Achieving Zero Discharge in Industrial Waste Water Treatment Plants

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ACHIEVING ZERO DISCHARGE IN INDUSTRIAL WASTE WATER TREATMENT PLANTS

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Introduction

With an increasing demand on natural water resources, and unabated pollution posed by industrial discharges into the environment, it has become necessary to implement zero discharge systems in industrial waste water treatment plants. In a waste water treatment facility, zero discharge theoretically means no discharge of any kind of pollutants into the environment. But this is practically impossible and, the term zero discharge is loosely used to define no liquid discharge into the environment. So, quite often, zero discharge and zero liquid discharge are used in the same meaning. For all practical purposes, the concept of zero discharge necessarily means the following: 1) recovery of reusable water/other materials from waste water; 2) minimization or, no discharge of polluting substances into the environment away from the waste water treatment facility.

In India, the concept of zero discharge essentially emerged from the situation where industry is unable to meet the discharge norms set by the State and Central Pollution Control Boards. This led to pollution of the environment and subsequent litigation. Initially, the polluters were penalized to an extend necessary to clean the environment that they polluted. This concept was called *Polluters Pay Policy*. The essential ingredient of this policy, however, led the industry to initially pollute the environment - and later pay for environmental losses. Realizing that pollution is still uncontrolled and monitoring has become very much difficult with so many industries discharging the waste water into the environment, finally a solution was conceived and the concept of zero discharge has emerged.

This article addresses how zero discharge can be achieved in a waste water treatment facility. A discussion is also being made on the issues facing implementation of zero discharge in any waste water treatment plant.

As with conventional waste water treatment systems, zero discharge system also includes primary treatment, secondary treatment and tertiary treatment. However, the main objective in a zero discharge treatment system is to see that i) the processes utilized for waste water treatment does not generate any additional pollutants; ii) production of waste is minimized by suitable selection of unit processes and adjusting operating parameters; iii) as far as possible, pollutants in the wastewater are transfered to solid phase (sludge); iv) sludge is stored in a secured landfill; v) recovery of reusable materials, especially water, is achieved.

To achieve the above mentioned objectives, definition and adoption of suitable primary, secondary and tertiary treatment processes based on the physico-chemical characteristics of the waste water are very much essential. It is also essential to develop a template for mass-balance in each unit process. Irrespective of unit processes adopted in each treatment step, the

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main goal of primary treatment is to make the waste water suitable for water recovery during secondary treatment utilizing reverse osmosis system[2]. And, the main objective of tertiary treatment is to treat the reject generated by the reverse osmosis system to recover water and, if possible, other useful materials[3].

Since the concept of zero discharge system is to ensure essentially no discharge of pollutants into the environment, recovery of water gains primary importance. It achieves two purposes: i) by reusing process water, utilization of natural waster resources is minimized; ii) reuse of recovered water enhances the capacity of the industry to efficiently utilize available water as well as control its quality to the required level.

Design of a zero discharge system requires many insights to be made at the outset: i) quality of the waste water to be treated; ii) efficiency of the treatment system; iii) ability of the treatment system to withstand variability in the quality of waste water being treated over short-time (*shocks*) and long-time basis; iv) performance degradation of the machinery over a period of time; v) operation and maintenance issues such as backwash and cleaning operations; vi) mass-balance under different perceived operating conditions.

Primary Treatment

The quality of waste water determines the overall design of any zero discharge treatment system. Depending on waste water quality, waste water is subjected to suitable primary treatment which is normally meant to equalize influent, and to remove/reduce i) suspended solids; ii) oil & grease; iii) biological (BOD) and chemical oxygen demand (COD); iv) colour and odour; vi) toxic trace elements; vii) total dissolved solids (TDS). The food to microorganisms ratio (F/M), and biodegradability of organics in the waste water, are some of the important parameters that decide whether anaerobic digestion is necessary before allowing aerobic respiration[4]. During these operations, it may be necessary to adjust process pH, add necessary chemicals, and maintain dissolved oxygen concentration to achieve desired results. Though these processes are well-known in the industry, some aspects that need focus during implementation of a zero discharge system are considered here.

Equalization:

Controlling variability of influent characteristics is one of the important aspect in the design of a zero discharge system. As process efficiency down the line largely depends on the quality of waste water received for treatment, designing an equalization system to absorb *shocks* is of

2 Water recovery may also be achieved with the use of only an evaporator. The economies of various treatment options are to be considered before a final decision. The chosen system of treatment, however, largely depends on waste water quality.

3 Depending on the nature of waste water, material recovery may be achieved either after secondary treatment or, during tertiary treatment. The processes and machinery may be a bit different. For example, nano filtration may be used in secondary treatment for salt recovery from textile waste water. But, in practice, this has not provided desired results.

4 Anaerobic digestion degrades organic substances that are normally not digestible by microorganisms growing under aerobic conditions. Normally, the degradation products of anaerobic digestion are easily digestible by aerobic bacteria.

paramount importance for successful operation of any zero discharge system. Quality of waste water may change slowly over a period of time or, there may be sudden changes. Of these two, sudden changes, known as *shocks,* are hard to control and may pose significant threat to the treatment system. However, by suitable design of equalization process, it is possible to control the shocks to certain extent. Variability in waste water quality over a period of time should also be taken into account during the design phase.

Variability in waste water physico-chemical characteristics is normally quantified using standard deviation (σ) of respective physico-chemical characteristic, observed over a period of time[5]. The treatment system should be designed to handle at least 3-σ levels of variation in each quality parameter of well equalized effluent[6]. Higher variability in quality parameters may impose heavy investment in machinery. To circumvent this problem, it is very much essential that equalization is properly designed. Recirculation of a certain portion of equalized effluent with the influent and/or dilution with recovered pure water are some of the options that may refine the equalization process – though it imposes the requirement for higher treatment capacity of the system in place[7]. Apart from this, in the case of a Common Effluent Treatment Plant (CETP), the effluent from each member unit may be stored in their respective effluent storage tanks for a minimum period determined by the *transient period* of variability of waste water quality[8]. This ensures that the quality of influent received at the equalization tank of the CETP does not change much. Bye passing the influent with significantly higher concentration of the pollutants than that of the design capacity of the treatment system, and storing it in a separate tank for equalization and later treatment is another option. Essentially, equalization is a very important step in a successful implementation of a zero discharge system for any kind of industry. Otherwise, whenever waste water quality exceeds the design parameters of the treatment system, the performance of the treatment system shall get affected. If this happened, then the system shall take its own time – which is again a *transient process* – to restore to its normal operation. During this time, the recovered water quality, balance between microbial populations, biological assimilation and its kinetic parameters could all have been disturbed.

Filtration:

This is meant for the removal of suspended solids, color, and odour. Pressure Sand Filter (PSF) and Activated Carbon Filter (ACF) are normally utilized. Some of the design aspects that require attention are:

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5 Long period observation is necessary for this purpose. Further, this variability should be measured after equalization. On the other hand, if measurements of raw effluent quality are made (*i.e.*, before equalization), the data obtained shall yield higher variability – invariably pointing to requirement for a high capacity treatment units.

6 This ensures that statistically 95% of the variation falls within design limits.

7 There are definite advantages with recirculating a portion of the treated effluent. Process stability is one of them. Since process stability is very much important for any zero discharge facility, recirculation should be considered during plant design whenever found appropriate and necessary.

8 Transient period is the one within which a particular waste water characteristic returns to its normal value. Normally this follows an exponential curve. For all practical purposes, 3τ can be chosen where, τ is half-life of the transient process. The *transient period* of all waste water parameters should be considered and the one that has a maximum value should be chosen.

i) Design of PSF and ACF should also consider reducing the frequency of backwash to ensure that the performance of the zero discharge system is not getting affected.
ii) Treating the effluent with two parallel streams of filters and/or automated switching of filters, and provision for additional stand-by filters, are some of the options to ensure better filter performance.
iii) Removal of suspended solids should be achieved gradually (*viz.*, larger particles are removed first and smaller ones in the next stage) by cascaded and suitably designed filters to ensure that shocks do not significantly affect the performance of filters.
iv) It may be necessary to treat the waste water resulting from the backwash of PSF and ACF in a sand-bed for the removal of suspended solids – and then pass this waste water to the equalization tank to prevent frequent clogging of the filters.
v) The expected life-time of the filtering materials and their quantity have to be known in advance as these solid wastes are to be transferred to the secured landfill whose design requires the estimated waste solids output from each unit process.
vi) Under situations where colour and odour removal by the filtration equipment is inadequate, ozonation prior to filtration may be considered[9]. But ozonation also produces hydroxides of transition metals, especially iron, that may be present in the waste water. This shall increase turbidity of the feed to the filters and may increase backwash frequency. However, there are certain benefits associated with this process. Almost all toxic trace elements present in the waste water shall get adsorbed by iron hydroxides; this shall reduce accumulation of toxic substances in the anaerobic/aerobic digester that may reduce microbial growth over a period of time due to built up of toxicity. Secondly, since iron poses significant threat to reverse osmosis system, its removal is very much essential prior to secondary treatment.

Mixers:

Mixers mainly play the role of mixing necessary chemicals with waste water *viz.*, acid/alkali for pH adjustment, flocculants for precipitation, anti-fouling agents for prevention of fouling *etc.,* and bring about homogenization. Like equalization, mixing is one of the important steps in a waste water treatment facility. Incomplete mixing may pose significant threat to process stability, and in some cases to the equipment. Consider the case of aeration where incomplete mixing shall reduce oxygen transfer efficiency and increase power consumption. In this case, BOD reduction may not be effective. Addition of sodium meta bi-sulfite (SMBS) for free chlorine removal shall leave traces of residual chlorine as a result of incomplete mixing, which may damage the reverse osmosis membrane. Variability of mixing efficiency with time is one of the prime factors to consider in the design of a zero discharge system. Corrosion of blades over time, geometrical configuration of placement of mixers within the tank, tank geometry and fluid flow pattern can all affect mixing. In a zero discharge treatment facility, all mixing tanks should be subjected to tracer studies to find whether *short-circuiting* of waste water occurs. Short-circuiting essentially means that a packet of waste water that entered the tank has not resided there for a period of design detention time. If this happens, even if the mixer is efficient, the waste water shall not have completely mixed. Often it is possible to increase the overall performance of the waste water treatment system just by augmenting mixing efficiency in all the tanks. This also reduces power consumption,

9 After ozonation, residual ozone in the effluent should be removed. If this is not done, the machinery in the next treatment stage, and microbial growth in the biological digesters shall get affected.

increases treatability of the waste water, prolong the life-time of some of the machinery (for example, reverse osmosis membranes) and increases overall treatment system performance.

While the things discussed above are also important for any waste water treatment facility, its significance in a zero discharge system mainly arises from the fact that *variability-over-time* in mixing efficiency leads to operational problems and achievement of zero discharge shall be in question. This happens even when the design capacity of all the equipments are suitably selected. It should also be remembered that efficient mixing is very much important both in anaerobic and in aerobic treatment of waste water.

Aeration:

Aeration is an energy intensive process and it should be properly designed and actively monitored during operation. Insufficient aeration shall affect the BOD level of the treated waste water and unit processes down the line, especially water recovery in the secondary treatment system. Excess aeration shall enhance dissolved bicarbonate and carbonate species concentration in the waste water due to the dissolution of carbon dioxide from the air[10]. Therefore, zero discharge waste water treatment facilities shall require Oxygen Transfer Efficiency (OTE) tests prior to actual commissioning to ensure that the aeration system is able to meet peak oxygen demand. Another requirement of the aeration system is to ensure that at any given moment, the supplied air should be just enough to oxygenate required quantity of waste water to maintain necessary level of dissolved oxygen concentration. Tank size and geometry, flow characteristics, geometrical arrangement of diffusers, water column depth, mixing efficiency within the aeration basin should all be considered during the design of an aeration basin to ensure that uniformity in dissolved oxygen profile is maintained across the entire basin.

Aeration has some inherent problems:

i) The BOD level of influent may not be constant over time.
ii) Apart from normal diurnal variations, there is a possibility for shocks in the BOD levels.
iii) Due to clogging, performance of the diffusers may get reduced over a period of time and that shall affect oxygen transfer efficiency and BOD reduction.
iv) The dissolved oxygen level in the influent may vary from time to time. However, the ability to maintain a consistent level of dissolved oxygen concentration is essential to ensure better biological assimilation – especially, when anaerobic process is followed by aeration[11].

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10 This is especially true if the waste water pH is in the alkaline range. Increased dissolution of CO_2 in the waste water shall result in the generation of carbonates and bicarbonates. Increased frequency of membrane fouling is one of the consequence of high level carbonate content in the waste water. Carbonate removal before membrane filtration, then, requires more quantity of acid. Operating the membrane filtration process at lower pressure is another option but that shall result in lower water (*permeate*) recovery.

11 The degree of anoxicity determines the electron acceptor utilized by the microbial community. It also decides the nature of the microbial community that can populate under given environmental conditions. The following sequence of electron acceptors are sequentially utilized by microorganisms as oxygen depletes due to microbial respiration: oxygen > nitrate > sulphate > carbon dioxide [this is a very much simplified list and should not be considered final].

A good aeration system shall have the following properties:

i) *Higher oxygen transfer efficiency:* This largely depends on the depth of water column, type of diffuser used (fine bubble diffuser, coarse bubble diffuser, surface aeration system or, venturi aerators), air flow rate, tank geometry, and waste water characteristics. Better oxygen transfer efficiency means lower ratio of aerated waste water volume (m^3) /oxygen transferred (kg O_2/hr) to the water column. Decreasing the air bubble size and optimizing water column depth are essential to achieve better oxygen transfer. The first step towards implementing a good aeration system is achieved by the estimation of Standard Oxygen Transfer Rate (SOTR; kg O_2/hr) of the given aeration equipment. SOTR is essential for the estimation of Standard Oxygen Transfer Efficiency (SOTE; oxygen transferred to water column/oxygen supplied by the aerator x 100) of any aeration system. Since SOTR and SOTE tests are conducted with clean water, they only represent the efficiency of the aeration system – and somewhat useful in sizing the aeration tank, air flow rate and other parameters. As far as possible, these tests should mimic field conditions. The obtained test data is mainly useful for the comparison of different aeration systems available in the market.

ii) *Lower energy consumption/unit oxygen transferred:* This depends on oxygen transfer efficiency and the efficiency of power consuming devices in the aeration system. This ability of the aeration system is measured by Standard Aeration Efficiency (SAE) while, actual field tests may be necessary to determine Process Water Aeration Efficiency (PWAE). The second step towards implementing better aeration system is by estimating OTE for the waste water in question. OTE tests must be conducted in the field under actual conditions using process water to determine Process Water Oxygen Transfer Rate (PWOTR). An important aspect of this is the determination of *α–factor*[12]. This is essential to check whether the supplied air shall be enough to meet peak oxygen demand. This provides necessary data for estimating power consumption by the aeration system after adjusting the results for field conditions.

iii) *Ability to withstand shocks in BOD levels:* Though shocks are largely controlled by a properly designed equalization process, necessity for the design of aeration tank to sustain shocks is due to disturbance of the anaerobic digestion process (that may be employed prior to aerobic process) resulting from changes in chemical characteristics of influent that perturb microbial population composition and their balance. Secondly, when equalization is immediately followed by aerobic digestion, *short-circuiting* in equalization tank may also result in shocks in BOD levels and other parameters. Whenever shocks in BOD levels of the influent occurs, the aeration system shall be able to smooth out the shock and still be able to maintain a steady level of effluent BOD level. This mainly depends on residence time and aeration tank geometry – that decides the flow regime of the aeration basin.

iv) *Ability to meet peak oxygen demand:* This situation arises when the influent BOD raises drastically. Then the ability to meet the peak oxygen demand depends on the quantity of air supplied, oxygen transfer efficiency, mixing efficiency, and ability of the aeration tank design to adjust residence time and/or, flow characteristics. In addition, it also depends on the microbial growth rate. Peak oxygen demand can be met with two techniques: i) by incresing air supply – this invariably means that within

12 The ratio of process water K_{La} – the volumetric gas transfer rate constant - to that of clean water is known as α-factor. This ratio represents the impact of dissolved constituents in the waste water on oxygen transfer rate.

the given time frame – the *detention time* - microbes shall be able to populate and consume excess oxygen required; ii) by increasing the residence time of the effluent in the aeration tank. While increased air supply, better oxygen transfer efficiency, and proper mixing may promote availability of oxygen, to ensure that oxygen is completely consumed by the microorganisms, adjustment of residence time may be essential to give more time for microbial degradation.

Anaerobic/Aerobic Digester and Biodegradability of Organics:

Even when the BOD/COD ratio and their levels are kept relatively constant, the nature of the chemical constituents that contribute to BOD may affect the performance of the anaerobic and aerobic treatment processes. This is essentially due to differing degree of biodegradability of the chemical constituents in the waste water. Easily degradable organics takes comparatively lesser time when compared to hardly digestible organic matter present in the waste water. Thus, their ratio is one of the parameter that shall have an impact on required residence time for treatment. The species composition of the microbial population thriving on the effluent organics is mainly dependent on waste water chemical characteristics. Thus, any significant change in the ratio of easily digestible organics to that of hardly digestible one shall destabilize the balance among microbial populations and upset the system performance[13]. This problem is most probable in CETPs treating textile waste water where, utilization of different dyes at different times by the member units may pose operating challenges[14]. Overcoming this problem is essentially that of a plant operator who has to adjust sludge wasting to control solids retention time (SRT) which shall also affect sludge production. In conventional anaerobic/aerobic digester, controlling SRT independent of hydraulic retention time (HRT) is difficult and employment of membrane bioreactor (MBR) may be necessary[15].

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13 Depending on the chemical nature of organics present in the waste water, there shall be different kinds of microbial populations thriving together. If the chemical nature of organics present in the waste water does not change much then, over a period of time, a steady-state is established. Under this situation, each community of microbial population has a certain role to play in degrading the organics. The degradation products of one microbial community forms the feed to the other. As a result, with time, a balance is maintained among these populations with respect to their species diversity and population so as to effectively degrade the organics present in the waste water. Whenever a significant change in the chemical nature of the organics present in the waste water occurs, the species diversity and their population dynamics are affected. This shall have a dramatic effect on degradation kinetics as well as the biochemical pathways of degradation. This effect shall be enhanced if one of the microbial communities populate the digester very slowly – for example nitrifiers. It takes some time for the microbial population to adjust to changed environmental conditions. Therefore, any sudden change in waste water quality is likely to affect the treated water quality. This situation continues until microbial communities adjust to the new environment.

14 The CETPs in Tirupur are good candidates for such a study.

15 Two CETPs in Tirupur *viz.*, Sirupooluvapatti CETP and S.Periyapalayem CETP, have implemented zero discharge system after primary treatment of the effluent with a Membrane Bioreactor (MBR). These CETPs have so far not started their full-fledged operation. However, due to the employment of MBR, these two CEPTs are likely to face comparatively lesser problems in addressing variability in the nature of organics present in the effluent. For details on advantages of employing MBR refer http://www.ecpconsulting.in/docs/Textile_waste_water_treatment-MBR.pdf

Secondary Treatment System

In a zero discharge treatment system, the main purpose of secondary treatment is to recover reusable water (from permeate) and/or other useful materials (from reject). Design of the secondary treatment process consisting of reverse osmosis system should consider the following:

i) It should be able to treat the effluent resulting after primary treatment. Stating otherwise, the primary treatment should address all the requirements of the secondary treatment system.
ii) It should recover as much water as possible to reduce the load on the tertiary treatment system that ensures that zero discharge is always maintainable.
iii) Low fouling membrane should be used to avoid frequent cleaning.
iv) Waste water resulting from cleaning operations should be disposed to solar pond for evaporation as it may contain lot of impurities.
v) The design should consider down time due to cleaning and other maintenance purposes.
vi) Permanent fouling of permeable pore spaces and membrane degradation results in decreased recovery and increased *salt pass* over a period of time. Provision of additional filtration modules may be necessary to maintain treatment capacity as filtration efficiency decreases with age. These additional filtration modules may be operated whenever necessary.
vii) There may be variations in the feed quality, especially with respect to dissolved salts. The reverse osmosis system may adopt *stage* and *pass* configurations and employ by-passing, mixing and partial recirculating techniques to adjust itself to influent characteristics and maintain treated water quality. Engagement of additional modules should be automated depending on feed quality and the state of system performance.
viii) pH of the recovered water may be varying from time to time. It is essential to neutralize this water. Apart from this, the dissolved salt concentration in the recovered water may also be varying. At any point in time, the recovered water TDS should be maintained below the desired level.
ix) The chemical composition of reject from the reverse osmosis system is subject to feed water quality and percentage of recovery achieved. The reject quality and quantity may vary from time to time; it is essential to equalize this before treating with an evaporator in the tertiary treatment process.
x) Reverse osmosis system runs under high pressure. After filtration, this energy is lost in the permeate and reject. This energy can be recovered using energy recovering devices and utilized for membrane filtration process; this might reduce overall energy requirement of a reverse osmosis system, thereby reducing operating costs.

In cases, where the primary treated waste water TDS exceeds allowable limit for membrane filtration (for example, in the case of distilleries), either dilution for membrane filtration[16] or, employment of evaporator without dilution are the options available. Choosing the right option should be based on energy consumption, expected life period of the machinery, and

16 Note that dilution only increases treatability of the waste water – not water recovery. Due to the development of high osmotic pressure, microbial growth is retarded in high TDS waste water. By reducing the TDS concentration to desired levels, it is possible to remove organic contaminants by facilitating growth of microorganisms. Then, water recovery may be achieved utilizing appropriate methods.

applicability of technology for the given waste water quality. Even if dilution is opted, employment of evaporator for recovery of water from reverse osmosis reject is unavoidable as this is essential to achieve zero discharge. Forced natural evaporation may be considered another viable option – but meteorological conditions may not be suitable all the times. Further, forced natural evaporation may also result in atmospheric pollution.

Tertiary Treatment

The primary objective of tertiary treatment is to recover water and segregate dissolved solids present in the reject obtained from reverse osmosis system. As the concentration of dissolved solids in the reject of a reverse osmosis system increases, it becomes increasingly difficult to extract water using reverse osmosis. Further, when treating the reject, fouling potential on the membrane surface increases drastically. Evaporator is an ideal solution for this purpose which can handle much higher total dissolved solids in its feed. In the absence of volatile organic substances in the feed, the purity of recovered water from an evaporator shall be normally high. However, depending on the constituents of the feed, purity of solids recovered from an evaporator shall vary to a greater degree. Therefore, it is necessary to purify these solids before reuse. Otherwise, the solids have to be disposed to secured landfill.

The main design aspect of an evaporator is controlling the quantity of total solids (TS) in the feed at each stage. The design mainly focuses on evaporating a certain quantity of water from the feed to achieve required effluent density.

In an evaporator, the water in the effluent is evaporated using steam as a heating source. Low pressure is maintained to bring down boiling point so that less energy is utilized for boiling water. The generated water vapour is then condensed with a cooling medium for water recovery. The heat content of the vapour is transferred to the cooling medium and, therefore, vapour is condensed to water. The heat transferred to the cooling medium increases its temperature; therefore, with time, the vapour condensation diminishes. In order to maintain vapour condensation, it is necessary to reduce the temperature of cooling medium temperature using a cooling tower. Thus, in a single stage evaporation, the latent heat in the vapour is largely wasted to the environment. Since evaporation is an energy intensive process, employing single stage evaporator is not economical – and this shall increase operating costs.

In order to utilize the latent heat of vapour, following mechanism is handled: i) the evaporator is constructed with multiple stages (otherwise called as *Multiple Effect Evaporator*). For the first calandria (first effect), externally supplied steam is the heating medium. Due to heating, water vapour is produced from the feed of the first effect. As the steam losses its heat to waste water, it condenses to water, which is recovered. The vapour produced from waste water is separated from liquid feed with the use of a vapour-liquid separator. Then, the vapour is compressed with the use of a *Thermal Vapour Recompressor* (TVR)[17], which operates on the principle of a *jet-pump*. The TVR increases the vapour temperature by a few degree Celsius. Then, this vapour serves as the heating medium for the second effect – where, again vapour is

17 Other type of evaporator that employs *Mechanical Vapour Recompression* (MVR) does not have multiple effects as the vapour generated in a the first stage is condensed in the same stage. Thus, evaporators employing MVR does not have multiple stages.

generated from the feed and the heating medium condenses to water which is recovered. For each stage, feed is obtained from its previous stage which is nothing but the liquor remaining after evaporation. The same process is repeated for *n*-number of effects. Thus, the steam requirement for treating a given volume of feed in a Multiple Effect Evaporator is reduced to $1/n$[18] (where, *n* is the quantity of steam required if single stage evaporator is employed).

There are some aspects that require more attention with respect to employing an evaporator in a zero discharge system.

i) Maintaining the heat conducting surfaces clean, is a very important aspect in maintaining efficient operation of an evaporator. By doing this, energy consumption of an evaporator can be reduced – as efficiency increases. This is essential to ensure that, reject generated in the secondary treatment is completely treated by an evaporator[19].
ii) Monitoring the ratio of condensate/feed for a given time period is one of the best indicators to assess the efficiency of an evaporator. This should be regularly monitored at regular intervals and recorded. This data shall help in fixing the cleaning interval.
iii) Comparison of the ratio of condensate/feed for given energy input is an indicator to compare the performance of different types of evaporators. It should be noted that while conducting these tests, the feed quality employed in two different evaporators should remain the same.
iv) An evaporator may have to be allowed to bleed at specific intervals to remove unwanted solids that do not crystallize.
v) The bleed, and evaporator cleaned waste water, should be sent to solar evaporation pond for drying, and the generated solids should be disposed in a secured landfill.
vi) One of the main operating parameter for a multiple stage (or, multiple effect) evaporator is the design density of the feed at each stage. As far as possible, the initial feed total solids should be maintained at specified level. However, in practice, changes in recovery percentage of reverse osmosis system may affect the concentration of total solids in the reject, which may affect the operation of an evaporator. Thus, it is essential to equalize the reject before being fed to an evaporator. Apart from this, evaporation rate at each stage should be tuned to suit the concentration of total solids in the feed, so that desired levels of total solids concentration in the concentrate in achieved. At any moment, if the total solids concentration in the feed goes down below the design limit, it may be necessary to evaporate more water. This shall require an evaporator with a higher treatment capacity. This aspect should be kept in mind while choosing an evaporator to achieve zero discharge.

18 This is true only on theoretical basis. On practical grounds, this is not correct – as there shall be heat loss in the evaporator system.

19 Reduction in evaporator efficiency shall reduce the quantity of water evaporated per hour – resulting in the accumulation of excess reject from the reverse osmosis system. Therefore, achievement of zero discharge may be difficult if efficiency is not maintained.

Other Issues

The implementation of a zero discharge plant also involves setting up a pilot plant to test process validity and scalability, reducing energy consumption through optimal measures to reduce operating costs for successful operation and efficient maintenance of machinery. They are discussed in detail.

Uses of Pilot Plant:

Before designing a zero discharge system, employment of pilot plant with important unit processes is very much essential to ascertain that chosen treatment procedure is able to successfully achieve its purpose. The data collected from pilot plant tests may be useful for the following purposes:

i) Applicability of the chosen process for given waste water can be studied.
ii) Development of mathematical model using the collected data is important for scale-up.
iii) Variability in the feed characteristics over a period of time and the ability of the system to respond to these variations can be studied.
iv) Adequacy of each unit process can be validated beforehand. This ensures that full-scale plant does not attract process modifications/additions on a later date due to performance inadequacy.
v) Details on process adequacy, efficiency, and system performance can be studied. This shall provide enough input for full-scale plant design.
vi) The preliminary data obtained from a pilot plant may also be useful in mass balance calculations to achieve zero discharge.

Measures for Energy Efficiency/Energy Saving:

i) Utilizing energy recovery device in the reverse osmosis system.
ii) Increasing the number of effects in a Multiple Effect Evaporator; 7-effects is found economical (However, capital investment shall be higher with increasing effects).
iii) Reduction of scale formation in boilers, evaporators, and reverse osmosis system by adopting necessary measures. Cleaning with calculated interval is also necessary to maintain good performance.
iv) Utilization of natural evaporation for evaporating *bleed* from an evaporator and, waste water generated from cleaning operations.
v) Wherever feasible, employment of anaerobic reactor for biogas production should be considered. The biogas can be used for power generation or, for heating purposes, resulting in reduced operating costs. Co-generation is another option to utilize heat from waste steam.
vi) Heat recovery may be considered wherever feasible. The waste heat can be utilized to heat process water or, the feed to an evaporator. Proper planning may be necessary at the outset to achieve this goal.

vii) Utilization of energy efficient motors and pumps is necessary to reduce operating costs.

viii) Selection of suitable pipe size is an important factor that helps to reduce energy requirement in waste water collection system and treated water distribution lines in the case of a CETP.

Operation, Maintenance and Interruptions:

Operation here means suitably adjusting the operating conditions of the treatment system with time to ensure better performance whereas, maintenance is essentially to ensure that each and every equipment in place is maintained within their operating limits given by the supplier. Thus, while operation is meant to tune the system performance, maintenance shall enforce that the operating range of the equipment set by the manufacturer is not exceeded at any moment. Interruptions are unexpected and may be due to failure of any equipment, power and any other unforeseeable circumstances. All these things should be considered while designing a zero discharge system. Inclusion of additional storage tanks, treating the effluent with two or more parallel streams (depending on the treatment capacity), provision of stand-by equipments, setting up of alarms (which only alert the operator) and triggers (automatically takes necessary action) using PLC (Programmable Logic Controllers) and SCADA (Supervisory Control and Data Acquisition System) are other necessary requisites for a zero discharge system. The performance of the system should be checked from time to time by retrieving performance data stored using SCADA. This may also be useful in diagnosis of reasons for equipment failure. Quality control charts are also very much important in the maintenance of a zero discharge system.

Finally, though a zero discharge plant may have been designed with so many inputs, optimization is very much essential. This should be done in two steps: i) optimization of each equipment/unit process; ii) optimization of whole treatment system. The earlier one is somewhat easier than the later – but maintenance of a zero discharge system requires complete optimization. Of all optimization techniques available, *neural networks* present one of the best ingredients – that each unit process may be given a variability associated with the process, and a suitable performance data for the fully functioning plant can be estimated. Optimization of unit processes reduce energy consumption and increases performance. This ensures that a waste water treatment system always meet its legal requirement of maintaining zero discharge. Optimization of waste water treatment plant, especially one implementing a zero discharge system, is a growing area of science. I do hope that it shall attract the attention of all waste water treatment facilities in the near future.