Sustainable Development of Zero Liquid Discharge (ZLD) Water Treatment Process

Abstract

Purpose – The purpose of this research is to analyze the wastewater discharge and a zero-liquid discharge (ZLD) reproduction plan which is designed for Municipal or Industrial Applications.

Zero Liquid Discharge (ZLD) is a treatment process that its goal is to remove all the liquid waste from a system. The focus of ZLD is to reduce economically wastewater and produce clean water that is suitable for reuse.

1. Introduction

Many countries all over the world are facing water shortages. As population increases, water is being perceived as a very valuable resource. Every effort is exerted to use water more efficiently and to make use of every drop of water to ensure the well being of future generations. New trends are developed and practiced in the area of water resources use and water saving. These trends vary from one country to another according to the degree of water scarcity, economic situations, and other factors. Developing non-conventional water resources is an example of the recent trends in developing new water resources and water savings. Unlike rainfall, rivers, and groundwater which are considered conventional freshwater resources, the non-conventional water resources include sea water desalination, agriculture wastewater reuse, and municipal wastewater reuse. This paper deals with the reuse of agriculture, municipal, and industrial wastewater as a new trend in developing additional water resources. Special interest is given to municipal wastewater, its characteristics and necessary treatment. Environmental and human health considerations for wastewater reuse, especially in agriculture, are also discussed. Possible consequences of wastewater reuse are introduced. Examples of wastewater reuse practices in some countries are also mentioned.

ZLD technologies consist traditionally from brine concentrators and crystallizers that use thermal evaporation to turn the brine into highly purified water and solid dry product ready for landfill disposal or for salt recovery. While evaporator/crystallizer systems are the most commonly used in ZLD processes, other promising technologies (ED/EDR, FO and MD which will be explained later) with high recoveries have taken foothold and are used in different combinations in order to lower the cost and raise the efficiency of the systems.

The increasingly tighter government regulations on the discharge of brine due to the environmental effect make ZLD necessary when water is scarce or the local water bodies are protected by law. Thus many industrial facilities and brine effluent contributors that up to now where either discharging brine to nearby available surface water or the sea and to wastewater treatment plants, are trying to find new ways to tackle this issue.

The industrial involvement with brine is twofold. Many industrial processes require water which they contaminate and releasing it may cause irreversible damages to the local environment.

In some countries during the last decade due to heavy contamination of local waters by industrial wastewater was followed by strict regulations that make ZLD necessary in order to ensure the future of their rivers and lakes. In Europe and North America, the drive towards zero ZLD has been applied due to the high costs of wastewater disposal at inland facilities. These costs increase exponentially by government fines and the costs of disposal technologies.

ZLD can also be used to recover valuable resources from the wastewater which can be sold or reused in the industrial process. Some examples are as follows,

- Generation of valuable potassium sulfate (K_2SO_4) fertilizer from a salt mine
- Concentration of caustic soda (NaOH) to 50 and 99% purity
- Recovery of pure, saleable sodium sulfate ($NaSO_4$) from a battery manufacturing facility
- Reduction of coal mine wastewater treatment costs by recovering pure sodium chloride (NaCl) which can be sold as road salt
- Lithium (Li) has been found in USA oil field brines at almost the same level as South American salars
- Gypsum ($CaSO_4 \cdot 2H_2O$) can be recovered from mine water and flue gas desalinization (FGD) wastewater, which can then be sold to use in drywall manufacturing

Other advantages to the application of ZLD are:

- Decreased volume of wastewater lowers the costs of waste management.
- Recycling water on site thus decreasing the need for water intake and meeting with treatment needs.
- Reduce the truck transportation costs for off-site disposal and the related environmental risks.

2. Literature review

Wastewater discharged into the environment is polluted and huge amount of water is highly visible, making it necessary to treat the effluents and minimize wastewater discharge. During wastewater treatment, there is a hybrid process that has two interdependent treatment processes, biological treatment and membrane filtration, which are attractive wastewater treatment technologies producing high-quality recyclable treated water. The reproduction process changes are to minimize the use of water in the process more practical and cost effective to recycle and reuse for the wastewater. Overall, there is a need to increase the water recycling rate to reach the ZLD goal. Still, there are multi-qualitative measures need to be addressed in the assessment process.

Prior studies on ZLD is focused on bio-indicators, where as the data process is focused on the process auditing and input–output model in the technical solution. The major attributes are biological treatment and membrane filtration to use biodegradability of organic matter to obtain a high effluent quality.

Table 1, ZLD Drivers

1. Meeting tight brine disposal government regulations
2. Recovery of valuable materials in the waste streams
3. Decreased waste volumes and management costs
4. Recycling water on-site
5. Reducing truck costs for off-site disposal

3. ZLD applications

There is a wide diversity of sources for discharge flow streams that include:

- Cooling tower blowdown in heavy industry and power plants
- Ion exchange regenerative streams particularly in food and beverage processing
- Flue gas desulfurization, wet wastewater stream
- Municipal potable water systems, wastewater streams
- Process water reuse from agricultural, industrial and municipal streams
- Various industrial wastewater streams from the textile, coal-to-chemical, food and dairy or battery industries

Table 2, ZLD Wastewater Stream Applications

Membrane System Reject (*NF, MF, UF, RO*)	Mine Drainage
Flue Gas Desulfurization (*FGD*) Blowdown / Purge	Refinery, Gas to Liquid (*GTL*), and Coal to Chemical (*CTX*) Wastewaters
Produced Water (*Conventional, Fracking, SAGD*)	Scrubber Blowdown
NO_x Injection Water	Demineralization Waste
Integrated Gasification Combined Cycle (*IGCC*) Gray Water	Landfill Leachate

The discharge sources can be further categorized according to volume and complexity. A ZLD solution must take the latter into consideration along with the location of the waste stream.

4. ZLD Determining Factors

The most important factors that determine the ZLD design depend on,

1. The specific contaminants in the discharge stream
2. The volume of the dissolved material
3. The required design flow rate

Table 3, Typical Chemical Constituents of Concern

Sodium (Na^+)	TDS/TSS	Phosphate (PO_4^{3-})	Strontium (S^{2+})	Sulfate (SO_4^{2-})
Potassium (K^+)	COD/TOC/BOD	Ammonia (NH_3)	Oil & Grease	Fluoride (F^-)
Calcium ($Ca^{2+)}$	pH	Boron (B^+)	Barium (Ba^{2+})	Nitrate (NO_3^-)
Magnesium (Mg^{2+})	Chloride (Cl^-)	Alkalinity	Silica	-

These parameters need to be accurately measured before requesting a quote in order so as to get an accurate estimation of the system's cost. If the feed is prone to changes in flow and the concentration of the contaminants, inlet buffering tanks regulate the peaks.

5. Operation costs

Each technology that makes up the ZLD chain has a certain purchasing cost, but an important parameter for calculating the costs and eventually the payback period are the operating costs. The OPEX can change drastically based on what process is selected especially for electrical power and steam-generating facilities. For a long term investment the benefits and drawbacks of each choice have to be weighed as well as what works better for each company and their working staff. This will help to get an initial versus a long-term cost investment.

On a last note for a cost benefit analysis you must always take into consideration factors like,

- Taxes or additional purchasing fees
- Possible utility costs in the installation area
- Environmental regulatory fees or permits
- Regular compliance testing

6. Basic ZLD Design - ZLD Blocks

Despite the variable sources of a wastewater stream, a ZLD system is generally comprised by two steps which are represented in Figure 1.

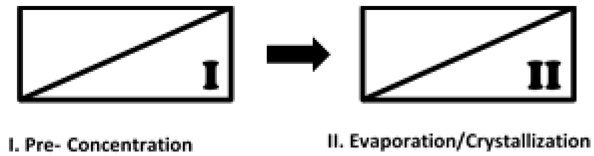

Fig.1, ZLD Basic Blocks

1. **Pre-Concentration;** Pre-concentrating the brine is usually achieved with membrane brine concentrators or electrodialysis (ED). These technologies concentrate the stream to a high salinity and are able to recover up to 60–80% of the water.
2. **Evaporation/Crystallization;** The next step with thermal processes or evaporation, evaporates all the leftover water, collect it, and drives it for reuse. The waste that is left behind then goes to a crystallizer which boils all the water until all the impurities crystallize and are filtered out as a solid.

6.1. Pre-concentration

The pre-concentration of the liquid waste stream is a very important step due to the fact that it reduces the volume of the waste and downsizes significantly the very costly evaporation/crystallization step. Usually it is achieved with electrodialysis (ED) or membrane processes which consist of Forward Osmosis (FO) and Membrane Distillation (MD) (Figure 2).

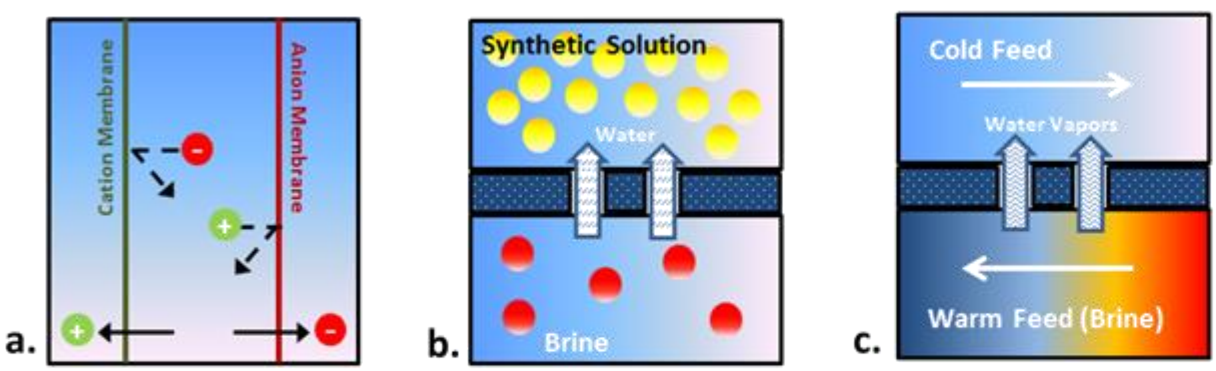

Fig.2, Brine treatment technologies, (a) Electrodialysis, (b) Forward Osmosis, (c) Membrane Distillation

ED, FO and MD can function efficiently with a much higher salinity content than RO (150,000 ppm, 200,000 ppm, 250,000 ppm and 70,000 ppm respectively).

6.1.1. Electrodialysis/ Electrodialysis Reversal

Electrodialysis is a membrane process that uses electrodes to create an electric field which pushes negative and positive ions through semipermeable membranes with attached positively or negatively charged species respectively. ED is used in multiple stages to concentrate the brine to saturation levels. It is often used together with RO for very high water recovery. ED differs from RO because it removes the ions and not the water and vice versa for RO. Due to this fact silica and dissolved organics are not removed with ED which is important if the clean stream is to be reused. ED requires solids, as does RO, solids and organics removal from the feed.

Electrodialysis reversal (EDR)

In EDR the polarity of the electrodes is reversed several times an hour and the fresh water and the concentrated wastewater are exchanged within the membrane stack to remove fouling and scaling.

6.1.2. Forward Osmosis

FO is an osmotic membrane process with a semipermeable membrane that unlike RO doesn't use applied pressure in order to achieve separation of water from dissolved solutes like ions, molecules and larger particles. That means a lot less of energy for the process in comparison to RO. In general FO uses thermal and electrical energy. Thermal energy can be substituted with low grade waste heat which can be found everywhere in most industrial or nearby areas.

6.1.3. Membrane Distillation

MD is a thermally driven transport process that uses hydrophobic membranes. The driving force in the method is the vapor pressure difference between the two sides of the membrane pores, allowing for mass and heat transfer of the volatile solution components (e.g. water). The simplicity of MD along with the fact that it can use waste heat and/or alternative energy sources, such as solar and geothermal energy, enables MD to be combined with other processes in integrated systems, making it a promising separation technique.

6.1.4 The importance of Pre-Concentration in a ZLD Process

The pre-concentration technologies have very high recoveries but usually not enough like the typical thermal evaporation technologies to drive the brine into saturation concentration levels. So why are they so important? The reason is the CAPEX/OPEX of the evaporators/crystallizers.

1) Due to the corrosive nature of the brine it takes more and more resistant metal alloys in order to resist corrosion as the concentration rises. That means that the bigger is the evaporation/crystallizer module, the bigger will be the CAPEX required (which can be 60-70% of the whole process).

2) High energy demand due to the rise of the boiling point of the brine as concentration goes higher.

6.2 Evaporation and Crystallization

After pre-concentration of the waste stream the next step is to use thermal processes or evaporation to generate solid and reuse the evaporated water. Evaporation is essentially heat transfer to a boiling liquid with the intent to concentrate a non-volatile solute from a solvent, which is usually water, by boiling off the solvent. The evaporation process normally stops just before the solute begins to precipitate, otherwise it is considered as crystallization.

Falling film evaporation is an energy efficient method of evaporation that concentrates the water up to the initial crystallization point (super saturation). Adding acid will neutralize the solution so, when heating it, as to prevent scaling and harming the heat exchangers. De-aeration is also often used in order to release dissolved oxygen, carbon dioxide, and other non-condensable gases.

The exiting brine from the evaporator goes into a *forced-circulation* crystallizer where the water is concentrated beyond the solubility of the contaminants and formed crystals. The result product is dewatered by a filter press or a centrifuge and the centrate (mother liquor) is returned to the crystallizer.

The collected condensate (water) from the three steps returns to the process, eliminating the discharge of liquids in the system. If organics are present, condensate polishing may be required before reusing it. The product water is then driven to a holding tank.

The solid waste, at this point, will go either to a landfill or for reusing.

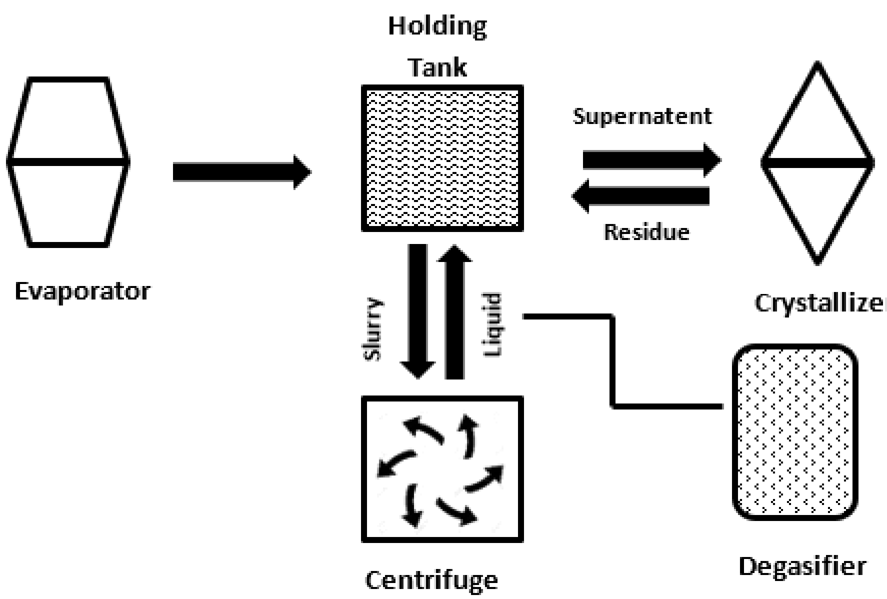

Fig.3, ZLD Evaporation/Crystallization phase

7. Wastewater Recycling

In addition to irrigation supply and demand and water quality requirements, there are other considerations specific to agricultural water reuse that must be addressed. Both the user and supplier of reclaimed water may have to consider modifications in current practice that may be required to use reclaimed water for agricultural irrigation. This requires that those investigating reclaimed water programs have a working knowledge of the appropriate regulations, crop requirements, and means of application. Important considerations include:

- System reliability;
- Site use control and setback distances for irrigation;
- Monitoring requirements;
- Runoff controls;
- Marketing incentives; and
- Irrigation equipment.

8. Conclusions

This study uses a calculation involving uncertainties in production process integration to determine qualitative information and quantitative data together. ZLD reproduction planning has been developed to obtain the maximum overall wastewater recovery rate in an industry.

In addition, the Wastewater Recycling to use the treated water in many applications like the Agricultural Irrigation is a successful trend that provides the two benefits of developing a new non-conventional water resource, and utilizing a low cost natural fertilizer. However, the most critical restriction in a wastewater reuse program is to assure that public health is not compromised.

Other objectives, such as preventing environmental degradation, avoiding public discomfort, and meeting user requirements, must also be satisfied in implementing a successful wastewater reuse program. The starting point remains in the use of properly treated reclaimed water for the right crop in the right soil using the right method of irrigation. Several wastewater reuse standards and guidelines have been demonstrated. It is important to follow wastewater reuse guidelines and standards regarding the degree of treatment for cultivating different crops, and the necessary precautions that need to be taken.

In general there are certain measures that are required for health protection. They include:

- treatment of wastewater – to reduce the concentrations of pathogens in the reclaimed water;
- crop restriction – to restrict the use of treated wastewater to restricted crops;

• wastewater application – to supply wastewater via subsurface, localized irrigation systems, and recommended method of irrigation for different crops;

• human exposure control – by limiting contact, inhalation, and ingestion of the reclaimed water;

• continuous monitoring – to assure the quality of treated wastewater, monitoring should be maintained on treated wastewater, groundwater in the vicinity, soils, and crops.

Furthermore, investment in sewage collection systems and wastewater treatment plants have a number of advantages, especially in countries with scarce water resources. It, not only, prevents the environmental hazards of improper disposal of wastewater, but it provides the opportunity for implementing the recent trend of reusing wastewater in Agriculture, Flush Water or Industrial Water Applications.

Regards;

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