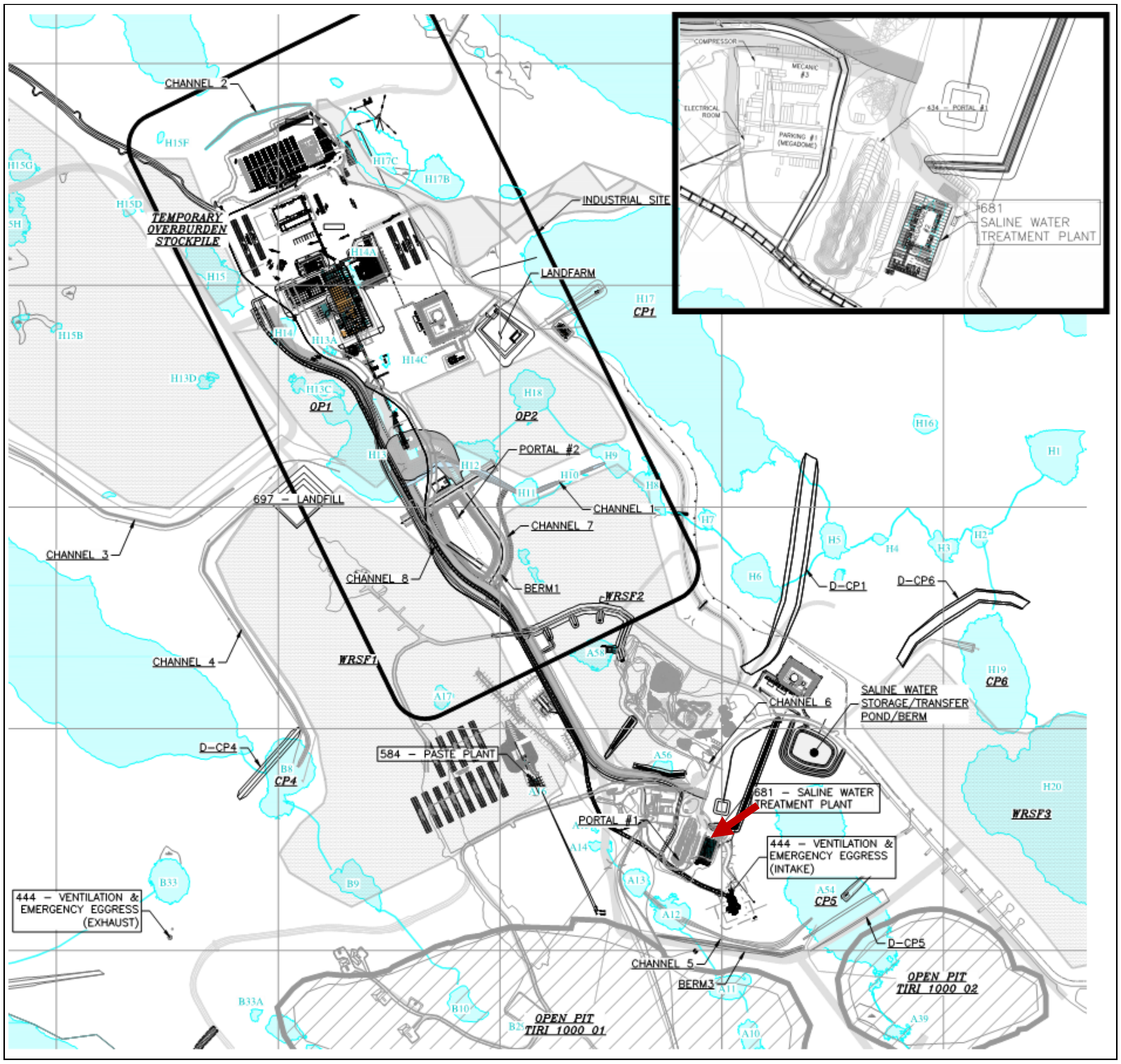

Figure 1 : Location of the SWTP

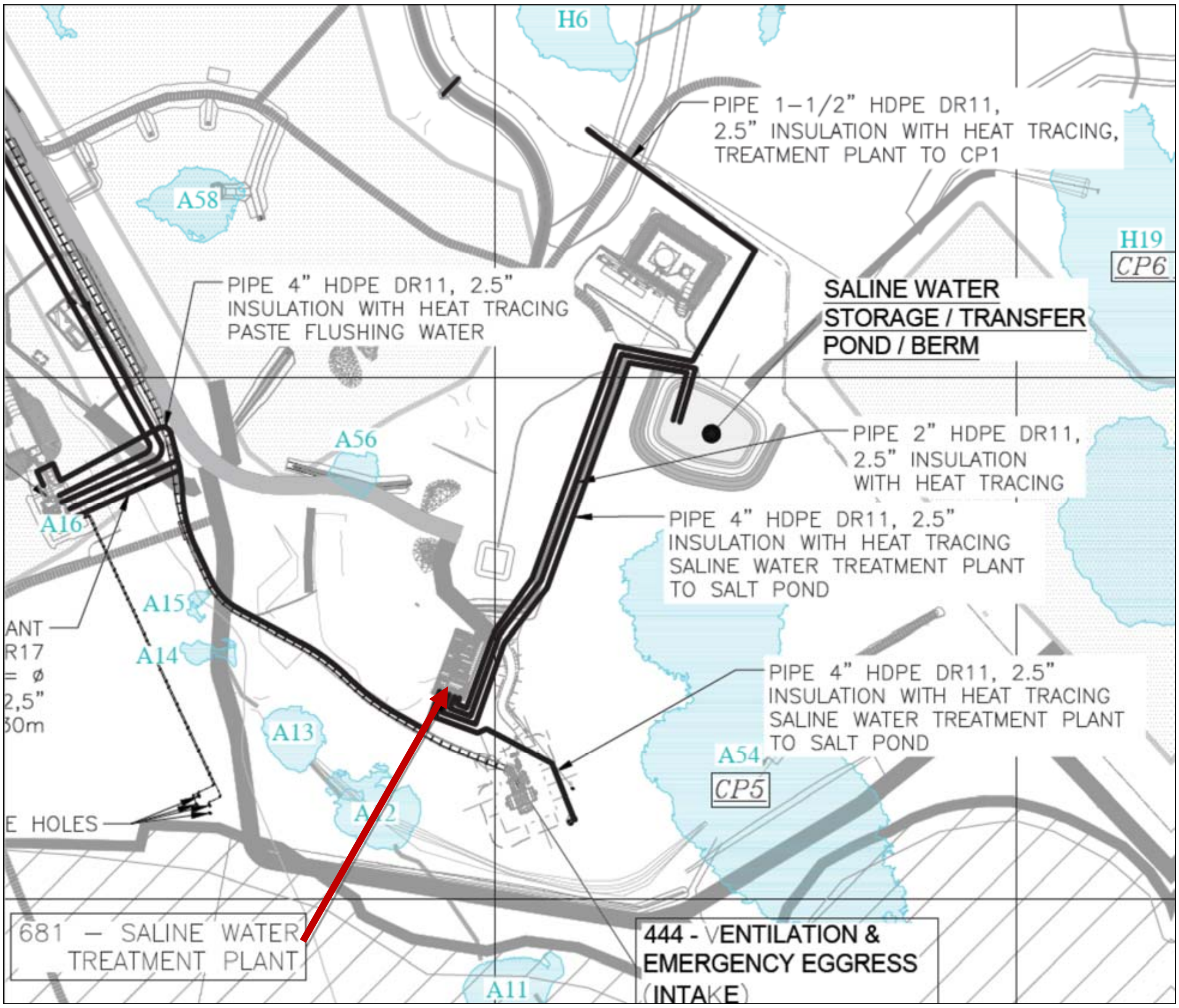

Figure 2 : Location of SWTP and Pipeline

2 DESIGN METHODOLOGY

2.1 SALINE WATER MANAGEMENT STRATEGY

Underground saline water is firstly stored in an underground stope that has a total capacity of approximately 11 000 m^3 and is then transferred to the surface Saline Pond which has a total storage capacity of approximately 33 000 m^3. From there, the saline water will be transferred to the SWTP for treatment. The storage capacity is managed to keep the saline pond and stope volumes as low as possible, in order to have enough space for abnormal flow condition or SWTP shutdown.

2.2 METHODOLOGY

The SWTP design was based on hydrogeology and underground water quality data collected on a regular basis in the underground mine that is currently under development. Effluent quality of the SWTP are set to comply with the Licence A requirements.

2.1 WATER CHARACTERISTICS

The SWTP is designed based on water quality of underground water inflow. Table 1 presents the water quality used for the design of the SWTP.

Table 1 : Feed Water Quality[1]

Representative Months		May 2016	June 2016	August 2016	September 2016	October 2016	November 2016	December 2016	February 2017	March 2017
Parameters (total metal)	**Units**									
Aluminum (Al)	mg/L	9.55	12.5	3.9	0.1	5.85	12.2	6.81	1.2	4.02
Ammonia Nitrogen (NH_3-NH_4)	mg/L	885	827	596	545	230	260	290	400	440
Arsenic (As)	mg/L	6.551	<0.1	0.4	0.22	0.252	0.0646	0.0355	0.011	0.024
Cadmium (Cd)	mg/L	0.00197	0.67	0.37	0.55	0.0002	0.00052	0.00182	<0.0010	0.0017
Chloride	mg/L	86 824	59 000	32 000	39 000	33000	45000	61000	67000	77000
Copper (Cu)	mg/L	0.14	0.15	0.08	0.17	0.014	0.03	0.029	<0.050	<0.050
Iron (Fe)	mg/L	28.5	15.2	1.31	0.37	12.4	23.7	13.4	<1.0	5.4
Lead (Pb)	mg/L	0.0097	0.37	0.32	0.2	0.0081	0.0151	0.0241	<0.020	0.022
Mercury (Hg)	mg/L	0.00154	<0.01	<0.01	<0.01	0.00001	0.00003	<0.00001	nd	<0.00001
Molybdenum (Mo)	mg/L	0.0886	N/A	N/A	N/A	0.059	0.055	0.056	<0.10	<0.10
Nickel (Ni)	mg/L	1.514	0.71	0.41	0.35	0.032	0.061	0.059	<0.10	0.13
Nitrate (NO_3) as N	mg/L	884	928	622	533	235	296	272	435	406
Nitrite (NO_2) as N	mg/L	5.97	71.4	97.5	49	35.9	36.8	31.6	27.2	27.1
Selenium (Se)	mg/L	1.67	0.002	0.002	0.003	0.0025	0.0015	0.008	<0.010	<0.010
Total Dissolved Solids (TDS)	mg/L	144 400*	110 000	62 700	69 000	69 800	74 400	102 000	123 000	163 000
Total Suspended Solids (TSS)	mg/L	806	N/A	136.2	45.4	260	1100	520	1900	260
Thallium (Tl)	mg/L	0.087	0.018	0.005	0.0007	0.00053	0.0155	0.0547	0.0519	0.0872
Uranium (U)	mg/L	0.006	0.006	0.008	0.002	0.0019	0.0029	0.0044	<0.010	<0.010
Zinc (Zn)	mg/L	0.338	0.49	0.43	0.23	0.096	0.091	<0.10	<0.50	<0.50
Silver (Ag)	mg/L	N.A.	<0.01	<0.01	<0.01	0.00023	0.00049	0.00086	<0.0020	<0.0020

Treated water will be sampled for water quality periodically (pH, Total Suspended Solids (TSS), C10-C50, aluminum, arsenic, boron, cadmium, chloride, copper, chromium, mercury, ammonia, nickel, nitrite, nitrate, phosphorus, lead, selenium, total dissolved solids (TDS), thallium, total cyanides and zinc) and sent to a certified laboratory for analysis. Table 2 presents the treatment target which should be reached by the SWTP.

[1] Used for Tender request.

Table 2 : Treatment Objectives of the SWTP[2]

Parameter (Total, mg/L)	Maximum Allowable Salt Plant Effluent Concentration[3]
Aluminum	6
Arsenic	1
Boron	4
Cadmium	0.0003
Chloride	2500
Copper	0.7
Chromium	0.003
Mercury	0.0001
N-NH4	35
Nickel	1.3
N-NO2	0.2
N-NO3	2
Phosphorous	0.1
Lead	0.6
Selenium	0.0025
TDS[4]	1400
Thallium	0.003
Total Cyanide	1.5
Zinc	1.3
pH[5]	5-8
TSS[6]	<10
Temperature[7]	<40ºC

2.2 EFFLUENT FLOW RATE

In order to maintain the saline water balance, a treatment flow rate of 120 m^3/d is required which corresponds to the average inflow of saline water underground.

3 DESCRIPTION

3.1 SALINE WATER TREATMENT PLANT (SWTP)

3.1.1 Process Summary

The purpose of the SWTP is to remove total dissolved solids (TDS), which is also referred to as salinity, in underground saline water. The expected TDS in underground water varies from approximately 60 000 to 160 000 mg/L. The treated water will be discharged into CP1. The equipment has an operational flow rate of 120 m^3/d. It is expected that the SWTP will be in use 24 hours, 7 days per week.

2 Treatment objective values come from geochemical model made by Golder (2017) for a dry climate, taking into account the dilution occurring into CP1 (Ref: 6515-E-132-013-105-DGC-003).
3 Treatment objective values come from geochemical model made by Golder (2017) for a dry climate, taking into account the dilution occurring into CP1 (Ref: 6515-E-132-013-105-DGC-003). Theses concentrations are guaranteed by the supplier.
4 Maximum concentration for the final effluent (ref: Water License No. 2AM-MEL1631).
5 Possibility to adjust pH if required. Will depend on the CP1 alkalinity.
6 Value expected to be low since effluent is treated in a reverse osmosis process prior to be discharged to CP1.
7 Reverse osmosis post treatment should be perform below 35-40ºC .

The treatment concept is presented in Figure 3. Water is pumped from the underground sump to the saline storage pond or directly into the SWTP. Water then flows into the two SaltMaker S125 units. Three products are generated during the process: distilled water, a salt slurry and a high-salinity blowdown.

The distilled water is treated in an oxidation reactor for nitrite removal, followed by a reverse osmosis (RO) step used to remove ammonia. The RO permeate is then discharged into CP1. The RO brine containing high ammonia concentration is stored in a tank and oxidized with chorine before being cycled back to the two SaltMaker S125 units.

The salt slurry is discharged into a big bag rack. Free water is drained from the bag and recycled to the SaltMaker. The expected solid content into the big bag after drainage is estimated at approximately 80%.

The blowdown is a by-product containing high concentrations of nitrate. Evaporation efficiency depends on the viscosity of the water which can be affected by the high concentrations of nitrate that can occur within the SaltMaker due to its high degree of solubility. Nitrate accumulates within the system as a consequence of the different streams being recirculated.

The SWTP will be installed in the third quarter of 2018 and operational in the last quarter 2018.

The SWTP general flow diagram is illustrated in Figure 4.

The following sections describe the SWTP components.

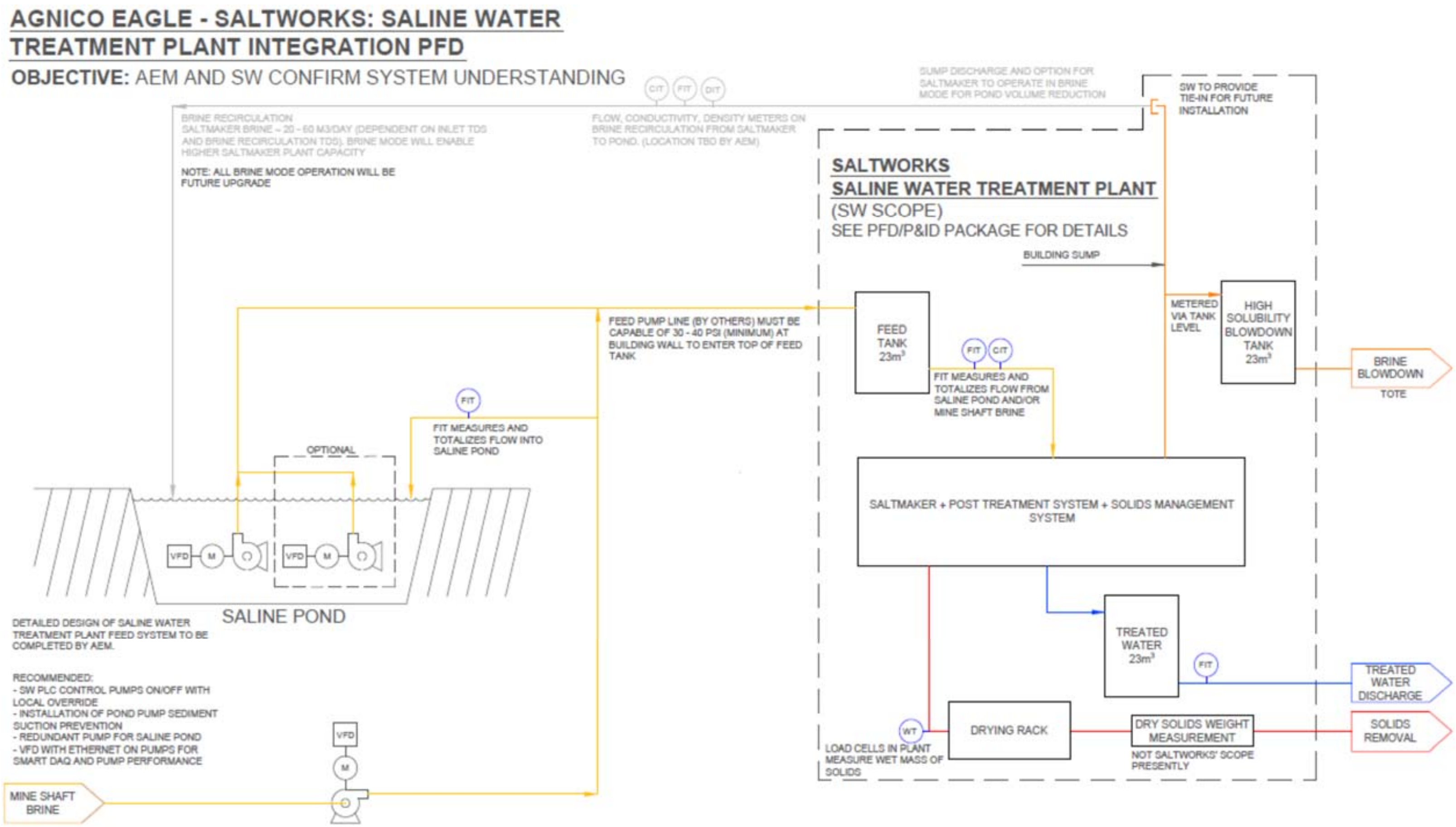

Figure 3 : SWTP Overall Process Concept

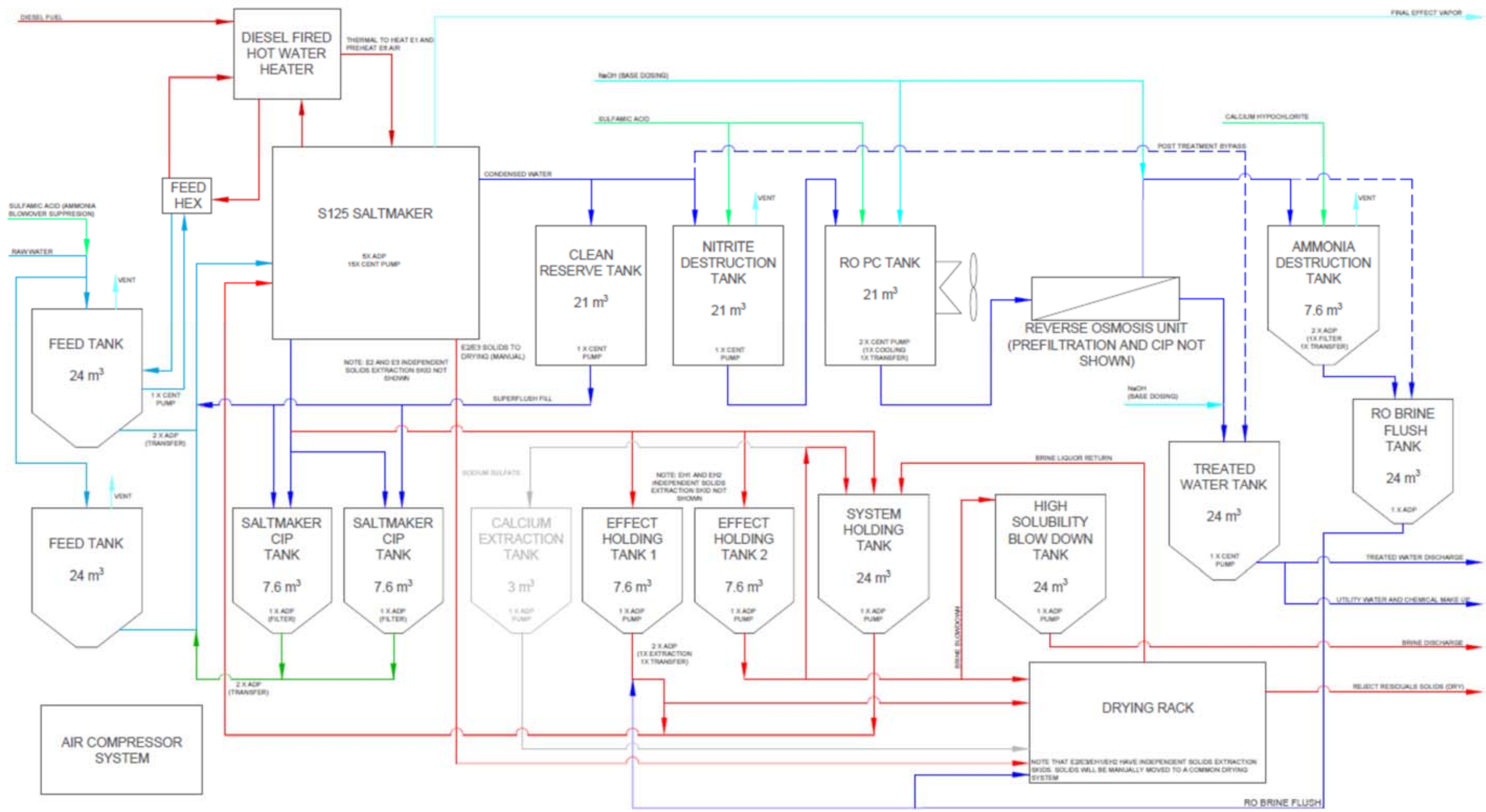

Figure 4 : SWTP Overall Process Flow Diagram

3.2 PRE-TREATMENT

Before being fed to the SaltMaker, water is filtered through strainers, in-line filters and heated to a specific temperature.

3.3 SALTMAKER

The SaltMaker uses a Humidification-Dehumidification (HDH) cycle to concentrate saline water and produce freshwater. The use of a humidified air cycle enables operation at temperatures below 90ºC and pressures near atmospheric (1 bar). These attributes allow the use of engineered plastics in place of more costly corrosion-resistant metallic parts, thereby saving capital cost while also reducing scaling risk due to the much lower surface energy of plastics. In addition, evaporation occurs on a non-heated surface, further reducing scaling and enhancing reliability.

The SaltMaker is a thermally driven plant, producing freshwater and highly concentrated discharge and/or solids via a multiple-effects HDH cycle. The thermal energy is used to evaporate and condense water in successive "effects". The latent heat of condensation is recycled as it is downgraded, with each effect operating at a temperature approximately 15°C lower than the previous one. Each effect produces freshwater and successively concentrates the saline water. The final effect uses the downgraded heat (<40°C) to concentrate brine into solids.

A simplified process diagram is shown in **Erreur ! Source du renvoi introuvable.**. This diagram describes a four-effect concentration in which the first three effects entail a closed air loop and the fourth effect is open to the atmosphere. The S125 for this application is a five-effect plant which recycles the heat an additional time. The final effect can be a closed air loop for zero air emissions and more water recovery.

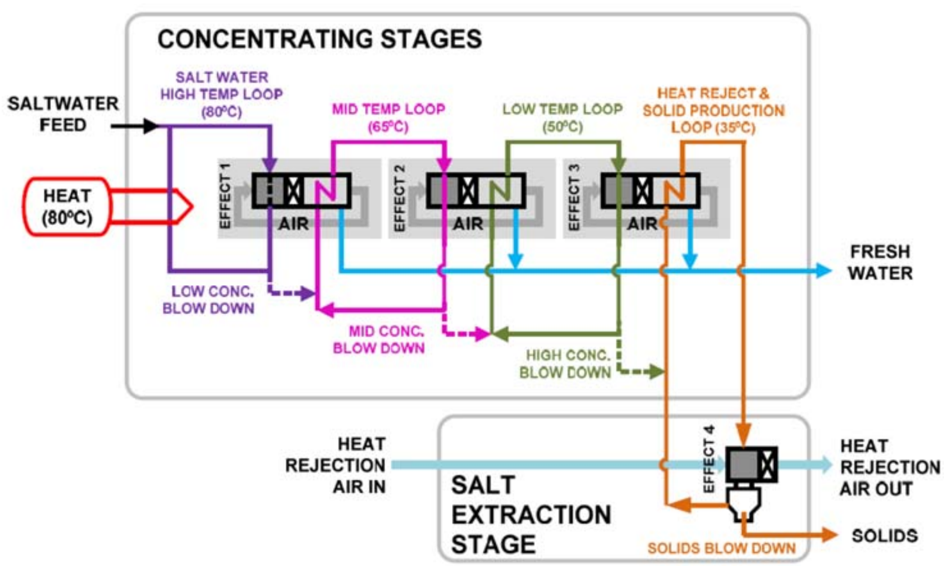

Figure 5 : Conceptual Operation

SaltMaker can accept any wastewater salinity; lower inlet TDS increases system freshwater recovery. Additionally, the scaling potential of the wastewater impacts the frequency of the wash cycles and the plant's production capacity. However, the built-in cleaning systems are flexible enough to accept almost any water type.

The SaltMaker general flow diagram is illustrated in Figure 6.

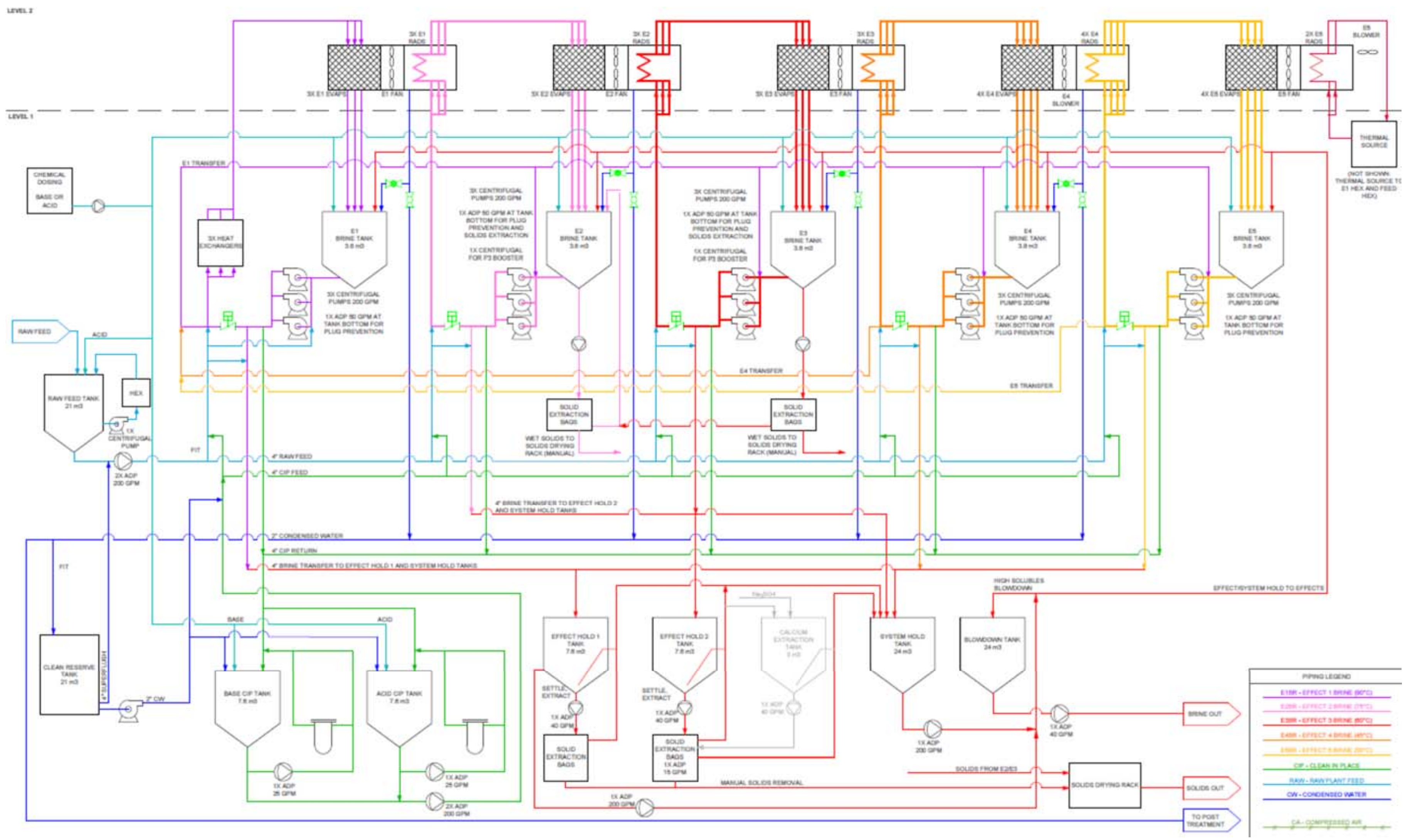

Figure 6 : Saltmaker Process Flow Diagram

3.4 POST-TREATMENT

Distilled water from the SaltMaker unit needs to be treated mainly for volatiles such as ammonia and nitrite (resulting from ammonia oxidation). The proposed chain is a chemical oxidation of nitrite with sulfamic acid followed by a reverse osmosis filtration step.

3.4.1 Nitrite Removal

The overall reaction between nitrite and sulfamic acid is presented below:

$NaNO_2 + H_3NSO_3 \rightarrow N_2 + NaHSO_4 + H_2O$

This reaction leads to the formation of nitrogen as the final product of nitrite removal.

Distilled water from the two SaltMaker units is stored in two 21 m^3 tanks. Sulfamic acid is then added in batch mode to remove nitrite (one reactor is treated while the second one stores distilled water). Acid dosage is controlled by a pH sensor. An optimum pH of 2-3 needs to be reached for effective nitrite removal. The reaction time is about 1-2 minutes in the reactor. The pH of the water from the nitrite removal tank is then adjusted to 4.5 using caustic soda prior to the reverse osmosis process.

3.4.2 Ammonia Removal by Reverse Osmosis

Reverse osmosis (RO) is a water purification technology that uses a semi-permeable membrane to remove ions and molecules. In RO, an applied pressure is used to overcome osmotic pressure. Normally, water to be treated with RO has to be pretreated for suspended solids, bacteria, and scaling compound. In the present case, as the water comes from an evaporation process, no specific pre-treatment would be required. A recovery of 96% is expected.

The RO system operates at variable recovery based on the conductivity (salt and ammonia content) of permeate. If the permeate conductivity is too high, the RO will lower recovery by opening the concentrate valve, allowing more water to flow to the concentrate stream and less water to be directed to the product stream.

Filtration is done at low pH (approximately 5.5) to promote the ammonium form which is best retained by the RO step.

The flowsheet for the RO process is presented in Figure 7.

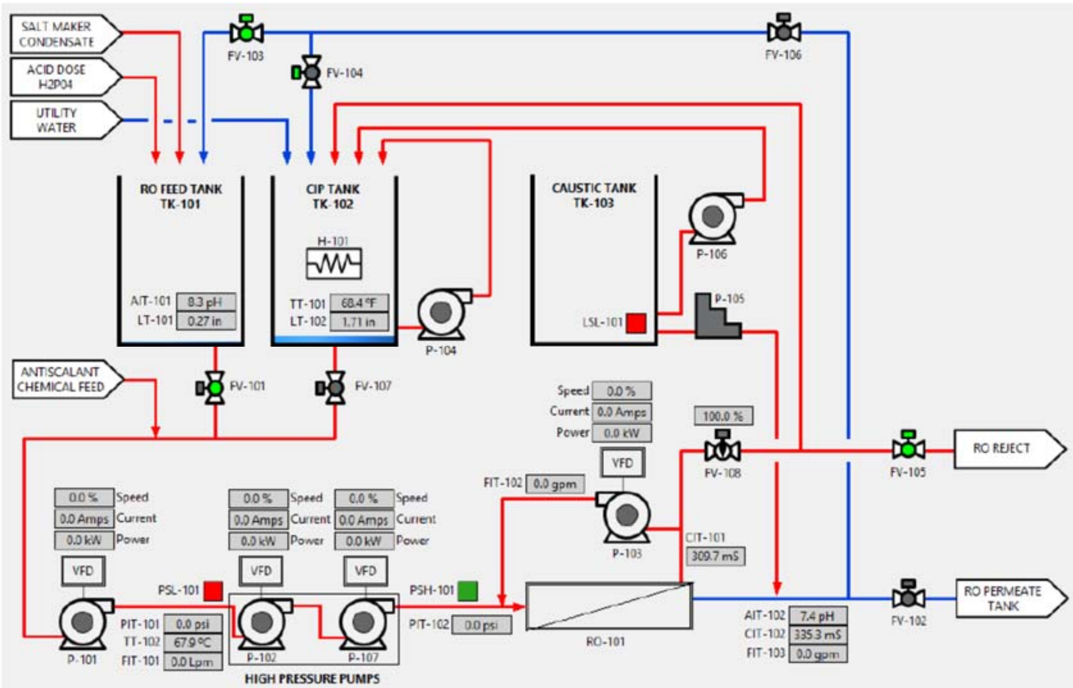

Figure 7 : RO Treatment

3.5 REVERSE OSMOSIS BRINE TREATMENT

Brine from the RO process contains a high concentration of ammonia. In order to prevent a build-up of ammonia in the process, this compound is oxidized with calcium hypochlorite in a 7.6 m^3 tank (this reaction is also commonly called ‘breakpoint chlorination’). Two tanks are available for brine storage (one in ammonia destruction mode; the second in brine storage mode). The treatment is done manually in batch mode by the operator. The pH is adjusted to alkaline values. The required quantity of calcium hypochlorite is determined by the operator on the basis of the ammonia analysis obtained with a colorimetric test kit. Calcium hypochlorite is added directly in solid form. The retention time is also determined by the operator and is typically around 10 minutes.

The overall reaction leading to the release of nitrogen and nitrate as a final product is presented below:

$NH_4^+ + 1.5\ HOCl \rightarrow 0.5\ N_2 + 1.5\ H_2O + 2.5\ H^+ + 1.5\ Cl^-$
$NH_4^+ + 4\ HOCl \rightarrow NO_3^- + H_2O + 6\ H^+ + 4\ Cl^-$

Treated water is recirculated back to the SaltMaker units.

3.6 SALT BAGGING SYSTEM

Salt slurry is discharged into a big bag rack. Loading of each big bag is controlled by load cells. An automatic valve discharges the slurry into a big bag until it is full. Once the bag is full, another big bag is positioned to be filled. The big bag is left to drain of free water until it only contains solid salts. Free water (high salinity leachate) is recycled to the SaltMaker unit for further treatment. Figures 8 and 9 present the concept for the salt bagging system. The expected dryness is between 80 and 90 %.

Solid salt produced will be placed in double bags which will be stored into seacans to prevent dissolution of the salt. When required, the salt will be reused for underground mining activities. The exceeding bags of solid salt will be sent south on the barges for final disposal in accordance with regulations.

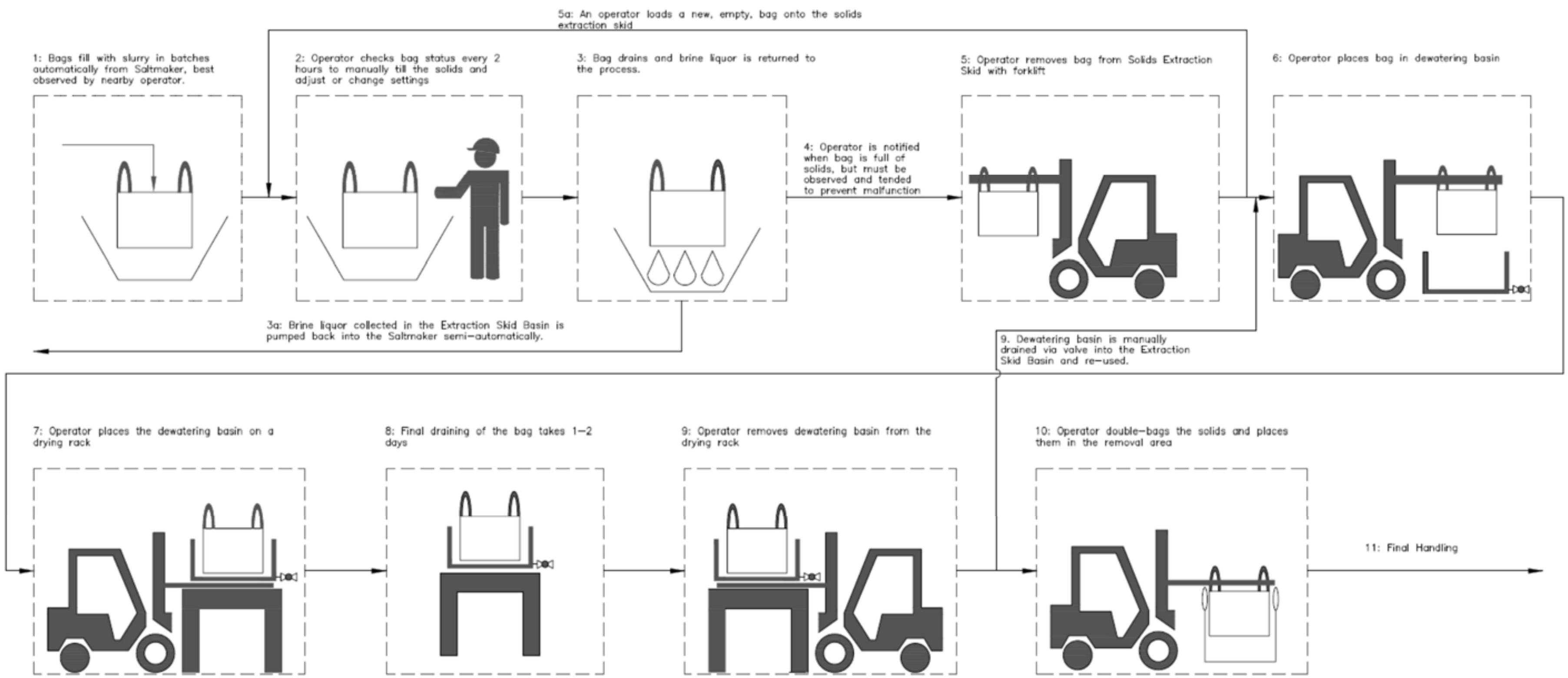

Figure 8 : Salt Bagging Concept

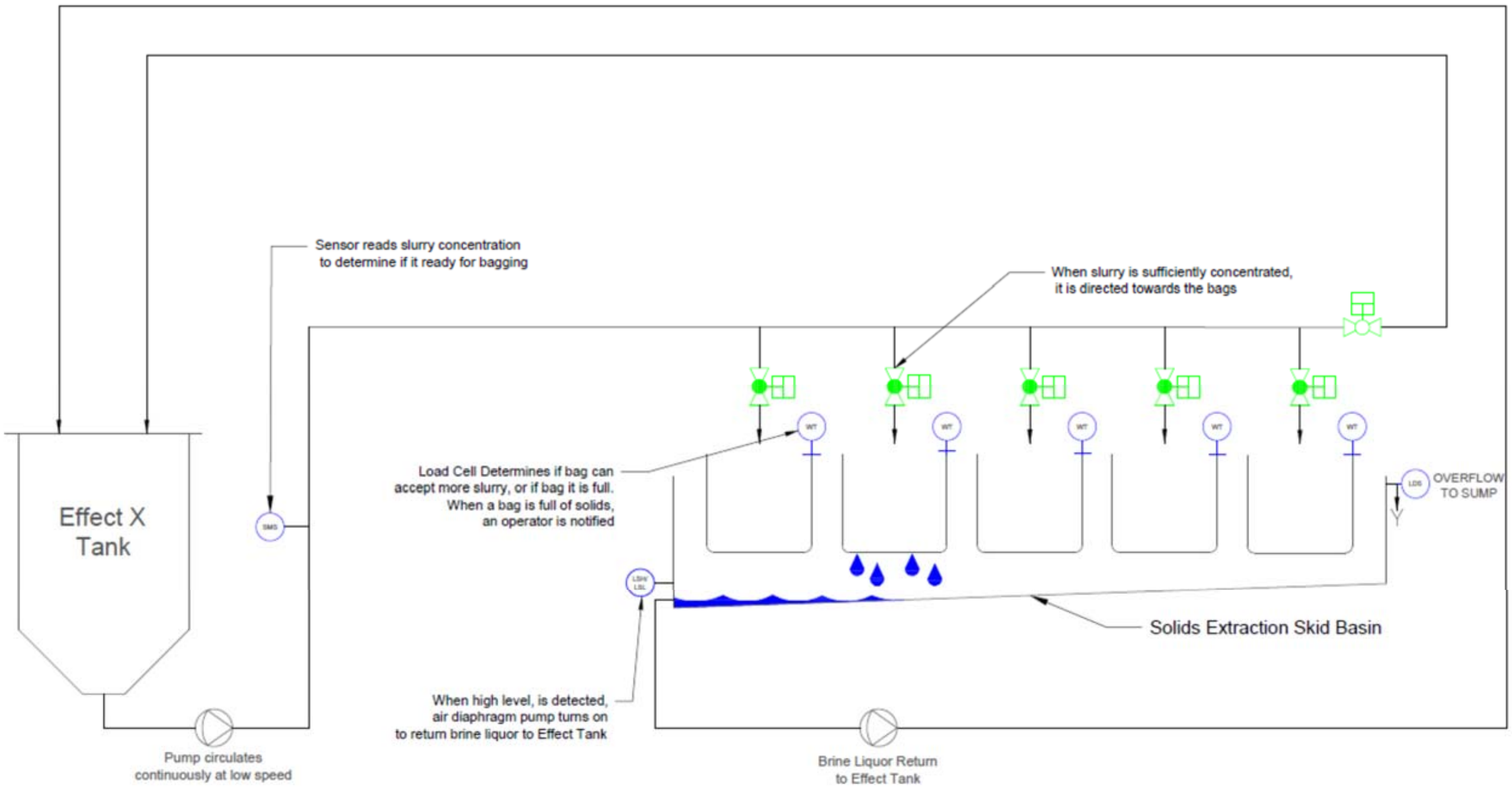

Figure 9 : Salt Bagging Flow Diagram

3.7 BLOWDOWN MANAGEMENT

The salt is mainly composed of Ca, Na and Cl. Underground water also contains a non-negligible amount of nitrate which does not precipitate during the salt production step. Therefore, the nitrate is recirculated in the SaltMaker where it accumulates. Overly high concentrations of nitrate leads to an increase in the viscosity of the water to be treated, causing the efficiency of the Saltmaker to decrease significantly. To prevent a nitrate build-up, approximately 1% of the feed flow should be removed. This corresponds to a volume of approximately 1.2 m^3 per day. During the operation, a volume of 10 m^3 is periodically removed and stored in a blowdown tank.

The blowdown solution is stored in tote tanks within sea cans. Once a year, the sea cans are sent back south whereby the totes are dealt with by a subcontractor who disposes of the solution according to regulations.

3.8 WATER HEATER

Three water heaters are required to heat water to approximately 80ºC (first effect of the SaltMaker unit). Heat plate exchangers are used to transfer heat between the water to be treated and the thermal source. The thermal units are diesel driven.

3.9 SERVICE WATER SYSTEM

The service water system is mainly based on reusing distilled water produced within the plant. A 21 m^3 clean water reserve tank is being used for storage.

3.10 CONTROLS

The SWTP Pump is equipped with a variable frequency drive (VFD) that allows the flow to be modulated.

The SaltMaker system and post-treatment use a variety of sensors and automation hardware to achieve reliable plant operations. Sensors include temperature, pressure, flow, level, conductivity, and pH.

The electrical and control system for the post-treatment consists of a main control panel with multiple alternating current (AC) drives, switch gear, terminal blocks as well as the Programmable Logic Control (PLC) and modules. AC drives allow variable speed on the feed pump, high pressure pumps, and RO recirculation pump. The drives allow the control system to make flow and pressure adjustments to maximize RO recovery and efficiency. The panel houses the Human Machine Interface (HMI), conductivity and pH transmitters for operators. All instrumentation and automation functions are carried out by the PLC based on signals from sensors.

Saltworks is standardized on 4-20 mA analogue sensor outputs to minimize signal loss issues. 4-20 mA signals are read by input/output (I/O) modules on the PLC or Remote I/O units.

The SaltMaker and post-treatment use the following types of instruments:

Pressure:

These sensors are used to measure pump discharge pressure on main water lines on each effect. Trends in pressure readings can help the operator identify pipe scaling issues. They can also be used to identify pump problems. These pressure sensors use piezoresistive measuring cells (similar to a strain gauge) to measure pressure being applied on the sensor connector. A built-in transmitter amplifies this signal and converts it into 4-20 mA to communicate with the PLC modules.

For the post-treatment, these sensors are used to measure the pump inlet/discharge pressures. Trends in pressure readings can help the operator identify filter clogging or membrane fouling issues. They can also be used to identify pump problems.

Level:

These sensors are used to measure the level on SaltMaker tanks and post-treatment. Different types of sensors are used depending on the fluid and process conditions.

> ***Pressure:*** These sensors use piezoresistive measure cells that are calibrated at high resolution to measure level changes in tanks. They are mounted near the bottom of the tank. Because they measure hydrostatic pressure, they are affected by density changes of the fluid.
>
> ***Ultrasonic:*** These sensors send ultrasonic sound pulses and measure the time it takes for the pulses to reflect and bounce back from the process medium below and return to the sensor. This is translated into a level measurement. These sensors are mounted on top of the tank and do not come into direct contact with process fluids.
>
> ***Radar:*** These sensors send radar pulses and measure the time it takes for the pulses to reflect and bounce back from the process medium below and return to the sensor. This is translated into a level measurement. These sensors are mounted on top of the tank and do not come into direct contact with process fluids. In general, radar has performance and reliability advantages over ultrasonic. Suitability of radar versus ultrasonic sensors depends on actual tank conditions and is outside the scope of this manual.

Level sensor feedback allows for automated level control by filling and transfer of water in process tanks. The system is vital to continuous operation of the SaltMaker. Proper SaltMaker operations produce a unique saw-tooth pattern on main effect tanks, with a slow decrease in tank level due to evaporation and a fast increase in levels due to the transfer of process fluids into the tank. Automated level warnings help operators locate issues before they become serious enough to interrupt operations.

For the post-treatment, level sensor feedback allows for automated level control by filling and transfer of water in process tanks. The system is vital to continuous operation of the Post-Treatment RO. Automated level warnings help operators locate issues before they become serious enough to interrupt operations.

Conductivity:

These sensors are used to measure the conductivity of water, which is proportional to the ionic or salt concentration of the water. The SaltMaker deploys two different types of conductivity sensors:

> ***Contacting Conductivity Sensors:*** These sensors employ a potentiometric method. Two or four electrodes are submersed in the sample fluid. The sample fluid completes the electrical

circuit. A potential is proportional to the conductivity of the fluid. Saltworks uses this type of sensor to measure a conductivity range from 0-5 mS.

Inductive Conductivity Sensors: Two coils are wound inside the ring-shaped sensor. One coil drives a magnetic field with a known voltage and induces a current on the second coil. This current is proportional to the conductivity of the measured fluid. This type of sensor is suitable for measuring conductivity in the 5-1000 mS range.

Conductivity sensor signals help operators monitor the concentration of process water in different effects. By tracking an increase in concentration of brine over time, these sensors ensure that the SaltMaker is functioning normally.

For the post-treatment, conductivity sensor signals help operators monitor the concentration of the concentrate and permeate process streams. By tracking conductivity changes over time, these sensors ensure that the Post-Treatment RO is functioning normally.

pH:

These sensors contain a potentiometric cell made of pH-sensitive electrodes. Voltage is measured across the electrodes and the signal is amplified and processed into a 4-20 mA signal. pH sensors help monitor the condition of treated and untreated water. They are also used in optional acid and base dosing systems to monitor and control pH to adjust the solubility of the process water to different salts.

Temperature:

These sensors measure the temperature of the process streams. The SaltMaker and post-treatment use resistive RTDs (resistance temperature detectors) which are sensors that measure a change in resistance due to a change in temperature. This signal is amplified and processed into a 4-20 mA signal with a transmitter. Temperature differences between the effects provide the main driving force for the humidification-dehumidification (HDH) process. Abnormal temperature differences would indicate problems with heat transfer between one effect and the other. These sensors help operators track temperature across all the effects to confirm normal operations.

Weight:

Load cells measure the mass of the salt produced and stored in big bags. This information lets the operator know when to replace the big bag.

3.11 REAGENTS

The following reagents will be used at the SWTP:

- sulfamic acid
- calcium hypochlorite
- trisodium phosphate
- sodium meta-bisulfite
- caustic soda
- Antifoam (AF-64)
- Antisclant (CC 7430)
- Biocide (KATHON™ CF150 BIOCIDE, AQUCAR™ DB 20 Water Treatment Microbiocide)

- Cleaning chemical (BAR COR CWS-55, ROclean L211 and P303, E-Series Blends.

Most of the chemicals are supplied in liquid form (and dosed using a dosing skid pump directly into the process) except for the sulfamic acid, calcium hypochlorite, sodium meta-bisulfite and trisodium phosphate which must be prepared manually before dosing. The solutions made with these products are prepared according to the MSDS provided by the suppliers.

The application for each of these reagents is detailed in the Operation and Maintenance Manual (OMM). The MSDS are available in the OMM as well.

4 PUMPING AND PIPING

For the operation of the SWTP, pumping and piping are required to convey water:

- from underground stope to the Saline Water Pond;
- from the Saline Water Pond to the SWTP;
- treated water from SWTP to the containment pond 1 (CP1).

Appendix A: SWTP Drawings

Appendix B: Pumps selection