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Techno-Economic Options for the Treatment of High TDS RO Reject from a Textile Industry to achieve Water Recycling and Cost Savings.

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Abstract — **Water shortages and unreliable water quality are considered major obstacles to achieve sustainable development and improvement in the quality of life. The water demand in the country is increasing fast due to progressive increase in the demand of water for irrigation, rapid industrialization, population growth and improving life standards. Water reuse is already an important element in water resource planning. Use of highly treated wastewater effluent is receiving more attention as a reliable water resource. For local authorities, supplying fresh water to everyone has become a key environmental and economic issue.**

Evaporation, or distillation, is the oldest form of treatment capable of removing soluble contaminates from water or other solvents. Desalination is the process where high TDS water is heated to produce water vapor that is then condensed to form fresh water. At present desalination is the most reliable and efficient method to treat the high TDS water. The water obtained after the process of desalination can further be used in any of the industrial processes that require mainly fresh water for their various manufacturing processes. THE RESULT shows that the presence of TVR plays a major role in increasing the total quantity of the distillate produced. It was noticed from the trials taken that the increase in the TVR pressure resulted in: the increase in condensate generation, decrease in the steam consumpion, decrease in the costing of the steam, increase in the efficiency of the system, increase in the Gain Output Ratio, Performance Ratio.

Keywords-Membrane RO-Reject, Total Dissolved Solids(TDS), Desalination, Multi-effect Distillation, Multi-Effect Evaporator, GOR, PR.

I. INTRODUCTION

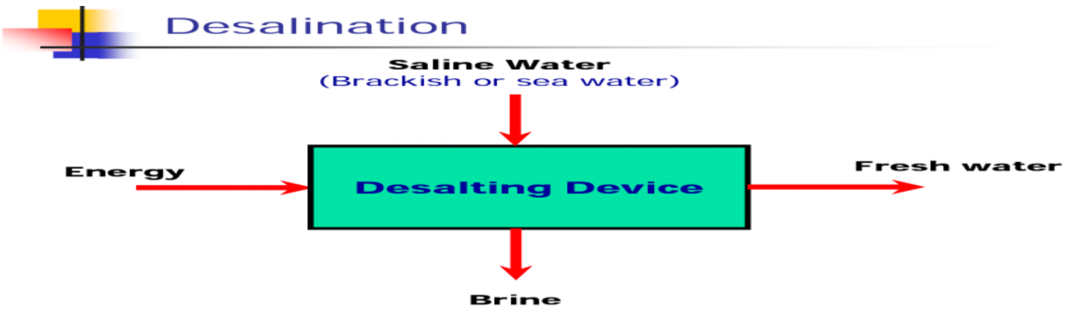
The world's water consumption rate is doubling every 20 years, outpacing by two times the rate of population growth. The availability of good quality water is on the decline and water demand is on the rise. Worldwide availability of fresh water for industrial needs and human consumption is limited.

Water shortages and unreliable water quality are considered major obstacles to achieve sustainable development and improvement in the quality of life. The water demand in the country is increasing fast due to progressive increase in the demand of water for irrigation, rapid industrialization, population growth and improving life standards. Continued population growth, contamination of both surface and ground water, uneven distribution of water resources and periodic draughts have forced water agencies to search for new sources of water supply. Water reuse is already an important element in water resource planning. Use of highly treated wastewater effluent is receiving more attention as a reliable water resource. For local authorities, supplying fresh water to everyone has become a key environmental and economic issue.

Evaporation, or distillation, is the oldest form of treatment capable of removing soluble contaminates from water or other solvents. But until recently it was rarely used in wastewater treatment or water recycling. The high capital and operating costs associated with distillation had limited its use to applications where the water could not be treated with other technologies or where the recovered distilled products had sufficient value to warrant the additional cost. One of the most promising of these applications is in the treatment and recycling of produced water.

Desalination is the process where high TDS water is heated to produce water vapor that is then condensed to form fresh water. At present desalination is the most reliable and efficient method to treat the high TDS water.

The water obtained after the process of desalination can further be used in any of the industrial processes that require mainly fresh water for their various manufacturing processes.The physical characteristics of produced water, specifically the extreme Total Dissolved Solids content (soluble salts) make distillation the only practical choice for water recovery. Produced waters typical have Total Dissolved Solids in excess of 100,000 parts per million (ppm,) thereby eliminating the use of all other traditional technologies.



[Figure: principle of desalination]

II. MULTI-EFFECT DISTILLATION

Basic functioning in a MED system..
1.Distillation, Followed by
2.Compression of the Distillate
3.Recovery of the Heat into the Boiling Zone
4.Condensing of the Vapor

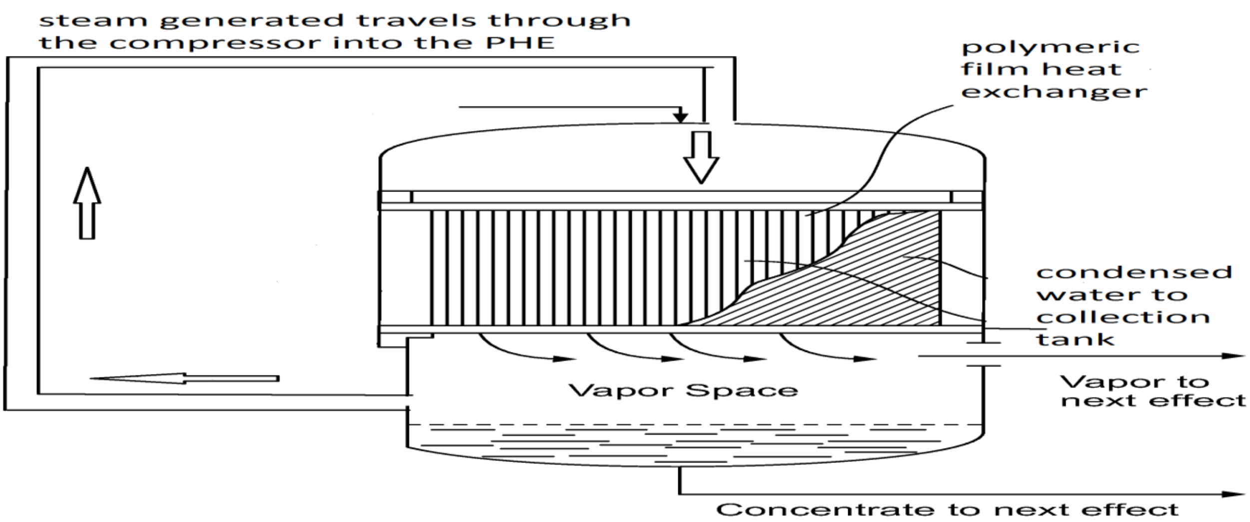


FIG. 7

[Figure: working of MED]

MED is a very effective technique for heat recovery from the steam produced in liquid solution concentration and distillation processes.

It consists in increasing the steam temperature through compression, which can thus be re-employed as heating fluid in the process itself, in which it is allowed to condense. In this way, in respect with a comparatively moderate contribution, in terms of electric power spent for the operation of the compressor, it is possible to recover the condensation heat.

Being said heat equal to the one required for evaporation, the whole process is able to self-sustain without the supply of additional heat, but for the starting phase, and for the compensation of heat losses, for the amount possibly exceeding the thermal contribution of the demanded electric power.

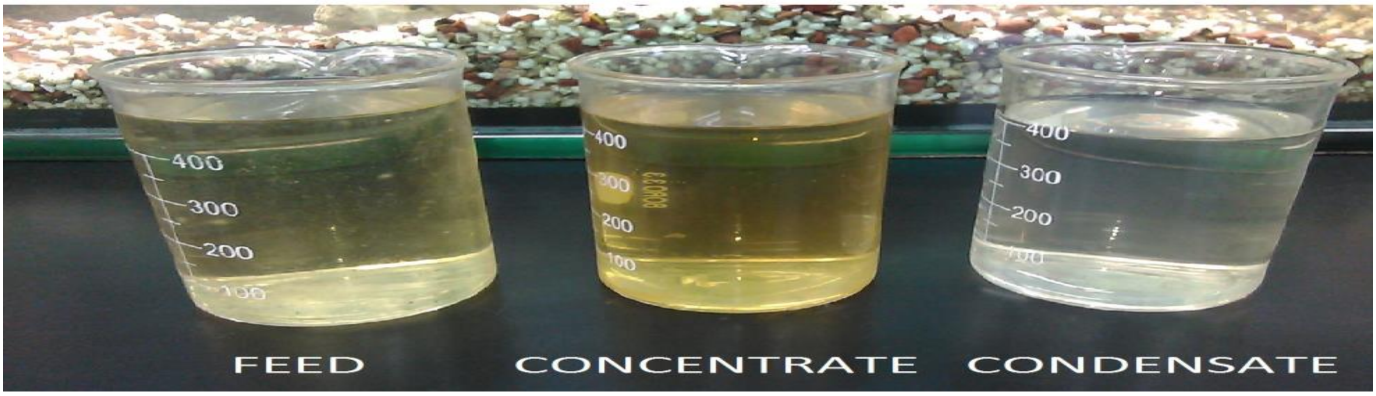
Brine from one effect to the other would move on its own. i.e., the brine coming out from one unit reaches the next effect under the pressure of steam itself. The distillate and brine are withdrawn from each effect at a fast-enough rate so that no flooding occurs.

The liquid feed moves on the "hot" inner walls in an evaporator. Heat is continuously transferred from the outside of the wall to the inside, thereby heating up the liquid to the boiling point where water evaporates from the liquid feed. One of the most important issues influencing the effectiveness of the evaporation is the distribution of the liquid on the inner walls. To make the evaporation effective the liquid film on the inner walls should be as thin as possible. However, if the film is too thin, the product will burn on the walls, therefore it is very important to be able to control the thickness of the film also known as "the wetting rate".

Among the various processes of desalination, MED process, the oldest desalination method, is more effective and the most successful than other methods capable of desalination of salty water also in removing soluble contaminates from water or other solvents. The MED installations usually have a series of evaporators to produce distilled water and the heat supply is from an external steam generation plant.

At present, the applications of MED have made a great success on RO water desalination, for example, The Arvind Pvt. Ltd, located at Santej, practice desalination of RO reject water by using MED plants with a production of 300 m^3/Day and the operated conditions can be adjusted reliably and flexibly.

Sr. No.	Parameters	Unit of parameters	RO Reject	Water quality after pre-treatment to be fed to MED	Water quality after MED plant.	MED concentrate quality after the MED desalination technology
1.	Volume	m^3	288	288		144
2.	pH		6.9	5.5	6.2	6.8
3.	Electrical Conductivity	Micro seimens	70000	72000	1000	175000
4.	TDS	mg/l	45500	48000	600	90000
5.	TSS	mg/l	15	5	Nil	10
6.	TH	mg/l	2120	150	10	310
7.	COD	mg/l	1500	350	Nil	600
8.	BOD	mg/l	ND	ND	Nil	ND
9.	Colour	PtCo	3980	350	10	600
10.	Turbidity	NTU	5	5	0	5
11.	Total alkalinity	As $CaCO_3$	350	250	45	530
12.	Silica	As SiO_2	370	45	3	370
13.	Iron	Iron	12	1.1	0.03	2.3



[Figure: image of feed to MED, concentrate and condensate from MED]

III ADVANTAGES AND DISADVANTAGES OF MED

ADVANTAGES:

- Higher energy efficiency, resulting in important operation cost saving.
- Upgrade of evaporation plants without the need for adaptation of steam generators.
- More compact plants at equal performance, so that the same can be better housed in buildings.
- Cooling water requirements were reduced.
- Higher performance coefficient.
- Gentle evaporation of the product due to low temperature difference.
- Simplicity of the process, operation and maintenance.

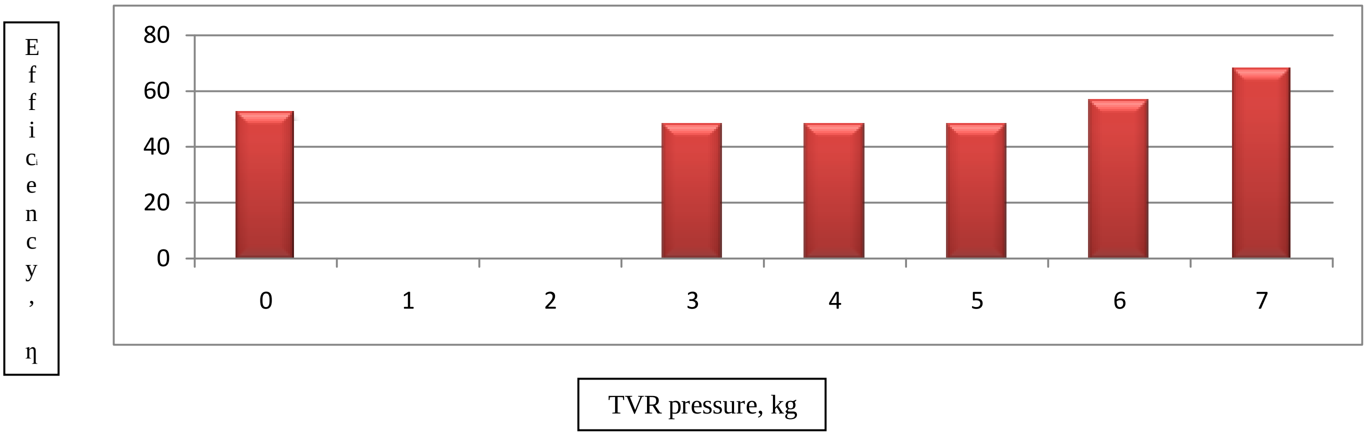
DISADVANTAGES:

- Comparatively **high cost of electric power**, making this technology less attractive from the economical point of view than in other contexts.
- Technology **requiring higher investments** than the competitive technology.
- Reliability of **compressors not** completely **satisfactory.**
- Use of **complex equipment**, requiring **more skilled personnel.**

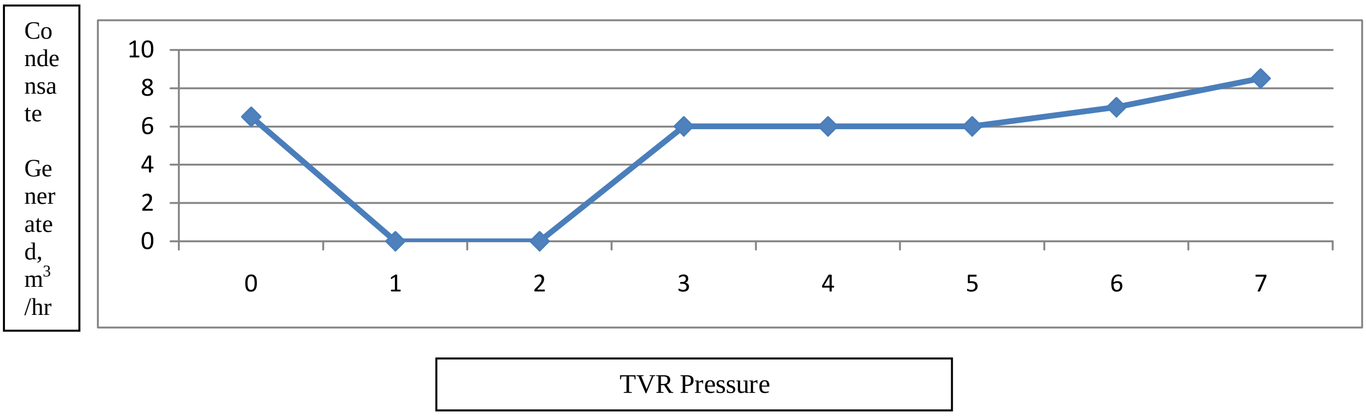
THE PRESENT WORK investigates the promotion of the desalination technology, their efficiency and cost effectiveness. The cost analysis has been carried out by taking into consideration the daily fixed cost and daily operating costs. Daily fixed cost was worked out considering annuity, maintenance cost, and number of working days. The daily operating cost includes the labour and fuel charges. A number of trials were conducted to find out the changes in the various parameters in Multi-effect Distillation such as, Temperature, Pressure, Effect of effect numbers, Steam consumption, Costing, Gain output ratio (GOR), Performance ratio (PR), Concentration ratio (CR), Effect of presence of Thermal Vapor Recompressor (TVR), Condensate generation from each effect, Efficiency of the system. The temperature and pressure of the system were recorded by varying the pressure of TVR from 0-7 kg by carrying out the working of MED plant at a constant feed flow.

Study has been carried out by using the principle of thermal desalination in the Multi-Effect Distillation system. The data was collected by taking trails by working the MED system at varying TVR pressures from 0kg-7kg. The various parameters were calculated by keeping the inlet feed flow constant. The various parameters that were recorded were: the temperature and pressure in the flash effect, temperature in the last effect, the effect of effect numbers the condensate generated, the steam consumption, the costing of the system, the efficiency of the system by change in the TVR Pressure, the GOR, the PR, the CR, the condensate generated in each effect.

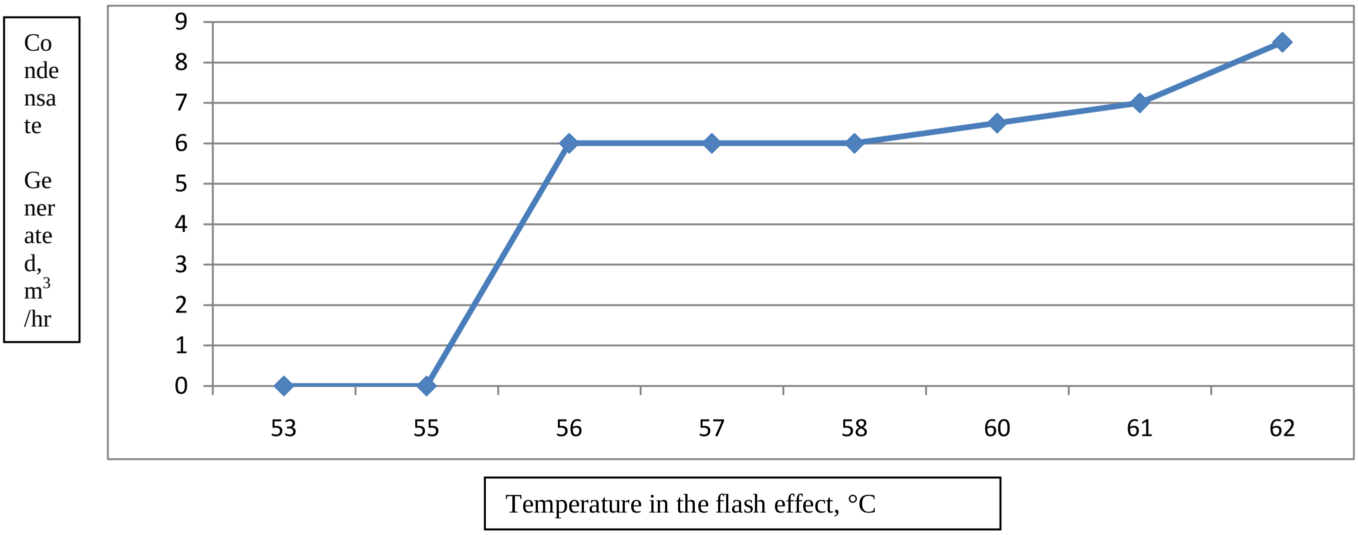
TVR Pressure, kg	Condensate generated, m^3/hr	Steam consumption, kg/hr	Decrease in the costing of the steam, @ 1.2 Rs/kg	Efficiency, η
0	6.5	1100	-	52
1	0	1070	864	0
2	0	1055	1296	0
3	6	1040	1728	48
4	6	990	3168	48
5	6	1020	2304	48
6	7	1050	1440	56
7	8.5	1032	1958.4	68



Graph: efficiency v/s TVR Pressure



Graph : condensate Recovered v/s TVR Pressure



Graph: condensate generated v/s Temperature in the flash effect, °C

The efficiency was calculated by considering a constant feed flow, so that the values of the condensate generated by the usage of each TVR pressure remain comparable.

As it was found in the previous tables and graphs, that as the pressure in the TVR increases, there is a considerable decrease in the steam consumption.

Also it can be said that the decrease in the steam consumed is directly related to the decrease in the costing of the system.

GAIN OUTPUT RATIO:

Experimental studies were made and simulation studies were carried out.

The performance of the unit was evaluated in terms of total distillate produced, and the overall cost per unit distillate.

Gain output ratio: it is the ratio of kg of distilled water produced per kg of steam supplied.

$$GOR = \frac{(\text{kg of distilled water produced})}{(\text{kg of steam supplied})}$$

PERFORMANCE RATIO:

It is the ratio of kg of water produced per 3168 KJ of the heat consumed.

$$PR = \frac{(\text{kg of water produced})}{(\text{kg of steam consumed})}$$

TVR Pressure, kg	Condensate generated, m^3/hr	Gain output ratio, GOR	Performance Ratio, PR
0	6.5	5.90	2.05
1	0	0	0
2	0	0	0
3	6	5.76	1.89
4	6	5.76	1.89
5	6	5.76	1.89
6	7	6.66	2.209
7	8.5	8.23	2.68

The efficiency of the MED system is from 50-68%, the concentrated slurry obtained after the MED is then fed into the multi-effect evaporator for the recovery of the remaining water and salts.

IV SALT RECOVERY:

An alternative to disposal of the concentrate stream is to recover it for beneficial uses. The concentrate stream contains a large quantity of a variety of salts, which may actually be a resource instead of a waste problem.

In addition, most of the salt is used as brine, so it would not be necessary to recover the salts in concentrate to a dry product for them to be useful.

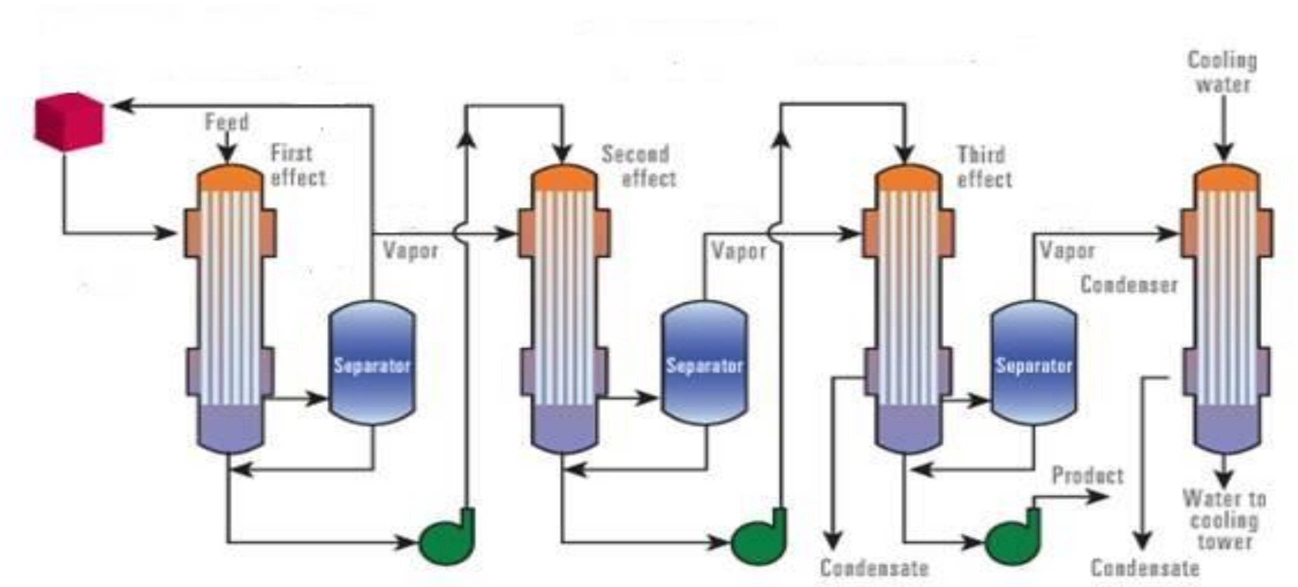
V MULTI-EFFECT EVAPORATOR:

Multi-effect evaporation is used as a crystallizer uses the steam produced from evaporation in one effect to provide the heat to evaporate product in a second effect.

In a two effect evaporator, it is possible to evaporate approximately 2 kgs of steam from the product for each kg of steam supply.

As the number of effects is increased, the steam economy increases. On some large duties it is economically feasible to utilize as many as seven effects.

Increasing the number of effects, for any particular duty, does increase the capital cost significantly and therefore each system must be carefully evaluated.



[Figure: Multi-effect Evaporator]

In the evaporation process, concentration of a product is accomplished by boiling out a solvent, generally water. The recovered end product should have optimum solids content consistent with desired product quality and operating economics. A multiple-effect evaporator is an apparatus 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. Because the boiling point of water decreases as pressure decreases, the vapor boiled off in one vessel can be used to heat the next, and only the first vessel (at the highest pressure) requires an external source of heat. The concentrate obtained from the MEE is totally a salt slurry, this slurry is then sent to the open-pan crystallizer to obtain a dry salt.

[Figure: dry salt recovered]

VI FACTORS AFFECTING THE COST OF DESALINATION

Energy source: All desalination technologies require some energy input to facilitate the separation of low salinity product water from the saline feed water. The form of energy available, the associated cost and the environmental constraints related to the energy source, will all play a major role in the desalination technology selection.

- **Electrical energy**: All desalination processes use electrical energy. Processes such as RO, EDR and VC use electrical power as the primary source of energy, i.e. for both the desalination processes and to drive ancillary equipment such as transfer pumps. Whilst distillation processes such as MED, use electricity as the secondary source of energy, i.e. to drive recirculation and transfer pumps only.

- **Thermal energy**: Most distillation desalination processes, apart from VC and solar stills, use thermal energy exclusively in the form of steam as the primary source of energy. Thermal energy may originate from a number of different sources, and is typically associated with waste heat streams at existing plant site, such as gas turbines, heated industrial processes, solid waste incinerators, and other industrial waste heat sources.

Feed water: The feed water source is significant in the choice of the desalination technology selected. The most common feed water sources are:

- Sea water
- Brackish water
- Saline water
- effluent

In almost all instances, where a distillation desalination process is chosen, sea water is the feed source. Whilst RO can also be used for this application, and is often the application of choice for sea water feeds when waste heat sources are not available, it generally is more commonly used for the desalinating brackish feed sources, and also for effluent reuse.

Location: The location of the source dictates the viability of a desalination plant with reference to the following:

- **Remoteness**: the cost of transporting water to and from, the cost of power transmission and infrastructure may detract from viability.
- **Environmental constraints**: The location of the source may dictate that certain environmental constraints would be imposed, for example: noise, brine disposal, ground water flow system and aquifer yield, disturbance to marine life, seafloor ecology etc which could detract from the viability of the project. The further away the feed water is from the desalination plant, the higher the construction and operating costs associated with the plant.

Feed water quantity: The quantity yield of the source, total delivery capacity of the source, and the capability to extract an economically justified quantity of feed water are all important factors in assessing the viability of a desalination plant and the particular technology to be applied.

Feed water quality: The quality of the feed water will heavily dictate the desalination technology selected. In general, distillation technologies tend to be more flexible than membrane based technologies with feed waters that have high quality fluctuations. The key water parameters to consider in the design of the pre-treatment and the main process system are:

- Salinity (TDS),
- Turbidity,
- Organic content,
- pH and,
- Concentration of the scale forming salts and non-ionic fouling species.

The salinity of the feed water is perhaps the major factor in the selection of the appropriate desalination technology. There is generally a direct relationship between the salinity and the capital and operational costs for the membrane processes, however for distillation desalination processes, this relationship isn't as evident.

Pre-treatment and the post-treatment needs: Pre-treatment design is crucial to the successful operation of the desalination systems. Pre-treatment requirements for the large sea-water desalination plants, be it either distillation or RO, will typically comprise of the trash-racks, band screens and the filtration units, however membrane pre-treatment is typically more rigorous than for distillation processes.

Land availability: Generally desalination units do not require large area of land for plant installation. Ideally land should be located as close as to the feed water source and the necessary services in order to minimise costs. Large RO plants typically require a similar footprint area as that required for the distillation plants. In general 0.5ha is needed for each 50MLD of production capacity.

Concentrate / Brine disposal: The by-product of all desalination processes is water highly concentrated in those elements removed during the desalination process, called brine. This includes dissolved salts, but also any chemical treatment that are used in desalination processes to control the formation of mineral scale and biological growth.

Depending on its physical and the chemical content, brine can sometimes be returned, untreated or diluted, to its source of origin or a nearby water body (i.e. out fall to sea or surface water systems, or injecting into a saline aquifer). These options are generally the cheapest and easiest to implement, particularly if the desalination plant near the sea. Pumping, construction of pipelines and / or bores, together with the operation and maintenance costs of this infrastructure, are the only significant cost items.

All above mentioned methods can significantly add to the cost of the process, and thus the method of disposal of the brine stream should be one of the first items investigated in determining the feasibility of a proposed desalination plant.

VII CONCLUSION

Results show that as the TVR pressure varies, a considerable increase in the condensate generation, a decrease in the steam consumption and the costing of the steam consumed was noticed. The condensate generation depends upon the temperature in the first and the last effect. The efficiency of the system also increases with the increase in the TVR pressure. also it was found that as the TVR pressure increases the condensate generation keeps on increasing

The gain output ratio and the performance ratio also play a major role in increase in the condensate generation. Higher the GOR and PR, higher will be the condensate generation and better will be the performance of the system.Also temperature in the first and last effect also have an effect upon the GOR and the condensate generated, higher the temperature in the first effect, higher will be the condensate generation from the starting.

The MED system consists of a total of six effects. The effect of the effect numbers also plays a main role in the total condensate generation of the system, higher the effect number, higher will be the total condensate generated. The increase in the TDS concentration, the electrical conductivity and the condensate generation in each effect was noticed.

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