Assessment of performance of Zero Liquid Discharge (ZLD) operations in some tannery clusters

Vellore Districts, Tamil Nadu, India

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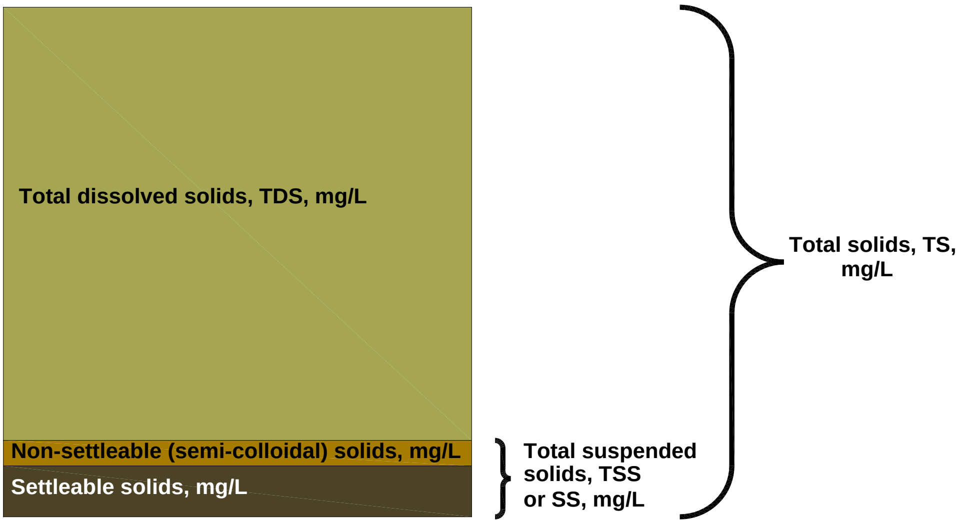
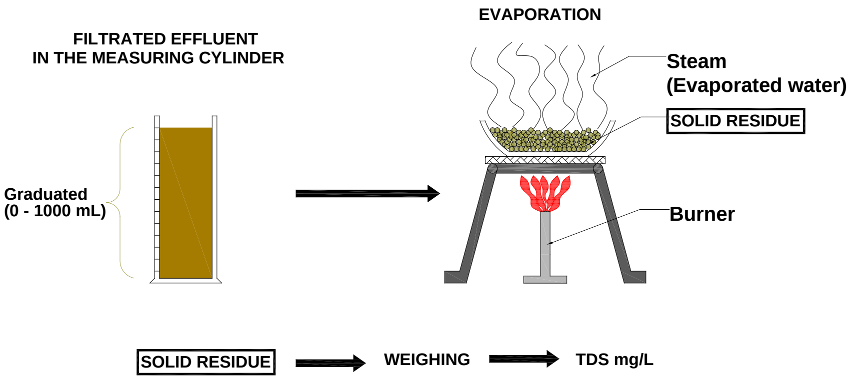
Glossary and some fundamentals

Total solids, TS are made of all measurable solids present in the effluent; TS consist of two components i.e. of insoluble, suspended solids (Total Suspended Solids, TSS) and dissolved solids (Total Dissolved Solids, TDS). The following is the approximate solids balance in the composite tannery effluent:



Total Dissolved Solids, TDS[1] is a measure that indicates the amount of all inorganic and organic substances dissolved in waste water; essentially, it is everything present in water other than pure H_2O and suspended solids. In the case of tannery effluents, the main relevant components are **sulphates** and **chlorides;** very often TDS is colloquially referred to as salinity or salt.



For quick determination TDS meters are used, which in reality are conductivity meters that measure the conductivity of the solution containing dissolved ionized solids; however, under reasonably stable conditions in a particular tannery a satisfactory approximation of

[1] For more details see UNIDO paper *Pollutants in tannery effluents – Sources, descriptions, environmental impact, 2013 (Revised edition)*

conductivity to TDS conversion ratio that will include dissolved organic solids such as sugar and microscopic solid particles such as colloids can be established.

The main sources of TDS in a tannery processing hides & skins preserved by salting and following the conventional technology are soaking, liming/deliming, pickling and chrome tanning.

Sulphates (SO_4^{2-}) in tannery effluent emanate from the use of sulphuric acid or auxiliary chemicals with high (sodium) sulphate content; chrome tanning powders and many synthetic retanning agents contain high levels of sodium sulphate. Removal of sulphide in the effluent by aeration (beamhouse stream, homogenization tank) also generates (sodium) sulphates; sulphates cannot be removed completely from a solution by chemical means; normally, they either remain as sulphates in the effluent or are broken down by anaerobic bacteria to produce malodorous hydrogen sulphide.

Chloride (Cl^-) in effluent is chiefly sodium chloride originating from the large quantities of common salt used in hide and skin preservation and/or in the pickling process. Chlorides are highly soluble and stable, unaffected by effluent treatment. Excessive concentrations inhibit the growth of plants, bacteria and fish in surface waters. Also, increased salt content in groundwater is now becoming a serious environmental hazard.

Zero Liquid Discharge (ZLD) concept attempts to eliminate the problem of high TDS waste streams by removing all dissolved solids on-site and reclaiming water. Designs differ, but ZLD systems concentrate dissolved solids until only damp solid waste remains. Solid waste is disposed of off-site and nearly all water is reclaimed and reused.

While ZLD is often considered as a wastewater treatment system there are views that it is more accurately described as a salt removal and sequestration system.

A ZLD system must operate with constant chemistry and constant flow. ZLD systems cannot tolerate deviations from the chemistry for which they were specifically designed and must be monitored continuously. It is ironic that the ZLD "salt removal system" often requires large amounts of salt in various forms to operate.

Water hardness is in practice taken as a measure of the amount of calcium and magnesium salts in water. Calcium and magnesium enter water mainly through the weathering of rocks. The more calcium and magnesium in water, the harder the water. There are several water hardness scales in use, it seems that it prevails expressing it in ppm of $CaCO_3$.

More accurately, there are categories like total hardness, permanent and temporary hardness, carbonate and non-carbonate hardness etc.

Water softening is the process of removing the dissolved calcium and magnesium salts that cause hardness in water. This is achieved either by adding chemicals that form insoluble precipitates (e.g. lime) or by ion exchange. In ion exchangers Ca^{2+} and Mg^{2+} ions are replaced with sodium ions provided by cation exchange resin. When all the available Na^+ ions have been replaced with Ca^{2+} or Mg^{2+} ions, the resin must be re-charged by eluting them using a solution of NaCl or NaOH. Thus, water softening ultimately leads to increased salinity of water processed.

Ultrafiltration (UF) is a variety of membrane filtration used for separation of suspended solids and solutes of high molecular weight; the driving force is pressure and the particles size range is 10^3 - 10^6 Da. Regular backwashing and cleaning of the membrane is needed to prevent the accumulation of foulants and reverse the degrading effects of fouling on permeability and selectivity. Furthermore, acidic solutions are required for the control of inorganic scale deposits and alkali solutions for removal of organic compounds.

Nanofiltration is a relatively recent membrane filtration process that uses nanometre sized cylindrical through-pores that pass through the membrane at 90°. Nanofiltration membranes have pore sizes from 1-10 nanometres, i.e. smaller than that used in microfiltration but just larger than that in RO.

Main advantages of nanofiltration as a method of softening water are that during the process only larger ions such as Ca and Mg ions are retained and that (unlike with ion exchangers) filtration is performed without adding extra Na cations.

Osmosis is a process by which molecules of a solvent tend to pass through a semipermeable membrane from a less concentrated solution into a more concentrated one.

In the case of **Reverse osmosis, RO** solvent passes through a porous membrane in the direction opposite to that for natural osmosis due to a hydrostatic pressure greater than the osmotic pressure. Using a semipermeable membrane and applying external pressure, industrial scale reverse osmosis (RO) technology is able to remove ions and molecules from water.

Osmotic Pressure in RO systems is the pressure required to prevent the flow of water across a semi-permeable membrane separating two solutions having different ionic strengths. A useful "rule of thumb" is that for every 100 mg/L of TDS difference between feed and permeate there is 6.9 kPa of osmotic pressure.

Desalination or **desalinization** is a process that removes minerals from saline water. In practice, salt water is desalinated to produce fresh water suitable for human consumption or irrigation. Due to relatively high energy consumption, the costs of desalinating sea water are generally higher than the alternatives (fresh water from rivers or groundwater, water recycling and water conservation), but alternatives are not always available and rapid overdraw and depletion of reserves is a critical problem worldwide.

Typical desalination methods are vacuum distillation (essentially the boiling of water at less than atmospheric pressure and thus a much lower temperature than normal) and, more and more, reverse osmosis (RO). Energy consumption of sea water desalination as low as 3 kWh/m^3, including pre-filtering and ancillaries is reported. Reject is disposed and not evaporated.

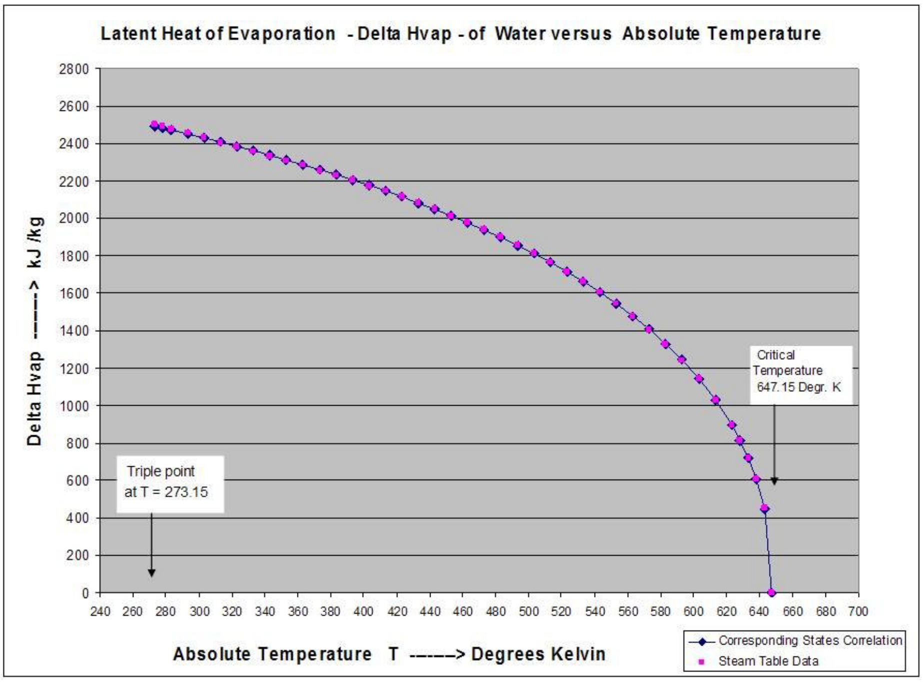
Solar desalination is a technique to desalinate water using solar energy. In the direct method, a solar collector is coupled with a distilling mechanism and the process is carried out in one simple cycle; normally, it is applied for plants with production capacities less than $200m^3$/day.

Indirect solar desalination employs two separate systems; a solar collection array, consisting of photovoltaic or fluid based thermal collectors, and a separate conventional desalination plant.

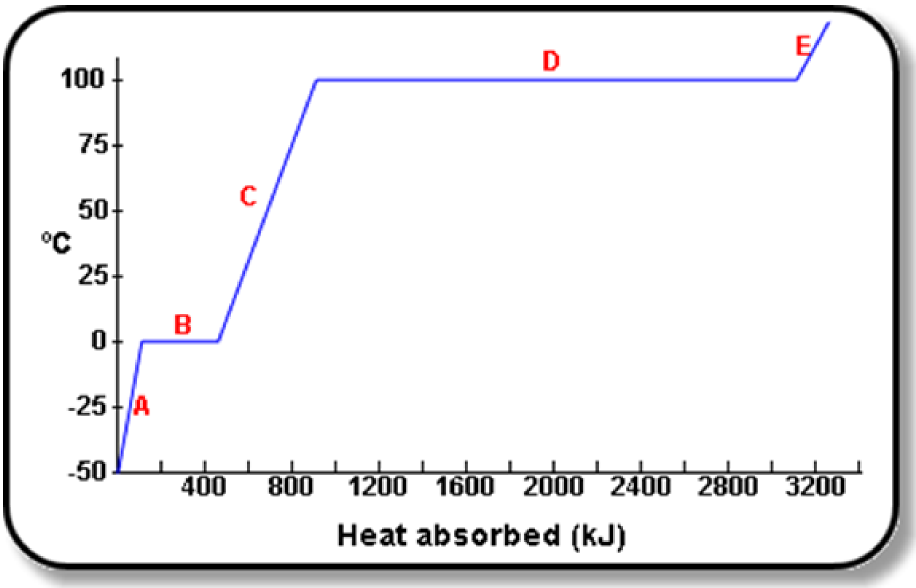
The **solar humidification-dehumidification (HDH)** process (also called the multiple-effect humidification-dehumidification process, *solar multistage condensation evaporation cycle* (SMCEC) is a technique that mimics the natural water cycle by evaporating and condensing water to separate it from other substances. The driving force in this process is thermal solar energy to produce water vapour which is later condensed in a separate chamber. This system is effective for small- to mid- scale desalination systems in remote locations.

An interesting application of this principle is a concrete tower with a tank containing saline water at the top while the entire structure is covered with glass. The water from the tank drips out onto the concrete walls of the tower; due to solar radiation, the water on the wet surface and in the tank evaporate and condense on the inner surface of the glass cylinder and flow down into the collecting channel.

The **heat of evaporation** (enthalpy of vaporization, latent heat of vaporization) is the energy (enthalpy) that must be added to the substance, typically a liquid, to transform a quantity of that substance into a gas. The enthalpy of vaporization is a function of the pressure at which that transformation takes place. ; it is also temperature-dependent, it diminishes with increasing temperature and it vanishes completely at a certain point called the critical temperature.
The enthalpy of vaporization is usually given for the normal boiling temperature, for water it is 2257 kJ/kg at 100 °C.



The **heat of evaporation** is also temperature-dependent, it diminishes with increasing temperature and it vanishes completely at the point called the critical temperature.



Section D: water boils and absorbs the latent heat of vaporization, no temperature increase.

Source: http://www.physchem.co.za/Heat/Latent.htm

Multi-stage flash distillation (**MSF**) is a desalination process that distils water by *flashing a* portion of the water into steam in multiple stages of what are essentially countercurrent heat exchangers.

Multiple-effect evaporator is a system for efficiently using the heat from steam to evaporate water. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the last.

Organic scavengers are pre-treatment units designed to protect deioniser resins and Reverse Osmosis (RO) membranes from organic or colloidal fouling. Different scavenger resins are employed for different impurities; the rate of removal depends on the type of organics to be removed and properties of the resin selected. **Scavenger resins** are polymers (resins) with bound functional groups that permit the use of many different scavengers, as the functional groups either confined within the resin or simply bound to the solid support of a bead.

For good efficiency regular backwash and regeneration (adding additional salts!) are essential.

Scaling is the deposition of particles on a membrane, causing it to plug. Without some means of scale inhibition, RO membranes and flow passages within membrane elements will scale due to precipitation of mainly calcium carbonate and calcium sulphate due to presence of calcium, sulphates and bicarbonate ions in water.

Antiscalants are surface active materials that interfere with precipitation reactions in three primary ways: i) by threshold inhibition (maintaining the supersaturated solutions) ii) crystal modification (distorting the crystal shapes, resulting in soft non-adherent scale and iii) dispersion (keeping the crystals separated).

Antiscalants are injected into the feedwater before it enters the RO membranes. Their presence delays the reaction between calcium magnesium and bicarbonate.

Mechanical Vapour Recompression Evaporation, MVRE is essentially a distillation process designed to reduce wastewater volumes by recovering most of the water in the waste; at the same time, distillation in itself is a separation process, separating components in a mixture by making use of the fact that some components vaporize more readily than others.

MVRE takes the process one step further by using a compressor to increase the pressure of the water vapour (steam), produced. The increase in vapour pressure increases the condensation temperature of the steam, rendering it usable to heat the original mixture in a heat-transfer apparatus. As the steam condenses in the heating chamber, it releases its latent heat of vaporization to further heat the original mixture, which in turn produces more steam. This recycling of heat is what renders MVRE so efficient.

Molecular Weight Cut-Off (MWCO) usually refers to the lowest molecular weight of the solute (expressed in daltons) at which 90% of the solute is retained by the membrane.

Dalton, the unified atomic mass unit (symbol u or Da) is the standard unit used for indicating mass on atomic or molecular scale.

Ångström (Å) is a unit of length corresponding to 10^{-10} m or 10^{-4} μm or 10^{-4} μm or 0.1 nm (one tenth of nanometre, one ten millionth of a millimetre) used to express the size of extremely small particles, atoms and molecules.

Carbon Footprint (CF)
Weighted sum of greenhouse gas emissions and greenhouse gas removals of a process, a system of processes or a product system, expressed in CO_2 equivalents.

Another good definition of CF: A carbon footprint is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or a product. It is expressed in grams of CO_2 equivalents.

Introduction

Total Dissolved Solids (TDS), mainly chlorides and sulphates (colloquially salinity) in effluent have become the major environmental concern in arid and semi-arid regions of the world as it makes the receiving water recipients (rivers, lakes) unfit both for livestock watering and for irrigation.

High salinity in irrigation water causes high osmotic pressure, which results in reduced water availability and retarded plant growth of crops. In addition, while the presence of calcium and magnesium ions in tannery effluent that ends up in irrigation water stabilises the soils, high concentrations of sodium can cause dispersion of clay and reduces water infiltration and drainage.

Although a certain percentage emanates from pickling, deliming, tanning and wet finishing, the main source of TDS, especially of sodium chloride, is salt from preservation. It is estimated that worldwide at least 3.0 million tons of common salt per year are discharged into water recipients.

Understandably, environmental authorities in most countries have set specific discharge limits for TDS presence in effluents; whilst such standards vary from country to country and often within each country, they cannot not be achieved by conventional treatment processes.

Since the environmental damage caused by preservation by salting more and more prevails over its convenience aspects, the tanning industry in Europe has already largely switched to processing of fresh hides, i.e. salt-free raw material and this trend is continuously expanding (e.g. Brazil).

For a host of reasons, environmental authorities and the tanning industry in the state of Tamil Nadu, India have chosen a different strategy: to adopt a Zero Liquid Discharge approach.

Essentially, Zero Liquid Discharge (ZLD) concept attempts to eliminate the problem of high TDS waste streams by removing all dissolved solids on-site and reclaiming water. Designs differ, but ZLD systems concentrate dissolved solids until only damp solid waste remains. Solid waste is disposed of off-site and nearly all water is reclaimed and reused.

In practice, it means that the existing Common Effluent Treatment Plants (CETPs) following the usual treatment technology i.e. on-site pre-treatment, primary (physico-chemical) and secondary (biological-activated sludge) servicing tannery clusters have been supplemented by advanced, energy intensive methods like Reverse Osmosis (RO) and Multi Effect Evaporation together with the necessary preparatory steps (tertiary treatment, water softening etc.).

In this paper, it is aimed to highlight and analyse some of the important performance parameters of three CETP/ZLD system(s) in Vellore District, Tamil Nadu after a few years of operations. Being the best documented, the focus is on the Ranipet Tannery Effluent Treatment Co. Ltd. (RANITEC).

In that context, it is worth mentioning that a pilot two-stage RO plant of 1 m^3/h capacity together with all accessory equipment (multigrade filter, photo chemical oxidizer, activated carbon, softener, albeit using solar pans instead of advanced evaporators) was already installed and operated in cooperation with CLRI under UNIDO assisted project from March 1998-Nov 2000.

It was concluded that the system *per se* was technically viable but that investment and O&M cost were quite prohibitive mainly due to high energy inputs. These costs were only partly off-set by the price paid for fresh water: at that time, the tanners of Vellore district had to bring quality water from far away at the cost ranging US $ 0.43 -0.64/m^3.

Main features of three tannery clusters in Vellore District

Vellore District, one among 32 districts of Tamil Nadu State in the southeast of India has the population of about 5.3 million. In the tanning area of Ranipet with population of about 62,000 (the nearby town of Vellore about 500,000) there are about 200 tanneries grouped in three clusters; in the largest of them, RANITEC, tanneries process from raw to finished leather, in VISHTEC it is predominantly from raw to E.I. and/or fully-finished vegetable tanned and in SIDCO from wet blue to fully finished leather. Each cluster is serviced by a CETP with treated effluent ultimately ending in the Palar River in which in the recent years is mostly dry with no flow. Since there is neither municipal sewerage network nor sewage treatment plant and presently no possibility of diluting tannery effluents with municipal wastewater environmental authority saw ZLD as the only option for tanneries.

Although not originally conceived in that form, with substantial downstream capacities the area of Vellore District has evolved many features of integrated leather complex.

Figure 1. Layout of the RANITEC CETP/ZLD plant

Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

The logic for selection of plants for assessment

The plants selected cover the three main types of clusters: processing raw hides/skins to finished leather, (RANITEC), predominantly from raw to wet blue (VISHTEC) and from wet blue/EI to finished leather (SIDCO). The three plants basically follow the same technology, are operated by quite professional staff and the managements willing to cooperate. They are all connected to the Care AIR centre (server) of the TNPCB, the flow data are recorded in real time and counterchecks are possible.

Table 1. The main features of some CETP/ZLD systems in tannery clusters in Vellore District, Tamil Nadu, India at a glance

ITEM/DESCRIPTION	RANITEC	SIDCO I *	VISHTEC
Total number of tanneries	90	87	37
Tanneries presently operational	88	82	27
Raw hides/skins to wet blue stage	42	-	16
E.I. and/or fully-finished vegetable tanned leathers	44	82	17
Wet blue & E.I. to finished leathers	46	82	
Raw hides/skins to finished leathers	22	-	6
Raw material processed	Cow hides and buffalo calf	Wet blue or EI tanned leather	Cow hides and buffalo calf
Total daily input, tonnes of wet salted weight/day	107	--	25.01
Cluster output, finished leather, m^2/day	24525	14644	5709
Estimated value of finished leather produced, millions Rs./year	9150 - 17530	5465 - 10471	2130 - 4082
Total length of effluent conveyance pipeline (km), number of pumping stations	13.2; 3	5.1; 2	2.5; 2
Total consented flow rate/CETP capacity, m^3/d	4500	2500	3400
CETP capacity as defined under CEMCOT project, m^3/d	3000	2500	600
Average flow rate to the CETP, April 15-March 16, m^3/y	415859		142453
Average CETP capacity utilization rate, April 15-March 16, %	38%		65%
Designed capacity of the ZLD plant	3000	2500	600
The ZLD system commissioned, year	2012	2012	2010
Average flow rate to ZLD (RO Feed), April 15-March 16, m^3/d	1155	951	396
Average ZLD capacity utilization rate, April 15-March 16, %	38.5	38	65.95
Recovered Water distributed to tanneries, m^3/d	1152	920	399
The length of Recovered water distribution pipeline (km), number of overhead tanks	11.4; 3	4.4; 1	2.8; 1

ITEM/DESCRIPTION	RANITEC	SIDCO I *	VISHTEC
Sludge at 40% DM generated, tonnes/year (April 15-March 16)	4350	3215	2280
Amount of salt residue generated by the ZLD plant, tonnes/year (April 15-March 16)	5043	1591	1818
Total CETP/ZLD investment cost incurred until March 2016, INR Rs.	586.7 million	326.9 million	147 million
Total CETP/ZLD investment cost incurred until March 2016, USD @ Rs. 66 to 1 USD	8.89 million	4.95 million	2.23 million

** Throughout the paper the data for SIDCO are for the period Sep 2015 – May 2016, i.e. for nine months only.*

RANITEC CETP is the largest in the tanning sector in Tamil Nadu, with computerized operations and management system, well equipped leather testing laboratory, ISO certified, etc. and the main source of data for this study. Some data have also been collected from CETP/ZLD plant at Ambur (AMBURTEC) using the Mechanical Vapour Recompression Evaporation, MVRE system and Pernambut (PERTEC), the latter being one of the earliest to be commissioned in the state and receiving continual technical assistance and support from organizations such as CLRI, NEERI etc.

Investment, funding

The ambitious Zero Liquid Discharge (ZLD) scheme was triggered with establishment of the Chennai Environmental Management Company of Tanners Ltd. (CEMCOT) by the managements of seven CETPs in the Vellore District as a Special Purpose Vehicle (SPV) with the view of setting up six ZLD systems/projects.

Funding structure of individual ZLD projects:

Government of India	50 %
State Government (Tamil Nadu)	15 %
CETP (CETP shareholders)	35 %

The non-grant capital (35% plus any contingencies, any gap in actual Government funding and any extra works) was raised among CETP users according to their respective capacity allocation which in turn essentially corresponds to their CETP share capital.

Each project had separate project accounts (trust and retention account) in which the individual CETP companies first deposited their share of project cost in four instalments; on realization of this amount, contributions by the Government of India and the State Government were released.

The implementation contract was awarded following two tier tendering: one pre-qualification based on Request for quotation (RFQ) and tendering among the pre-qualified bidders based on Request for proposal (RFP). A tender evaluation team (with two external experts) scrutinized the offers and selected the contractor based on lowest life cycle cost.

Unlike earlier government assisted projects, the subsidy from Governments was approved *after* tendering of the project and was based on actual cost quoted by the successful bidder. This ensured that the full financial commitment was known to all parties beforehand and hence provided better financial security.

Regrettably, no information is available about the cost of non-grant capital; since it is apparently fully born by tanneries – CETP shareholders, the interest rates might vary depending on their individual financial situations.

A case study – Ranipet Tannery Effluent Treatment Co. Ltd. (RANITEC)

Due to its scale, management structure, documentation etc. RANITEC is possibly the most suitable site to review investment (as well as most of other) aspects of the ZLD projects.

Like in other cases within the scheme, the vehicle for the project of setting up a Zero Liquid Discharge (ZLD) system at the RANITEC CETP was the Chennai Environmental Management Company of Tanners Ltd. (CEMCOT) and it was implemented as a public private partnership whereas the construction itself was on a turn-key basis.

Contributions from the Government of India (DIPP), Government of Tamil Nadu and member tanneries were 50%, 15% and 35% respectively. The designed capacity of the ZLD "*addition*" plant was 3600 m^3/d and the overall project cost as follows:

Table 2. Overview of investment costs at the ZLD plant RANITEC

Item		Million Rs.	Million US $*
The cost of setting up of the **4500 m^3/d** CETP with effluent collection network over a period of more than 20 years		65 (6.5 crores)	0.98
ZLD System	Rehabilitation & upgrading of the primary, secondary and tertiary (PST) treatment stages (e.g. new blowers and diffusers, additional sludge dewatering, water softening, advanced monitoring), new collection and conveyance system required as precondition for smooth operations of the RO & MEE.	110.0 (11.0 crores)	1.66
	Reverse Osmosis (RO) and reject Multiple Effect Evaporator (MEE) with auxiliary equipment for **3600 m^3/d**	350 (35 crores)	5.28
Total		**525 (52.5 crores)**	**7.92**

** at 66.3 INR to 1 US $*

Not unlike in the case of other CETPs worldwide, for a number of reasons (costing of modifications over long periods, currency rates as well as inconsistencies in informative leaflets), figures in the table should be seen as historical and indicative but good enough for general guidance i.e. providing the order of magnitude of investment cost for such a plant under local conditions.

Similarly, it is not always possible to draw a clear, segregating line between the rehabilitation and upgrading of the conventional CETP and investment cost pertaining to the ZLD "addition": tertiary treatment, better monitoring and control system etc. may be needed anyway.

Thus, somewhat in contradiction to the previous table and rather arbitrarily, i.e. almost limiting the ZLD component to Reverse Osmosis (RO) and reject Multiple Effect Evaporator (MEE) stages, investment costs in relation to capacity are given in the following table.

Table 3. Investment costs for 4500 m^3/d CETP & 3600 m^3/d ZLD system

Item	Million Rs.	Rs./m^3	*US $/$m^3$
CETP investment cost (initial/earlier+ rehabilitation/upgrading after 20 years of operations, capacity 4500 m^3/d.	65 + 110 = 175	39,000	587
The ZLD stage - Reverse Osmosis (RO) and reject Multiple Effect Evaporator (MEE) with auxiliary equipment	350	97,000	1,466
Overall investment costs for 3600 m^3/d	**525**	**145,800**	**2,200**

** at 66.3 INR to 1 US $*

Obviously, the original CETP designed treatment capacity was far beyond actual needs; some could claim that the future expansion of the tanning industry was grossly overestimated and the scope for water savings grossly underestimated. However, proper assessment in that respect cannot be made without the possible impact of tannery relocations to ZLD-free regions but such information is currently not available.

Quite unfortunately, the pro rata costs computed based on the flow level of 1650 m^3/day[2] are significantly higher.

Table 4. Investment costs for the CETP/ZLD system at the flow rate of 1650 m3/d

Item	Million Rs.	Rs./m^3	*US $/$m^3$
CETP investment cost (initial/earlier+ rehabilitation/upgrading after 20 years of operations	65 + 110 = 175	106,000	1,600
The ZLD stage - Reverse Osmosis (RO) and reject Multiple Effect Evaporator (MEE) with auxiliary equipment	350	212,120	3,200
Overall investment costs for 1650 m^3/d	**525**	**318,180**	**4800**

** at 66.3 INR to 1 US $*

However, with the current flow of only 1155 m^3/day the overall investment costs come to Rs. 454,500 or **US $ 6850/m^3**.

There are plans for further upgradation of the CETP/ZLD by adding the third stage of RO, installation of a solar power plant and a nanofiltration unit.

For reference, indicative figures for the PERTEC CETP/ZLD are as follows:

Table 5. Investment costs for 1000 m^3/d ZLD plant (50% of the consented ZLD capacity)

Item	Million Rs.	Rs./m^3	*US $/$m^3$
Overall investment costs for 1000 m^3/d; it includes augmenting the PST capacity from original 891 m^3/d to 1925 m^3/d in 2009-2011, before installation of ZLD in 2012; it also includes the conveyance system and landfill (SLF).	252 (25.2 crores)	**252,000**	**3,800**

** at 66.3 INR to 1 US $*

[2] *And even higher at the actual flow rate.*

Water consumption, flow rates, yield

Water consumption in tannery clusters with ZLD systems, the very starting point in any flow considerations is a somewhat controversial issue.

At the first sight the figures about (in)flows for the last few years are very encouraging. Since the tanners are charged based on effluent volume it appears that addition of the ZLD stage (RO & and multistage evaporation) to the conventional CETP system eventually has resulted in substantial decrease of water consumption. This development is also supported by the claim that concentrations of pollutants such as BOD, COD, etc. went up significantly above the design parameters with an undesirable effect - reduced output of RO.

It is claimed that water consumption has been brought down from about 28 l/kg to only 11-12 l/kg of wet salted weight. The opposing view is that the tanners from the area have a long history and experience in economizing with water; for quite some time it has been a precious commodity brought by tanks from considerable distances. To halve such already reasonably low consumption within 3 – 5 years does not look quite likely. Furthermore, according to some old UNIDO studies, the theoretical lowest limit is about 12 l/kg and reaching it requires quite sophisticated recycling equipment.

In any case, only by relating comprehensive data about raw material input (soaking), production of finished leather and strict monitoring of effluent flows over longer period firm conclusion about actual pro rata water consumption (m^3/tonne of wet salted weight) can be made. Currently no such data are available.

Reportedly, there have been some relocations of processing capacities to other localities with more favourable environmental situation.

The overall flow balance is satisfactory from the tanners' viewpoint: all losses due to evaporation (rather low due to high air humidity) and water removed with sludge are compensated by additions for dissolution of chemicals, water softening and washes. Ultimately, the effluent inflow coincides with the volume of water sent back to tanneries for reuse, its quality is superior to fresh water is due to low hardness; however, most likely due to absence of proper nitrification/denitrification during the biological treatment, there is strong presence of nitrogen in the condensate.

The following chart shows a simplified outline of water loop of the ZLD system. It should be noted, however, that losses due to natural evaporation in humid climate like in southeast India are not significant.

Figure 2. A simplified chart of water additions and water losses during CETP/ZLD treatment

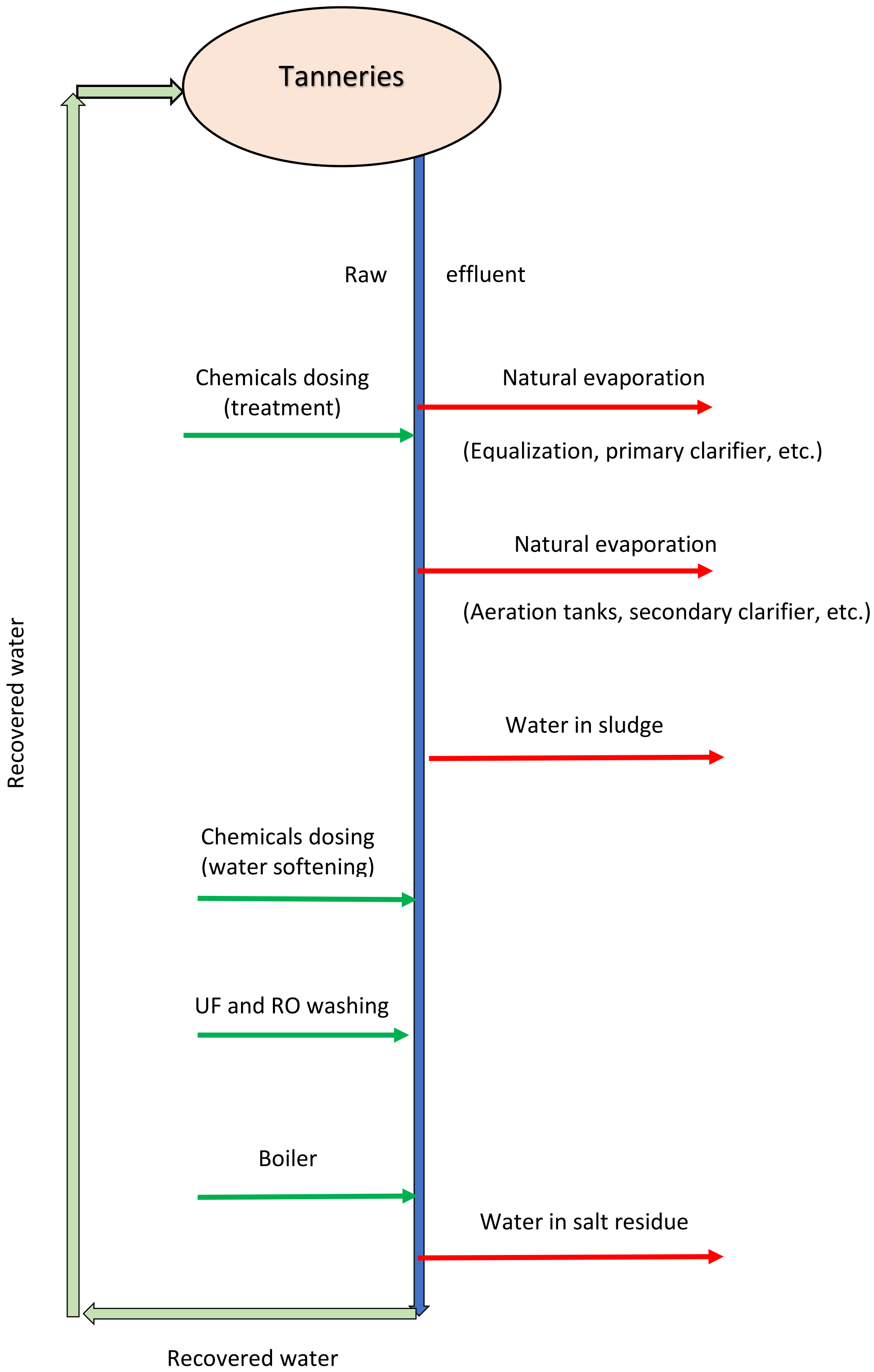


Table 6. Effluent flows, ZLD plant RANITEC, April 2015 – March 2016

ITEM	Unit	TOTAL
Inflow to CETP	m^3	415,185
RO Feed	m^3	411,652
RO Feed vs. inflow	%	99 %
RO Permeate	m^3	296,331
Permeate vs. RO feed	%	72 %
RO Reject	m^3	115,321
RO reject vs. RO feed	%	28 %
Evaporator feed	m^3	118,632
Evaporator condensate	m^3	121,770
Evaporator condensate vs. evaporator feed, %	%	103 %
Total recovered water	m^3	414,963
Total recovered water vs. RO feed %	%	102 %
Total recovered water vs. inflow to CETP %	%	101 %
Salt residue	tons	5,043
Salt residue vs. raw effluent, kg/m^3	kg/ m^3	12.1

The (full) table shows some expected but also some perplexing figures and proportions.

- RO feed vs. inflow to CETP ratio varies from 81 – 114, average 99 %
- Permeate vs. RO feed varies from 57 – 80, average 72 %
- RO reject vs. RO feed varies from 20 – 43, average 28 %
- Evaporator condensate vs. feed varies from 97 – 109, average 103 %
- Total recovered water vs. RO feed from 96 – 106, average 102 %
- Total recovered water vs. inflow to CETP varies from 80 – 113, average 101 %
- Salt produced is 5043 tonnes, from 9.7 – 14.3 average 12.1 kg/m^3

For an accurate flow balance, it would be necessary to take into account additions such as water used for dissolving of chemicals and water from boilers as well as all losses (evaporation, sludge).

The main flow parameters for SIDCO and VISHTEC follow a similar pattern and are merged into a summary table.

Table 7. Comparison of flows in three CETP/ZLD plants in tannery clusters in Vellore District

ZLD	RANITEC	SIDCO	VISHTEC
ITEM	Apr 15 – Mar 16	Sep 15 – May 16	Apr 15 – Mar 16
	Average flow rates and ranges		
RO feed vs. inflow to CETP	99 % (81 – 114)	99 % (97 – 101)	101 % (99 – 104)

ZLD	RANITEC	SIDCO	VISHTEC
ITEM	Apr 15 – Mar 16	Sep 15 – May 16	Apr 15 – Mar 16
Permeate vs. RO feed	72 % (57 – 80)	76 % (67 – 83)	75 % (71 – 81)
RO reject vs. RO feed	28 % (20 – 43)	24 % (17 – 33)	25 % (19 – 29)
Total recovered water vs. inflow	101 % (80 – 113)	98 % (94 – 101)	101 % (97 – 105)
Total recovered water vs. RO feed	102 % (96 – 106)	97 % (94 – 101)	100 % (98 – 101)
Salt residue vs. raw effluent, kg/m^3	12.1 kg/m^3 (10.6 – 14.3)	6.2 kg/m^3 (4.7 – 8.5)	12.8 kg/m^3 (11.0 – 13.9)

Note: In the case of SIDCO, the inflow to CETP is actually the flow measured at the outlet of the equalization tank.

The overall flow balance is from the tanners' viewpoint satisfactory: all losses due to evaporation (rather low due to high air humidity) and water removed with sludge are compensated by additions for dissolution of chemicals, water softening and washes. Ultimately, the effluent inflow coincides with the volume of water sent back to tanneries for reuse. Its quality is superior to fresh water due to low hardness; however, there is nitrogen in the condensate, most likely due to inadequate nitrification/denitrification during the biological treatment.

For a more accurate flow balance, it would be necessary to take into account some less visible additions such as water used for dissolving of chemicals and water from boilers as well as losses due to evaporation from homogenisation and aeration tanks (currently estimated to be close to 10 %) and water removed with sludge and residual salt.

The issues of cost and footprint implications are discussed separately, under other headings.

Main features of the ZLD process

Essentially, the ZLD technology attempts to eliminate the problem of high TDS in waste streams by removing all dissolved solids on-site and reclaiming water. Designs differ, but ZLD systems concentrate dissolved solids by RO and evaporation until only damp solid waste remains. Solid waste is disposed of off-site and nearly all the water is reclaimed and reused. Thus, the ZLD is not so much treatment but rather a salt removal and sequestration system.

For good results, ZLD systems should operate with constant chemistry and constant flow for which they were specifically designed and must be monitored continuously. Preparatory, post-CETP "conditioning" steps, in particular water softening, often require dosing of different chemicals, including salts, which is quite a paradox for what is essentially a salt removal system.

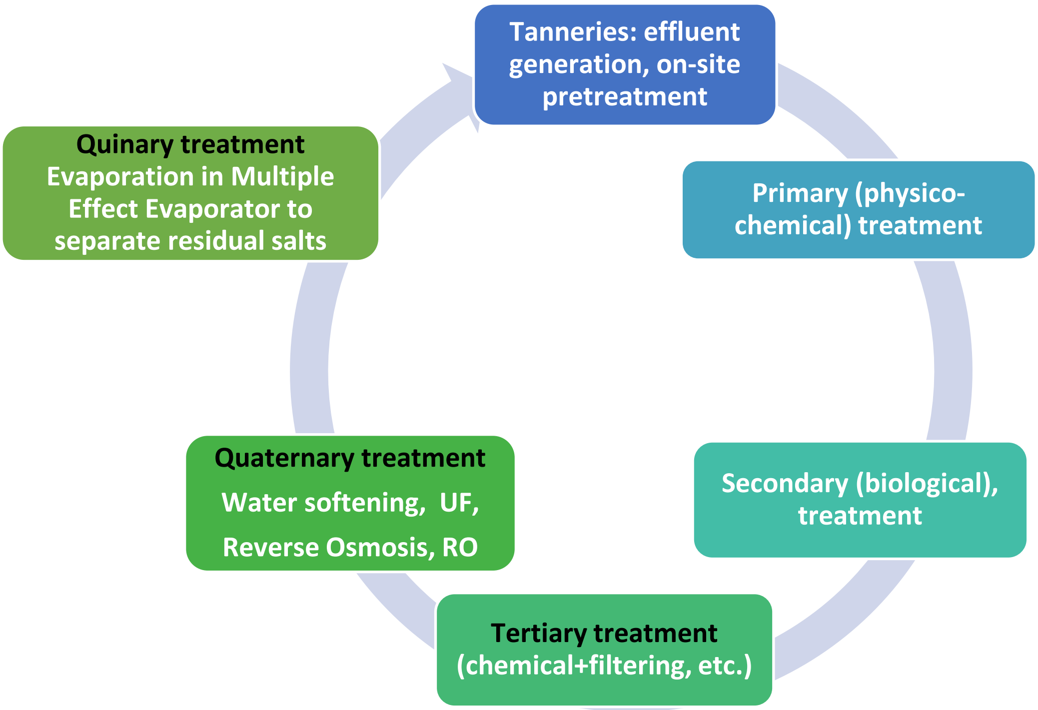


Figure 3. Schematic of water flow in RANITEC CETP/ZLD plant

Extensive reconstruction and some modifications of the old collection network and the CETP operating several years was needed to produce the effluent with characteristics in accordance with requirements of ZLD system: replacement of the collection and conveyance lines, new mixing system and odour control system in receiving sump, new mechanical screen, pre-settler, new aeration tank with new blowers and diffusers, additional mechanical sludge dewatering, softening to remove hardness and improvement in monitoring.

Interestingly, sulphide oxidation at RANITEC is done in two places, namely (1) using aspirators in equalization tank and (2) using liquid oxygen as pre-aeration before the aeration tank.

Figure 4. A simplified flow-chart of the CETP/ZLD treatment at RANITEC, Vellore District

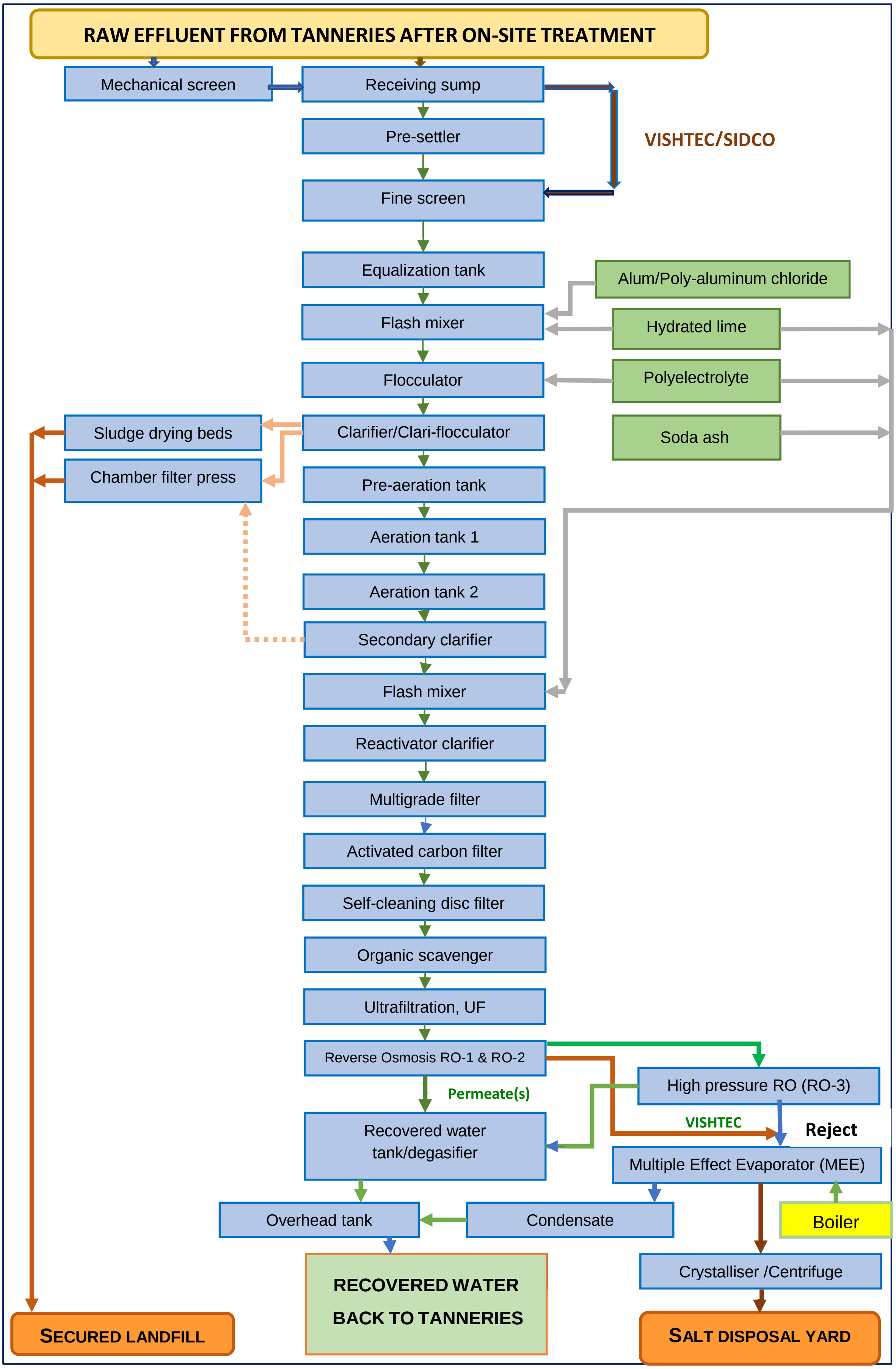
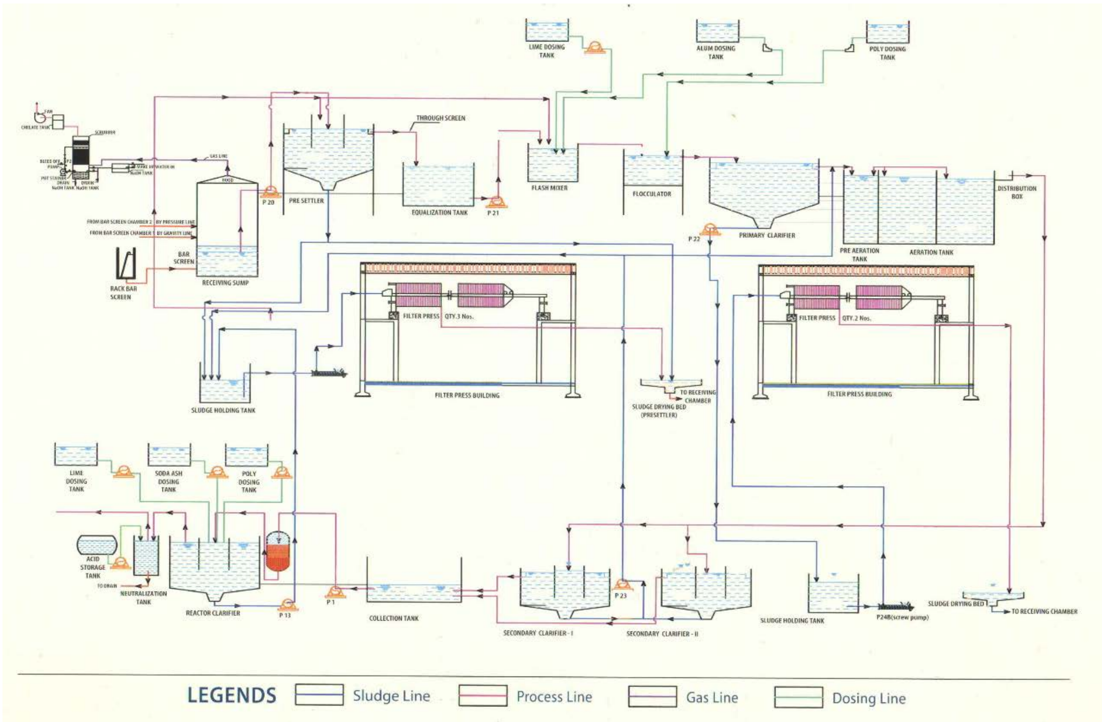


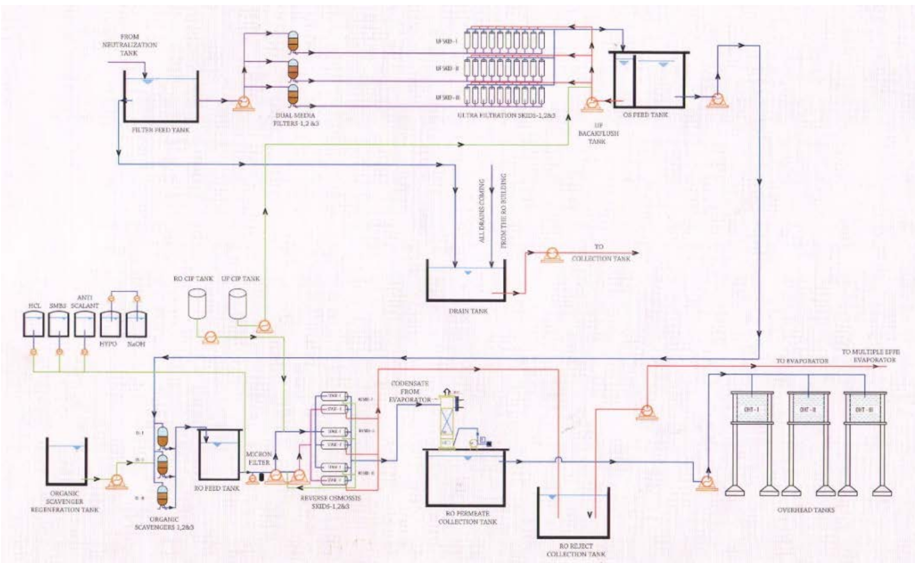
Figure 5. Process flow diagram of the Common Effluent Treatment Plant (CETP) RANITEC



Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

The treated effluent reaching the RO system is first subjected to softening through lime-soda process in a reactivator clarifier, then filtered in multigrade filters (MGF) and in an ultrafiltration system (UF) with hollow fibre membranes to be is polished in organic scavenger before it is desalinated in a two-stages Reverse Osmosis unit.

Figure 6. Process flow diagram of the Reverse Osmosis Plant at RANITEC



Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

The saline rejects from RO units are evaporated in a seven stage multiple effect evaporator (MEE) with four stages of falling film and three stages of forced circulation evaporation towers (calandrias). The fuel used for producing steam is firewood and biomass briquette. The salt-laden solid residue is removed in a pusher centrifuge.

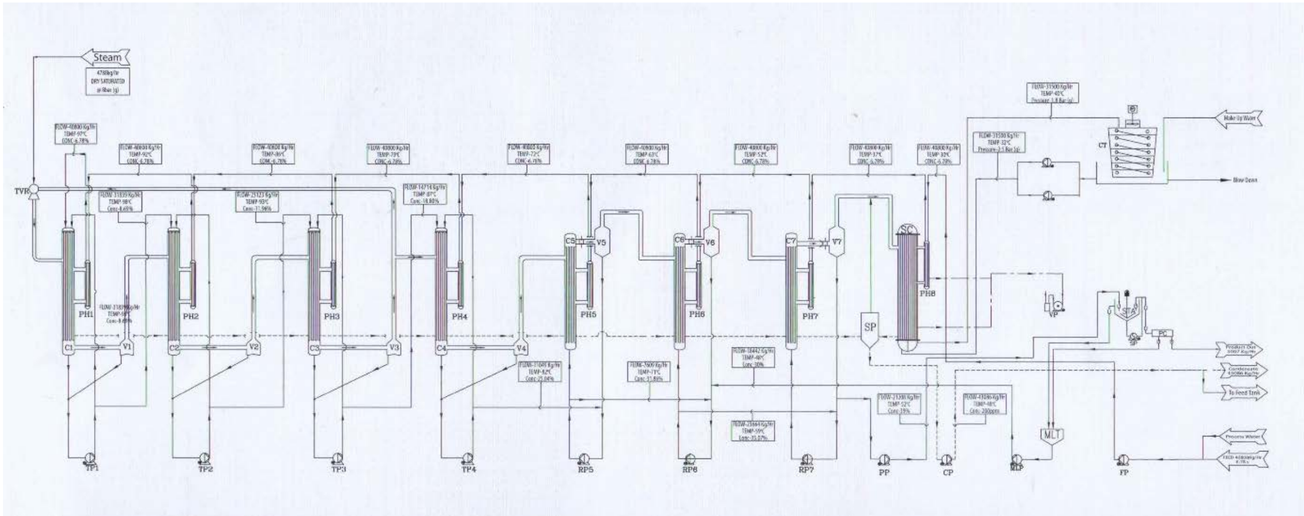
Figure 7. Ultrafiltration at RANITEC

Figure 8. Reverse osmosis at RANITEC

Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

The multistage evaporation, designed to minimize energy consumption, is a very complex, advanced system, describing it far beyond the scope of this paper.

Figure 9. Process flow diagram of the Multiple Effect Evaporation Plant at RANITEC



CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION
FP	FEED PUMP	ICP	INSTRUMENT CONTROL PANEL	SWT	SEALING WATER TANK
SC	SPRAY CONDENSOR	MCC	MOTOR CONTROL CENTER	MLT	MOTHER LIQUOR TANK
PH	PRE-HEATER	AC	AIR COMPRESSOR	HWT	HOT WELL TANK
C	CALENDRIA	STA	SETTLING TANIK	RP	RECIRCULATION PUMP
V	VAPOUR SEPARATOR	PC	PUSHER CENTRIFUGE	PP	PRODUCT PUMP
TP	TRANSFER PUMP	SP	SCREW PUMP	CWSP	COOLING WATER SUPPLY PUMP
CP	CONDENSATE PUMP	MLP	MOTHER LIQUOR PUMP	CWRP	COOLING WATER RETURN PUMP
VP	VACUUM PUMP	SWP	SEALING WATER PUMP	CT	COOLING TOWER
TVR	THERMO VAPOUR COMPRESSOR	PHE	PLATE HEAT EXCHANGER		

Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

The permeate from RO system and the condensate from evaporator are combined and distributed back to the tanneries for use in manufacturing process through a recovered water conveyance system with overhead tanks at different locations in the cluster.

The salt-laden solid residue is stored in bags and a huge salt storage yard has been constructed for the purpose.

In addition to the treatment stages mentioned earlier, the CETP has the following facilities:

- Secure landfill for sludge generated from the first and second stage of treatment, solid waste generated from tanneries and screenings from on-site pre-treatment facilities in member tanneries
- Recovered water distribution system consisting of overhead water tanks and water distribution pipelines.
- Special landfill (storage yard) for salt-laden solid residue from evaporator
- Recovered water conveyance system: overhead tanks and piping system with metering for conveying the recovered water back to individual tanneries. Individual tanneries are providing individual storage tanks with more than one-day storage capacity.

Figure 10. Online monitoring of the Multiple Effect Evaporator (MEE) at RANITEC

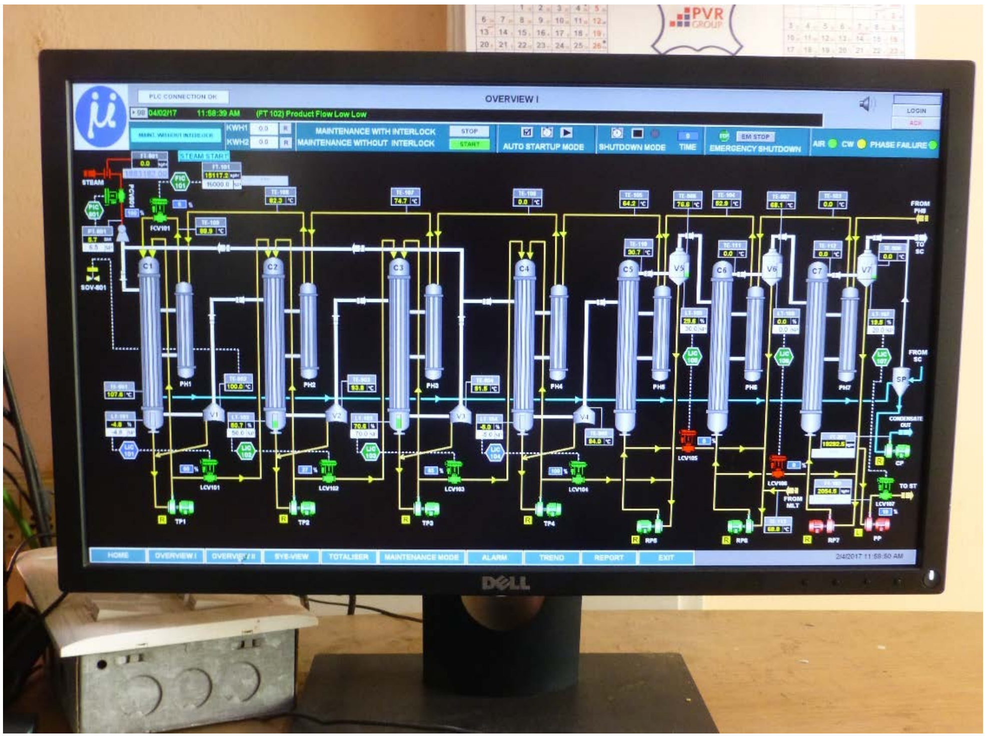


Figure 11. Pallavaram CETP/ZLD, Aeration and clarifier tanks; Ultrafiltration units; Reverse osmosis; Multiple evaporators

Norms, monitoring of the main pollutant parameters during the treatment

Serious situation with water and soil pollution along the Palar River basin prompted the Tamil Nadu Pollution Board (TNPCB) already in Dec 1992/Jan 1993 not only to classify it as *highly polluted area* but also to impose a ban on setting up new tanneries starting from raw hides & skins:

"…. *Hence in order to reclaim the original ground water quality and the soil fertility of North Arcot Ambedkar District it was decided not to entertain application from new tanneries adopting wet operations.*

Also it was decided to request the District Collector, North Arcot Ambedkar District to issue suitable instructions to the local bodies in North Arcot Ambedkar District not to issue building licence for new tanneries and not to renew running licence for the existing tanneries which are operated without valid consent of Board.

….. till all the existing tanneries set up facilities either individually or collectively for treating effluents…"

Water used in tanneries in clusters in the Vellore District is in most cases a mixture of water from own drilled wells and (better) water drawn from the Palar river bed further upstream and brought by tankers from considerable distances. As a corollary, the supply and characteristics of fresh water are inconsistent and unpredictable; comprehensive and systematic analyses of fresh water apparently are not available.

Reportedly, when it comes to parameters of the main interest for our considerations, the TDS of fresh water is in the range of 800-1500 mg/l, hardness 200-800 mg/l (tankers) and 1000 - 3000 mg/l, hardness 800-2000 mg/l (own wells). It means that the usual problem of TDS due to conservation with salt and various salts added during leather processing and effluent treatment is compounded by the high TDS/hardness level of fresh water.

As it is evident from the table, discharge norms in the Tamil Nadu state well coincide with similar norms worldwide.

Table 8. Discharge limits for tannery effluents, Tamil Nadu Pollution Control Board (TNPCB), 1984

Parameters	Standards for discharge of trade effluent into		
	Inland surface water	Public sewers	On land for irrigation
Color and odor	-	-	-
Suspended Solids, mg/L	100	600	200
Particle size of Suspended solid	shall pass 850 micron IS sieve	-	-
Dissolved solids (inorganic) mg/L*	2100	2100	2100
pH value	5.5 to 9	5.5 to 9	5.5 to 9
Temperature	40 ^{0}C at the point	45 ^{0}C at the point	-

Parameters	Standards for discharge of trade effluent into		
	Inland surface water	Public sewers	On land for irrigation
	of discharge	of discharge	
Oil & Grease, mg/L	10	20	10
Ammoniacal Nitrogen (as N), mg/L	50	50	-
Total Kjeldahl Nitrogen (as N), mg/L	100	-	-
Free Ammonia (as NH_3), mg/L	5	-	-
Biochemical Oxygen Demand (3 days at 27°C), mg/L	30	350	100
Chemical Oxygen Demand, mg/L	250	-	-
Arsenic (as As), mg/L	0.2	0.2	0.2
Mercury (as Hg), mg/L	0.01	0.01	0.01
Lead (as Pb), mg/L	0.1	1	1
Cadmium (as Cd), mg/L	2	1	1
Hexavalent Chromium (as Cr^{+6}), mg/L	0.1	2	1
Total Chromium (as Cr), mg/L	2	2	2
Chloride (as Cl), mg/L	1000	1000	600
Sulphates (as SO_4), mg/L	1000	1000	1000
Sulphide (as S), mg/L	2	-	2
Pesticides	Absent	Absent	Absent
Phenolic Compounds (as C_6H_6OH) mg/L	1	5	5

**Dissolved inorganic solids value is obtained by heating the filtered residue in muffle furnace at 550 ^{0}C for 30 minutes and it is lower than Total Dissolved Solids, TDS (drying in oven at 103 – 105 ^{0}C).*

Note:

In addition to some other parameters, the full list also contains norms for Marine coastal areas, the most relevant norms being BOD 100 mg/L, COD 250 mg/L, TKN 100 mg/L, Total Cr 2 mg/L, etc. but without limit for Dissolved solids (inorganic).

Applying on-site pretreatment and full-scale primary (physical-chemical), secondary (biological) and, in certain cases some tertiary treatment, it is possible to meet all TNPCB discharge norms except those pertaining to electrolytes (TDS, chlorides, sulphates), colloquially salinity. Avoidance of TDS calls for a very different set up in the whole chain, i.e. from slaughtering and preservation to storage, trading, soaking etc. and/or advanced (and expensive) methods of reducing TDS to acceptable level.

It is interesting to note the limits set by suppliers of RO membranes:

Table 9. Limits set by membranes suppliers for the RO inlet at RANITEC

PARAMETER	Supplier's limits for the RO inlet
pH	6.0-7
Total Dissolved Solids, TDS	As per design
Total Suspended Solids, TSS	Nil
Biochemical Oxygen Demand, BOD	5
Chemical Oxygen Demand, COD	200
Cr^{3+}	0.1

PARAMETER	Supplier's limits for the RO inlet
Sulphides	0.1
Calcium Hardness	200
Turbidity, NTU	2

All values except pH and turbidity in mg/litre

It should be noted that differences in values found by CETP's own laboratories and analyses carried out by independent laboratories (third parties) too often exceed normal and acceptable variations. Inevitably, this casts a kind of shadow of doubt and possibly undue reserve in considering the laboratory statistical data.

The Computerized Operations Management System for the Ranipet CETP includes analytical data for key treatment units as well as sludge disposal record and sludge & leachate analysis.

The main constraint here is that unlike in industrialized countries, there is no urban sewage and municipal waste water treatment plants to accept and dilute the trade effluent and the TNPCB could not postpone enforcement of the TDS limits anymore.

Thus, the only real question is whether the ZLD concept with its high costs for the RO and evaporation stages and with the resulting solid residue as the new environmental risk is the best answer to the TDS challenge.

Table 10. Pollutants' levels at the main treatment stages, CETP/ZLD plant RANITEC, monthly averages, April 2015 – March 2016

PARAMETER	RAW EFFLUENT	EQUALISATION	PRIMARY	SECONDARY	RO FEED	RO PERMEATE	RO REJECT	CONDENSATE
pH	7.6	7.7	7.7	8.2	7.3	7.1	7.5	9.4
Total Suspended Solids, TSS	1540	1330	510	90	2.5	Nil	15	Traces
Chemical Oxygen Demand, COD	4340	3570	2490	260	190	20	510	80
Biochemical Oxygen Demand, BOD	640	640	390	20	10	1	90	3
Total Dissolved Solids, TDS	**20090**	**20300**	**18930**	**17980**	**17830**	**860**	**39210**	**1110**
Chlorides, Cl^-	**10880**	**10430**	**9710**	**9280**	**8450**	**400**	**24760**	**420**
Sulphates, SO_4^{2-}	**3590**	**3480**	**3050**	**2290**	**1710**	**110**	**3080**	**N.A.**
Sulphide, S^{2-}	180	190	170	5	N.A.	N.A.	N.A.	N.A.
Cr total	N.A.	1	0	0	N.A.	N.A.	N.A.	N.A.
Oil & Grease	27	20	14	8	N.A.	N.A.	N.A.	N.A.
$N\text{-}NH_4$	N.A.	370	340	314	280	40	450	400
TKN	480	440	410	350	310	60	530	N.A.
Total Hardness	N.A.	N.A.	N.A.	N.A.	720	17	1340	19
Ca hardness	N.A.	N.A.	N.A.	N.A.	150	7	400	8
Mg hardness	N.A.	N.A.	N.A.	N.A.	570	10	940	11

Note : All values except pH in mg/litre (rounded up)

Explanatory notes:

1. The values are computed from monthly averages of daily analysis results. Whereas the first 8 parameters are tested daily, the rest is tested on a weekly/monthly basis. The parameters tested depends on the treatment stage.

2. The value of suspended solids reported earlier at inlet of RO and permeate were illogically high (no TSS retainable in the filter paper can pass through UF or RO which has much less pore size). On closer observation in the lab, it was found out that the erratic values were due to insufficient drying of the filter paper in the desiccator.
3. The apparent reduction in TDS and chlorides after primary treatment in RANITEC is due to addition of drain water to the flash mixer which includes backwash water from filters which uses RO permeate with low TDS for backwash.
4. The TDS value exceeds the design value (18,000 mg/l maximum and about 12000 mg/l average) significantly. Prior to the starting of ZLD, the TDS in the raw effluent was reported in the range of 10,000-11,000 mg/l, which indicates that there is a massive reduction of water consumption by the member tanners after they started paying the high tariff of ZLD (about INR 400 -500, which is about 10 times of earlier charges without ZLD).
5. The proportion of increase in chlorides and sulphates after ZLD regime is proportional to the TDS increase as above.
6. Reduction in Sulphates after biological treatment was surprising since normally an addition of sulphates would be expected (due to potential for oxidation of sulphides). It is assumed that the reduction of sulphates is due to the reduction of sulphates by sulphate reducing bacteria present in the degasifier tank. The high level of H_2S in this tank and high presence of elemental sulphur in the slime layer in the side of this tank reinforces this assumption.
7. Level of ammonia is very high in raw effluent and in the absence of a nitrification/denitrification stage in the treatment, little reduction is achieved in the treatment. It is noteworthy that prior to 2011 (i.e., before the ZLD starts operating) the ammonia levels were less than 100 mg/l and it is believed that the present increase is due to the tanners reducing the water consumption drastically. Though it did not appear to have severely affected the operation of the system, it is learned that many tanners complained about the high level of ammonia in the permeate as an issue in reuse.
8. Unlike other CETPs, RANITEC CETP has lower hardness, particularly calcium hardness in the raw and treated effluent. Calcium when present in the effluent can result in scaling of the membranes due to precipitation of calcium sulphate when the concentration exceeds its critical solubility limit (Calcium sulphate is amphoteric and will start precipitating in concentrations exceeding 2 g/l). This low concentration enabled the CETP to manage the membrane operation without separate softening system while other CETPs are required to go for softening as a tertiary treatment.

Table 11. Pollutants' levels at the main treatment stages, monthly averages, CETP/ZLD plant SIDCO, April 2015 – March 2016

PARAMETER	RAW EFFLUENT	EQUALISATION	PRIMARY	SECONDARY	RO FEED	RO PERMEATE	RO REJECT	CONDENSATE
pH	5.1	5.15	7.2	7.3	6.6	6.5	7.2	7.1
Total Suspended Solids, TSS	2010	1930	147	55.2	BDL	BDL	2.2	BDL
Chemical Oxygen Demand, COD	5342	4674	2470	647	546	ND	3280	12
Biochemical Oxygen Demand, BOD	1570	1556	991	69	1	BDL	5.2	BDL
Total Dissolved Solids, TDS	**11800**	**10660**	**9806**	**9986**	**9160**	**388**	**36100**	**225**
Chlorides, Cl^-	**1945**	**1888**	**1942**	**1945**	**1888**	**226**	**9725**	**106**
Sulphates, SO_4^{2-}	**3870**	**3945**	**3855**	**3766**	**3650**	**9**	**17225**	**9.2**
Sulphide, S^{2-}	26.8	16.2	14	1.8	NA	NA	NA	NA
Cr total	22.4	17.8	0.8	0.2	0.05	BDL	0.1	BDL
Oil & Grease	12.5	13.1	5.2	2.1	0.5	BDL	1.7	BDL
$N\text{-}NH_4$	22.8	24.6	26.2	16.1	14	3.2	31	16.5
TKN	55.4	61	48.6	51	52.2	5.6	108	66.4
Total Hardness	NA	NA	NA	2255	440	34.6	1602	16
Ca hardness	NA	NA	NA	1025	182	12.8	614	4.5
Mg hardness	NA	NA	NA	1230	268	21.8	988	11.5

Explanatory notes:

1. The data are from Sep 2015 to May 2016 instead of April 2015 to March 2016 because the tanneries connected to the SIDCO CETP were closed during the period Feb 2015 to Sep 2015.
2. Since the CETP treats effluent only from semi-finished to finished process TDS is lower but the COD is less biodegradable.

3. The values are computed from monthly averages of daily analysis results. Whereas pH, TSS, TDS and COD are tested daily in all samples, BOD, Cl^- and $(SO_4)^{2-}$ are tested daily in relevant samples. All parameters are tested at all points relevant on weekly basis.
4. The TDS value exceeds the design value (8000 mg/l maximum and 5000 mg/l average) significantly. Prior to the starting of ZLD, the TDS in the raw effluent was reported in the range of 4500-5000 mg/l, which indicates that there is a massive reduction of water consumption by the member tanners after they started paying the high tariff of ZLD (about INR 450 -550, which is about 10-12 times of earlier charges without ZLD).
5. The rate of increase in chlorides and sulphates after ZLD regime is proportional to the TDS increase as above.
6. The increase in Chlorides after chemical treatment may be due to the usage of poly aluminium chloride (PAC) in primary treatment
7. Absence of any reduction of TDS after the biological treatment indicate the relatively lower level of organic (volatile) TDS in the effluent.
8. Due to high level of hardness, the CETP resort to lime soda softening at the tertiary stage. In addition, the CETP uses a special antiscalant at RO inlet to supress the precipitation potential of calcium salts.

Table 12. Pollutants' levels at the main treatment stages, monthly averages, CETP/ZLD plant VISHTEC, April 2015 – March 2016

PARAMETER	RAW EFFLUENT	EQUALISATION	PRIMARY	SECONDARY	RO FEED	RO PERMEATE	RO REJECT	CONDENSATE
pH	7.2	7.4	7.6	7.1	6.8	6.6	6.9	7.6
Total Suspended Solids, TSS	NA	2565	188	122	BDL	BDL	BDL	BDL
Chemical Oxygen Demand, COD	6108	5115	3220	442	366	2.2	944	BDL
Biochemical Oxygen Demand, BOD	NA	1612	944	26.6	6.2	BDL	1	BDL
Total Dissolved Solids, TDS	**16760**	**16110**	**16820**	**17222**	**17920**	**465**	**39420**	576
Chlorides, Cl^-	NA	**8652**	**8724**	**9220**	**9312**	**212**	**26210**	282
Sulphates, SO_4^{2-}	NA	**3212**	**2865**	**2932**	**3115**	**31.4**	**11412**	61
Sulphide, S^{2-}	NA	42.4	14.8	2.1	0.1	BDL	0.1	BDL
Cr total	NA	92.6	4.2	1.8	0.1	BDL	0.15	BDL
Oil & Grease	NA	22	17.6	6.1	2.8	0.1	BDL	BDL

PARAMETER	RAW EFFLUENT	EQUALISATION	PRIMARY	SECONDARY	RO FEED	RO PERMEATE	RO REJECT	CONDENSATE
$N\text{-}NH_4$	NA	N.A.	198	215	212	102	288	178
TKN	NA	NA	206	265	265	112	306	188
Total Hardness	NA	N.A.	N.A.	N.A.	422	20	1455	1340
Ca hardness	NA	N.A.	N.A.	N.A.	210	9	725	406
Mg hardness	NA	N.A.	N.A.	N.A.	212	11	730	734

Explanatory notes:

1. The values are computed from monthly averages of daily analysis results. Whereas the first 9 parameters are tested at equalised effluent, secondary clarifier outlet on a daily basis. Samples such as Raw effluent, RO feed, permeate and reject are checked for these 9 parameters on a weekly basis. The remaining test parameters, except the hardness for samples till RO feed, are checked on fortnightly basis.
2. Though the ammonia level at the inlet of RO is lower than Ranitec, the ammonia level in permeate is quite high in VISHTEC. It may be due to the difference in the type of membranes.
3. The TDS value exceeds the design value of RO membranes (12,000 mg/l maximum and about 10,000 mg/l average). Till 2010, prior to the starting of ZLD, the TDS in the raw effluent was reported in the range of 9,000-10,000 mg/l only, which indicates that there is a significant reduction of water consumption by the member tanners after they started paying the high tariff of ZLD.
4. The rate of increase in chlorides and sulphates after ZLD regime is proportional to the TDS increase as indicated above.
5. VISHTEC CETP has moderate level of hardness at the treated effluent stage and hence a lime soda softening is employed in the process.

Table 13. Comparison of monthly averages of pollutants' levels at some treatment stages, April 2015 – March 2016

PARAMETER	EQUALISED RAW EFFLUENT			RO FEED			RO PERMEATE			RO REJECT		
	RANITEC	SIDCO	VISHTEC	RANITEC	SIDCO	VISHTEC	RANITEC	SIDCO	VISHTEC	RANITEC	SIDCO	VISHTEC
pH	7.7	5.15	7.4	7.3	6.6	6.8	7.1	6.5	6.6	7.5	7.2	6.9
TSS	1330	1930	2565	20	BDL	BDL	4	BDL	BDL	15	2.2	BDL
COD	3570	4674	5115	190	546	366	20	ND	2.2	510	3280	944
BOD	640	1556	1612	10	1	6.2	1	BDL	BDL	90	5.2	1
TDS	**20300**	**10660**	**16110**	**17830**	**9160**	**17920**	**860**	**388**	**465**	**39210**	**36100**	**39420**
Cl^-	**10430**	**1888**	**8652**	**8450**	**1888**	**9312**	**400**	**226**	**212**	**24760**	**9725**	**26210**
SO_4^{2-}	**3480**	**3945**	**3212**	**1710**	**3650**	**3115**	**110**	**9**	**31.4**	**3080**	**17225**	**11412**
S^{2-}	190	16.2	42.4	N.A.	NA	0.1	N.A.	NA	BDL	N.A.	NA	0.1
Cr total	1	17.8	92.6	N.A.	0.05	0.1	N.A.	BDL	BDL	N.A.	0.1	0.15
Oil & Grease	20	13.1	22	N.A.	0.5	2.8	N.A.	BDL	0.1	N.A.	1.7	BDL
$N\text{-}NH_4$	370	24.6	N.A.	280	14	212	40	3.2	102	450	31	288
TKN	440	61	NA	310	52.2	265	60	5.6	112	530	108	306
Total Hardness	N.A.	NA	N.A.	720	440	422	17	34.6	20	1340	1602	1455
Ca hardness	N.A.	NA	N.A.	150	182	210	7	12.8	9	400	614	725
Mg hardness	N.A.	NA	N.A.	570	268	212	10	21.8	11	940	988	730

Note : All values except pH in mg/litre (rounded up)

The Computerized Operations Management System for the Ranipet CETP/ZLD includes analytical data for key treatment units as well as sludge disposal record and sludge & leachate analysis.

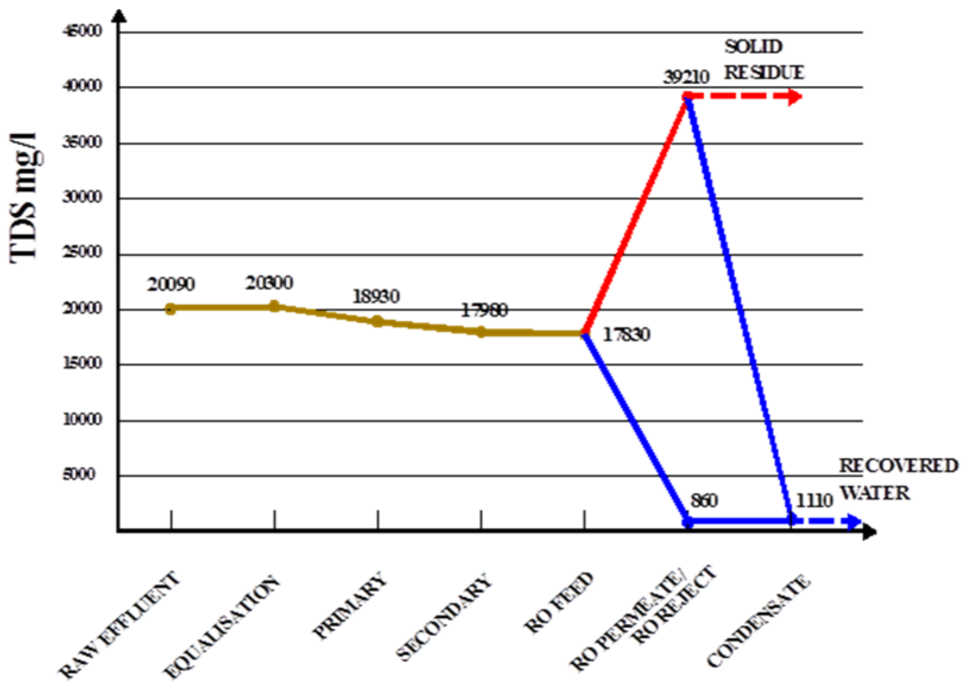
Below detectable limit, BDL for TSS 5.0 mg/l, for BOD 2.0 mg/l, for COD 5.0 mg/l, for ***Cr^{6+}*** *0.02-1.0 mg/l, for Total Cr 0.02 mg/l and for Total carbon 5.0 mg/l*

Table 14. Analytical results of streams in reject evaporation area, CETP/ZLD plant AMBURTEC

Parameter	Pellet reactor outlet	MVRE condensate	MVRE concentrate	Mother liquor
Total hardness (as $CaCO_3$)	**3410**	**440**	**5640**	**79340**
Chlorides	27400	4700	45010	103910
Sulphates	7100	1270	9780	15020
pH	7.6	9.6	7.9	6.9
Total dissolved solids, TDS	**51660**	**9170**	**88100**	**193100**
Calcium hardness (as $CaCO_3$)	1980	40	3500	1300
Total organic carbon	40	25	250	350
Sodium (as Na)	16000	2970	28900	72200
Calcium (as Ca)	790	16	1400	520
Magnesium (as Mg)	350	100	520	1620

Based on the values in the table it can be concluded that for satisfactory removal of hardness, media in the pelletizer should be replaced on time and that the high TDS and chloride content in the MVRE condensate and ultimately in recovered water might be due to carryover of reject from feed to condensate in the MVRE.

Figure 12. Total Dissolved Solids (TDS), monthly averages, RANIPET, April 2015 – March 2016



The average TDS contents in the permeate differ considerably: from only 450 mg/l at PERTEC, 860 mg/l at RANITEC to 1348 mg/l at AMBURTEC (reportedly reduced to less than 800 mg/l).

In some cases results of some tests conducted by an external laboratory differ significantly.

Energy considerations

Energy consumption in tanneries depends on factors such as tannery location (geographic zone), production method, equipment, performance of electric motors, the ratio of manual vs. mechanical/automated handling (e.g. in moving the hides), drying methods, solid waste treatment, effluent treatment technology etc. As a consequence, energy consumptions vary within very wide ranges.

According to the EU BREF 2013 document in tanneries following the Best Available Technology (BAT), energy consumption for processing bovine hides from raw to wet blue/wet white is up to 3 GJ/tonne, for processing bovine hides from raw to finished leather is up to 14 GJ/tonne, whereas processing sheep skins from raw to finished leather requires up to 6 GJ/tonne; the figures do not include energy for effluent treatment. Furthermore, in a European tannery electrical energy typically represents approx. one quarter and thermal energy three quarters of the energy consumed.

Generally, water (float) heating and drying, almost equally, make about two thirds of the energy consumption for leather processing itself.

The type of energy source is also very relevant: fossil fuel (natural gas, coal, Diesel), renewable (wood, biomass) or self-generated renewable (solar energy, wind).

Optimisation of electric motors, use of modern electric motors with higher efficiency and, in particular, reducing the level of reactive energy are very important part of (electric) energy savings measures while the use Diesel generators is limited to emergencies.

The tannery waste water temperature is usually higher than the temperature of the fresh water and the ambient air temperature due to use of warm floats in the process; however, due to transportation and relatively long time of the treatment, the temperature during the treatment almost entirely depends on the ambient air temperature.

The LWG Environmental Protocol Audit Responses Report, Issue 6.0 G estimates the consumption of the electric energy for the effluent treatment at 10 kWh/m^3 of the effluent; at the water consumption level of 25 m^3/t of the raw hide it corresponds to 900 MJ/t of raw hides.

In reality the electric energy consumption in the (C)ETP very much depends on its capacity. According to UNIDO study the advantage of scale is obvious: the range is, for example, from 265 kWh/t raw hide (100 m^3/day) to 90 kWh/t raw hide (5000 m^3/day). In any case, the main energy consumer in the conventional (C)ETP is biological (aerobic) treatment.

It is interesting to note that while the biological treatment in hot climate zones is positively influenced by higher effluent temperature, lower solubility of oxygen and lower oxygen transfer rate (OTR) have a negative effect and result in a slightly higher consumption of electric energy than in the moderate climate.

From the very outset it was clear that power consumption for RO and evaporation would be of crucial importance for the overall performance and viability of the ZLD concept. Now, a few years of operations of the system it should be possible to make a reasonably accurate and realistic assessment of energy consumption, both electrical and thermal.[3]

Table 15. Energy consumption & cost, Primary, Secondary & Tertiary Treatment, RANITEC, April 2015- March 2016

ITEM	Unit	TOTAL
Inflow to CETP	m^3	415,185
Units consumed in KWh (EB)	kWh	2,349,980
Diesel litres (DG)	L	47,711
Units consumed in KWh (DG)	kWh	110074
Units consumed in KWh (EB+DG)	kWh	2,460,054
Total units vs. inflow	kWh/m^3	5.9
EB cost per unit	Rs.	9.1
EB power cost	Rs.	21,567,943
Diesel price	Rs./L	62
Cost of Diesel	Rs.	2,958,082
Total energy cost	Rs	24,526,025
Total energy cost vs. inflow	**Rs. /m^3**	**59 (USD 0.9)***

At Rs. 66.3 to 1 USD

Table 16. Energy consumption & cost, Reverse Osmosis + Evaporation, RANITEC, April 015- March 2016

ITEM	Unit	TOTAL
Inflow to CETP	m^3	415,185
RO reject	m^3	115,321
Units consumed in kWh (EB)	kWh	4,168,830
Diesel litres (DG)	L	74,029
Units consumed in kWh (DG)	kWh	196,992
Units consumed in kWh (EB+DG)	kWh	4,365,822
Total units vs. inflow	kWh/m^3	10.0
EB cost per unit	Rs.	9.10
Total EB power cost	Rs.	37,492,478
Diesel price	Rs./L	62

[3] *A serious constraint in analysing energy consumption is that very often it is not metered and logged separately for leather processing and effluent treatment, or, in particular, for the conventional (primary, biological, sludge handling) and ZLD stage.*

ITEM	Unit	TOTAL
Cost of Diesel	Rs.	4,589,798
Total power cost (EB + Diesel)	Rs.	42,082,276
Power cost (EB + Diesel)	Rs./m^3	101
Firewood used	kg	7,406,396
Firewood price	Rs./kg	4.2
Firewood/m3 of reject	kg/m^3	64
Cost of fuel (firewood) for MEE	Rs.	31,106,863
Total energy cost	Rs.	73,189,139
Total energy cost vs. inflow	**Rs./m^3**	**176 (USD 2.7)**

The main energy parameters for SIDCO and VISHTEC generally follow a similar pattern and are merged into a summary table.

Table 17. Energy consumption & cost, Reverse Osmosis + Evaporation, RANITEC, SIDCO & VISHTEC 2015-2016

ITEM	Average per month			
	Unit	RANITEC	SIDCO	VISHTEC
Inflow to CETP	m^3	34,599	28,533	11,871
Units consumed in kWh (EB)	kWh	347,403	227,004	9,5795
Units per inflow	kWh	10.0	8.0	8.1
Total electricity cost (EB)	Rs.	21,567,943	1,407,422	593,928
Diesel consumed	L	6,169	1,193	732
Diesel cost	Rs.	382,483	73,959	45,353
Cost of power (EB + Diesel)	Rs./m^3	101	52	54
Firewood used	kg	617,200	512,902	259,916
Firewood/m^3 of reject	kg/m^3	64	77	88
Cost of fuel for evaporator	Rs.	2,592,239	2,277,283	1,143,632
Total energy cost	Rs.	6,099,095	3,756,618	1,833,784
Total energy cost vs. inflow	**Rs./m^3**	**176 (USD 2.7)**	**132 (USD 2.0)**	**154 (USD 2.3)**

Remark:

Despite some variations, the price of firewood has been taken as Rs. 4.2/kg. Similarly, despite variations in Diesel prices during the year, its cost was calculated at Rs. 62/L as the yearly average; also, there are significant differences among plants in using Diesel as a source of energy.

Table 18. Comparison of energy consumption & cost, PST vs. ZLD stage (Reverse Osmosis + Evaporation), RANITEC, April 2015- March 2016

Item	Unit	PST	ZLD	Total	Total vs. PST %
		1	2	3 (1+2)	4 (3/1)
Inflow	m^3/year	415,185			
Electrical energy (EB)	kWh/year	2,349,980	4,168,830	6,518,810	277%
Total electrical energy vs. inflow	kWh/m^3	5.7	10.0	15.7	277 %
Cost of electrical energy (EB)	Rs./kWh	9.10			
Cost of electrical energy (EB)	Rs./year	21,384,818	37,936,353	59,321,171	277%
Cost of electrical energy (EB) vs. inflow	Rs./m^3	52	91	143	275%
Total electrical energy (EB) consumed in MJ	MJ/year	8,459,928	15,007,788	23,467,716	277%
Consumption of Diesel fuel	L/year	47,711	74,029	12,1740	255%
Diesel price	Rs./L	62			
Cost of Diesel	Rs./year	2,958,082	4,589,798	7,547,880	255%
Consumption of fuel, Diesel in MJ	MJ/year	1,860,729	2,887,131	4,747,860	255%
Consumption of firewood	kg/year		7,406,396	7,406,396	
Cost of firewood per kg	Rs./kg		4.2	4.2	
Total cost of firewood	Rs./year		31,106,863	31,106,863	
Total firewood consumption, MJ	MJ/year		122,205,534	122,205,534	
Overall energy consumption (EB+Diesel+ firewood)	MJ/year	10,320,657	140,100,453	150,421,110	1457%
Total energy cost (EB+Diesel+ firewood)	Rs./year	24,342,900	73,633,014	97,975,914	402%
Total energy in MJ vs. inflow	**MJ/m^3**	**25**	**337**	**362**	**1457%**
Total energy cost vs. inflow	**Rs./m^3**	**59**	**177**	**236 (USD 3.6)**	**402%**

Note: Minor discrepancies due to rounding up!

The following table shows shares of the main components of energy consumption and costs.

Table 19. Energy consumption & cost comparisons, RANITEC, April 2015- March 2016

Item	Rate %
Share of PST energy in Total energy consumed	7%
Share of ZLD energy in Total energy consumed	93%
Share of PST energy cost in Total energy cost	25%
Share of ZLD energy cost in Total energy cost	75%

Item	Rate %
Share of electrical energy in Total energy consumed, MJ	16%
Share of thermal (Diesel) energy in Total energy consumed. MJ	3%
Share of thermal (firewood) energy in Total energy consumed. MJ	81%

** including Diesel   Values rounded up!*

Figure 13. Firewood being prepared for firing in the MEE boiler

The impact of addition of ZLD (RO + MEE) to the conventional treatment can be summarized as follows:

- The consumption of electrical energy went up nearly three times
- The overall energy consumption (electrical and thermal) went up nearly 15 times
- The cost of electrical energy, including its unit cost (Rs./m^3) went up nearly three times
- The total cost of energy (electrical and thermal) went up about 4.5 times
- The share of ZLD energy in total energy consumed is about 94 %
- The share of ZLD energy cost in total energy cost is about 78 %

Consumption of chemicals in the course of treatment, consequences

Due to considerable differences in the types of raw material input (hides, skins) process (E.I., vegetable tannage, wet blue, fully finished etc.), differences in the raw effluent pollution load and ultimately differences in effluent treatment methods, direct comparison of consumption of chemicals in CETP/ZLD plants operating in the area is not possible.

Yet, there is no doubt that here we have an obvious paradox. With the aim of preserving the environment, and, in particular, avoiding discharges of well purified (low BOD, COD, suspended solids, etc.) but still saline effluent, large amounts of chemicals are added, especially in the course of post-conventional treatment, i.e. during tertiary treatment, water softening, RO and evaporation steps.

Ultimately, the ZLD concept protects the water recipients but, in addition to conventional sludge, also produces tonnes of solid residue (mainly composed of chlorides and sulphates) posing new environmental risks and challenges.

Although the information in the following table are not quite consistent and detailed, they, nevertheless, provide a good overview of chemicals dosed in the course of various stages of treatment.

Table 20. Typical consumption rates/dosing of chemicals at PERTEC and AMBURTEC (2014/15)

Process stage, chemicals	**Consumption rate**	
	PERTEC	***AMBURTEC***
Primary treatment		
Lime	600 – 700 mg/l of raw effluent	100 mg/l of raw effluent (pH of the effluent > 7)
Alum	800 – 900 mg/l of raw effluent	200 mg/l of raw effluent
Polyelectrolyte	1 mg/l of raw effluent	0.5 – 0.7 mg/l of raw effluent
Tertiary treatment		
Softening		
Lime	800 – 900 mg/l of secondary treated effluent	1000 mg/l of secondary treated effluent
Soda ash	2500 mg/l of secondary treated effluent	
Poly aluminium chloride	300 – 400 mg/l of secondary treated effluent	
Alum		1000 mg/l of secondary treated effluent
Polyelectrolyte	1 mg/l of secondary treated effluent	1 mg/l of secondary treated effluent
Neutralization		
Hydrochloric acid	800 – 1000 mg/l of RC outlet	500 – 1000 mg/l of tertiary outlet
Reverse osmosis		
Sodium metabisulphite	20 - 40 mg/l of feed	3 mg/l of feed
Antiscalant	10 – 50 mg/l of feed	4 mg/l of feed

Process stage, chemicals	Consumption rate	
Cleaning chemicals (bimonthly)		
Caustic soda		3 kg
SLS (washing powder)		½ kg
EDTA		3 kg
Sodium tripolyphosphate		3 kg
HCl		5 kg in m^3
Softening		
Caustic lye		300 - 400 ppm
Sodium bicarbonate		300- 400 ppm

Table 21. Overview of the consumption of chemicals during the PST and RO stages, RANITEC, April 2015 – March 2016

ITEM	Unit	TOTAL	Average per month
INFLOW to CETP	m^3	415859	34655
Lime	kg	519085	43257
Alum	kg	643980	53665
Polyelectrolyte	kg	1137	95
RO CHEMICALS			
Caustic Soda	kg	6444	537
SMBS	kg	3235	270
Sodium Hypochlorite	kg	18785	1565
Antiscalant (RO)	kg	1625	135
Hydrochloric Acid (RO+HP RO)	Litres	1511959	125997

Table 22. Overview of the consumption of chemicals at the evaporation stage, RANITEC, April 2015 – March 2016

ITEM	Unit	TOTAL	Average per month
INFLOW to CETP	m^3	415,859	34,655
Antiscalant (Boiler)	kg	502	42
Oxygen Scavenger	kg	612	51
Antiscalant	kg	304	25
Biodispersant	kg	130	11
Biocide I	kg	149	12
Biocide II	kg	110	9
Nitric Acid	Litres	4405	367

Remark: More details about chemicals are needed such as concentrations, purity, dosing (dilution).

Reportedly, the cost of chemicals for the operations of the CETP/ZLD PERTEC April 2014 - March 2015 was Rs. 1541057 corresponding to approx**.** Rs. 18/m^3 of raw effluent. While it is not negligible, it is not the cost but the scale and impact of chemicals used which are of concern.

Table 23. Summary overview of consumption of chemicals, ZLD plant RANITEC, April 2015 – March 2016

ITEM	Unit	TOTAL
Inflow to CETP	m^3	415150
Lime	kg	519085
Alum	kg	643980
Polyelectrolyte	kg	1137
Caustic soda	kg	6444
SMBS	kg	3235
Sodium hypochlorite	kg	18785
Antiscalant (RO)	kg	1625
Hydrochloric acid (RO+HP RO)	Litres	1511959
Antiscalant (Boiler)	kg	502
Oxygen scavenger	kg	612
Antiscalant	kg	304
Biodispersant	kg	130
Biocide I	kg	149
Biocide II	kg	110
Nitric Acid	Litres	4405

In absence of information about concentration/dilution and purity of various inorganic and organic chemicals, precipitations and sludge and solid residue discharges etc. simple adding up of the quantities of chemicals used is not possible.

Table 24. Consumption of chemicals, CETP/ZLD plant SIDCO, Sept 2015 – March 2016

Chemical	Total (nine months)
Flow, raw effluent, m^3	213205
Primary treatment	
Lime	310092
Polyaluminium chloride	432522
Polyelectrolyte	845
Secondary treatment	
Urea	692
Diammonium phosphate	702
Defoamer	1394
Tertiary treatment	
Soda ash	335337
Lime	247787
Polyaluminium chloride	583124

Chemical	Total (nine months)
Polyelectrolyte	654
Reverse Osmosis	
Antiscalant	1100
Hydrochloric acid	363489
Sodium metabisulphite	1010
Caustic soda	10262
Sodium laryl sulphate	15
Evaporator	
Nitric acid	7659
Antiscalants for evaporator	1183

Operation and maintenance

The case of RANITEC CETP/ZLD plant is quite illustrative and enlightening.

Originally it was envisaged that the contractor selected to build the ZLD system at RANITEC would operate it for 10 years at a tendered rate of operation of Rs. 80/m^3. However, the actual cost of operation turned out to be Rs. 320-400/ m^3 or four times the tendered rate with more than 50% of cost accounted for energy, electric and thermal. Thus, both contractors failed to carry out this part; one of them even collapsed mid-way through the project implementation so that the rest of the implementation was virtually done by CEMCOT.

Distribution of O&M costs

O&M costs consist of two parts. All capital expenditures/repairs/spares are charged as fixed cost and recovered according to participation in the CETP share capital.

The variable cost is spread according to actual effluent flow measured at the tannery outlet; linking the variable charges to the pollution load (more precisely to TDS concentration) is still at discussion stage. Distinction between tanneries processing from raw to finished and from wet-blue and E.I. (vegetable tanned) to finished leather as a possible transition stage is not on the agenda either.

As said in the Investment chapter, no information is available about the cost of non-grant capital; since it is apparently fully born by tanneries – CETP shareholders, the interest rates might vary depending on their individual financial situations. In any case, the cost of investment capital – loan repayment is not included in the O&M costs.

Warranties, depreciation

The ZLD project as a whole had a warranty for 18 months from the date of physical completion or 12 months from the date of satisfactory commissioning whichever was later. Wherever individual equipment (e.g. Diesel Generator) had a longer warranty period, the Contractor passed the same on the CETP/ZLD.

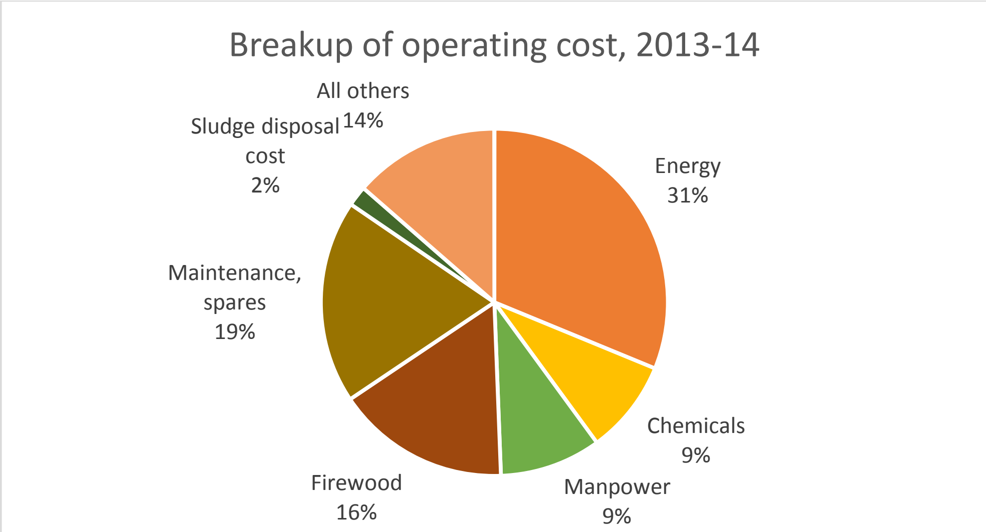
Reportedly, the membrane manufacturers provide warranty with a rider related to characteristics of effluent in such a way that in reality there is no genuine warranty for membranes.

In accordance with the local (unhealthy) customs, none of the CETP/ZLDs computes and charges any depreciation, the users are charged replacement cost of equipment as and when occur.

During the year 2013-14, the CETP treated about 588,000 m^3 of effluent sent by tanneries whereas the cost of treatment was about Rs. 143 million (14.3 crores) or Rs. 243.2/m^3 corresponding to USD 2.16 million and USD 3.67/ m^3 at the rate of Rs. 66.3 to 1 USD.

However, as said earlier, the figure includes neither the costs of depreciation nor the cost of non-grant capital. Furthermore, it does not include any allocation for the anticipated cost of disposal of salt residue resulting from the evaporation process.

Figure 14. Break up of O & M cost, RANITEC, 2013-14



Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

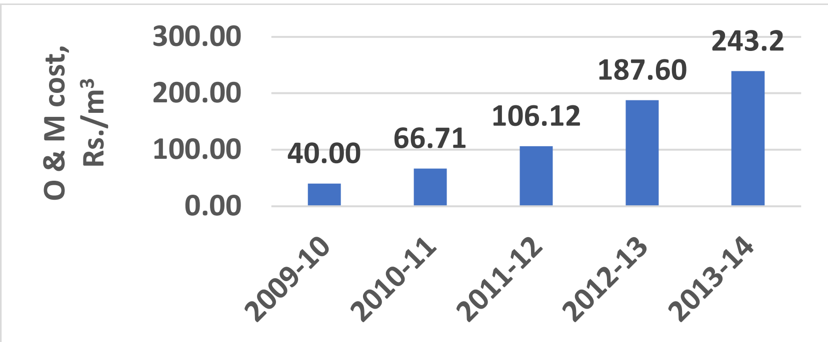
It has to be emphasised that more time is needed for proper assessment of the operational life of RO membranes.

For example, at the PERTEC plant, operational since June 2015, out of 915 tubes 500 tubes already had to be replaced. It is expected with the initial, stabilization period being over the membranes life will be substantially longer.

The impact of operation and maintenance cost

The cost of operation and maintenance of effluent treatment plant is completely borne by the members of the CETP.

Figure 15. Historical overview of the escalation of the O&M charges, RANITEC, 2009 -2014



Source: Ranipet Tannery Effluent Treatment Co. Ltd., RANITEC brochure, 2105

Tanners of the RANITEC cluster claim that the cost of effluent treatment has reached the level of over Rs. 4 per sq.ft of leather whereas their margin is only a Rupee per sq.ft. and it drastically affects their competitiveness. However, no comprehensive and reliable data about raw hides and skins inputs and leather production are available to support these claims.

It is quite understandable that due to complexity and cost of monitoring system required for that purpose it is difficult possible to introduce charging individual tanneries according to the specific pollution load of effluent they send for treatment. However, apparently, there is no distinction between different categories of effluents either, i.e. whether they emanate from the full process, raw to semi-tanned or from semi-tanned (wet blue, E.I.) to finished leather.

Table 25. Overview of O &M costs in relation to leather output, RANITEC

	RANITEC	SIDCO	VISHTEC
Total ZLD cost of the year, INR	175,362,530	120,824,000	81,768,022
Volume of effluent treated, m^3	415,859	256,801	142,453
Cost per m^3, INR	422	470	574
Total raw material processed in the cluster, tons/year	32,059	11,249*	7,502
Cost of ZLD per kg/raw material, INR	5.47	12.6	10.9
Total sq.ft of leather produced	96,353,038	57,535,238	22,429,944
Total sq.m of leather produced	8,951,486	5,345,196	2,083,809
Cost of ZLD per sq.ft of leather produced, INR	1.82	2.1	3.65
Cost of ZLD per sq.m of leather produced, INR	19.6	22.6	39.2
Value of production - range during past 5 years, INR	9150-17530 Mill	5465-10471 mill	2130-4082 mill
Appr. value of production in the year, INR	9,45,00,00,000	5,46,50,00,000	3,25,50,00,000
% of the ZLD cost as a factor of production	1.86	2.21	2.51

INR: Indian Rupee (1 USD ~ 66.7, INR as in Nov 2016)
** wet blue/E.I. weight*

<u>Explanatory notes:</u>

1. As seen from the above table, CETP/ZLDs have one of the highest OPEX : CAPEX Ratio. The O & M cost vs. Installation costs at RANITEC, SIDCO and VISHTEC for the year 2015-2016 were about 30%, 37.0% and 56% respectively. This means that in 2-3 years O & M cost may exceed the installation cost.
2. In case of RANITEC and VISHTEC, the quantity of raw material processed has been indicated as weight of raw stock, converting the quantity of production in semi-finished to finished too as raw weight. In SIDCO tanneries, the production is only semi-finished to finished and hence the raw material weight has been expressed in weight of semi-finished leather.
3. There are no subsidies to meet the O & M cost of the ZLD system.
4. ZLD installation is given a one-time grant of 50% of installation cost by Government of India (and in case of CEMCOT 15% from State Government) Tanners of Vellore district had the Government to increase the subsidy limit to 75% considering the benefit to the

society citing that through ZLD withdrawal of water from ground water body is obviated, thus freeing that much water for public distribution.

5. Production figures are based on the data provided by hundreds of member tanneries taken as confidential information.
6. Cost of ZLD indicates the total cost of effluent management, i.e., maintenance of collection & conveyance lines, effluent treatment, desalination, evaporation of reject and storage of salt and secured landfill for sludge. This does not include any disposal cost for salt in future (depends on final disposal mode which could be purification & reuse of salt or disposal of the same in sea if no re-use option works out)

Table 26. Details of O & M costs, RANITEC, April 2015 - March 2016

Month & Year	Total Cost Rs.	Total Flow m^3	*Operating cost Rs./m^3	*Capital expenditures Rs./m^3	*Total Cost, Rs./m^3
Apr-15	14856368	31943	465	30	495
May-15	16035937	34964	459	10	469
Jun-15	14740851	37525	401	48	449
Jul-15	15905593	36167	440	18	458
Aug-15	15062458	37453	402	37	439
Sep-15	15542976	31156	499	39	538
Oct-15	13349850	32220	414	37	451
Nov-15	11479296	36543	314	24	338
Dec-15	14037960	35818	359	33	392
Jan-16	14244862	33155	396	35	431
Feb-16	15980426	33249	481	1	482
Mar-16	16066873	35799	449	47	496
TOTAL	**177303450**	**415992**	**(average) 426**	**(average) 30**	**(average) 456**
Average	**14775288**	**34666**	**426**	**30**	**456**

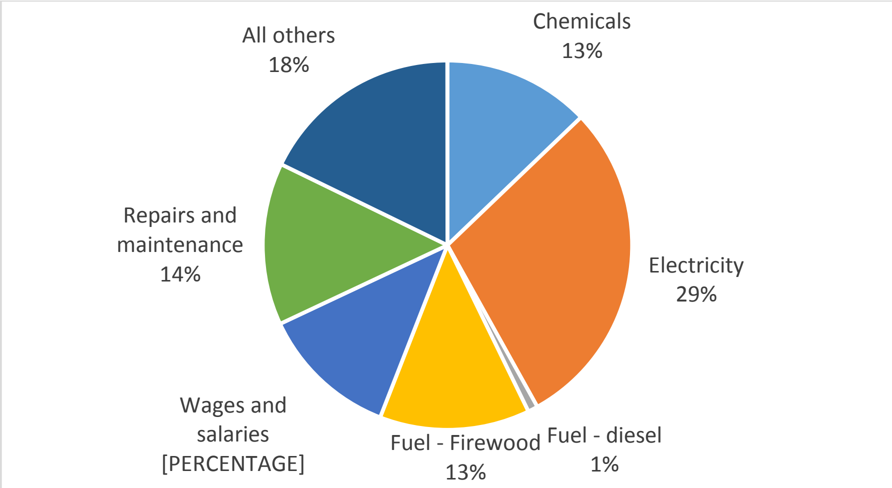
**Figures rounded up resulting in minor discrepancies.*

Table 27. Overview of O & M costs, ZLD plant SIDCO, Sept 2015 – May 2016

Description	Total, Rs.	Specific cost, Rs./m^3
Raw effluent, m^3	163719	
Chemicals	10547059	64.4
Electricity	23881933	145.9
Fuel - diesel	719582	4.4
Fuel - Firewood	10779641	65.8
Wages and salaries	9917064	60.6
Repairs, maintenance	11666938	71.3

All others	14615523	89.3
Total	82127740	**502**

Figure 16. Main components of the O & M costs, CETP/ZLD plant SIDCO, Sept 2015 – May 2016



In late 90-ies UNIDO, the Indian Leather Industry Foundation (ILIFO) and M/s Archana Agrotech Pvt. Ltd. jointly designed and implemented a project under which a barren, degraded plot of land of about 3.55 ha adjacent to the CETP SIDCO, Ranipet was (with special permission from the Pollution Control Board) elaborately irrigated with 800 m^3/d of treated effluent with TDS <4500 mg/l and chlorides <900 mg/l.

The key parameters of the treated effluent (pH, BOD, TDS, Cl, SO_4^{2-}, Cr, Na^+ etc.), soil (at the surface, 0.3 m and 0.6 m depth) and ground water (at 6' and 40'depth) were regularly tested and plants growth continuously monitored by an all-women team lead by Ms. Shanmugavadivu, agricultural expert.

After 3 - 4 years the barren land was turned into a "mini-forest" with substantial fauna, an attractive picnic place without any significant adverse impact on soil and ground water. It was found that the most suitable saline-resistant species were *Casuarina equisetifolia*, *Acacia mangium, Eucalyptus tereticornis* and *Azadirachta indica* whereas species such as *Tectona grandis*, *Terminalia arjuna* and *Pongamia pinnata* survive, but at a slow rate of growth. It was also believed that that some of the trees, particularly the *Acacia mangium*, had good commercial potential. For more details see the document PDU 9.

Degraded land (1998)

Mini-forest, June 2001

Reportedly, strict enforcement of the ZLD concept meant the end of these trials.

Neglected mini-forest, February 2017

Sludge and salt residue

Production of conventional sludge at CETP/ZLD plants does not significantly differ from the original CETPs and that is why it is not analysed here.

The great quantities of salt residue, the product of the last stage of the entire process, are a very serious environmental challenge. For example, in 2015/2016, the RANITEC plant produced 5043 tonnes, VISHTEC 1818 tonnes and SIDCO 1591 tonnes.

Evidently, the amount and composition of the solid residue generated depend on:

- TDS content of raw effluent, which, in turn, depends on the raw hide & skin preservation method and on the amount (percentages) and characteristics of chemicals used in the tanning process
- Type and amount of chemicals dosed during effluent treatment
- TDS levels in in permeate and condensate and, ultimately, in recovered water sent back to tanneries for reuse

Reportedly, the salt residue produced contains, on dry basis, chlorides 54.1 %, sodium 35.0 %, calcium 0.9 %, magnesium 0.3 %, sulphates 1.5 %, silica 1.3 % etc. The moisture is about 11 % and loss on ignition (organic matter) about 5%.

Figure 17. Storage of the salt residue at RANITEC, February 2017

Unfortunately, currently there are substantial differences between the theoretical values for the RO + Evaporation stage and the actual outputs of salt residue at three plants considered.

Table 28. Apparent gaps in TDS balance at RO stage, tonnes per year (2015/2016)

Item	Unit	RANITEC	VISHTEC	SIDCO*
RO feed	m^3/year	411,652	143,753	254,955
TDS in RO feed	mg/L	17,830	17,920	9,160
TDS in RO Feed	t/year	7,340	2,576	2,335
Permeate	m^3/year	296,331	108,315	194,113
TDS in permeate	mg/L	860	465	388
TDS in permeate	t/year	255	50	75
Reject	m^3/year	115,321	35,438	60,842
TDS in Reject	mg/L	39,210	39,420	36,100
TDS in Reject	t/year	4,522	1,397	2,196
TDS in permeate + TDS in Reject	t/year	4,777	1,447	2,271
Difference: TDS in RO Feed – (TDS in permeate + TDS in Reject)	t/year	**2,563**	**1,129**	**64**
Difference	%	**35 %**	**44 %**	**3 %**

**actually for nine months only*

There are views and computations suggesting substantially lower figures. According to them, the unaccounted loss at RANITEC is 4.65 %, at SIDCO 3.72 % and only 0.15 % at VISHTEC. However, some logic and estimates in those computations such as the share of *Volatile portion of salt lost in evaporation* or in transportation and some other are very questionable.

Obviously, the complexity of the issue requires extensive, independent monitoring and analysis over at least one year.

Carbon footprint - the impact of ZLD on CO_2 emissions

Values used for computations:

- Average CO_2 emissions for electricity production in India: 0.9.kg CO_2/kWh (2012)[4]
- Calorific value of Diesel used by DG: 39 MJ/L
- CO_2 emissions from Diesel: 74.1 kg CO_2/GJ of thermal energy[5]
- CO_2 emission/L of Diesel: (39 x 74,1)/1000 = 2.9 kg CO_2/L of Diesel
- Calorific value of firewood used by evaporation boilers: 16.5 MJ/kg
- CO_2 emissions from firewood burning: 109.6 kg CO_2/GJ of thermal energy[6]
- CO_2 emission/kg of firewood: (16.5 x 109.6)/1000 = 1.8 kg CO_2/kg of firewood
- COD of effluent before biological treatment: 2490 mg O_2/L
- COD of effluent after secondary clarifier: 260 mg O_2/L
- COD degraded during biological treatment: (2490 – 260)=2230 mg O_2/L
- Estimated COD : TOC ratio: 3 : 1
- CO_2 : TOC ratio: 3.67 : 1

Table 29. Leather production, flow, electrical energy & firewood consumption at RANITEC, 2015-2016

Item	Unit	CETP	ZLD	Total CETP & ZLD
Total estimated leather produced	sq.ft	96,353,038		
Total estimated leather produced	m^2	8,951,486		
Flow	m^3/year	415,185		
Consumption of electrical energy (EB)	kWh/year	2,349,980	4,168,830	6,518,810
Consumption of Diesel	L/year	47,711	74,029	12,1740
Consumption of firewood	kg/year		7,406,396	7,406,396

Based on above values and data it is possible to derive figures for the CF pertaining to the RANITEC plant and relate them to the estimated leather output.

Table 30. CO_2 emissions from the CETP/ZLD plant RANITEC, March 2015 – April 2016

Item	Unit	CETP	ZLD	Total CETP/ZLD
Total estimated leather produced	sq.ft	96,353,038		
Total estimated leather produced	m^2	8,951,486		
Flow	m^3/year	415,859		
Consumption of electrical energy (EB)	kWh/year	2,349,980	4,168,830	6,518,810
Consumption of Diesel	L/year	47,711	74,029	121,740
Consumption of firewood	kg/year		7,406,396	7,406,396

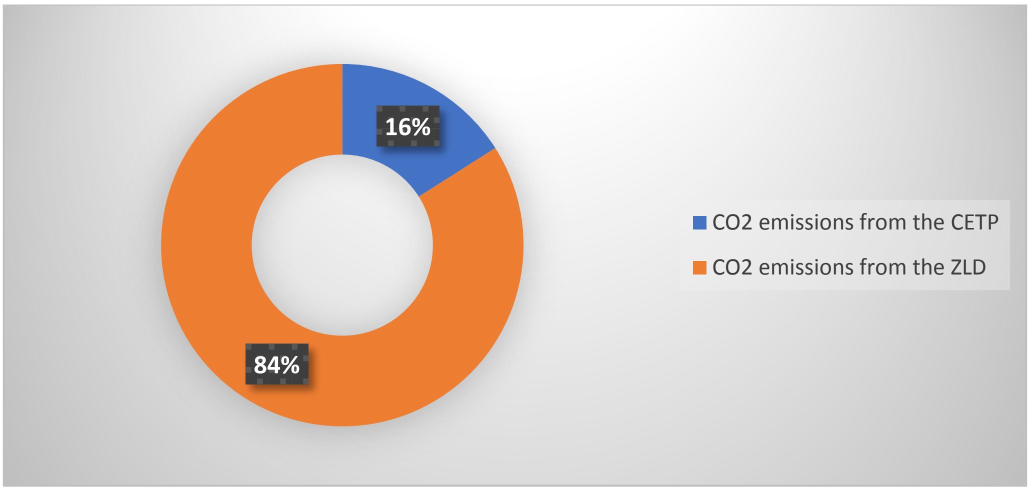
[4] www.iea.org/statistics/statisticssearch
[5] www.volker-quashning
[6] www.volker-quashning

Item	Unit	CETP	ZLD	Total CETP/ZLD
COD removed	kg/year	927,366	-	-
TOC removed during biological treatment	kg/year	309,122	-	-
CO_2 emissions from consumption of electrical energy (EB)	kg/year	2,114,982	3,751,947	5,866,929
CO_2 emissions from Diesel	kg/y	138,362	214,684	353,046
CO_2 emissions from biological treatment	kg/year	1,134,478		1,134,478
CO_2 emissions from firewood for MEE boiler	kg/year	-	13,331,513	13,331,513
Total CO_{2e} emissions, year	**kg/y**	**3,387,822**	**17,298,144**	**20,685,966**
Total CO_{2e} emissions, year	**tonnes/year**	**3,388**	**17,298**	**20,686**
Total CO_{2e} emissions, %	**%**	**16**	**84**	**100**
CO_{2e} est. emission vs. leather production	**kg/sq.ft**	**0.04**	**0.18**	**0.22**

Note: The figures about CO_2 emissions include neither leather processing nor sludge disposal, they pertain only to conventional effluent treatment (CETP) and RO and evaporation stage (ZLD) albeit without disposal of residual salt.

In summary, the ZLD stage has increased the CO_{2e} emissions of the RANITEC plant by about six times.

Figure 18. Shares of CETP/ZLD stages in the total CO_2 emissions, RANITEC, 2015-16



Conclusions

The dramatic situation with water and soil pollution along the Palar River together with public and buyers' pressure eventually prompted the TNPCB to enforce the discharge limit for Dissolved solids (inorganic) of 2100 mg/L; apparently, the ZLD system was imposed as the only approach to supplement the conventional treatment.

Essentially, the ZLD technology attempts to eliminate the problem of high TDS in waste streams by removing all dissolved solids and reclaiming water. Designs differ, but ZLD systems concentrate dissolved solids by Reverse Osmosis (RO) and evaporation until only damp solid waste remains.

The Chennai Environmental Management Company of Tanners Ltd. (CEMCOT) was the vehicle for establishment of seven autonomous ZLD systems/projects. Individual ZLD projects were funded by the Government of India (50 %), State (Tamil Nadu) Government (15 %) and tanners, CETP shareholders (35%).

Investment costs are illustrated with the case of the ZLD plant RANITEC. The cost of rehabilitation & upgrading of the primary, secondary and tertiary (PST) treatment stages was about Rs. 110 million (US$ 1.66 million), the cost of the ZLD stage (RO, MEE, auxiliary equipment) for 3600 m^3/day about Rs. 350 million (US$ 5.28 million).[7]

Assessment of the RO and multiple effect evaporation (MEE) processes and equipment is far beyond the scope of this paper, the emphasis is on the flow input/output and energy considerations. The carbon footprint of the ZLD addition is also computed.

Since the charges to tanners are based on effluent volume it appears that addition of the ZLD stage (RO & MEE) eventually resulted not only in decrease of water consumption to the level long time considered as the theoretical minimum (some 12 m^3/tonne of wet salted weight) but also to substantial underutilization of CETP/ZLD plants. A very strong opposing view is that i) the tanners from the area already had a long experience in economizing with water ii) rather complex water saving and float recycling system is required to achieve such low level iii) the necessary technology modifications take time and that iv) a close, independent scrutiny is needed to verify this claim.

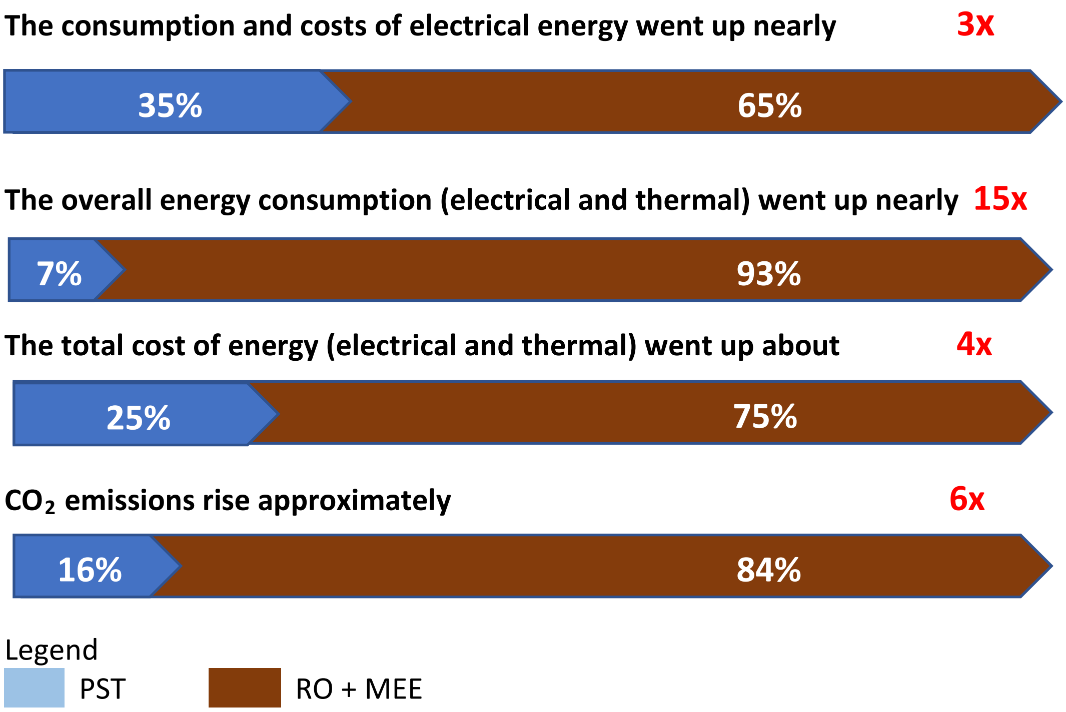
The average yearly flow rates along the treatment line in three ZLD plants considered are:

- ✓ **RO feed vs. inflow to CETP** **99 - 101 %**
- ✓ **RO permeate vs. RO feed** **72 – 76 %**
- ✓ **RO reject vs. RO feed** **24 – 28 %**
- ✓ **Total recovered water vs. inflow** **97 – 102 %**

[7] *at 66.3 INR to 1 US $*

It means that various water additions virtually offset all losses and the volume of recovered (reusable) water well coincides with the CETP inflow.

The energy impact of the ZLD in relation to the conventional treatment at RANITEC 2015/2016 are as follows:



Furthermore, the share of ZLD (RO+MEE) energy in total energy consumed is about 94 % whereas its share in total energy cost is about 75 %.

Operation and maintenance costs, as computed locally, consist of two parts. All capital expenditures/repairs/spares are charged as fixed cost and recovered according to participation of individual member tanneries in the CETP share capital.

The variable cost (electricity, firewood, chemicals, manpower, repairs, sludge disposal, sundries) is spread according to actual effluent flow measured at the tannery outlet; linking the variable charges to the pollution load (more precisely to TDS concentration) is still at discussion stage. Distinction between tanneries processing from raw to finished and from wet-blue and E.I. (vegetable tanned) to finished leather as a possible transition stage is not on the agenda either.

No information is available about the cost of non-grant capital; since it is apparently fully born by tanneries – CETP shareholders, the interest rates might vary depending on their individual financial situations. In any case, the cost of investment capital – loan repayment is not included in the O&M costs. It also seems that no provision is made for permanent safe disposal of salt residue.

The reported O&M costs vary considerably from one plant to another and the calculation methodology may not necessarily be identical.

The reported O&M cost for the year 2015/2016 at RANITEC is Rs. 456/m^3 (USD 6.9/m^3) of effluent. However, the rate of INR 550/m^3 (USD 8.3/m^3) at which the recovered water (nominally free of charge!) is actually available to the RANITEC members may better coincide with the real O&M unit cost.

Part of this cost is assumingly offset by saving of INR 90/m^3 (USD 1.4/m^3), the cost of fresh water now replaced by recovered water.

In any case, the figures for the O&M costs given here should be only taken as indicative.

The amount of the salt residue generated during evaporation stage depends on the TDS content of raw effluent, which, in turn, depends on the raw hide & skin preservation method and on chemicals used in the tanning process. Chemicals dosed during effluent treatment, the rate of TDS levels in permeate and condensate and, ultimately, in recovered water sent back to tanneries for reuse also affect the quantity and composition of the solid residue.

The quantity and characteristics of the salt residue, pose a very serious challenge; in 2015/2016 it was 5043 t (RANITEC), 1818 t (VISHTEC) and 1591 t (SIDCO).

Unfortunately, currently there are substantial differences between the theoretical values for the RO + Evaporation stage and the actual outputs of salt residue at three plants considered; large quantities of salt are "missing" without convincing explanation.

The dramatic increase of energy consumption has a direct impact on carbon footprint as well.

Computing average CO_2 emissions for electricity production in India (0.9.kg CO_2/kWh), calorific value of firewood used by evaporation boilers (16.5 MJ/kg), CO_2 emissions/kg of firewood (1.8 kg), COD degraded during biological treatment: (2230 mg O_2/L), estimated COD : TOC ratio (3 : 1) and CO_2 : TOC ratio (3.67 : 1), it works out that the ZLD (RO+MEE) has increased the CO_2 emissions of the RANITEC plant by more than six times.

After a few years of continuous operations a preliminary review of key ZLD performance parameters, a kind of *macro-scan,* can be summarized as follows:

- There is no doubt whatsoever that industrial scale ZLD concept in treatment of tannery effluents is technically feasible.
- Rather complex, advanced technologies applied for treatment of tannery effluents are certainly impressive. The purified water (permeate and condensate) could be used for various purposes, the present solution (recycling to meet the needs of the tannery cluster) is both logical and practical.
- The system is very sophisticated but not robust and it is quite vulnerable in day-to-day operations.
- Both thermal and electrical power requirements and the corresponding costs are very high.
- Paradoxically, the system designed to remove or at least drastically reduce the TDS actually uses/adds large amounts of various chemicals.

- Ultimately, the "original" TDS present in effluents, augmented by fresh TDS brought in by the ZLD process results in huge quantities of salt containing solid residue posing a new environmental risk.
- Despite extensive investigations, a viable solution for reutilization and/or safe disposal of solid residue is not in sight; it is just being accumulated and it is even a more difficult challenge than disposal of sludge.
- There are plans for further upgrading of the CETP/ZLD by adding the third stage of RO, installation of a solar power plant and a nanofiltration unit and thus reducing the energy costs.
- Tanners from the clusters claim that the cost of effluent treatment has reached Rs. 4/sq.ft of leather whereas their margin is only a Rupee per sq.ft. and it drastically affects their competitiveness. However, no comprehensive and reliable data about raw hides and skins inputs and leather production are available to support these claims.
- Additional costs have affected the competitiveness of the tanneries with ZLD vis-à-vis tanneries without. A decline in production and number of tanneries in clusters of Tamil Nadu (arguably, started well before the ZLD issue) is continuing with gains shared by other clusters like Kanpur, Kolkata and Jullundur. Yet, there was no drastic shutdown of the local tanning units.
- CETP/ZLDs have one of the highest OPEX : CAPEX Ratio. The O & M cost vs. Installation costs at RANITEC, SIDCO and VISHTEC for the year 2015-2016 were about 30%, 37.0% and 56% respectively. This means that in 2-3 years O & M cost may exceed the installation cost.

Taking into account ground realities it is late but possibly not too late to thoroughly consider potential alternatives – or rather - a combination of short- and long-term options to replace and/or supplement the ZLD concept. More specifically, the following options should be looked into:

- ➢ Construction of proper sewage systems, including Wastewater Treatment Works (WWTW) in the townships in the Vellore District with current population of more than 200,000 inhabitants and likely to expand further. While this would significantly improve the living and hygienic standards, the treated effluent from CETPs could be mixed (entirely or in certain proportions) with treated urban wastewater so that it can be discharged into the river.[8]
- ➢ Simultaneous strong systematic support to organized slaughter of some livestock (buffaloes, goats/sheep)[9] and transport modes facilitating short-term salt-free preservation and discouragement of salting as environmentally hazardous method.

[8] *It seems that the CETP plant at the Pallavaram cluster near Chennai is already benefitting from the existence of the municipal wastewater works (WWW); reportedly, it is permitted to skip the evaporation stage.*

[9] *There are already large scale, mechanized abattoirs in the Kanpur area.*

Here, the general interest and ultimately cost implications should prevail over traders' preference for salt-preserved raw material mainly for speculative reasons.

- Concentration of wet blueing works ideally close to the sea side, whereas the finishing facilities could be retained at original sites in the proximity of downstream users (shoe and apparel manufacturers).
- A combination of stimulation & punitive measures for tanners for using salt-free preserved raw material.
- Coordinated effort to introduce cleaner low-salt content leather processing methods (e.g. carbon dioxide deliming, use of chemicals with low salt content).
- Mandatory analysis of the TDS content of the composite effluent discharged by individual tanneries with the view of linking it with the distribution of ZLD treatment costs.
- Improve and optimize the performance of the ZLD treatment stage resulting, *inter alia*, in better permeate/reject/condensate ratios.

Finally, further work by a multidisciplinary ground team is needed to closer study issues such as detailed water mass balance, the exact impact of chemicals added and changes in the TDS composition along the process, optimization of auxiliary processes (ultrafiltration, water softening) to possibly establish a more rigorous data recording etc. Similarly, full mass balances, as provided for the MEE Ranipet, should also be made for other individual components (CETP, UF/RO) and the entire system.

Acknowledgments

The authors appreciate the cooperative spirit and the willingness of the managements of the CETP/ZLDs to provide the basic data used for preparing the analyses presented in this paper. Views and comments by C. Money are also gratefully acknowledged.

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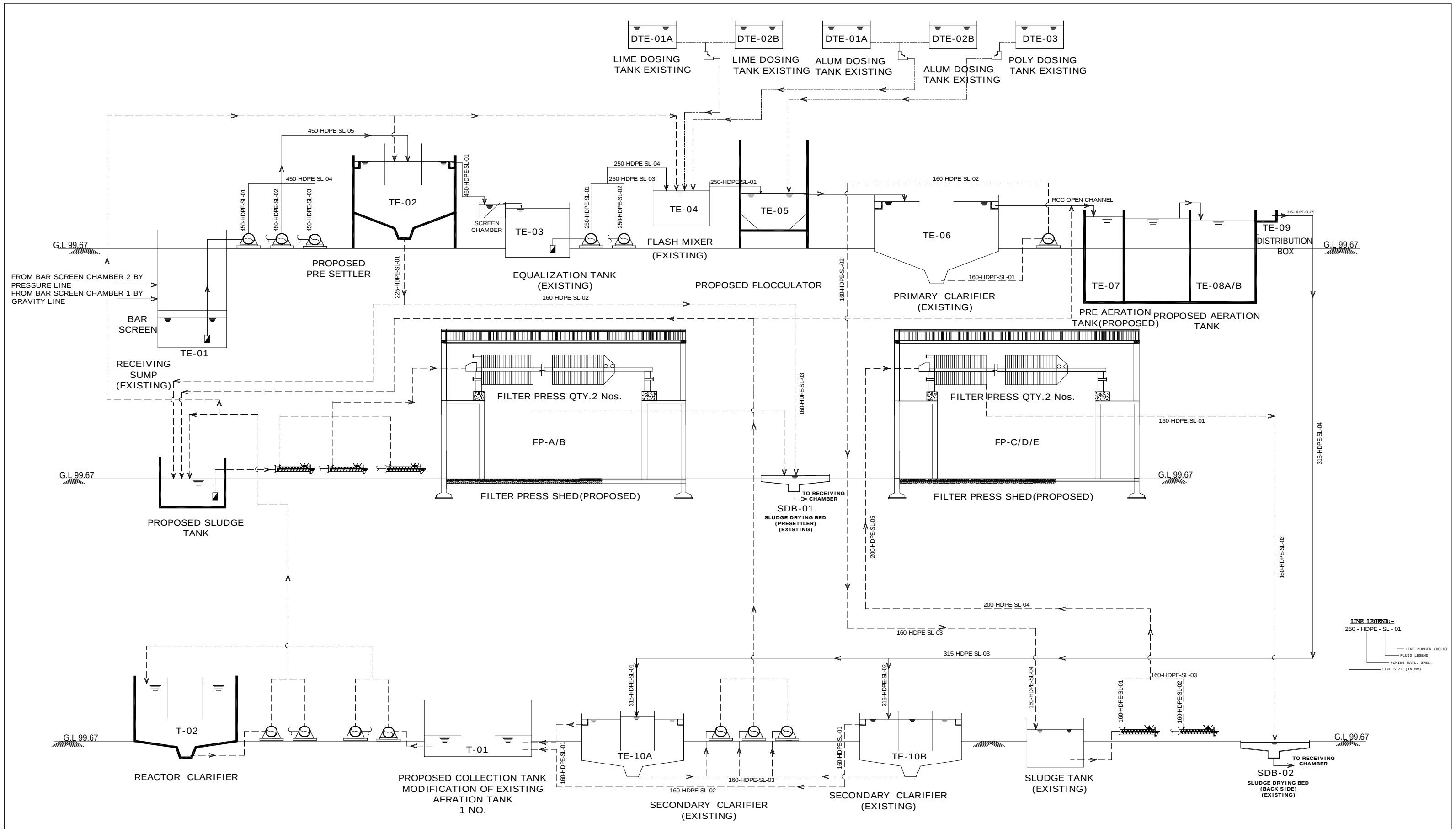
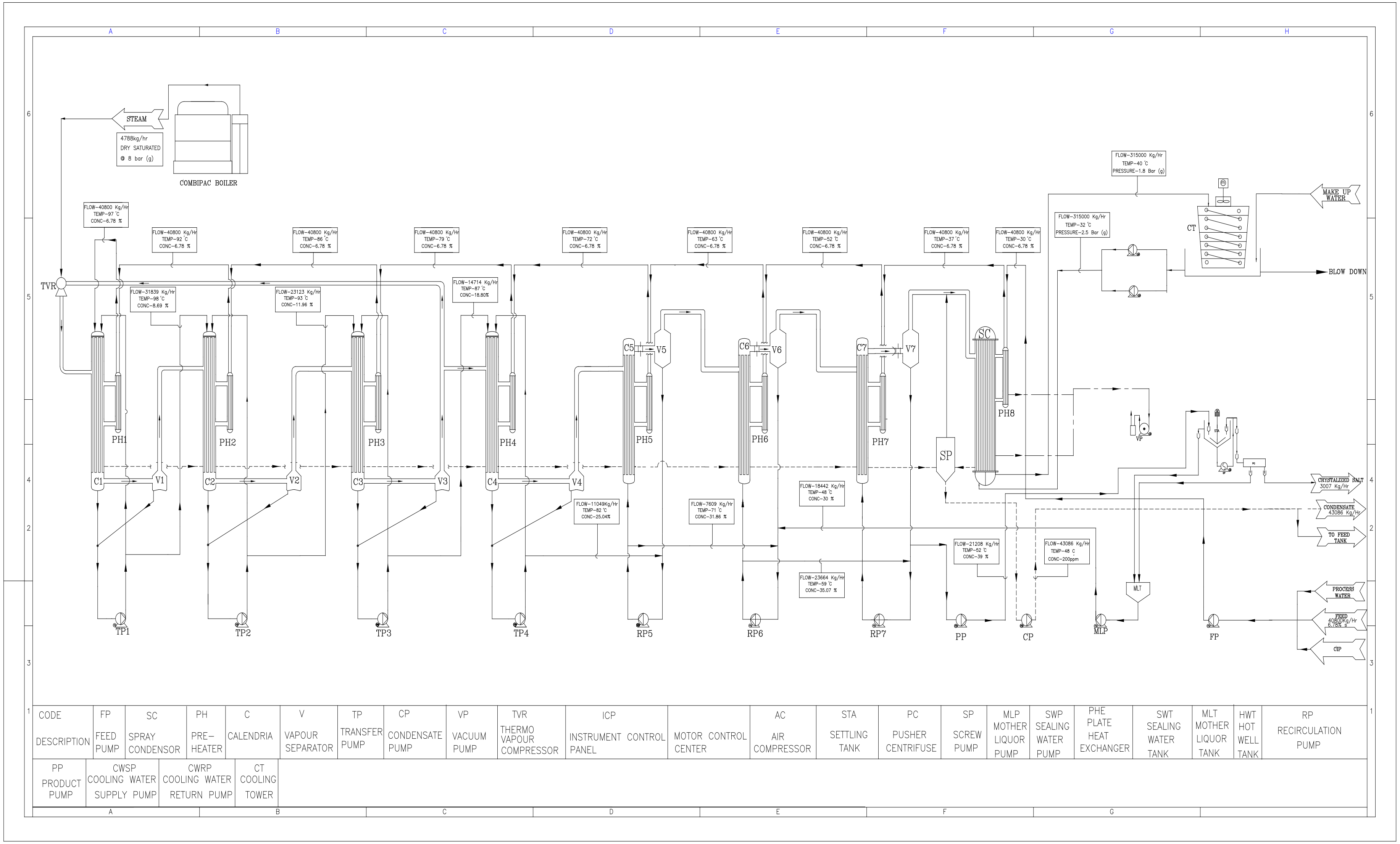
Annexes

Annex 1. P&I flow diagram of the CETP stage of the RANITEC plant

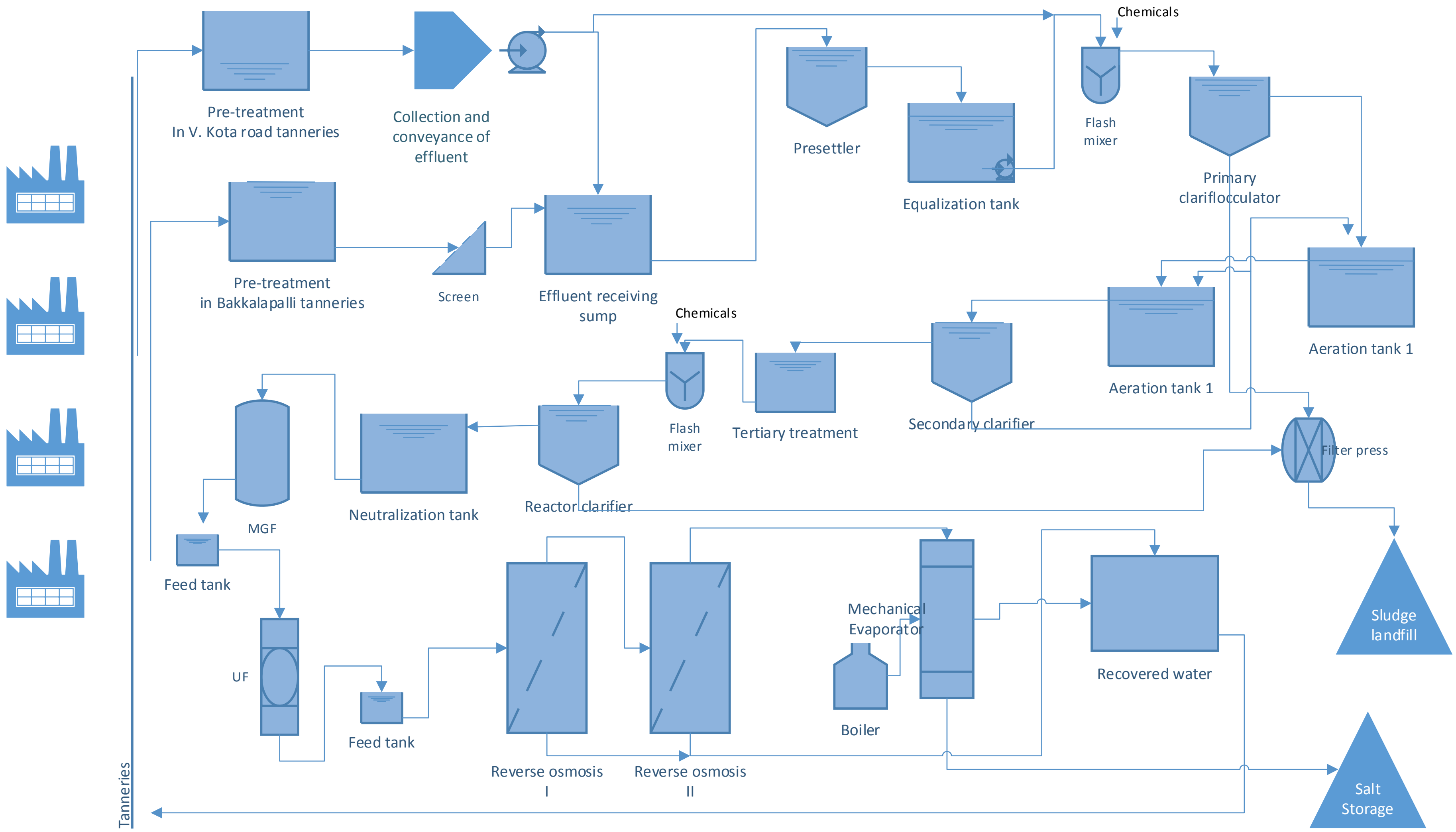


SR.NO	DESCRIPTION	DIMENSION	SR.NO	DESCRIPTION	DIMENSION
1	RECEIVING SUMP (EXISTING)	8m Dia X 2.3m SWD + 4.8 FB	11	PROPOSED COLLECTION TANK	23.25 m X 28 m X 3.4m TD(1.3 m SWD)
2	PROPOSED PRESETTLER	8m Dia X 3.0m SWD + 0.4 FB	12	PROPOSED REACTIVE CLARIFIER	15.4m Dia X 3.5 m SWD + 0.5m FB
3	EQUALISATION TANK (EXISTING)	42m X 20m X 3.375m SWD + 0.5m FB	13	PROPOSED SLUDGE TANK	1.5m X 1.5m X 1.5m + 0.5m FB
4	FLASH MIXER	2.5m X 2.5m X 2.0 m SWD	14	FILTER PRESS SHED	13m X 4.5m X 8m
5	PROPOSED FLOCCULATER	4.5 m X 4.5 m X 2.5m SWD + 0.3m FB	15	SDB (PRESETTLER) EXISTING	16m X 9.25m X 1.0m (8 NUMBERS)
6	PRIMARY CLARIFIER (EXISTING)	15 m Dia X 3.0m SWD + 0.5m FB	16	SDB (BACKSIDE) EXISTING	15m X 8.0m X 1.0m (45 NUMBERS)
7	PROPOSED PRE AERATION TANK	10 m X3m X 5.2 m SWD + 0.5m FB	17	LIME DOSING TANK EXISTING	
8	PROPOSED AERATION TANK	50 m X 10 m X 5m SWD + 0.5m FB	18	ALUM DOSING TANK EXISTING	
9	PROPOSED DISTRIBUTION BOX	2m x 2m x 0.7m SWD	19	POLY DOSING TANK EXISTING	
10	SECONDARY CLARIFIER (EXISTING)	15 m Dia X 2.5 m SWD + 0.5m FB			

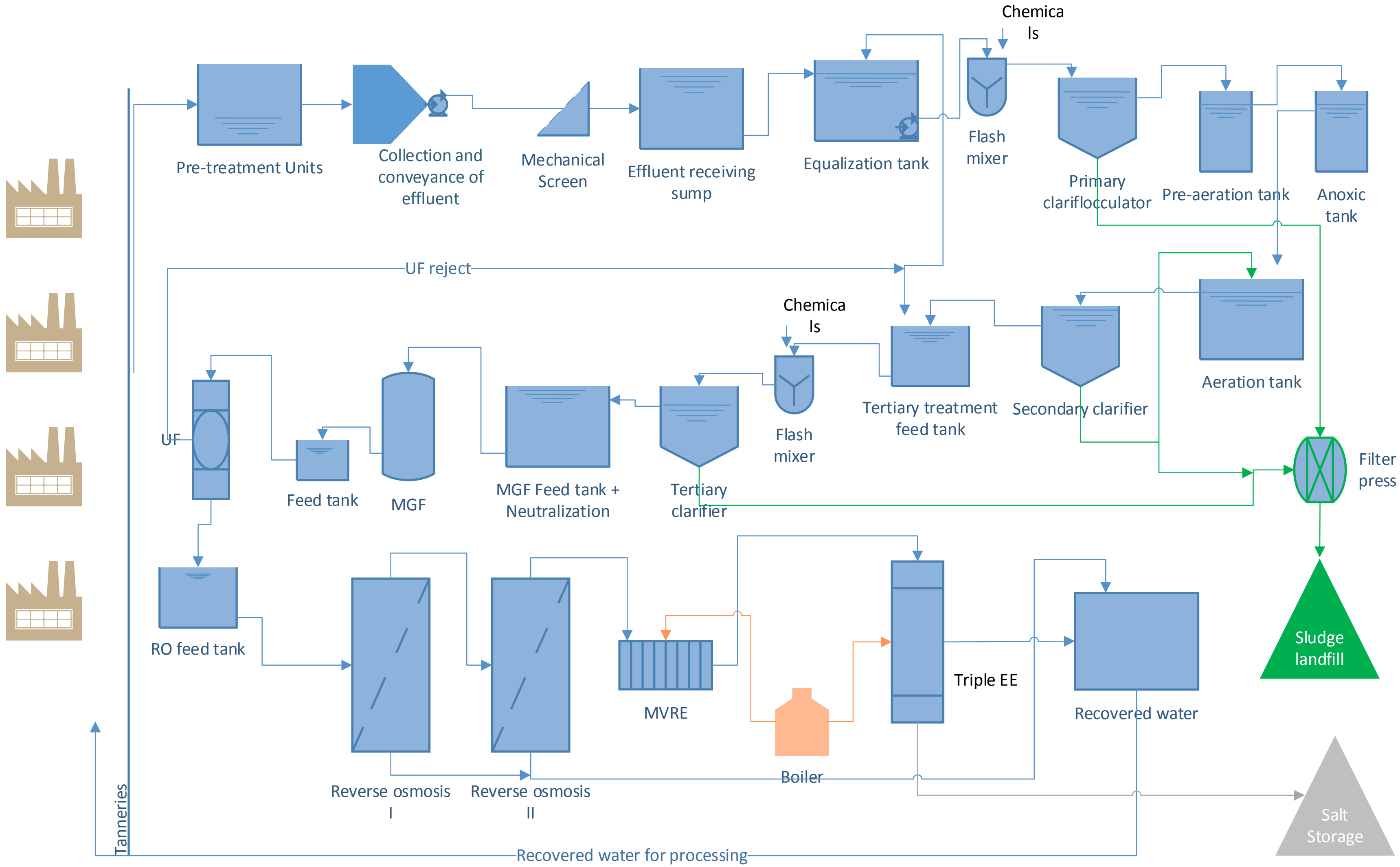
Annex 2. P&I flow diagram of the evaporation system, ZLD stage of the RANITEC plant



Annex 3. Flow diagram of the PERTEC treatment plant (CETP/ZLD)



Annex 4. Flow diagram of the AMBURTEC treatment plant (CETP/ZLD)



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