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Analysis of flow and energy aspects of Zero Liquid Discharge (ZLD) technology in treatment of tannery effluents in Tamil Nadu, India

(Presented during the XXXIV IULTCS Congress Chennai/India 05-08 February 2017)

J. Buljan, K.V. Emmanuel, M. Viswanathan, M. Bosnić, I. Král'

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This paper was presented during the XXXIV IULTCS Congress Chennai/India 05 – 08 February 2017

Acknowledgments:

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

Analysis of flow and energy aspects of Zero Liquid Discharge (ZLD) technology in treatment of tannery effluents in Tamil Nadu, India

J. Buljan[1], K.V. Emmanuel[2], M. Viswanathan[3], M. Bosnić[4], I. Král'[5]

Abstract

In the course of conventional treatment of tannery effluent the composition of Total Dissolved Solids (TDS) somewhat changes but its total level remains virtually constant and considerably exceeds typical discharge norms. The global trend of processing of fresh hides, i.e. salt-free raw material is continuously expanding; for a host of reasons this approach is non-existent in India.

The precarious situation with water and soil pollution in the area of tannery clusters along the Palar River prompted the state environmental authorities to press for adherence to TDS discharge limits as well as to impose an approach not practiced in the tanning industry: a Zero Liquid Discharge (ZLD) concept.

Essentially, the ZLD systems concentrate dissolved solids by Reverse Osmosis (RO) and some kind of Multi Effect Evaporation (MEE) until only damp solid waste remains. Solid waste is disposed and nearly all water is reclaimed and reused. Accordingly, some of the existing Common Effluent Treatment Plants (CETPs) have been supplemented by RO and MEE, together with auxiliary steps (tertiary treatment, water softening etc.).

The analysis investigates and relates raw and equalized effluent inflows, RO feed, permeate and reject, evaporator feed and condensate and the yield of recovered, reusable water. Since the energy costs are critical for the viability of the entire concept, data about energy consumption (thermal, electrical main and Diesel) at key stages (RO, multistage evaporation) are consolidated, analysed and correlated. Additional energy needs and costs are compared with those for conventional (CETP) treatment and estimates made of the carbon footprint increase caused by the ZLD operations.

Keywords: TDS, ZLD, effluent flows, evaporation heat, energy consumption, energy costs, carbon footprint

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Introduction

In the tanning area of Ranipet, Vellore District there are about 200 tanneries grouped in three clusters, each serviced by a CETP with treated effluent ultimately ending in the Palar River which in the recent years is mostly dry with no flow. There are neither sewerage networks nor sewage treatment plants in the adjacent municipalities.

Total Dissolved Solids (TDS), mainly chlorides and sulphates in tannery effluent have become the major environmental concern in arid and semi-arid regions as they make the receiving water recipients unfit both for livestock watering and for irrigation. 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. Whilst specific discharge limits for TDS vary, generally they cannot not be achieved by conventional treatment.

Environmental damage caused by salting gradually prevails over its convenience aspects; the tanning industry in Europe has already largely switched to processing of salt-free raw material and this trend is continuously expanding (e.g. Brazil). For a host of reasons, while enforcing the TDS limit of 2100 mg/l, state environmental authorities and the tanning industry have chosen a different strategy: to adopt a Zero Liquid Discharge (ZLD) approach. The existing CETPs, following the usual treatment technology, have been supplemented by advanced, energy intensive methods like Reverse Osmosis (RO) and Multi Effect Evaporation (MEE) together with the necessary auxiliary steps (tertiary treatment, water softening etc.).

This paper attempts to analyse effluent flows, energy aspects and the impact on carbon footprint of the ZLD segment at three CETP+ZLD system(s) in Vellore District after a few years of operations. In that context, experience from the CLRI - UNIDO project in 1998-2000 in operating a pilot two-stages RO plant of 1 m^3/h capacity (albeit using solar pans instead of advanced evaporators) proved quite useful. The conclusion was that the system *per se* was technically viable but that O&M cost (only partly off-set by the price paid for fresh water) were quite prohibitive mainly due to high energy inputs.

Selection of plants for analysis

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.

Water consumption, effluent flows, yield

One claim is that addition of the ZLD stage has resulted in water consumption decrease from about 28 to only 11-12 l/kg of wet salted weight; increase in concentrations of pollutants support that claim. The opposing view is that local tanners already have long experience in economizing with water brought by tanks from considerable distances. To further halve such low consumption within 3 – 5 years is does not look quite likely. In addition, according to some UNIDO studies, the theoretical minimum is about 12 l/kg and it requires sophisticated recycling equipment.

The permeate from RO system and the condensate from evaporator are combined and distributed back to the tanneries through a recovered water conveyance system.

Table 1. Effluent flows, 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 2. Comparison of flow rates in three 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 spans		
RO feed vs. inflow to CETP	99 % (81 – 114)	99 % (97 – 101)	101 % (99 – 104)
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 tanner's 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 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.

Figure 1. A simplified scheme of water adding & losses in the course of ZLD process

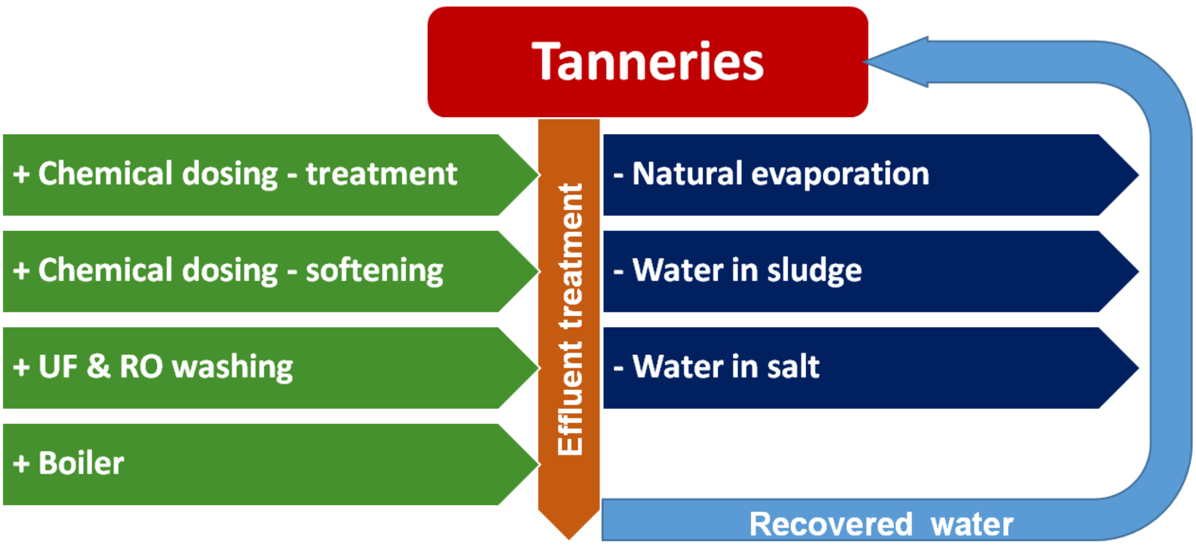
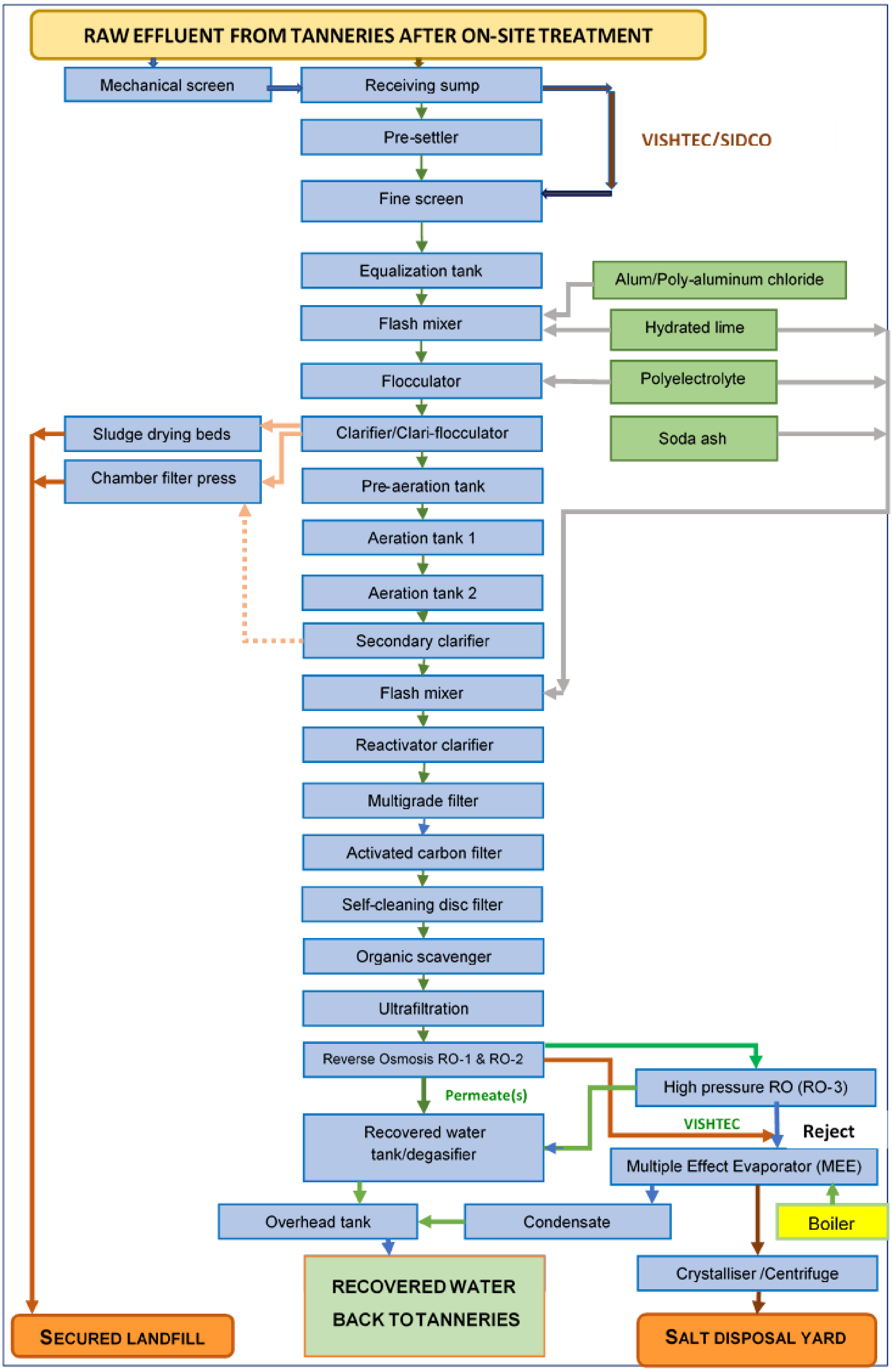


Figure 2. A simplified flow-chart of the ZLD treatment at RANITEC, Vellore District



The ZLD is not so much treatment but rather a salt removal and sequestration system. For good results, it 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. Pallavaram CETP, Aeration and clarifier tanks; Ultrafiltration units; Reverse osmosis; Multiple evaporators

The permeate from the RO system and the condensate from evaporator are combined and as the recovered water and metered distributed back to one-day storage capacity tanks in individual tanneries. The salt-laden solid residue is stored in bags in a huge salt storage yard.

Norms, monitoring

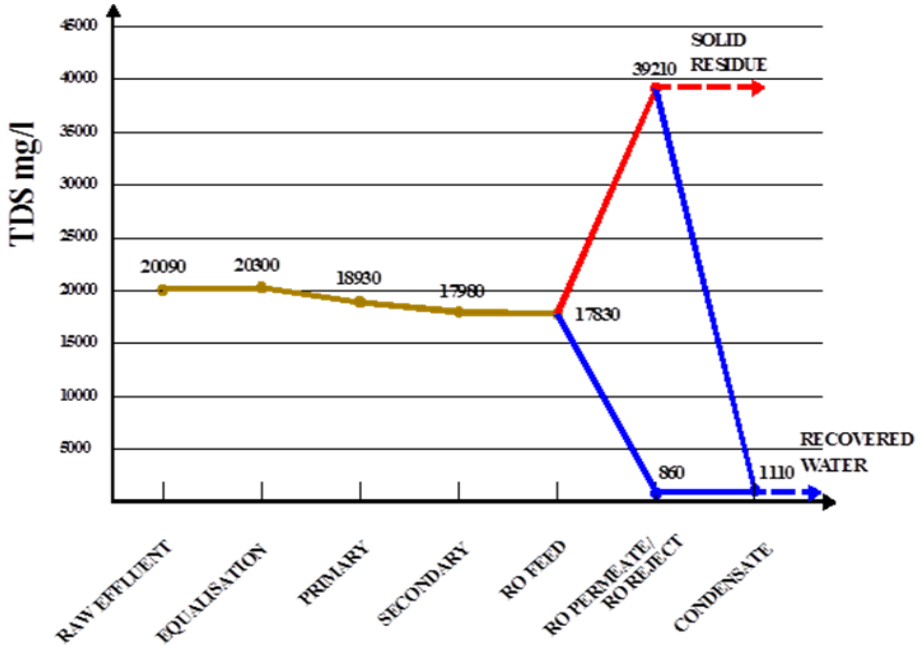
Water used in tanneries in clusters in the Vellore District is in most cases a mixture of water from own drilled wells and (better) water drawn from the Palar River bed further upstream and brought by tankers; the supply and characteristics of fresh water are inconsistent and unpredictable and comprehensive analyses of fresh water apparently are not available. Reportedly, 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). Thus, the usual problem of TDS is compounded by the high TDS/hardness level of fresh water.

To meet the TNPCB discharge norms for Dissolved solids (inorganic), 2100 mg/L, Chloride 1000 mg/L and Sulphates 1000 mg/L, a very different set up in the whole supply chain, mixing of treated effluent with municipal wastewater and/or advanced methods of decreasing the TDS level are required.

Unfortunately, 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.

Figure 4. Total Dissolved Solids (TDS), monthly averages, RANIPET, April 2015 – March 2016



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.

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 electric motors with higher efficiency and reducing the level of reactive energy are an important part of (electric) energy savings measures. The use Diesel generators is limited to emergencies.

Table 3. Energy consumption & cost, Primary, Secondary & Tertiary Treatment (PST), 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 4. 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
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

ITEM	Unit	TOTAL
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 5. 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)/m^3	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 6. 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	84,59,928	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 ($ 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 7. 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%
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!*

The impact of addition of the ZLD stage (RO + MEE) to the conventional treatment can be summarizedas 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 93 %
- The share of ZLD energy cost in total energy cost is about 78 %

Chemicals from the ZLD stage, O&M costs, salt residue

In addition to sodium chloride applied for preservation of hides and skins, chemicals used in the course of leather processing and usual chemicals used for during the primary treatment (lime, alum, polyelectrolytes), significant amounts of chemicals affecting the TDS content are added during tertiary treatment, water softening, RO and evaporation steps: hydrochloric acid, sodium metabisulphite, antiscalant, polyphosphates, caustic soda, sodium bicarbonate etc.

According to some local lab analysis, the salt residue produced contains, on dry basis, chlorides 54.10 %, sodium 35.03 %, calcium 0.86 %, magnesium 0.30 %, sulphates 1.45 %, silica 1.30 % etc. The moisture is about 11 % and loss on ignition (organic matter) about 5%.

The reported, indicative O&M cost for the year 2015/2016 are between USD 6.9 – 8.7/m^3, part of it assumingly offset by saving the cost of fresh water of about USD 1.4/m^3. In absence of reliable data about raw material input, yields etc. it is not possible to relate the O & M cost to leather output, educated guesses put them from about Rs. 20/m^2 (RANITEC), Rs. 23/m^2 (SIDCO) to Rs. 40/m^2 (VISHTEC), corresponding to USD 0.30, USD 0.35 and USD 0.60 per square metre.

The salt residue represents a very serious environmental challenge, quantities generated are impressive. Only in year 2015/2016, the RANITEC plant has produced 5043 tonnes, VISHTEC 1818 tonnes and SIDCO 1591 tonnes. 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 8. Apparent gaps in TDS balance at RO stage, tonnes per year

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 stage on CO_2 emissions

Values used for computations:

- Average CO_2 emissions for electricity production in India: 0.9.kg CO_2/kWh (2012)[6]
- Calorific value of Diesel used by DG: 39 MJ/L
- CO_2 emissions from Diesel: 74.1 kg CO_2/GJ of thermal energy[7]
- 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[8]
- 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

[6] www.iea.org/statistics/statisticssearch
[7] www.volker-quashning
[8] www.volker-quashning

Table 9. Leather production, flow, electrical energy & firewood consumption at the CETP+ ZLD plant 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.

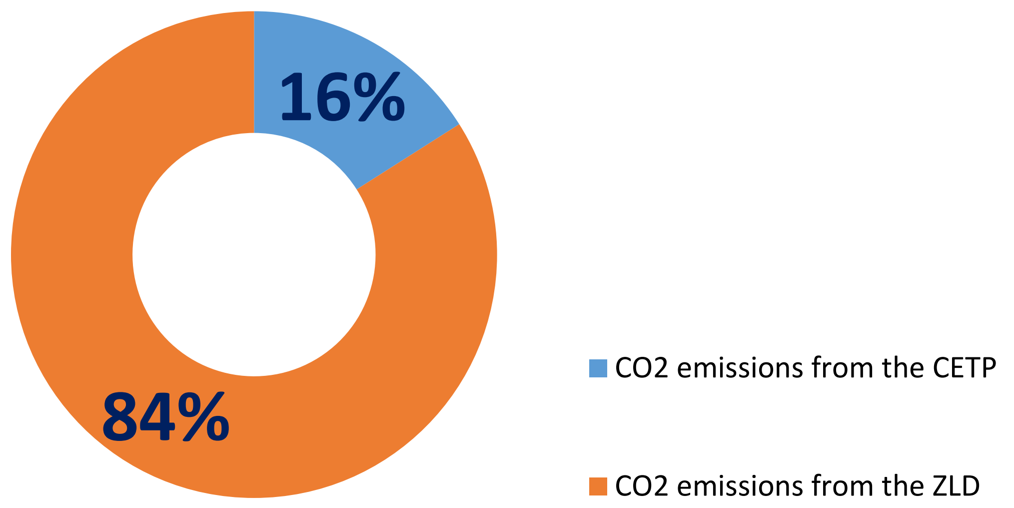
Table 10. CO_2 emissions from the CETP + ZLD plant RANITEC, March 2015 – April 2016

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
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/year	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/year**	**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 5. 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.

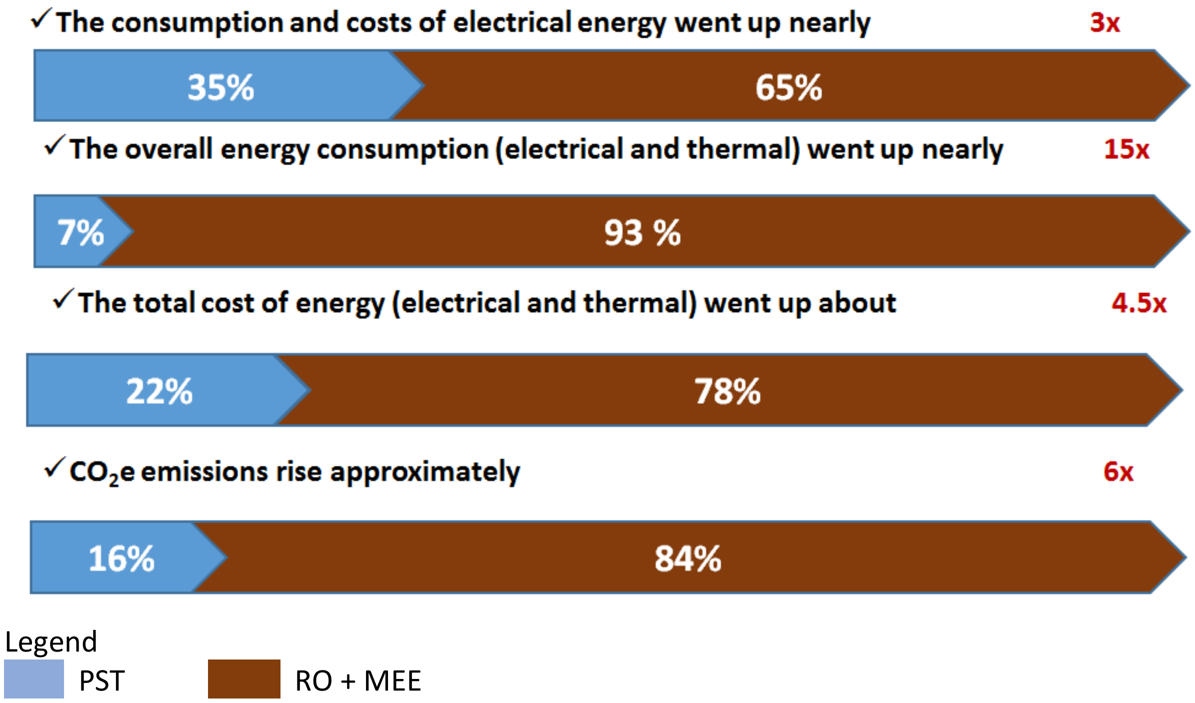
Reportedly, this has resulted in water consumption close to the theoretical minimum (12 m^3/tonne) and substantial underutilization of CETP & ZLD plants. A very strong opposing view is that i) the tanners from the area already had a long experience in economizing with water ii) rather complex water saving 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 from**	**99 - 101 %**
✓ **RO permeate vs. RO feed**	**72 – 76 %**
✓ **RO reject vs. RO feed**	**24 – 28 %**
✓ **Total recovered water vs. inflow**	**97 – 102 %**

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

Figure 6. The energy impact of the ZLD stage in relation to the conventional treatment



The reported, indicative O&M cost for the year 2015/2016 are between USD 6.9 – 8.7/m^3, part of it assumingly offset by saving the cost of fresh water of about USD 1.4/m^3.

The salt residue produced poses a very serious environmental challenge; in 2015/2016 it was 5043 t (RANITEC), 1816 t (VISHTEC) and 1591 t (SIDCO). Unfortunately, there are substantial differences between the theoretical values and the actual outputs; large quantities are "missing" without convincing explanation.

Computing average CO_2 emissions for electricity production in India, calorific value of firewood used by evaporation boilers, CO_2 emissions/kg of firewood, COD degraded during biological treatment, estimated COD/TOC ratio and CO_2/TOC ratio, it works out that the ZLD stage has increased the CO_{2e} emissions at RANITEC by more than six times.

There is no doubt that industrial scale ZLD in treatment of tannery effluents is technically feasible, advanced technologies applied impressive, recycling of the purified water is both logical and practical. However, the system is not robust and a viable solution for reutilization and/or safe disposal of solid residue is not in sight; moreover, within about three years O & M cost may exceed the installation cost.

It is quite late but possibly not too late to thoroughly (re)consider potential alternatives, a combination of short- and long-term options such as construction of proper sewage systems & WWTW in the townships in the Vellore District allowing mixing of treated tannery effluents with urban waste water[9], simultaneous strong support to organized slaughter of some livestock (buffaloes, goats/sheep) and salt-free preservation, concentration of wet blueing works etc.

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), possibly establish a more rigorous data recording etc.

[9] 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.

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