“ZERO DISCHARGE OF EFFLUENT FROM TEXTILE INDUSTRY”

A Major Project Report

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IN

CHEMICAL ENGINEERING
(ENVIRONMENTAL PROCESS DESIGN)

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Certificate

This is to certify that the Major Project Report entitled “Zero Discharge of Effluent from Textile Industry” submitted by Mr. Chhaiya Ambrish Bhojabhai, (04MCH002), towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Chemical Engineering (Environmental Process Design) of Nirma University of Science and Technology is the record of work carried out by him under my/our supervision and guidance. The work submitted has in my/our opinion reached a level required for being accepted for examination. The results embodied in this Major Project Work to the best of my/our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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ABSTRACT

Water-Pollution control is presently one of the major areas of scientific activity. In the present scenario of environmental pollution, particularly water pollution, textile industries are facing serious problems in effluent treatment. The textile industry typically uses large quantities of water, it being water intensive industry and generates large quantities of the effluent ranging from as low as 5000 liters/hr to as high as 3,00,000 liters/hr which contains various objectionable impurities such as Color, COD, BOD, TDS etc. After imparting suitable treatment with the conventional treatments, these effluents are being discharged into the receiving bodies.

In recent times, Compliance of ‘Zero Discharge’ requirement, in which, the industry is not supposed to discharge any effluent outside its premises is really a very tough requirement from the techno-economic viewpoint. Various conventional technologies such as Reverse Osmosis, Incineration, Multiple-Effect Evaporation, Solar Evaporation etc are intrinsically and techno-economically unsuitable for sustained, long-term compliance of ‘Zero Discharge’ at Industrial Scale. Besides, they are far too expensive and are prone to frequent maintainance problems and resultant degradation of their efficiency.

This project deals with the newer approach to ‘Zero Discharge’ which genuinely and techno-economically ensures ‘Zero Discharge’ without suffering from the deficiencies of the conventional technologies as outlined above. The two types of synthetic textile effluent of 0.1 %, 0.3%, & 0.5% w/v dye solution were used and were characterized. The ‘Zero Discharge’ system pilot plant developed at ATIRA convert the liquid into vapor which gets evaporated naturally without heat input and separates dissolved solids from the wastewater as a by-product powder that can be reused. Initially the wastewater from the storage tank is pumped into the duct wherein it gets split into water droplets of 50-100 micron size with the help of high pressure system placed into the duct. These water droplets are kept airborne for the natural evaporation to occur with the help of air provided from the bottom of the duct with the help of air blower.

The Batch and Continuous study were performed wherein (i) The net water evaporated in an hour, (ii) Power unit consumed in an hour and for 1000 ltr of water

evaporation as well as (iii) Operating cost for an hour and for 1000 ltr of water evaporation were estimated at varying pressure in pump. Besides this, the comparative study of batch and continuous operation was conducted. The results show that this newer approach may genuinely and techno-economically ensure ‘Zero Discharge’.

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A1	High Pressure System
AB1	Air Blower
AC	Activated Carbon
AO	Advanced oxidation
AOPs	Advanced Oxidation Processes
ATIRA	Ahmedabad Textile Industry's Research Association
B	Bypass from the pump
B_D	Bottom of the Duct
BOD	Biochemical Oxygen Demand
BOD_5	5 day Biochemical Oxygen Demand
BIS	Bureau of Indian Standards
$CaCO_3$	Calcium Carbonate
CETP	Common Effluent Treatment Plant
Cl	Chloride
CMC	Carboxy Methyl Cellulose
CMH	Meter cube per hour
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CWA	Clean Water Act
CT1	Pump Bypass Collection Tank
CT2	Recollect Tank
D1	Duct
E^o	Oxidation Potential
EC	Electrochemical Oxidation
ETP	Effluent Treatment Plant
Fe	Iron
$FeCl_2$	Ferrous Chloride
$FeSO_4$	Ferrous Sulphate
GL	Ground Level
H	Hour
$HO\cdot$	Hydroxyl radical
H_2O_2	Hydrogen peroxide
H_2O	Water

Hp	Horse power
I	Input to the pump
KL	Kiloliter
KWH	Kilo-Watt-Hour
L	Liter
LPH	Liter per hour
M	Meter
MB	Methylene Blue
mg	milligram
Mn	Manganese
M.O.C.	Material of construction
MPa	Mega Pascal
MPCETP	Manickapurampudur Common Effluent Treatment Plant Private Limited
Na	Sodium
NaCl	Sodium Chloride
NF	Nanofiltration
nm	Nanometer
NTU	Nephelometric Turbidity Unit
O	Outlet from the pump
O_2	Oxygen
O_3	Ozone
P	Pressure
P1	Pump
PAC	Powdered Activated Carbon
pH	Potentia Hydrogenii
ppm	Part Per Million
R	Recollect from the bottom of the duct
RH	Relative Humidity
RO	Reverse Osmosis
RPM	Revolution per minute
Rs.	Rupees
RSE	Rapid Spray Evaporation
SiO_2	Silica
SO_4	Sulphates

SS	Suspended Solids
ST1	Storage Tank
T1	Collection Tank
T_D	Top of the Duct
TDW	Textile dye wastewater
TDS	Total Dissolved Solids
TEF	Totally Effluent Free
TFC	Thin-film composite
TiO_2	Titanium Dioxide
TNPCB	Tamil Nadu Pollution Control Board
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	Ultrafiltration
µm	Micrometer
UV	Ultraviolet
V	Volt
V_I	Initial Volume
V_F	Final Volume
W	Weber
WW	Wastewater

CHAPTER - 1

INTRODUCTION

1.1 ZERO DISCHARGE OF EFFLUENT FROM TEXTILE INDUSTRY:

The world population is ever increasing putting a considerable amount of stress on the environment. Water will continue to become a major factor for the survival of human and human activities. This is especially true in the industrialized areas of the world. At present, approximately 50% of the water is being used by households, and the other 50% for industrial and agricultural activities. However, with an increasing population, there will be pressure for industries to reclaim and reuse some of its wastewater, or face the prospect of being shutdown. This is due to the combine pressures of increasing cost and non-availability of good quality water and increasing regulatory requirements of discharged wastewater.

Depending upon the amount and type of fabric/yarn processed, type of manufacturing operations employed and water consumption practices, textile mills and process houses generate a large amount of wastewater ranging from as low as 5000 liters/hr to 3,00,000 liters/hr.*(Bhatt S.R. et.al, 2005)* Some of the common objectionable impurities found in the textile effluent which need proper treatment, control and monitoring are pH, COD, BOD, Detergents, Color, TDS, Heavy Metals, Ammonical Nitrogen, Sulfates, Chlorides, Oil and Grease and Toxicity. Normally, the total effluent which is discharged into the receiving bodies after imparting suitable treatment is about 70-85% of the total water consumed by a typical composite textile mill. *(Bhatt S.R. et.al, 2000)* It is, however, not uncommon to find a mill or a process house where effluents from different processes are separately discharged either after some treatment or without any treatment at all.

If the nature of receiving system is a land locked area and there is no discharge facility like land, river, estuaries, coastal water etc then regulatory body ask to comply with the requirements of ‘Zero Discharge’ i.e. No discharge outside the industrial premises, no discharge on land for percolation which could lead to pollution of underground strata. This means one has to recycle the treated wastewater as many times as possible.

The project report mainly consists of six chapters:

- ⇒ Chapter 2 includes the literature survey of the project which is divided in to 4 sections. In section 1 and 2, various facts of water pollution in textile industry, existing treatment technologies - their limitations are described at a length while in section 3, concept of zero discharge is being described along with the pathway to achieve zero discharge, problems and prospects of zero discharge, its benefits, various zero discharge system and the operating cost to achieve zero discharge have been shown. The section 4 describes about the zero discharge system pilot plant at ATIRA, Ahmedabad, its principle, the system's theory of evaporation, worldwide analogous technologies, factors affecting the rate of evaporation have been described in detail.
- ⇒ Chapter 3 describes about the zero discharge pilot scale experimental set up at ATIRA, Ahmedabad and its details.
- ⇒ Chapter 4 shows all the details about experiments carried out along with results and discussion.
- ⇒ Chapter 5 includes the conclusion drawn from the project work.
- ⇒ Chapter 6 describes the scope for the future work of the project.

1.2 PROJECT OBJECTIVE:

- ⇒ The main objective of the project is to achieve sustained, genuine and techno-economically viable 'Zero Discharge' compliance requirement of the textile industry by the regulatory body.

CHAPTER – 2

LITERATURE REVIEW

2.1 TEXTILE INDUSTRY:

2.1.1 HISTORY:

Since times immemorial, the three basic needs of mankind have been food, clothing and shelter. The units producing cloth by any mechanisms are called textile units. Textile industry is one of the oldest and largest industries of the India. Not going far back in the history of textile industry in India, the East India Company started its business by cotton industry. Now a days India is a major exporter of textile-finished material. The textile industry in India is a fast growing industry. As per the recent date published by the textile commissioners' office there are 1569 textile industries in India; of these 1294 are spinning industries and 275 are composite industries. The major textile industries are located in the city like Ahmedabad, Bombay, Bangalore, Baroda, Bhilwara, Kanpur, Madras, Tirupur etc. *(Hussain J. et.al, 2004)*

The textile process requires large volumes of water of high purity and generates equally large volumes of wastewater, which are complex and highly variable both in regard to quantity and characteristics. *(Hussain J. et.al, 2004)*

2.1.2 PROCESSES INVOLVED:

The manufacturing processes of cotton textiles consist of a series of unit operations which are complex and highly specialized. *(Indian Standard IS: 9508-1980)* They may be broadly divided into four production stages as (1) yarn formation, (2) fabric formation, (3) wet processing, (4) fabrication which is shown in figure 2.1.2.1. *(http://www.p2pays.org/ref/01/00506.pdf referred on 02/10/2005)*

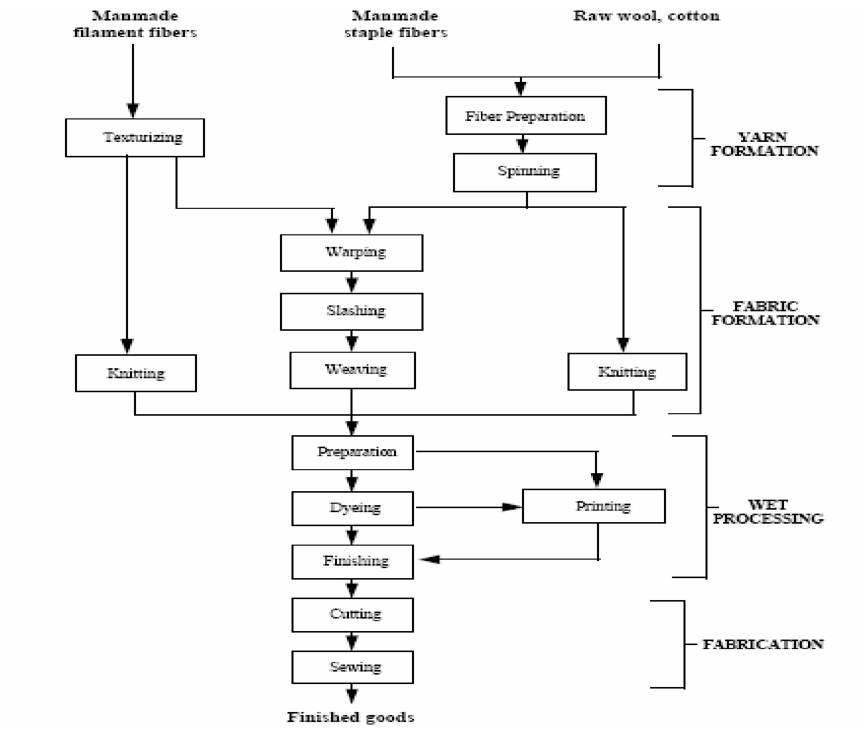


Figure 2.1.2.1: Typical Textile Processing Flow Chart *(http://www.p2pays.org/ref/01/00506.pdf referred on 02/10/2005)*

2.1.3 SOURCES OF RAW WATER AND THEIR PROBLEMS: *(Bhatt S.R. et.al, 2000 & 2005)*

There are four major sources of raw water for the textile industry:

(i) Own bore wells or bore wells of the industrial estates.
(ii) Supply from Municipal Corporation.
(iii) Nearby inland surface waters such as river, pond, reservoir, etc.
(iv) Supply from distant places through tankers.

It has been observed in many parts of the country in the recent times that the water table has receded alarmingly and quality of water has deteriorated drastically. Considering rapid industrialization and concentration of water-intensive industries in certain locations, it is not surprising that these industries are experiencing increasing shortage of water. Gradually dwindling rains also have aggravated the situation. Textile mills and process houses in certain parts of Rajasthan, Gujarat and South India (Tamil Nadu) have started experiencing these problems so gravely that it threatens to endanger their manufacturing activities.

Quality of raw water in textile centres of Pali, Balotra and Bhilwara in Rajasthan is so bad in terms of hardness and TDS (Total Dissolved Solids) that even after softening; it is not fit for use in the textile processing. It is not uncommon to encounter water containing hardness and TDS in the range of 1000-2000 ppm and 4000-10000 ppm respectively in some of these regions. During the summer time, the water table recedes to as deep as 800 feet and the bore-wells dry up. Consequently, raw water has to be imported from distant places through tankers, incurring heavy expenses.

Textile centres of Tirupur, Madurai, Madras and Bangalore in the South India are perhaps the worst affected in the whole country. They spend about 50-150 Rs. /KL for obtaining raw water through the tankers. In spite of paying such a heavy price, the quality of water is not good and its supply uncertain.

In Mumbai, quality of raw water is good because the municipal corporation supplies it from the lakes. Its TDS and Hardness are in the range of 300-400 ppm and 100-150 ppm respectively. But its price is much higher. Its present price is Rs. 25-40/KL. Less than a year ago, its price was Rs. 12/KL.

Secondly, many industrial units do not get adequate water from the corporation and, therefore, they have to make up the balance requirement through water tankerage. A typical composite textile mill in Mumbai spends about Rs. 5-6 million per year only for raw water. *(Bhatt S.R. et.al, 2000 & 2005)*

2.1.4 WATER USAGE:

The water requirement for textile processing is large and varies from one mill to another and this depends on factors like:

(i) Source of water and its availability
(ii) The quantity and quality of the fabrics produced
(iii) The type of processing and its sequence.

The water usage for different purposes in a typical cotton textile mill and synthetic textile processing mill is given in the Table 2.1.4.1**.** To produce One meter of finished cloth the water consumption is in the range of 12 to 65 liters. The longer the processing sequence, the greater will be the quantity of water used. The processing of yarn also requires equally large volume of water. Bulk of the water consumed is in the washing of the fabric at the end of each process. *(Indian Standard IS: 9508-1980)*

Table 2.1.4.1: Water Usage in Textile Industry *(Indian Standard IS: 9508-1980)*

Sr. No.	Purpose	Cotton Textiles (%)	Synthetic Textiles (%)
1	Steam Generation	5.3	8.2
2	Cooling Water	6.4	-
3	Demineralized water for specific processes	7.8	30.6
4	Process Water (raw water)	72.3	28.3
5	Sanitary use	7.6	4.9
6	Miscellaneous and fire fighting	0.6	28.0

2.1.5 SOURCES, QUANTITIES AND CHARACTERISTICS OF WASTE WATER:

2.1.5.1 Sources: *(Indian Standard IS: 9508-1980)*

The main sources of waste water in a textile mill are the following:

(a) Preparation of the yarn – slashing process waste;
(b) Textile Processing – (i) desizing, (ii) kier, (iii) bleaching, (iv) mercerization, & (v) dyeing and printing;
(c) Waste Water from the washing operations in each step of textile process;
(d) Miscellaneous waste streams, namely, cooling water and boiler blow down, house keeping and spills and leaks;
(e) Sanitary wastes.

2.1.5.2 Quantities: *(Indian Standard IS: 9508-1980)*

The quantity of the wastes discharged from each unit process is very small compared to the volume of wastes derived from the washing and rinsing of the cloth. The quantities of the wastes are highly variable from one mill to another and depend on the factors like;

(a) Source of water and its availability
(b) The quantity and quality of the fabrics produced
(c) The type of processing and its sequence.

The waste water discharged by the mills lies in the range of 57 to 800 m^3 per 1000 kg cloth produced.

2.1.5.3 Characteristics:

The Characterization of textile industry can be divided into the following broad categories:

1. Basic Pollution (i.e. Colour, Odour, Temperature, pH)
2. Physico-chemical pollution (i.e. TDS, TSS etc.)

3. Organic pollution (i.e. COD, BOD etc.)
4. Inorganic pollution (i.e. metallic and non-metallic pollutants such as chlorides, sulphides, phosphates, alkalinities etc.) *(Shukla S.R., 2005)*

The Characteristics of the waste streams from the different processes are governed by factors such as the quantity of and type of process chemicals used, water usage and intensity of the washing process as shown in the Table 2.1.5.3.1. *(Indian Standard IS: 9508-1980)* The chemical characteristics of the different process waste waters are shown in Table 2.1.5.3.2. *(Indian Standard IS: 9508-1980)* The Characteristics of the concentrated effluent from a typical textile industry is given in Table 2.1.5.3.3 *(Ansari A. A., 2005)* and the water quality standards for the textile wet processing is given in Table 2.1.5.3.4**.** *(Ansari A. A., 2005)*

Table 2.1.5.3.1: Characteristics of Process Waste Streams of Textile Industry
(Indian Standard IS: 9508-1980)

Sr. No.	Unit Process	Possible Pollutants in the Waste Water	Waste Water Volume	Nature of Waste Water
1.	Desizing	starch, glucose, CMC, polyvinyl alcohol, resin, fats and waxes	Very small, approximately 50 l/kg of cloth	High BOD (35-50% of total); carboxymethyl cellulose and polyvinyl alcohol do not exert a high BOD.
2.	Kiering	caustic soda, waxes & grease, soda ash, sodium silicate & fragments of cloth	Small – 10 l/kg of cloth	Strongly alkaline, dark colour, high BOD (30% of total)
3.	Bleaching	Hypochlorite, chlorine, caustic soda, hydrogen peroxide, acids, etc	Mostly washings	Alkaline, constitutes approximately 5 % of BOD
4.	Mercerizing	Caustic soda	Small, Mostly washings	Strongly alkaline, low BOD (< 1% of total)
5.	Dyeing	Various dyes, mordants & reducing agents like sulphides, hydrosulphide, acetic acid & soap	Large	Strongly colored, fairly high BOD (6% of total)
6.	Printing	Colors, starch, gums, oil, china clay, mordants, acids & metallic salts.	Very small	Highly colored, fairly high BOD and oily appearance
7.	Finishing	Traces of starch, tallow, common salt, glauber salt, etc	Very small	Slightly alkaline, low BOD

Table 2.1.5.3.2: Chemical Characteristics of the Process Waste Waters
(Indian Standard IS: 9508-1980)

Sr. No.	Characteristic	Desizing	Kiering	Bleaching	Mercerizing	Dyeing	Printing
1	pH value	8.6-10.0	10.9-11.8	8.4-10.9	8.1-9.8	9.2-11.0	6.7-8.2
2	Alkalinity, mg/l	490-2480	4740–19000	2780-6280	930-1005	1250-3160	500-1080
3	Total Solid, mg/l	7870-8920	14220 -40580	2980-8240	2220-3030	3600-6540	2120-2750
4	TDS, mg/l	5580-6250	12260 -38500	2780-7900	2060-2660	3230-6180	1870-2360
5	SS, mg/l	2290-2670	1960-2080	200-340	160-430	360-370	250-390
6	BOD, mg/l	1000-1080	2500-3480	87.5-535	100-1222	130-820	135-1380
7	COD, mg/l	1650-1750	12800 - 19600	1350-1575	245-381	465-1400	410-4270

Table 2.1.5.3.3: Characteristics of Concentrated Effluent *(Ansari A. A., 2005)*

Sr. No.	Parameters	Values
1	Appearance	Colored and Turbid
2	Color, Hazen Unit	240-300
3	pH	9.0-11.0
4	Suspended Solid, mg/l	150-200
5	Total Dissolved Solid, mg/l	3500-4000
6	Chemical Oxygen Demand, mg/l	3000-5000
7	Bio-chemical Oxygen Demand, mg/l	1600-2600
8	Oil & Grease, mg/l	10-30
9	Total Hardness (as $CaCO_3$), mg/l	500-750
10	Iron (as Fe), mg/l	0.2-1.5
11	Manganese (as Mn), mg/l	0.06-0.08

Table 2.1.5.3.4: Water Quality Standards for Textile Wet Processing *(Ansari A. A., 2005)*

Sr. No.	Parameters	Permissible Limits	
		General	**Dyeing**
1	Appearance	Clear, Colorless	Clear, Colorless
2	Color, Hazen Unit	<5	5-20
3	Turbidity, NTU	<5	<5
4	pH	6-8.5	6-8.5
5	Suspended Solid, mg/l	<5	<5
6	Total Dissolved Solid, mg/l	100-500	<200
7	Total Alkalinity (as $CaCO_3$), mg/l	<100	<25
8	Total Hardness (as $CaCO_3$), mg/l	2-15	<2
9	Chloride (as Cl), mg/l	<100	<100
10	Sulfates (as SO_4), mg/l	<100	<100
11	Silica (as SiO_2), mg/l	2-10	<10
12	Iron (as Fe), mg/l	0.1-0.3	<0.1
13	Manganese (as Mn), mg/l	0.02-0.05	<0.02

2.1.6 OBJECTIONABLE IMPURITIES OF TEXTILE EFFLUENT FROM WATER REUSE VIEW POINT: *(Bhatt S.R. et.al, 2000 & 2005)*

Typically the composite textile waste water contains about 1% by wt. of impurities and about 99% by wt. of water. Out of the 1% impurities, objectionable impurities from water reuse point of view is less than 20-30%. Therefore, one of the promising paths of water conservation in the textile industry is regeneration of water and its recycling from effluent after a suitable treatment. For compliance of the statutory requirements on water pollution, the mill or the process house has to impart suitable treatment to the waste water before discharging it into the nearby receiving body. If this treatment can be suitably modified using atleast some part of the treated effluent, it would prove extremely beneficial to the industry.

The typical objectionable impurities in the raw textile effluent from pollution view point are: pH, S.S., B.O.D., C.O.D., Oil and Grease, TDS, Colour, Detergents, Ammonical Nitrogen, Sulfates, Chlorides, %Na., Heavy Metals and toxic substances. After conventional treatments like Coagulation - Flocculation - Sedimentation, Activated Sludge, Anaerobic Biological Treatments, etc. of the effluents, some of these impurities are brought within the prescribed tolerance limits and can therefore, be considered ‘Non-Objectionable’ from the point of view of statutory requirements of water pollution control. These treatments, however, can not remove colour, TDS, hardness, turbidity, sulfates, chlorides and % Na or Sodium Absorption Ratio, to the level which would render effluent ‘Recyclable’ or ‘Reusable’ in the processing.

In other words, even after adequate treatment of the textile waste water, residual impurities like Colour, Hardness, TDS, Turbidity, Sulfates, etc., can pose several problems in its reuse in the processing, particularly, in preparation of dye liquor, printing paste, finishing and so on. However, it may be possible to reuse the treated effluent in almost some of the washing operations including washing of screens and so on. But for substantial reuse of the effluent in almost all processing operations, on a continuous basis without any adverse effects on the processing, colour has to be removed almost completely. But the adverse effects of two other major impurities namely, TDS and hardness which owe a substantial part of their concentration to the raw water itself are still under a shroud of doubts and controversy. *(Bhatt S.R. et.al, 2000 & 2005)*

2.1.7 DIFFERENT APPROACHES TO EFFLUENT TREATMENT:

The unit operations necessary to be carried out for complete treatment of an effluent have been classified into Primary, Secondary and Tertiary Treatments which are subdivided and given in the Table 2.1.7.1 *(Shukla S.R., 2005)*

Table 2.1.7.1: Different Effluent Treatment Technologies *(Shukla S.R., 2005)*

Primary Treatment	Secondary Treatment	Tertiary Treatment
Screening	Aerated Lagoons	Advanced Oxidation
Equalization	Activated Sludge process	Adsorption
Neutralization	PAC Addition	Membrane separation
Coagulation & Precipitation	Trickling filtration process	Biological oxidation
Sedimentation	Oxidation ponds process	Chemical coagulation

2.2 EXISTING TREATMENT TECHNOLOGIES FROM WATER REUSE VIEW POINT:

2.2.1 COAGULATION AND/OR FLOCCULATION:

The wastewater which contains colloidal particles of size 0.01 to 1 µm has net negative surface charge. Due to this, the attractive body forces between particles are considerably less than the repelling forces of the electrical charge. Under these stable conditions, Brownian motion (i.e. random movement) keeps the particle in suspension which is brought about by the relatively small water molecules that surround them. Coagulation is the process of destabilizing colloidal particles so that particles growth can occur as a result of particle collisions. For destabilization of colloidal particles, chemical such as coagulant is added in wastewater for floc formation and flocculent which is an organic, is added to enhance the flocculation process. *(MetCalf & Eddy, 2003)*

The chemicals which are added, forms a precipitate, which, either during its formation or as it settles, collects other contaminants. This precipitate is then removed either through settling or by floating it to the surface and removing the sludge. This is a well-known method of purifying water. Both inorganic (Alum, Aluminium Chloride, Calcium Hydroxide or Lime, Ferric Chloride, Ferric Sulfate, Ferrous Sulphate, Sodium Aluminate, Polyelectrolyte etc.) (*MetCalf & Eddy, 2003 & Gupta S. V. et al., 2002)* and organic (polymers) coagulants have been used to treat dye effluent to remove color, both individually and in combination with one another. With the changes in dyes and stricter discharge limits on color, inorganic coagulants no longer give satisfactory results.*(Barclay Susan et al., 2000)* They have the added disadvantage of producing large quantities of sludge and the advantage of being economically feasible. The advantages and disadvantages are given in the Table 2.2.1. Organic polymers show improved color removal and produce less sludge, but then may have detrimental effects on the operation of the sewage works. Cationic polymers have also been shown to be toxic to fresh water and fish. *(Barclay Susan et al., 2000)*

Textile dye wastewater (TDW) is well known to contain strong color, high chemical oxygen demand (COD) and low biodegradability. Coagulation by aluminum or iron salts could not treat it adequately. *(Chen Junshui et.al, 2004)*

The compound structure of dyes can be very complex and impact on the degree of biodegradability. Generally, the coagulation and flocculation technique is effective in removing dyes with low solubility (e.g. disperse and vat dyes) whereas ineffective against removing water soluble dyes such as reactive dyes which is used extensively in the industry. *(Tak-Hyun Kim et.al, 2005)*

Bes-Pia A. et al. (2003) investigated the feasibility of the combination of physico-chemical treatments with membrane technologies to reuse wastewater of the textile industry. For physico-chemical treatments two coagulants i.e. $FeCl_3$ and $Al_2(SO_4)_3$ and an anionic flocculant were used. These coagulants, one containing Al^{+3} and other containing Fe^{+2} were compared by carrying out jar-tests using different concentrations and pH values and found out Fe^{+2} containing coagulant achieved 72.5 % COD removal efficiency while worst results were achieved in case of Al^{+3} containing coagulant. The optimal values of parameters were: pH = 8.5, C_{FeCl3}=200 mg/l, $C_{Anionic}$= 1 mg/l. This clarified water from physico-chemical treatment was then treated by means of ultrafiltration or nanofiltration which leads to a COD removal of almost 100 %.

Sheng H. Lin et al. (1996-97) studied two different treatment methods for the reuse of textile waste water, one using the chemical methods which consist of electrochemical method, chemical coagulation and ion exchange and the other consisting of Fenton's process, chemical coagulation and ion exchange. They concluded that the electrochemical method and chemical coagulation as well as Fenton's process and chemical coagulation are intended primarily to remove colour (97.7%), turbidity (92.5%) and COD (68%) of wastewater effluent while ion exchange is employed to further lower the COD concentration to (93%), Fe ion concentration (80%), conductivity (99%) and total hardness (79%) of the wastewater effluent to the reuse standard of the textile industry.

2.2.2 ADSORPTION:

Adsorption is the accumulation of a substance, the adsorbate, onto a solid, the adsorbent; it is driven by physical and chemical forces. Adsorption has been found effective in the removal of dyes, pigments and other colorants. *(Fawzi Banat et al, 2004)* With adsorption, Biorefractory compounds can be removed. *(Bes-Pia A., 2003)* Various adsorbents like activated carbon, polymeric resin, chitin, silica, plantparts etc, have been used. Among these activated carbon finds efficient and commonly used and it is effective in removing organic components from the effluent (but not inorganic compounds). *(Barclay Susan et al., 2000)* But it is expensive too. *(Sharma J. K. et al., 2005)* It is commercially prepared from lignite and bituminious coal, wood, pulp mill residue coconut and petroleum pitch, having surface area ranging from 500-1400 m^2/g. *(Reife Adraham et. al, 1996)* Properties generally vary depending on activation conditions when making the activated carbon from the raw materials. Activated carbon is divided into two types, namely powder and granules. The powder type cannot be easily regenerated and is usually discarded after use. The granular type is generally used in waste water treatment because of continuous use, easy handling and repeated regeneration. *(Reife Adraham et. al, 1996)* Once saturated, it must be regenerated or disposed of. Regeneration is costly, and in most cases it is trucked off site and disposed of in landfill. Care must be taken with the disposal method as the organics may leach out over time and cause pollution problems at a later date. *(Barclay Susan et al., 2000)*

Some of the alternative low cost adsorbents which are available are rice-husk, wood charcoal, flyash, sugarcane bagasse pith, saw dust, wood ash, coconut coir pith, brick powder, tea leaves etc. *(Sharma J. K. et al., 2005)*

The feasibility of adsorption on carbon for the removal of dissolved organic pollutants has been demonstrated by adsorption isotherms. Carbon adsorption isotherms are generated by contacting a fixed quantity of dye wastewater with different amounts of activated carbon for a fixed length of time in order to remove impurities. *(Reife Adraham et. al, 1996)* The advantage and disadvantage of adsorption is given in Table 2.2.1**.**

Fawzi Banat et al. (2004) investigated the effectiveness of using activated carbon (AC) in conjunction with ultrafiltration (UF) in the removal of methylene blue (MB) from aqueous solutions. Three types of AC were used as adsorbents and the combined process achieved better rejection of dye than that by the UF process alone. No rejection was observed using the UF process while the rejection coefficient of the integrated process reached 85% at a carbon dose of 800 mg/L and a feed dye concentration of 90 mg/L. The types of PAC were more effective than that of the granulated type for dye removal. The dye rejection coefficient increased with an increase in carbon dose while the flux remained almost constant. The permeate flux was linearly dependent on the operating pressure. The dye rejection coefficient was optimal at a pressure of about 1.5 bars.

Sharma J. K. et al. (2005) investigated the adsorptive capacity of 7 low cost adsorbents (wood, charcoal, sugar cane, bagasse pith, coconut coir pith, saw dust, wood ash, brick powder and fly ash) for the effluent obtained from dyeing of cotton fabric with Congo Red and Chrysophenine-G. Efficiency for effluent decolourisation of these adsorbents using variable doses were studied and compared with activated carbon and found that Wood ash was the best low cost adsorbent among all other with 98.06 % colour reduction compared with activated carbon having colour reduction of 99.27%. Effect of pH was also examined in colour reduction of dyes effluent.

Rathi A.K.A. (2000) investigated the effectiveness of the adsorbents in reducing COD and colour. The adsorption was used as the first stage of treatment of wastewater using inexpensive adsorbents, viz fly ash, bentonite and lignite followed by the conventional processes to meet the statutory requirements. COD equilibrium values were predicted using a new model Rathi Puranik equation and are compared with the experimental values. Single stage adsorption process was analysed and an equation was developed for designing adsorption system. He further concluded that the spent adsorbent in case of lignite could be mixed with the solid boiler fuel to solve the problem of hazardous waste disposal.

2.2.3 MEMBRANE TECHNOLOGY:

Membrane filtration can be broadly defined as a separation process that uses semi permeable membrane to divide the feed stream into two portions: a permeate that contains the material passing through the membranes, and a retentate consisting of the species being left behind. The most important types of membrane filtration are pressure driven processes including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). *(Zhou H. et al., 2002)*

More specifically, membrane filtration can be further classified in terms of *(MetCalf & Eddy, 2003)*

1. The type of material from which the membrane is made
2. The nature of the driving force
3. The separation mechanism
4. The nominal size of the separation achieved.

The general characteristics of membrane processes including typical operating ranges are reported in the Table 2.2.3.1. The membrane materials used include polypropylene, cellulose acetate, aromatic polyamides, polyacrylonitriles, polysulphones, polycarbonates, fluorocarbon-based polymers *(Reife Adraham et. al, 1996)* and thin-film composite (TFC). The principal types of membrane modules used for wastewater treatments are tubular, hollow fiber, spiral wound plate and frame. The two most common types in waste water treatment are spiral wound and the hollow fiber types. Further, the membranes can be damaged by certain chemicals. There are five types of fouling, namely: Membrane fouling by the salts of calcium, silica, barium etc, Metal Oxide fouling occurs when metals such as iron and manganese oxidize in the system and precipitate out on the membrane as oxides or hydroxides, Plugging is caused by suspended particles in the feed water that are too large to pass through the membrane pores, Colloidal plugging is caused by the entrapment of colloidal particles on the membrane surface and Biological fouling is caused by growth of microorganisms on the membrane surface. *(Stephenson Ralph L. et.al, 1998)*

Table 2.2.3.1: General characteristics of membrane processes: *(MetCalf & Eddy, 2003)*

Membrane Processes	Membrane driving force	Typical separation mechanism	Operating structure (pore size)	Typical Operating range, µm	Permeate description	Typical constituents removed
MF	Hydrostatic pressure difference	Sieve	Macropores (>50 nm)	0.08-2.0	Water + dissolved solutes	TSS, turbidity, protozoan oocysts and cysts, some bacteria and viruses
UF	Hydrostatic pressure difference	Sieve	Mesopores (2-50 nm)	0.005-0.2	Water + small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
NF	Hydrostatic pressure difference	Sieve + solution / diffusion + exclusion	Micropores (<2 nm)	0.001-0.01	Water + very small molecules, ionic solutes	Small molecules, some hardness, viruses
RO	Hydrostatic pressure difference	Solution / diffusion + exclusion	Dense (<2nm)	0.0001-0.001	Water, very small molecules, ionic solutes	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions

2.2.3.1 Reverse Osmosis:

Removal of TDS from raw water, which is popularly called Desalination, when raw water happens to be either sea water or bore/tube well waters ingressed by high salinity in the coastal areas, is principally carried out through a technology called Reverse Osmosis. This technology, which has already been used worldwide over several decades, employs the principle of exerting pressure on saline water exceeding the osmotic pressure (typically 200-500 psig) in order to bring about separation of sea water into clean water or potable water containing negligible TDS and reject water which contains most of the TDS of the raw saline water. Such separation under high pressure is brought about through a semi permeable membrane, which is normally made of polyamide. *(Bhatt S.R. et.al, 2005)* This process can remove up to 99% of salts and the complete removal of most organic compounds. The concentrate will require further treatment prior to disposal as the level of impurities are up to six times that of the original effluent stream. *(Barclay Susan et al., 2000)* While R.O. technology, indigenously available from several reputed Indian firms dealing with purification of water and wastewater is well proven and well established for commercial and domestic uses in the country. It inherently suffers from a few techno-economic limitations which are given in Table 2.2. Notwithstanding the above constraints, the R.O. remains the most widely used technology for desalination of seawater or high TDS raw water to obtain clean, drinking water. The same cannot be said for the use of R.O. of wastewater. *(Bhatt S.R. et.al, 2005)*

2.2.3.2 Nanofiltration:

Nanofiltration is similar to reverse osmosis and hence often referred to as 'loose reverse osmosis'**.** *(Sule A.D. et al., 2003)* In Nanofiltration, the membrane acts as a molecular filter, retaining polyvalent ions and compounds with a molecular mass greater than 200. The concentrate contains almost all of the organic impurities and a large proportion of the polyvalent inorganic salts and requires further treatment prior to disposal. The permeate contains the monovalent ions (e.g. sodium and chloride ions). This method of effluent treatment has been found to be effective in the treatment of dye baths from reactive dyeing where sodium chloride is used as the electrolyte, as the permeate produced contains the salt and is virtually colorless, and therefore, suitable for reuse in the reactive dyeing process, saving both water and the cost of the salt. *(Barclay Susan et al., 2000)*

2.2.3.3 Ultrafiltration and Microfiltration:

Ultrafiltration and Microfiltration are pressure driven membrane processes that remove solute from solution based on particle or molecular size differential. The degree of separation achieved and the pressures associated with the two are different.

The separation mechanism characterizing ultrafiltration is based on membrane pore size and the difference in size between the solute and solvent. It involves the separation of macromolecules from solvents of lower molecular mass. It is used to separate all solutes and particles larger than 0.001 µm; however the low flux rate through the membrane limits its practical use to particles less than 0.1 µm in diameter.

Microfiltrations are the most numerous on the market, are the least expensive and are commonly made of polypropylene, acrylonitrile, nylon and polytetrafluoroethylene. It is used for faster filtration of larger suspended and colloidal particulates greater than 0.1 µm. *(Reife Adraham et. al, 1996)*

The advantages and disadvantages of these membrane technologies are given in Table 2.2. Several approaches have been proposed to implement membrane technology to the treatment of textile wastewater for reuse and recycle.

Marcucii M. et al,(2002) investigated the application of different membrane technologies, supported by clariflocculation and ozonation on pilot scale for the reuse of textile waste water. Two different textile effluents i.e. secondary effluent coming from a biological activated plant and that coming directly from several textile departments were tested. In the first case the pilot plant used sand filtration and microfiltration (MF) as pre-treatments for nanofiltration (NF). The MF and NF membranes tested were of the spiral wound type. The NF permeate was used in all production steps. In the second case, the chemical-physical pre-treatment and the advanced treatment of water have been experimented for different kind of wastewater. UF with flat membrane was placed downstream an ozonation treatment. The result showed that UF permeate was suitable to the reuse in the production processes.

Tak-Hyun Kim et al, (2004) studied nanofiltration membrane and reverse Osmosis membrane were tested to investigate the optimal operating conditions for COD, color, salt rejection and permeate flux and evaluate the feasibility of nanofiltration and reverse osmosis membrane combined process to improve the permeate flux and separation efficiencies in reactive dye manufacturing process wastewater. Effects of pressure, types of membrane and dye solution on flux and rejections were investigated. Experiments showed that the type of membrane had a significant effect on both permeate flux and rejection efficiencies. Variations in the applied pressure also affected the COD, color and salt rejections, which increased with increasing pressure. Finally, the nanofiltration and reverse osmosis membrane combined process was found to be suitable for the removal of residual organics, color, salt greater than 97 % and the water recycling from waste stream arising from reactive dye manufacturing process.

Xu Y. et al, (1999) characterized a nanofiltration membrane by its pure water permeability, mass transfer coefficient of NaCl, and the mean radius of the membrane pores. Dye filtration experiments were performed with both pure and industrial dye pulp solutions at a maximum pressure of 4 MPa. Fluxes of up to 220 Wm^2h and dye rejection of greater than 98.5% were achieved. The study concluded that the identification of transfer phenomena in dye solution during nanofiltration is complex.

A. Erswell et al, (1988) was one of the first to investigate the prospect of a charged membrane for the reuse of reactive dye liquor. Charged ultrafiltration (another name for nanofiltration) membrane was used in a closed-loop recycling system. Membrane performance was monitored in terms of dye and salt rejection and permeates flux, under varying conditions. They concluded that charged ultrafiltration is a technically feasible process for treatment of the dye bath at high water recoveries. Also, the electrolyte recovered in the permeate is valued an order of magnitude greater than that of fresh water, making the process more economically favorable. However, low fluxes were achieved, maximum flux of 30 L/m^2h, even when high pressure was used (up to 4 MPa).

2.2.4 ADVANCED OXIDATION PROCESSES:

Advanced oxidation (AO) is a generic term covering several chemical oxidative treatments which are capable of rupturing the stable, strong configuration of the complex compounds by virtue of their strongly penetrative oxidative power. Such oxidation of the organic compounds breaks the complex molecules into less harmful or harmless compounds thereby resulting in reduction in COD, colour, BOD & toxicity. The AO treatment is capable of handling toxic and colored effluent with COD as high as 70,000 mg/l, BOD as high as 10,000 mg/l and TDS as high as 50,000 mg/l.

Conventional oxidation treatment have found difficulty to oxidize dyestuffs and complex structure of organic compounds at low concentration or if they are especially refractory to the oxidants. To ease the stated problems advanced oxidation processes (AOPs) have been developed to generate and use hydroxyl free radicals by different techniques. Table 2.2.4.1 shows the Oxidizing potential for conventional oxidizing agents. Generation of HO• is commonly accelerated by combining O_3, H_2O_2, TiO_2, UV radiation, electron-beam irradiation and ultrasound. *(Al-Kdasi Adel et. al, 2004 & Zhou H. et al, 2002)*

Table 2.2.4.1: Oxidizing potential for conventional oxidizing agents
(Al-Kdasi Adel et. al, 2004)

Sr. No.	Oxidizing agent	Electrochemical oxidation potential (EOP), V	EOP relative to chorine
1	Fluorine	3.06	2.25
2	Hydroxyl radical	2.80	2.05
3	Oxygen (atomic)	2.42	1.78
4	Ozone	2.08	1.52
5	Hydrogen peroxide	1.78	1.30
6	Hypochlorite	1.49	1.10
7	Chlorine	1.36	1.00
8	Chlorine dioxide	1.27	0.93
9	Oxygen (molecular)	1.23	0.90

The various AO treatments used are given below:

2.2.4.1 Ozonation using ozone as oxidative species
2.2.4.2 Ozone – Hydrogen Peroxide (Peroxone)
2.2.4.3 Ozone – UV radiation
2.2.4.4 Hydrogen Peroxide – UV
2.2.4.5 Fenton's Process
2.2.4.6 Heterogenous Photocatalytic Processes such as TiO_2 – UV radiation.
2.2.4.7 Electro Chemical Oxidation
2.2.4.8 Electrochemically assisted TiO_2 Photocatalytic system.

2.2.4.1 Ozonation:

Ozone is a powerful oxidant agent for water and wastewater. It has a low solubility in water (570 mg/l). Once dissolved in water, ozone reacts with a great number of organic compounds in two different ways: by direct oxidation as molecular ozone or by indirect reaction through formation of secondary oxidants like hydroxyl radical. The conventional fine bubble contactor is the most widely ozone generator used because of the high ozone transfer efficiency (90%) and high performance. Ozone application can be generalized into two; a powerful disinfection and a strong oxidant to remove color and odor, eliminating trace toxic synthetic organic compounds and assisting in coagulation. *(Zhou H. et al, 2002)*

$$O_3 + H_2O \longrightarrow HO_3^+ + OH^-$$

$$HO_3^+ + OH^- \longrightarrow 2HO_2$$

$$O_3 + HO_2 \longrightarrow HO^{\cdot} + 2O_2$$

$$HO^{\cdot} + HO_2 \longrightarrow H_2O + O_2$$

Ozone decomposes rapidly in water by the above sequential reactions *(MetCalf & Eddy, 2003)* to form more reactive secondary oxidants the more reactive secondary oxidants, the more important being the hydroxyl radical. The formation of the hydroxyl radical is important in which $^{\cdot}OH$ is a more powerful and less selective oxidant than ozone. As a result, many compounds that are unreactive with ozone can be oxidized by $^{\cdot}OH$. Ozone reacts with hydroxide ions to form an ozonide ion that via cyclic mechanism to form a hydroxyl radical which breaks the non biodegradable organic molecules to bio-degradable ones. Results presented by a few researchers revealed that ozone decolourize all dyes, except non soluble disperse and vat dyes which react slowly and take longer time. Alkaline pH and high temperature are favorable for high TOC and COD removal. Incomplete oxidation of organic material takes place to smaller organic materials like acetic acid, ketones, and aldehydes etc which are toxic instead of carbon dioxide and water. *(Al-Kdasi Adel et. al 2004)*

Although *Tomiyasu et.al (1985)* proposed a different ozone degradation pathways that did not involve the formation of two intermediate HO_3 and HO_4; they, too, proposed the formation of an ozonide ion that react to form $^{\cdot}OH$. As the hydroxide ion is a good promoter of ozone decomposition, the half life of the ozone is very short under alkaline conditions. *(Muthukumar M. et al, 2001)*

According to *Mehmet F. S. et al (2002)*, ozonation (300 mg/dm3) increased the biodegradability index of textile wastewater by 1.6 times. He also documented that colour removal using ozonation from textile wastewater is depended on dye concentration & the rate of dye oxidation increased slightly with increasing solution pH *(Muthukumar M. et al, 2001)*

2.2.4.2 Ozone – Hydrogen Peroxide (Peroxone):

Ozone/H_2O_2 has been promoted as the most practical of the advanced oxidation processes because of its simplicity and ease of operation. Although H_2O_2 reacts very slowly with the ozone molecule in water, its conjugate base (HO_2^-) can rapidly react with molecular ozone, thereby initiating the formation of hydroxyl radicals in two steps of reactions as stated below:

$$H_2O_2 + H_2O \longrightarrow HO_2^- + H_3O^+$$

$$HO_2^- + O_3 \longrightarrow HO^\cdot + O_2^- + O_2$$

The higher the pH, the more H_2O_2 that will be dissociated into HO_2^- ions. As a result, the ozone decomposition rate will increase with increasing pH. After the hydroxyl radicals are formed, the propagation of radical chain reactions and the oxidation of contaminants follow the same mechanisms as those occurring in ozonation at the elevated pH condition. The inhibitory performance of H_2O_2/O_3 process on microbial growth depends on the H_2O_2 to O_3 mass ratio. This ratio ranged from 0.3 to 0.6 for different type of dye. *(Al-Kdasi Adel et al, 2004 & Zhou H. et al, 2002)*

Arslan I. et al. (1999) documented that H_2O_2/O_3 treatment of synthetic dyehouse is highly depended on the pH of the effluent. They have documented 74% ozone absorption at pH 11.5 and 10 mM H_2O_2 whereas at the same concentration of H_2O_2 and pH 2.5, ozone absorption was only 11%.

Tanja K. et al (2003) used H_2O_2/O_3 process to decolourize C. I. Reactive Blue 220 which was difficult to decolorize and C. I. Reactive Yellow 15 which was the easiest to decolourize and the results showed that the complete decolorisation of both the dyes was achieved in 90 minutes.

2.2.4.3 Ozone/UV radiation:

Conventional ozonation of organic compounds does not completely oxidize organics to CO_2 and H_2O in many cases. Remaining intermediate products in some solution after oxidation may be as toxic as or even more toxic than initial compound and UV radiation could complete the oxidation reaction by supplement the reaction with it.

The O_3–UV process makes use of UV photons to activate ozone molecules, thereby facilitating the formation of hydroxyl radicals. Because the maximum absorption of ozone molecules is at 253.7 nm, the light source commonly used is a medium-pressure mercury lamp wrapped in a quartz sleeve. It can generate the UV light at a wavelength of 200–280 nm. The reaction mechanism starts with activating the ozone molecule by UV to form oxygen radical [O (^{1}D)], which then combine with water to form ·OH radicals:

$$O_3 + h\nu \longrightarrow O_2 + O(^1D)$$

$$O(^1D) + H_2O \longrightarrow 2\,^{\cdot}OH$$

Later, *Peyton and Glaze (1988)* observed that the UV photolysis of ozone would also yield H_2O_2:

$$O(^1D) + H_2O \longrightarrow H_2O_2$$

In this process the UV light is absorbed by the dye and very limited amount of free radical can be produced to decompose dye. The hydrogen peroxide formed during this process will further photolysed to form hydroxyl radical as such the photolysis of hydrogen peroxide is a slow process. The generation of hydrogen peroxide in this way is much less efficient than electrochemical method. Therefore, O_3/UV method would be expected to be more expensive than O_3-H_2O_2 process. High concentrations of ozone are required to enhance the efficiency of this mechanism. Ozone itself will absorb UV light, competing with organic compound for UV energy and using ozone to produce H_2O_2 is very inefficient as compared to just adding H_2O_2. Therefore this process is less economical than O_3/H_2O_2 and H_2O_2/UV processes. *(Al-Kdasi Adel et al, 2004 & Zhou H. et al, 2002)*

Bes-Pia A. et al. (2003) documented that O_3/UV treatment of biologically treated textile wastewater reduced COD from 200-400 mg/L to 50 mg/L in 30 minutes, while, using ozone alone COD reduced to 286 mg/L in same duration.

2.2.4.4 Hydrogen Peroxide/UV:

Under UV irradiation, H_2O_2 will be photolyzed to form two hydroxyl radicals. The formed hydroxyl radicals then react with organic contaminants or undergo an H_2O_2 decomposition–formation cycle as shown below.

$$H_2O_2 + h\nu \longrightarrow 2\,^{\cdot}OH$$

$$H_2O_2 + {}^{\cdot}OH \longrightarrow H_2O + HO_2$$

$$HO_2 + HO_2 \longrightarrow H_2O_2 + O_2$$

This decomposition–formation cycle of H_2O_2 was used to explain a nearly constant concentration of H_2O_2 during treatment. It is interesting to note that the H_2O_2 will also act as a scavenger for hydroxyl radicals as shown earlier, in which case an excessive H_2O_2 dose might hinder the radical degradation. On the other hand, sufficient H_2O_2 is necessary so that it can absorb UV to accelerate the generation of hydroxyl radicals. A trade-off between them will result in an optimum H_2O_2 dose, which still needs to be verified experimentally.

Unlike ozone, H_2O_2 has an exceptionally low molar absorptivity within the wavelength range of 200–300 nm. Thus, it is particularly susceptible to the competing absorption of UV by organic compounds and suspended solids in water. If organic compounds after activation could more rapidly react with H_2O_2, such direct photooxidation would be expected to have a major contribution to the overall degradation in the H_2O_2–UV system. *(Al-Kdasi Adel et al, 2004 & Zhou H. et al, 2002)*

Galindo C. et.al, (1998) documented H_2O_2/UV process was more effective in an acid medium (pH ≈ 3-4) in term of discolouration, removal of textile dye by H_2O_2/UV increased as doses of effective hydrogen peroxide increased up to a “critical” value, temperature did not have a significant effect on discolouration and finally documented the inverse relationship between the initial dye concentration and the efficiency of UV/H_2O_2 treatment. An increase in the dye concentration induces a rise of the internal optical density. Dyes react; consequently, the solution becomes more and more impermeable to UV radiation. Therefore, the rate of photolysis of hydrogen peroxide directly depends on the incident intensity. As a consequence, when initial dye concentration rises, the production of hydroxyl radicals decreases.

Shen Y. S. et. al, (2002) investigated relationship between UV light intensity and dye decomposition in UV/H_2O_2 process. The decomposition rate of dye was found to increase with increasing UV light intensity. They documented that more than 90% of the dye was decomposed at 82 Wm^{-2}. But for the UV light intensity higher than 102 Wm^{-2}, further increase of UV energy only slightly improved the decomposition efficiency of dye indicating the photons provided was excessive.

2.2.4.5 Fenton’s process:

It is a powerful oxidant. In presence of Fe^{2+}, H_2O_2 decomposes to form the hydroxyl radical, $^{\cdot}OH$.

$$Fe^{2+} + H_2O_2 \longrightarrow Fe^{3+} + OH^{-} + {}^{\cdot}OH$$

The $^{\cdot}OH$ radical can react with an organic compound C, or it can be scavenged by $[Fe^{2+}]$ or H_2O_2.

$$C + {}^{\cdot}OH \longrightarrow \text{Products}$$
$$Fe^{2+} + {}^{\cdot}OH \longleftrightarrow [-OH] + [Fe^{3+}]$$
$$H_2O_2 + {}^{\cdot}OH \longrightarrow H_2O + HO_2$$

It has been proposed the regeneration of Fe^{2+} occurs via series of steps

$$[Fe^{3+}] + H_2O_2 \longrightarrow [FeOOH^{+2}] + [H^+]$$
$$FeOOH^{+2} \longrightarrow HO_2^{\cdot} + Fe^{2+}$$
$$Fe^{3+} + HO_2^{\cdot} \longrightarrow Fe^{2+} + O_2 + H^+$$

The addition of Fe^{2+} will tend to be more effective in promoting the degradation of organic compound than the addition of Fe^{3+}. However, the presence of Fe^{3+} may enhance the production of hydroxyl radicals, particularly if Fe^{2+} is also present. Fenton's reagent is known to oxidize organic compounds. The reaction rate has been shown to increase with increasing pH. However at pH greater than 4 to 5, ferric iron precipitates and consequently the reaction slow down. The decrease in the reaction rate is presumed to be due in part; to the fact that iron atoms buried in the precipitate are not accessible to H_2O_2. *(Miyoshi Yasuhiko, 2000, Perkowski Jan et. al, 2002 & Thakur B. D. et. al. 1994)*

Perkowski Jan et. al (2002) investigated the applicability of fenton reagent in the treatment of textile dyeing wastewater. The wastewater from cotton, polyacrylonitrile and polyester were taken and optimum conditions and efficiency of the method were determined using 2 types of iron (II) salts viz. $FeSO_4$ and $FeCl_2$, 1 % calcium oxide solution was used to adjust the pH of wastewater. The influence of hydrogen peroxide alone for pollutant decomposition at different concentrations was investigated. It was found that the tested dyeing wastewater revealed high susceptibility to treatment using a combined action of ferrous salts and hydrogen peroxide. The main parameters of wastewater, i.e. the colour threshold number, chemical oxygen demand and anionic surfactants were reduced by greater percent. The highest COD reduction was achieved for the most concentrated wastewater from polyacrylonitrile dyeing (75-80%) and from cotton dyeing (78-80%), while the lowest was in the case of the least concentrated wastewater from polyester dyeing (60-73%). The complete colour reduction was achieved. Additionally, remarkable increases in suspceptibility to biodegradation were also investigated which is of special importance for further treatment of wastewater by biological methods.

2.2.4.6 Heterogeneous photocatalytic processes:

Heterogeneous photocatalytic processes use certain metal oxides that can readily generate hydroxyl radicals on the surface of particles when absorbing UV light. The anatase form of TiO_2 has low band-gap energy (approximately 3.2 eV), which is almost equivalent to 400 nm wavelength of light. Hence, the most important heterogeneous photocatalytic processes include TiO_2–UV and TiO_2–H_2O_2–UV. The principal reaction mechanisms include: *(Zhou H. et al, 2002)*

$$TiO_2 + h\gamma \longrightarrow h_{vb}^{+} + e_{cb}^{-}$$

$$O_2 + e_{cb}^{-} \longrightarrow O_2^{\cdot -}$$

$$h_{vb}^{+} + H_2O \longrightarrow {}^{\cdot}OH + H^{+}$$

The process is initiated by the band-gap excitation of TiO_2 under UV illumination (l, 385 nm). Excited by energetic photons, electrons are transferred from the valence band to the conduction band of TiO_2, leading to the generation of electron/hole pairs. The electrons and holes diffuse to the surface of TiO_2 and react with the adsorbed O_2, water and surface hydroxide group, respectively, leading to the production of $O_2^{\cdot}$ and $^{\cdot}OH$. Generally it is believed that $^{\cdot}OH$ is mainly responsible for the organic compounds degradation.

However, O_2 exists in the suspension at a low concentration due to its low solubility in water; quite a number of photogenerated electrons would recombine with photogenerated holes, causing a decrease in availability of photogenerated holes. The rapid unfavorable charge carrier recombination reaction in TiO_2 has become a drawback for TiO_2 photocatalysis in wastewater treatment. On the other hand, although $^{\cdot}OH$ could be generated from $O_2^{\cdot}$, the process is not a direct one, resulting in low quantum yields of $^{\cdot}OH$ from photogenerated electrons. All these factors reduce the utilization ratio of electron/hole pairs and the photocatalytic efficiency of TiO_2 under UV illumination. *(Chen Junshui et.al, 2004)*

Genc Nevim (2004) investigated the photocatalytic oxidation of a reactive azo dye and determined the improvement in the biodegradability when photocatalytic oxidation was used as a pretreatment step prior to biological treatment. The results obtained from the experiments by adding H_2O_2/TiO_2 showed that the highest decolourisation rate is provided by the combination of (UV+TiO_2+ H_2O_2). The decolourisation efficiencies were 18 %, 22 %, 34 % and 52 % in the runs UV, UV+ H_2O_2, UV+ TiO_2, and (UV+TiO_2+ H_2O_2) after approximately 100 min illumination periods, respectively. The decolourisation rate was increased significantly by initially increasing the concentration of TiO_2, in the dye solution;

how it was decreased due to reduced light transmission when the concentration of TiO_2 was in excess. The results of the obtained uptake rate measurements in biological activated sludge have shown that the photocatalytically treated dye was easier to degrade than untreated dye. The ability of the activated sludge to degrade glucose was not inhibited in the presence of photocatalytically treated and untreated dye. Also the biodegradability of photocatalytically treated and untreated dye was investigated via the biological oxygen demand (BOD) test. The results indicated that further degradation of the treated dye may take place by activated sludge in aerobic conditions.

2.2.4.7 Electrochemical Oxidation:

In electrochemical treatments, oxidation is achieved by mean of electrodes, where a determined difference of potential is applied, dipped in the effluent to treat. Efficiency of the method is a function of several parameters difference of potential, nature of the electrodes, pH. On this principle, several different processes have been developed as cathodic and anodic processes, direct and indirect electrochemical oxidation, and electrochemical *in situ* synthesis of oxidising agents, electrodialysis, electromembrane processes, and electrochemical ion exchange. *(Gianluca Ciardelli et.al, 2001)*

It is presented as an effective, selective, economical and clean alternative for dealing with wastewater bearing high loads of organic compounds, especially some bio-refractory organic pollutants. Such treatment produces total degradation of compounds to carbon dioxide and water or at least a considerable decrease in toxicity. A direct anodic process or an indirect anodic oxidation via the production of oxidants such as hydroxyl radicals, ozone, etc, usually destroys the organic and toxic pollutants present in wastewater such as dyes and phenols. Titanium electrodes covered with a very thin layer of electrodeposited noble metals have recently been used for electro-oxidation. Electrodes can also be coated with ruthenium, rhodium lead and stannum oxide. By means of electrochemical oxidation, pollutants in wastewater can be completely mineralized by electrolysis using high oxygen over-voltage anodes such as PbO_2 and boron-doped diamond. *(Chen Xuejun et. al, 2005)*

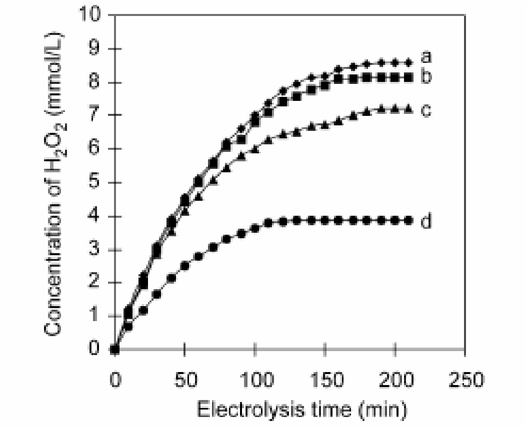


Figure 2.2.4.7.1: H_2O_2 accumulation in the reactor, (a) EC; (b) EC/UV; (c) EC/TiO_2; (d) EC/UV/TiO_2.
(Chen Junshui et.al, 2004)

Figure 2.2.4.7.1 shows the gradually growing concentration of H_2O_2 in different combination patterns among electrochemical unit (EC), UV and TiO_2. The steady concentration of H_2O_2 in EC, EC/UV, EC/TiO2 and EC/TiO2/UV system is 8.60, 8.15, 7.21 and 3.89 mmol/l, respectively. *(Chen Junshui et.al, 2004)* Though the concentration of H_2O_2 is maximum in EC, the decomposition of H_2O_2 is not enhanced leading to low quantum yield of hydroxyl radical generation.

Chen Xuejun et. al (2005) studied combined treatment of electrochemical oxidation and membrane filtration of textile waste water for reuse and found that these sequential process is feasible. Electrochemical oxidation has a high removal (89.8%) of COD of wastewater while the membrane filter can almost totally remove the total suspended solids (TSS) nearly 100 % and turbidity (98.3%). The treated water was able to be reused in the textile dyehouse factory.

2.2.4.8 Electrochemically assisted TiO_2 Photocatalytic system:

Over the past several decades, studies have revealed that nanosized TiO_2 particles can photocatalytically oxidize many organic wastes into inorganic substances (such as CO_2, H_2O, etc.) under moderate conditions, without any serious secondary pollution. However, not only the photo efficiency or activity but also the photo response of TiO_2 is not suitable for direct application in environmental optimization. One of the main factors responsible for these disadvantages is the high recombination of photogenerated electron/hole pairs. In order to enhance the photocatalytic process, much meaningful work has been carried out. Electro assisted photocatalytic process, which applied a positive voltage on the TiO_2 layer electrode, and modifications on TiO_2 by means of noble metal deposition, metal ions or oxides doping and etc. have already been proved promising methods.

In this system H_2O_2 is introduced into TiO_2 photocatalytic cell through an environmentally desirable way (electrolysis) to improve the photocatalytic process. The potential benefits of this system are:

(1) H_2O_2, one product of the electrochemical process, traps photogenerated electrons at a faster rate than O_2 for its higher oxidative potential, leading to the direct production of hydroxyl radicals (${}^{\cdot}OH$) and higher utilization ratio of photogenerated holes for redox reactions, so the photocatalytic process is greatly promoted.

(2) The method requires no more reagents added, so the cost of the set-up and operation does not rise apparently.

(3) If residual H_2O_2 left in the solution, it would decompose by itself to H_2O and O_2, without secondary pollution.

$$O_2 + 2H^+ + 2e^- \longrightarrow H_2O_2$$

$$H_2O \longrightarrow \tfrac{1}{2} O_2 + 2H^+ + 2e^-$$

$$H_2O_2 + H^+ + e_{cb}^- \longrightarrow {}^{\cdot}OH + H_2O$$

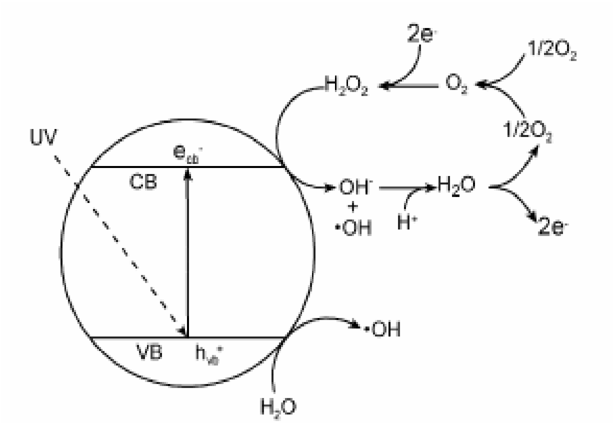


Figure 2.2.4.8.1: Schematic presentation and reaction mechanism of the production of hydroxyl radicals from electrochemically assisted TiO_2 photocatalytic system. *(Chen Junshui et.al, 2004)*

In this system, the decomposition of H_2O_2 produced from electrolysis is enhanced by the photo excited TiO_2 particles for the reaction between H_2O_2 and photogenerated holes as shown in figure 2.2.4.8.1.

H_2O_2 traps the photogenerated electrons faster and easier for its higher oxidation potential (E^o = 1.77 V) than O_2 (E^o = 1.23 V), which can promote the quantum yields of $^{\cdot}OH$ based on two reasons. (1) More electrons are trapped by H_2O_2, reserving more holes to react with adsorbed water surface hydroxyl group, producing $^{\cdot}OH$. (2) The reaction between H_2O_2 and photogenerated electrons can produce $^{\cdot}OH$ directly. *(Chen Junshui et.al, 2004)*

Chen Junshui et.al (2004) studied an electrochemically assisted TiO_2 photocatalytic system. The system was set-up by combining a TiO_2 photocatalytic cell with a three-electrode potentiostatic unit. The composite system revealed high photocatalytic activity towards organic wastes mineralization. After continuous treatment for 0.5 h, the maximum absorption of rhodamine 6G (R-6G) was reduced by more than 90%; chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) of textile dye wastewater (TDW) were decreased by 93.9 and 88.7%, respectively. The biodegradability of TDW was also improved because the COD/BOD_5 ratio decreased from 2.1 to 1.2. All these results indicated that the composite system could be used for effective organic wastes mineralization or as a feasible detoxification and color removal pretreatment stage for biological post treatment.

2.2.5 DEMINERALIZATION:

This technology employs anion and cation resins packed in columns through which high TDS water is pumped resulting in so-called 'Demineralization' of water. That is, the TDS are removed by the ion exchange process though the resins. Once the resins are saturated, they need to be periodically regenerated to obtain the same efficiency of the TDS removal. This technology is normally used for industrial purposes in general and, in particular, for TDS removal from boiler-feed water for high pressure steam boilers. Clogging of the resin beds by precipitates / colloids present in raw water, channeling, loss of resins, limited resin life are some of the low lights of this technology which is relatively better than R.O. in terms of capital and operating cost and electric power consumption. *(Bhatt S.R. et.al, 2005)*

2.2.6 MULTIPLE EFFECT EVAPORATION:

This technology employs the principle of evaporation of water from the saline or high TDS raw water by steam in a series of evaporators in which thermal energy of evaporated steam in the evaporators is reused through condensation process in the subsequent evaporators.

The Multiple-effect evaporators are relatively efficient, where as single effect evaporators are relatively inefficient. Each component unit of a multiple-effect evaporator is maintained in sequence at slightly lower pressure and temperature in order to permit the steam produced in one effect to become the source of heat in the next. When evaporated water vapor is condensed in the condenser, it produces 'Distilled Water'; which is almost free of TDS. This technology generates highly-concentrated residual water after evaporation which is an unwanted by-product that needs to be properly disposed off.

Since the 'prime-mover' in this technology is steam, its abundant availability at a relatively low cost is almost indispensable for commercial scale operation. In other words, it is economically viable, if the fuel used for generation of steam is cheap or if steam is available as a cheap by-product of the manufacturing operations. It is also unsuitable for low capacity operations. Severe corrosion of the plant, high capital cost, and frequent maintenance problems because of increasing viscosity of water as it gets more and more concentrated in the successive stages of evaporation, leakages due to corrosion and in high pressure, high vacuum parts of the plant are some of the other problems associated with this technology. It is widely employed in the Middle Eastern countries where fuel is cheap and natural drinking water resources are almost non-existent. *(Bhatt S.R. et.al, 2005)*

2.2.7 SOLAR DISTILLATION:

This technology also employs thermal energy for distilling water from raw water like the previous evaporation technology but of different kind namely 'Solar Energy' as a thermal prime mover. It usually employs the well-known heat transfer principles of Kirchoff's law, Wein's Displacement law and 'Green House Effect' in appropriate synergy so that the solar energy absorbed by the black body is transferred to pool of water in which the black surface is submerged. The solar energy so absorbed on the black body distills water at temperatures much lower than its normal boiling temperature of 100 ^{o} C to generate pure water vapor in the confined space covered by glass or UV-resistant, transparent plastic sheets. Vapor condenses on the glass or plastic surface to generate pure, potable low/no TDS distillate leaving behind thick, concentrated residual water on the black surface. Availability of adequate solar energy throughout the year, as in most part of India, is of principal importance in this low cost simple, grass-root technology. Similarly availability of large floor areas for construction of the solar distillers is yet another critical requirement. With abundant supply of the solar energy almost throughout the year and availability of large spaces in the rural across, India is ideally suited to this technology, particularly for the rural areas. It hardly needs any power or any other utilities for its continuous operation. Its very low operating cost, simplicity and near maintenance free operation makes it attractive for small as well as large-scale operation.

Low overall efficiency, coating of the black surfaces with precipitated solids resulting in gradual decline in output, very large floor area requirements, cracking of covering of glass with dust are some of the deficiencies of the technology. Besides, disposal of the concentrated sludge as a residue after the distillation is yet another problem encountered in this otherwise attractive technology. *(Bhatt S.R. et.al, 2005)*

Table 2.2.1: Summary of Existing Treatment Technologies from Water Reuse View Point:

Treatment	Advantages & Capabilities	Disadvantages & Limitations
1. Coagulation / Flocculation (alum, lime, iron, polyelectrolyte) *(Barclay Susan et al., 2000)*	1. Simple Equipment 2. Relatively rapid color removal 3. Significant reduction in COD	1. Large Volumes of sludge generated 2. Continual addition of chemicals 3. High running costs 4. Carry over of polyelectrolyte - affect sewage works 5. Product generally unsuitable for reuse 6. Precise pH control necessary
2. Adsorption (Activated Carbon, Silica, Charcoal, Peat, Synthetic Polymer etc.) *(Barclay Susan et al., 2000 & Murugesan P.T.,2005)*	1. Good color removal 2. Simple technology 3. Low operating costs for some adsorbents 4. High degree of organic matter removal 5. Less Space requirement	1. High capital costs 2. Slow process 3. Regeneration or disposal costs 4. Not suitable for all dye types 5. High carbon dosage required
3. Reverse Osmosis *(Barclay Susan et al., 2000 & Bhatt S.R. et.al, 2005)*	1. 99% of salts removal 2. Complete removal of most organic compounds 3. Removes impurities of molecular mass 0.0001-0.001µm 4. Removes very small molecules, color, hardness, sulfates, nitrate, sodium and other ions	1. High electric power consumption 2. High capital and operating cost 3. Pretreatment required before R.O. 4. Limited life of the R.O. membrane 5. Frequent maintenance problems
4. Nanofiltration *(Sule A.D. et al., 2003)*	1. Clean and efficient operation 2. Less space required 3. Multiple recycling is possible 5. Operational costs are low 6. Rapid and semi-continuous operation	1. High Capital Costs 2. Membranes need special care 3. Minimum salt recovery (around 75 %)
5. Microfiltration and Ultrafiltration *(MetCalf & Eddy, 2003)*	1. Smaller space requirements 2. Reduced labor requirements 3. Can be automated easily 4. Removes protozoan cysts, oocysts, and helminth ova 5. Remove limited amounts of bacteria and viruses	1. High energy consumption 2. Pretreatment required 3. Residuals handling and disposal of concentrate required 4. Replacement required every 3 to 5 years 5. Scale formation 6. Flux rate gradually declines over time 7. Recovery rates < 100 percent

Treatment	Advantages & Capabilities	Disadvantages & Limitations
6. Ozone *(Barclay Susan et al., 2000, Bes-Pia A., 2003, Gianluca Ciardelli et.al, 2001, Mehmet F.S. et al, 2002 & Murugesan P.T., 2005)*	1. Powerful Oxidation Potential 2. Hydrolyses & oxidizes complicated organic chain in very short time. 3. Generate neither sludge nor toxic products. 4. Over all TDS developed is less 5. Good Color Removal > 95% 6. COD removed 60-70% 7. Can Handle Large Volume	1. High Capital Costs 2. High Operating Cost (Rs. 10/m^3) 3. Not effective in removing color from all dye types.
7. Ozone – Hydrogen Peroxide (Peroxone) *(Barclay Susan et al., 2000 & Tanja K. et.al, 2003)*	1. Waters with poor UV transmission may be treated. 2. Special reactors designed for UV illumination are not required.	1. VOC will be stripped from the ozone contactor. 2. Production of ozone can be expensive and inefficient processes. 3. Gaseous ozone present in the off-gas of ozone contactor must be removed 4. Maintaining and determining the proper O_3/H_2O_2 dosages may be difficult. 5. Low pH is detrimental to the process.
8. Ozone/UV radiation *(Barclay Susan et al., 2000 & Wiley John et al., 2005)*	1. No need to maintain O_3/H_2O_2 dosage 2. Residual oxidant will degrade rapidly (typically half life of O_3 is 7 min.) 3. Ozone adsorbs more UV light than hydrogen peroxide (~ 200 times more at 254 nm)	1. O_3 and UV light required to produce H_2O_2 2. Using O_3 to produce H_2O_2 is very inefficient as compared to just adding H_2O_2. 3. Special reactors designed for UV illumination are required. 4. Ozone in the off-gas must be removed. 5. More expensive than O_3/H_2O_2.
9. H_2O_2 – UV *(Barclay Susan et al., 2000 & Wiley John et al., 2005)*	1. H_2O_2 – UV is quite stable & stored on-site for long periods prior to use 2. Good color removal 3. Powerful oxidant 4. Effective at destroying organic compounds	1. Poor UV absorption characteristics 2. Special reactors designed for UV illumination are required. 3. Residual H_2O_2 must be addressed. 4. High capital cost 5. Unknown oxidation products are formed.
10. Fenton's Process *(Barclay Susan et al., 2000 & Wiley John et al., 2005)*	1. Simple operation 2. Decompose bio-persistent colored substances. 3. Reaction proceeds rapidly 4. Rapid decolourisation 5. Sludge enhances sewage works operation 6. Removes odor ingredients and inorganic COD.	1. High running costs 2. Iron catalyst generates hydroxide slurry. 3. Process requires low pH.

Treatments	Advantages & Capabilities	Disadvantages & Limitations
11.Heterogeneous Photocatalytic process *(Chen Junshui et.al., 2004, Wiley John et al., 2005 & Zhou H. et al., 2002)*	1. Good color removal 2. Powerful oxidant 3. Effective at destroying organic compounds	1. Recombination of photogenerated electron /holes takes place. 2. Catalyst fouling 3. When used as slurry, the catalyst must be recovered.
12. Electrochemically assisted TiO_2 Photocatalytic system *(Chen Junshui et.al., 2004)*	1. The H_2O_2 decomposion is enhanced by photocatalytic activity 2. Recombination of electron/hole pair does not take place. 3. Cost effective 4. No secondary pollution	1. TDS removal is partial
13. Demineralization *(Bhatt S.R. et.al, 2005)*	1. Relatively better than R.O. in terms of a) Capital cost b) Operating cost c) Electric power consumption.	1. Clogging of the resin beds 2. Channeling 3. Loss of resins 4. Limited resin life
14. Multiple Effect Evaporation *(Bhatt S.R. et.al, 2005)*	1. Relatively efficient 2. Economically viable - if fuel used for generation of steam is cheap or if steam is available as a cheap by-product of the manufacturing operations.	1. Severe corrosion 2. High capital cost 3. Frequent maintenance problems 4. Leakages due to corrosion 5. Unsuitable for low capacity operations 6. Generates highly concentrated residual water after evaporation
15. Solar Distillation *(Bhatt S.R. et.al, 2005)*	1. Very low operating cost 2. Simple operation 3. maintenance free operation 5. No other utilities required 4. No power required	1. Low overall efficiency 2. Very large floor area requirements 3. Cracking of covering of glass with dust 4. Disposal of the concentrated sludge required

2.3 ZERO DISCHARGE:

2.3.1 History:

The Federal Water Pollution Control Act Amendments of 1972 were enacted with the passage of P.L. 92-500. P.L. 92-500 was unique in its time and established a comprehensive federal program to address water pollution control. From the outset, it was clear that P.L. 92-500 was changing forever the historic relationship between the states and the federal government with regards to water pollution. No longer were the states to set separate standards; with the passage of P.L. 92-500, the federal government, through the Environmental Protection Agency, was the primary entity responsible for water quality in the United States.

In 1977, Congress passed the Clean Water Act Amendments that made some mid-course corrections in the implementation of P.L. 92-500. Since that time, the Act has been referred to as the Clean Water Act.

It is the epitome of wastewater treatment – no discharge of pollutants in wastewater. It was included as an original goal of P.L. 92-500 and is still found in Section 101(a) of the Clean Water Act, the objective of which was to restore and maintain the chemical, physical and biological integrity of the Nation's waters and stated that

(1) *It is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985.*

The attainment of zero discharge by 1985 remains a stated goal as such 1985 has come and gone. Zero discharge has been attacked as an idealistic goal of another era, yet it continues to be revisited. Indeed, with the United States, a major project has been launched by certain environmental groups in attempt to have the industry and the agencies revisit the concept of zero discharge. *(Stephenson Ralph L. et.al, 1998)*

2.3.2 Definition:

It is a goal, in the preamble to the Clean Water Act (CWA), of zero pollutants in water discharges. *(www.nalms.org/glossary/lkword_z.htm)*

Zero discharge means that no wastes are discharged, that everything is recycled and no pollutants are being discharged into the environment. Another term for this is Totally Effluent Free (TEF). *(www.paperhall.org/info/glossary.html & http://www.cet.nau.edu/Projects/WDP /resources/Definitions.htm#references)*

Zero discharge also refers to halting all inputs from all human sources and pathways to prevent any opportunity for persistent toxic substances to enter the environment from human activity. To completely prevent such releases, the manufacture, use, transport, and disposal of these substances would have to stop. *(www.great-lakes.net/humanhealth/about /words_z.html)*

2.3.3 Description: *(Bhatt S. R. et. al, 2006)*

Evolution of treated wastewater discharge standards is a complex process requiring thorough expertise. Zero Discharge is one such standard/ requirement of pollution control authorities of India. In our country Bureau of Indian Standards – BIS has evolved the standards for:

1. Industrial effluents
2. Sewage effluents
3. Stream standards

The approved BIS standards for industrial effluents have been derived on the following parameters:

- ⇒ Information made available from agencies abroad;
- ⇒ Techno-economic feasibility of treatment techniques;
- ⇒ Environment Protection
- ⇒ The likely damage to receiving media; and
- ⇒ The usage of the receiving waters

The BIS admits the possibility of variance in the tolerance limits for industrial effluents. The factors responsible for such variation are:

- ⇒ The capacity of the plant;

- ⇒ The technology adopted;
- ⇒ Pollution in the receiving system from other industries;
- ⇒ Receiving capacity of the recipient system;
- ⇒ Nature of the receiving system, whether land, river, estuaries, coastal water etc., and
- ⇒ Usage of the recipient system.

Looking to the above mentioned factors, if the nature of receiving system is a land locked area and there is no discharge facility like land, river, estuaries, coastal water etc then regulatory body ask to comply with the requirements of ‘Zero Discharge’ i.e. No discharge outside the industrial premises, no discharge on land for percolation which could lead to pollution of underground strata. This means one has to recycle the treated wastewater as many times as possible.

Compliance of ‘Zero Discharge’ requirement, in which, the industry is not supposed to discharge any effluent outside its premises is really a very tough requirement from the techno-economic viewpoint. Considering that the textile process houses and composite textile mills use large quantity of water for their wet processing requirements of fabric, yarn, garments, hosiery etc for Desizing, Scouring, Bleaching, Mercerizing, Dyeing, Printing and Finishing operations, they generate large quantity of effluents ranging from 5000 liters/hr to 300,000 liters/hr depending upon the quantum of the goods processed. The discharge from a typical industry is shown in figure 2.3.3.1 whereas material and energy balance of industry is shown in figure 2.3.3.2.

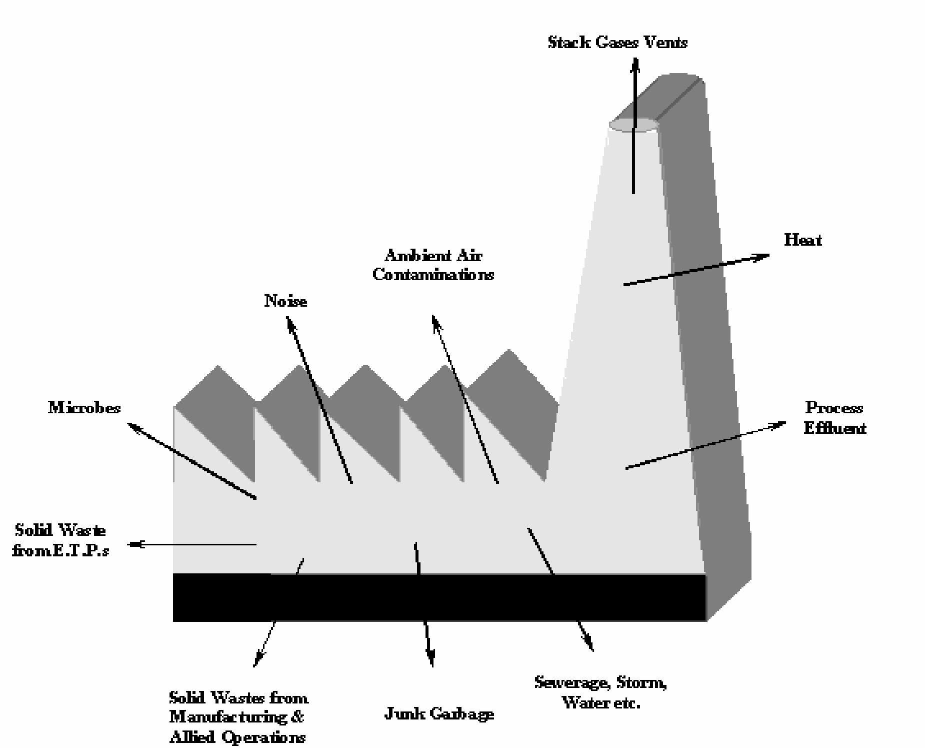
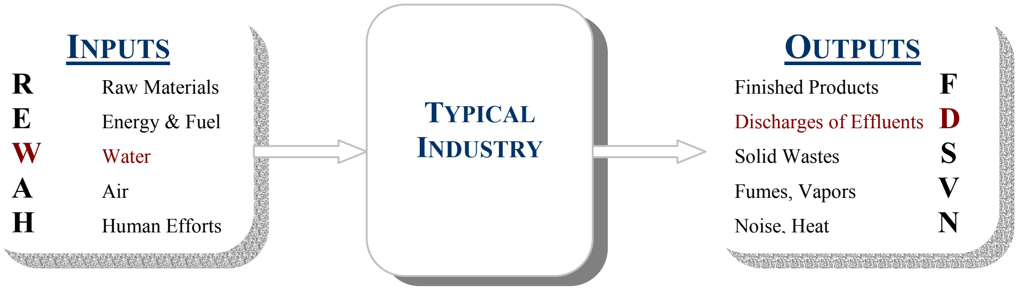


Fig. 2.3.3.1: Discharges from a Typical Industry *(Bhatt S.R. et.al. 2001 & 2006)*



Here, $R + E + W + A + H = F + D + S + V + N + B$

If $D = 0$, then $W = 0$. But, $W \neq 0$; $D \neq 0$

Fig. 2.3.3.2: Material and Energy Balance of Typical Industry *(Bhatt S.R. et.al. 2001 & 2006)*

Sustained, genuine and techno-economically viable 'Zero Discharge' compliance for such textile processing units is extremely difficult, if they have to adopt any of the conventional treatment for elimination of wastewater such as; Reverse Osmosis (R.O.), Incineration, Multiple Effect Evaporation, Solar Evaporation and so on. These technologies are intrinsically and techno-economically unsuitable for sustained, long-term compliance of 'Zero Discharge' at industrial scale. Beside, they are far too expensive and are prone to frequent maintenance problems and resultant degradation of their efficiency.

2.3.4 AVENUE TO ZERO DISCHARGE *(Bhatt S.R. et.al. 2001)*

1. Minimize water consumption
2. Minimize spillage wastages
3. Process change
4. Augmenting water quality
5. Substitution of water by recoverable solvent.
6. Solar Evaporation/Distillation
7. Thermal Evaporation : Multiple Effect Evaporation
8. Reverse Osmosis – Ultrafiltration, Nanofiltration
9. Resin Treatment – Demineralization
10. Partial or Total recycle/reuse in manufacturing
11. Irrigation, Plantation
12. Recharging of Underground water sources.
13. Adsorption : Silica gel

2.3.5 ZERO DISCHARGE SYSTEMS:

From the definition of Zero Discharge, it is clear that it means Zero addition of pollutants to an existing water source i.e. no discharge of wastewater to the receiving bodies and everything is recycled and reused. Few researches have been done in the field of Zero Discharge, some of which are as under.

Manickapurampudur Common Effluent Treatment Plant Private Limited (MPCETP), Tirupur have modernized and upgraded its old effluent treatment plant due to the order given by the Tamil Nadu Pollution Control Board (TNPCB) to implement zero discharge system. The MPCETP have implemented the zero discharge system for efficient reuse and recycle of water and salt. The present scheme of achieving zero discharge at the MPCETP is as follows:

1. Reverse Osmosis (R.O) system for treating 2000 m /day of textile dye effluent for recovery of pure water for reuse in textile wet processing.
2. NanoFiltration (N.F) assembly for salt recovery from R.O. reject and its reuse in dyeing/other industries.
3. Multiple Effect Evaporators for recovery of reusable water from 200 m /day of reject from nanofiltration assembly.
4. Solar pond for evaporation of mother liquor from Multiple Effect Evaporator, and separation of salts.
5. Windmills (6 x 250 kWh = 1500 kWh) for power generation to cater to the needs of the reverse osmosis, nanofiltration, and other electrical appliances of the Common Effluent Treatment Plant. Since reverse osmosis system is power intensive, implementation of windmill makes this project financially feasible. *(http://epicin.org/documents/zero%20 discharge.pdf)*

Lee H.H.W. et. al. (2001) have investigated a possible zero discharge system by integrating chemical and biological treatment systems for textile industry wastewater. The textile wastewater was first characterized in terms of COD, BOD_5, salinity and color and then treated by means of integrated chemical and biological treatments. The results showed that the wastewater was treated upto the reusable textile water quality standards. An economic analysis was conducted on the proposed integrated system which showed that the integrated system was economically more attractive than any of the single treatment technologies for achieving zero discharge.

The typical possible zero discharge systems in textile industries are given in Fig. 2.3.5.1, 2.3.5.2 & 2.3.5.3 (a&b).

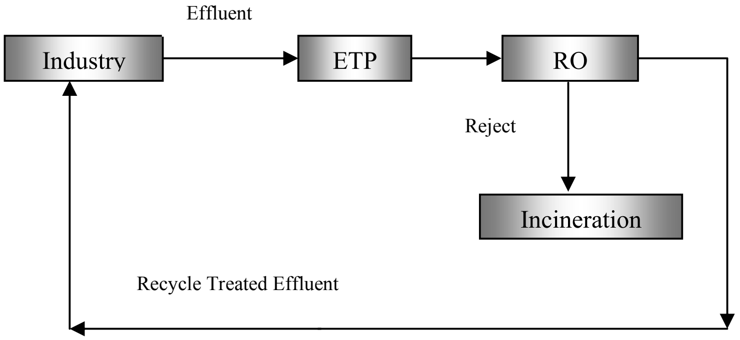


Fig. 2.3.5.1: A Typical 'Zero Discharge' System in Industry *(Bhatt S.R. et.al. 2001 & 2006)*

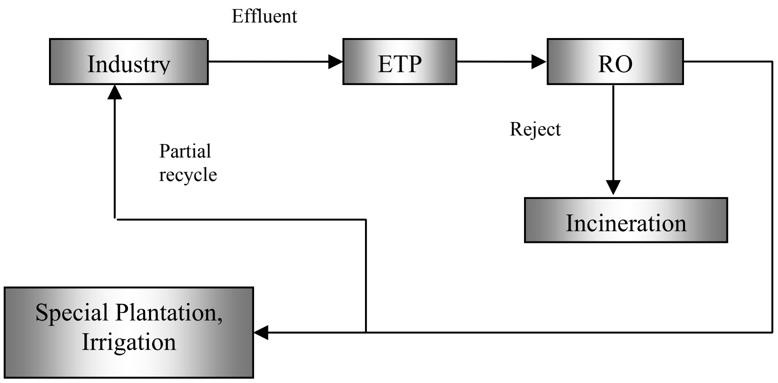


Fig. 2.3.5.2: 'Zero Discharge System involving partial recycling *(Bhatt S.R. et.al. 2001 & 2006)*

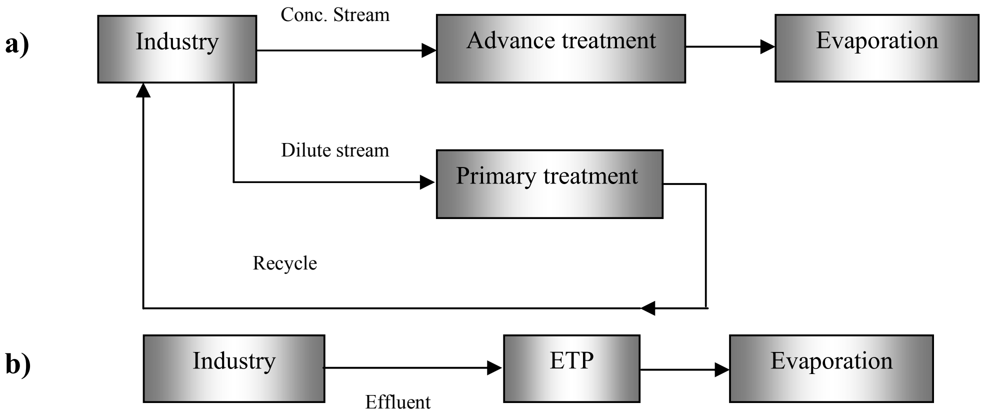


Fig. 2.3.5.3 (a&b): 'Zero Discharge System based on evaporation *(Bhatt S.R. et.al. 2001 & 2006)*

2.3.6 PROBLEMS AND PROSPECTS OF ZERO DISCHARGE IN INDUSTRIES: *(Bhatt S.R. et.al. 2001)*

1. TDS Build up
2. Bio fouling
3. Hardness Build up
4. Prohibitive costs
5. Spurious Recycle
6. Excessive power
7. Maintenance problems
8. Severe corrosion
9. Large space requirements
10. Poor raw water quality

2.3.7 BENEFITS OF ZERO DISCHARGE: *(http://epicin.org/documents/zero%20discharge.pdf)*

1. Natural resource such as water is conserved by reuse and recycles saving the cost of freshwater.
2. Various types of salts and other chemicals are recycled which gives economic benefit to the industry,
3. Reduces the dependency for fresh water.
4. Reduces the damages to the environment and economic loss.
5. Reduces the production of hazardous wastes.
6. Promotes in ground water recharge.

2.3.8 OPERATING COSTS TO ZERO DISCHARGE: *(Bhatt S.R. et.al. 2001 & 2006)*

The operating costs of .various treatment technologies to Zero Discharge in Rs. / KL are given in Table 2.3.8.1.

Table 2.3.8.1: Operating Costs of various treatment technologies *(Bhatt S.R. et.al. 2001 & 2006)*

Sr. No.	Treatments	Rs./KL
1	Reverse Osmosis	12-20
2	Thermal Evaporation	150-500
3	Incineration	500-1800
4	Solar Evaporation	1-5
5	Resin Treatment	20-50
6	Primary and Secondary Treatment	3-20
7	Activated Carbon Treatment	100-200
8	Advanced Filtration	5-12

2.4 ATIRA's ZERO DISCHARGE SYSTEM:

2.4.1 DESCRIPTION: *(Bhatt S. R. et. al, 2006)*

Few years before, due to technological limitations, it was concluded that if there is an input of water/liquid in the manufacturing operations, there would be discharge/effluent. It can be minimized; it cannot be totally eliminated.

Therefore, 'Zero Discharge' is a myth!!

In reality and over a long period, some discharges are bound to take place, unless there is an enormous storage capacity or it can be vaporized. *(Bhatt S.R. et.al, 2001)* The word "vaporized" was picked up and was thought that in various technological innovations, by and large the pollutants are targeted for the treatment but here the approach is different and the main emphasis was given to the "water part" of the wastewater and not the pollutants. In short water was treated / evaporated in a cost effective manner without any thermal means.

After carefully studying the 'Zero Discharge' problems of the textile industries and the limitations of the conventional technologies like Reverse Osmosis, Incineration, Solar Evaporation etc the Zero Discharge technique was developed by ATIRA which works on the principle that the contaminated water is ejected at high velocities through specialized high pressure system, which creates water droplets of 50-100 micron size. This water droplets are kept suspended long enough for the natural evaporation to occur by means of air provided from the bottom of the duct with the help of air blower. *(Bhatt S. R. et. al, 2006)* Hence wastewater changes from liquid to vapor within millisecond of ejection and gets evaporated into atmosphere without heat input and separates dissolved solids from the waste water as a by-product powder that can be reused. *(http://www.aquasonics.com/wastewatermgmt2003.html)*

Employing this basic principle, a small laboratory prototype was developed on which extensive trials using different types of effluents were scientifically conducted. Results of the initial lab trials were encouraging, therefore a pilot plant level design was scaled up and similar trials have been conducted on various types of effluents. Results of these trials, which have been going on for the last 6-8 months, are highly encouraging. These trials clearly show that effluent can be split into water vapors, which are emitted as exhaust along-with air and dissolved solids as solid powder by product.

2.4.2 HIGHLIGHTS OF THE SYSTEM: *(Bhatt S. R. et. al, 2006)*

Some of the highlights of the system are as given below:

- ⇒ Only input into the system is electrical energy, there is no thermal input.
- ⇒ Efficiency of the system ranges from 60-95%.
- ⇒ Estimated operating cost inclusive of all inputs ranges from Rs. 20-45 / 1000 liters of effluent, depending upon the quality of effluent.
- ⇒ The space requirement for the entire system is extremely low.
- ⇒ Minimal maintainance required
- ⇒ There are no unwanted, polluting by products.

2.4.3 WORLDWIDE ANALOGOUS TECHNOLOGIES:

In highly developed countries, similar technologies of very large capacities at industrial scale have been operating successfully for over 10-15 years. The technologies available are as follows:

1. Rapid Spray Evaporation (RSE) *(http://www.aquasonics.com/PDF/execsum.pdf)*
2. Turbo-mist Evaporators *(http://www.turbomist.com/db/images/EvapbookMay2005.pdf)*
3. SMI –Evaporators *(http://www.evapor.com/products.htm)*

Rapid Spray Evaporation Technology, developed by Aquasonics International, Atlanta, US is used for the desalination of sea water and is shown in fig. 2.4.3.1 (c). Turbo-mist Evaporators have been developed by Slimline Manufacturing Ltd, Canada, US and is used for the wastewater solution which is shown in fig. 2.4.3.1 (a). The SMI Evaporators, Midland, US is also used for wastewater solution which is shown in fig. 2.4.3.1 (b). One of the chemical industry generating an average effluent of 350 m^3/day and an average annual effluent generation of 10273 m^3 evaporated 6442 m^3 (average 63 % evaporation) of effluent annually using Turbo-mist Evaporators.

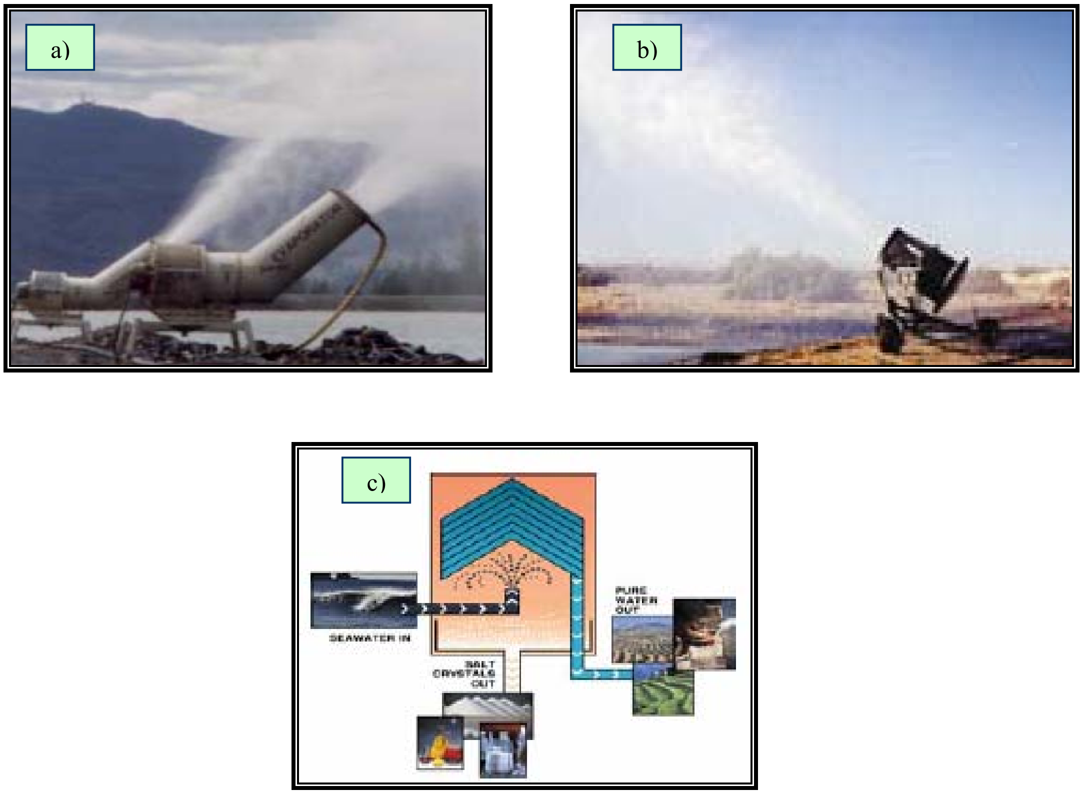


Figure 2.4.3.1: Worldwide Analogous Technologies

a) Turbo-mist Evaporators *(http://www.turbomist.com/db/images/EvapbookMay2005.pdf)*

b) SMI –Evaporators *(http://www.evapor.com/products.htm)*

c) Rapid Spray Evaporation (RSE) *(http://www.aquasonics.com/PDF/execsum.pdf)*

2.4.4 FEATURES OF THE SYSTEM AT INDUSTRIAL SCALE: *(Bhatt S. R. et. al, 2006)*

⇒ Ease of implementation of the system.

⇒ Minimal training required.

⇒ Minimal attention to ongoing operation of the system without manpower.

⇒ The annual minimum average elimination by one such prototype system is estimated at 150 m^3/day.

⇒ Number of such system can be adjusted according to need.

⇒ TDS of up to 160,000 mg/l has been effectively evaporated without plugging, Salts or toxicity are not a problem.

2.4.5 SYSTEM'S THEORY OF EVAPORATION:

In a natural environment such as a lake, only the top portion of the top layer of water droplets are exposed to the air, this allows natural evaporation to occur to that top layer of water. The natural evaporation can be accelerated by:

- ⇒ Exposing more surface area of the water in the form of more water droplets in the air.
- ⇒ Increased evaporation will occur as more air is allowed to surround each individual droplet.

It would follow that if a water droplet is exposed to the air, given enough time, that droplet would evaporate entirely, and that natural acceleration can be achieved by placing more water droplets into the air and keeping them suspended long enough for the natural evaporation to occur.

In this theory to accelerate evaporation, is to mechanically expose more water to the air, and maintain those droplets aloft long enough to evaporate them naturally. Specially designed Air Blower is used to suspend a large quantity of water droplets into the air and keeping them aloft long enough to allow nature to work.

The success of the system is based upon its ability to use mechanical means to achieve sufficient "hang time" to let nature work, the simplicity of which allows man to use nature and the environment to clean up man made problems by simple natural evaporation to a point where they became manageable by other means if necessary. ***(Bhatt S. R. et. al, 2006 &*** *http://www.turbomistevaporators.com/webpages/TheoryofEvaporation.cfm)*

2.4.6 FACTORS AFFECTING RATE OF EVAPORATION:

The factors affecting rate of evaporation are

- ⇒ Humidity
- ⇒ Temperature
- ⇒ Wind Condition
- ⇒ Droplet Size

2.4.6.1 Humidity and Temperature: *(http://ohioline.osu.edu/b816/b816_13.html)*

Relative humidity and temperature go hand-in-hand in affecting rate of evaporation. While they generally are not as critical as wind velocity, they are a strong influence in some geographic regions or under certain meteorological conditions. As a particle falls through the air, surface molecules of water evaporate into the atmosphere. This evaporation reduces the size and mass of the particle, enabling it to remain airborne longer and, under the right conditions, to drift farther from the application site (Fig.2.4.6.1.1). The rate at which water evaporates depends primarily on the ambient air temperature and relative humidity.

It has been shown that a 100-micron droplet requires a little over 5 seconds to free-fall 5 feet if no evaporation occurs. However, in relatively dry, warm air (e.g., 30 percent relative humidity and 78°F), the same 100-micron droplet quickly loses water by evaporation and becomes less than half its original diameter (one-eighth of its original volume) while falling only 2.5 feet. By comparison, in relatively moist air (e.g., 70 percent relative humidity and 78°F), a 100-micron particle will fall 5 feet and hit the ground before evaporating to half its original diameter. While evaporative loss of water droplets occurs under almost all atmospheric conditions, these losses are less pronounced under the environmental conditions that occur in the cooler parts of the day - early morning and late afternoon. The relative humidity is usually highest during these cool periods.

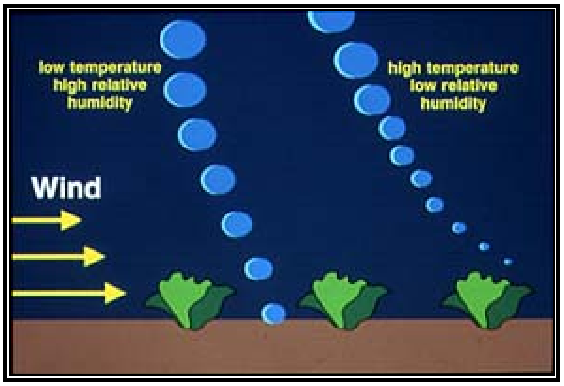


Fig.2.4.6.1.1: Effect of Temperature and Humidity on rate of evaporation

(http://ohioline.osu.edu/b816/b816_13.html)

2.4.6.2 Wind Conditions: *(http://ohioline.osu.edu/b816/b816_13.html)*

Wind conditions are usually the most critical factor of all meteorological conditions affecting the rate of evaporation. The greater the wind speed, the farther off-target a droplet of a given size will be carried which lengthens the hang time of exposure of the water droplets into air resulting into higher rate of evaporation.

⇒ *Therefore in short it is accepted that evaporation is effected by humidity, temperature and wind conditions. The greater the temperature, the less the humidity and the greater the wind conditions (which lengthen hang time), the greater the amount of evaporation.*

2.4.6.3 Droplet Size: *(http://www.turbomist.com/db/images/EvapbookMay2005.pdf)*

Spray droplet size is by far the most important factor affecting drift. Spray droplet diameters are measured in micrometers. A micrometer is 1/25,000 of an inch and is usually referred to as a *micron* (Fig. 2.4.6.3.1 (a)). For reference, the thickness of a human hair or a sheet of paper is roughly 75 microns.

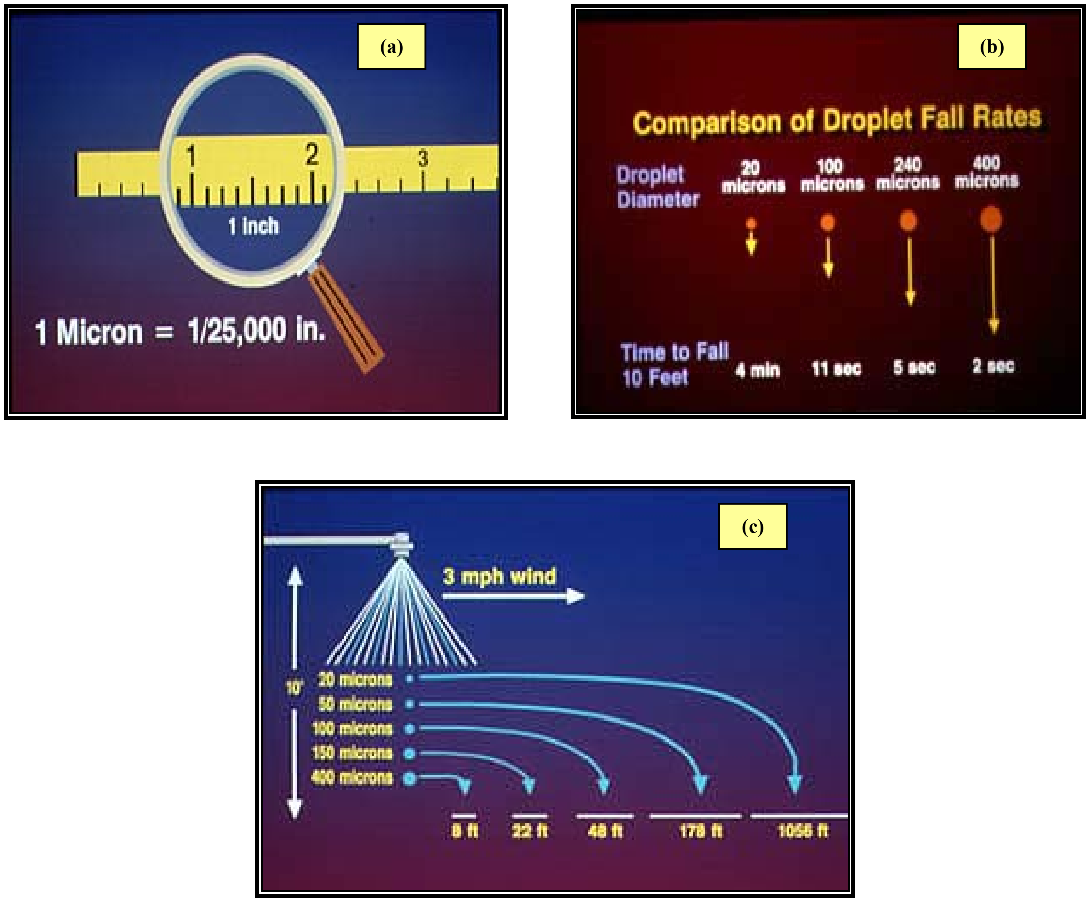


Figure 2.4.6.3.1: (a) Water-droplet diameters are measured in microns (b) Comparison of droplet fall rates (c) Smaller droplets drift longer distances (*http://ohioline.osu.edu/b816/b816_6.html)*

In general the longer the droplets remain airborne, the greater the chances they are going to be carried by wind away from the application site. Small spray droplets are more susceptible to drift than the larger droplets because they tend to remain airborne much longer than the larger droplets. For example, as shown in Fig. 2.4.6.3.1 (b), while it takes 4 minutes for a 20 micron droplet to travel a vertical distance of 10 feet, it takes only 2 seconds for a 400 micron droplet to travel the same distance.

Research shows there is a rapid decrease in the drift potential of droplets greater than about 150 or 200 microns. Droplet size where drift potential becomes insignificant depends on wind speeds, but lies in the range of 150 to 200 microns for wind speeds of 1 to 9 miles per hour. Small droplets can drift long distances because of their light weight. For instance, as shown in Fig. 2.4.6.3.1 (c), the theoretical distances that water droplets would be carried while falling 10 feet in air having a uniform horizontal velocity of 3 miles per hour would be only about 8 feet for 400-micron droplets, but about 1,000 feet for 20-micron droplets. Water particles under 50 microns in diameter remain suspended in the air indefinitely or until they evaporate.

It was observed that a water droplet size of 200 microns will drop at 2.4 ft/sec, and take 29 seconds to evaporate, therefore it must fall 69.6 ft to evaporate. A water droplet of 100 microns will fall 1.7 ft/sec and take 7 seconds to evaporate, which is a drop of 11.9 ft. Table 2.4.6.3.1 shows the evaporation and deceleration of various size droplets at a condition of 90 F, 36% RH, and 25 psi.

Table 2.4.6.3.1: Evaporation and Deceleration of Various Size Droplets *
(http://www.turbomist.com/db/images/EvapbookMay2005.pdf)

Droplet Diameter (microns)	Terminal Velocity (ft/sec)	Final Drop Diameter (microns)	Time to evaporate (sec)	Deceleration distance (in)
20	0.04	7	0.3	<1
50	0.25	17	1.8	3
100	0.91	33	7	9
150	1.7	50	16	16
200	2.4	67	29	25

* Conditions assumed: 90 F, 36% RH, 25 psi.

⇒ *In general it is considered that smaller the droplet size the faster it will evaporate and the greater the potential is for drift. Combining small droplets with elevation is necessary.*

CHAPTER - 3

EXPERIMENTAL SET UP

3.1 PROJECT EXPERIMENTAL SET-UP:

A pilot-scale Zero Discharge System facility has already been constructed in ATIRA, Ahmedabad. Process flow diagram of the existing Zero Discharge System for the batch and continuous operation is shown in fig. 3.1.1 and fig. 3.1.2. The Zero Discharge System employs the basic principle that the contaminated water is ejected at high velocities through specialized high pressure system, which creates water droplets of 50-100 micron size. This water droplets are kept suspended long enough for the natural evaporation to occur by means of air provided from the bottom of the duct with the help of air blower. Hence wastewater changes from liquid to vapor within millisecond of ejection and gets evaporated into atmosphere.

The Zero Discharge System for the Batch Operation consists of a Storage Tank (ST1), Pump (P1), Air Blower (AB1), Duct (D1), High Pressure System (A1), Pump Bypass Collection Tank (CT1), and Recollect Tank (CT2) whereas the Zero Discharge System for the Continuous Operation consist of Collection Tank (T1), Pump (P1), Air Blower (AB1), Duct (D1), High Pressure System (A1).

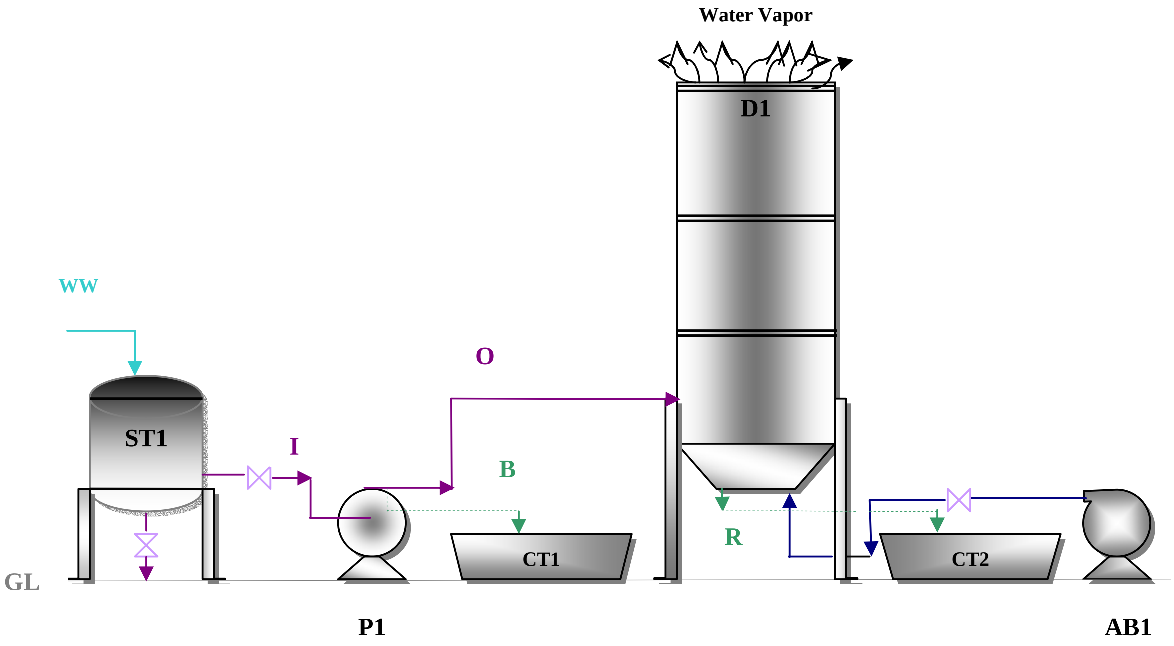


Figure 3.1.1: Process flow diagram of the existing Zero Discharge System for the batch operation

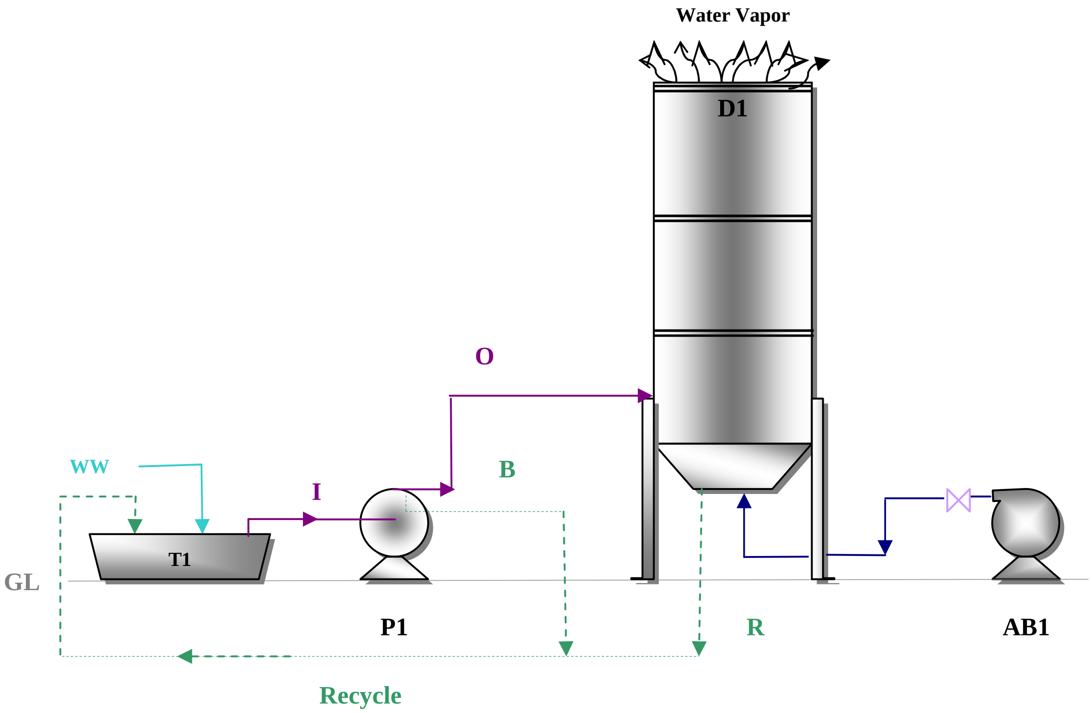


Figure 3.1.2: Process flow diagram of the existing Zero Discharge System for the continuous operation

3.2 DIMENSIONS OF EXISTING COMPONENTS OF ZERO DISCHARGE SYSTEM:

As shown in fig 3.1.1 and fig. 3.1.2 the existing Zero Discharge System pilot plant at ATIRA, Ahmedabad consists of Storage Tank (ST1), Pump (P1), Air Blower (AB1), Duct (D1), High Pressure System (A1), Pump Bypass Collection Tank (CT1), and Recollect Tank (CT2) & Collection Tank (T1).The dimensions and capacity of various components of Zero Discharge System are as given below:

- **Storage Tank (ST1)**

  Type - Cylindrical
  Height - 0.9 m
  Diameter - 0.57295 m
  Volume - 0.232 m^3
  M.O.C. - SS

- **Pump (P1)**

  Type - Plunger (Simplex)
  RPM - 90-SPM
  Capacity - 60 LPH
  Head - 100 m/kg cm^2
  KW/Hp - 1

- **Air Blower (AB1)**

Type - Roots
RPM - 1196
Capacity - 72 CMH
Vac/Press. - 1000 mmWG
Kw/Hp - 2.2/3.0
Motor RPM - 1430

- **Collection Tank (T1)**

Type - Cylindrical
Diameter - 0.67m
Height - 0.2 m
Volume - 70 ltr.

- **Pump Bypass Collection Tank (CT1)**

Type - Cylindrical
Diameter - 0.67m
Height - 0.2 m
Volume - 70 ltr.

- **Recollect Tank (CT2)**

Type - Cylindrical
Diameter - 0.67m
Height - 0.2 m
Volume - 70 ltr.

- **Duct (D1)**

Type - Rectangular
Height - 4.572 m
Length - 0.8382 m
Breadth - 0.8382 m
M.O.C. - MS

3.3 ZERO DISCHARGE SYSTEM PILOT PLANT AT ATIRA, AHMEDABAD:

Fig. 3.3.1 shows the layout of existing Zero Discharge System pilot plant at ATIRA, Ahmedabad. Experiments were conducted on this set up in two modes: Batch and Continuous.

Fig 3.3.1: Layout of existing Zero Discharge System Pilot Plant at ATIRA, Ahmedabad.

3.3.1 Batch Operation:

In Batch Operation, various components of the set-up include Storage Tank (ST1), Pump (P1), Air Blower (AB1), Duct (D1), High Pressure System (A1), Pump Bypass Collection Tank (CT1), and Recollect Tank (CT2) as shown in fig.3.1.1. Duration of the Batch Operation was 1 hour and a total number of experiments performed are 73 by varying the pressure in the pump.

3.3.1.1 Storage Tank (ST1):

The capacity of Storage Tank is 0.232 m^3 in which synthetic textile effluent is manually injected. Two types of dyes were used in preparation of synthetic textile effluent. They are Procean Brill Red HE-7B and Procean Brill Yellow HE-7R of 0.1, 0.3 & 0.5 % w/v each. There are two pipelines which is the output from this storage tank, one is for vacanting the storage tank and the other is the input (I) to the pump (P1).

3.3.1.2 Pump (P1):

The pump (P1) used for the experimental purpose is a simplex plunger pump having capacity of 60 LPH. The effluent from the storage tank (ST1) is pumped with varying pressure into the rectangular duct (D1). There are three streams in pump (P1) i.e. one, which is input (I) to pump from storage tank (ST1), second is the output (O) from the pump (P1) which is input to the high pressure system (A1) which are placed into the rectangular duct (D1) and the third is the bypass (B) which varies with varying pressure and is collected in pump bypass collection tank (CT1).

3.3.1.3 Air Blower (AB1):

The air blower (AB1) used for the experimental purpose is a roots blower having capacity of 72 CMH and operates at a pressure of 2 inch water column. The air with low relative humidity is injected from the bottom of the rectangular duct (D1).

3.3.1.4 High Pressure System (A1):

The high pressure system (A1) is placed into the rectangular duct (D1). The wastewater which is pumped from the storage tank (ST1) gets split into water droplets of 50-100 micron size which is kept in suspension with the help of air provided from the bottom of the rectangular duct (D1).

3.3.1.5 Rectangular Duct (D1):

The duct (D1) used for the experimental purpose is rectangular of dimensions 4.572 m * 0.8382 m * 0.8382 m. The water droplets of 50-100 micron size which is formed with the help of high pressure system (A1) placed in the rectangular duct is kept in suspension to achieve sufficient airborne/hang time in order to get evaporated naturally. The water vapor comes out as an exhaust from the duct along with the humidified air is shown in figure 3.3.1.5.1 and dissolved solids as a solid powder by product which can be reused. Besides this, some of the fine water droplets coming out of the high pressure system collide to form large droplet which reduces the drift potential, as a result this droplets do not achieve sufficient airborne time and fall down at the bottom of the duct and collected as a recollect in the recollect tank (CT2).

Fig. 3.3.1.5.1: Water Vapor coming out from the Duct (D1)

3.3.1.6 Recollect Tank (CT1):

The recollect tank used for the experimental purpose is of 70 lit. capacity. The recollect (R) coming out from the bottom of the duct vary with varying pressure in the pump (P1) and is collected in the recollect tank (CT1). The recollect is then measured with the help of measuring cylinder in liters.

3.3.1.7 Pump Bypass Collecting Tank (CT2):

The pump bypass collecting tank (CT2) is used for the collection of the bypass coming out from the pump (P1) which varies with varying pressure. The capacity of the tank is 70 lit. The measurement of the bypass is done with the help of the measuring cylinder in liters.

3.3.2 Continuous Operation:

The experiments were also conducted on continuous mode on the zero discharge system pilot plant at ATIRA, Ahmedabad. The main aim of the continuous operation was to check the time required to evaporate the fixed amount of wastewater initially taken. The flow diagram of the continuous operation is shown in figure 3.1.2.

In continuous operation, the collection tank (T1) of 70 lit capacity was taken instead of the storage tank (ST1) into which fixed amount i.e. 18.4 ltr of wastewater was initially taken. The difference in the batch and continuous operation is only that the bypass coming out from the pump (P1) and the recollect that is coming out of the duct (D1) are not measured individually but both this streams are combined and continuously recycled into the collecting tank (T1), rest of the operation is same as the batch operation.

3.4 EXPERIMENTAL ANALYSIS:

Experimental analysis involves the influent characterization of synthetic textile effluent in terms of COD (Chemical Oxygen Demand) as per Appendix A, TDS (Total Dissolved Solids) as per Appendix B, TSS (Total Suspended Solids) as per Appendix C, TS (Total Solids) as per Appendix D, Color and pH. It also involves the measurement of temperature and relative humidity at the bottom and top of the duct (D1) with the help of Digital Thermo hygrometer, measurement of the inlet (I) to the pump (P1) as per Appendix E, Outlet (O) from the pump (P1), Bypass (B) from the pump (P1), and recollect (R) from the bottom of the duct (D1) with the help measuring cylinder at varying pressures. The Net Water Evaporated is calculated as per Appendix E. The Power unit consumption of the pump (P1) and the air blower (B1) is measured in KWH with the help of energy meter provided at the pilot plant site.

CHAPTER – 4

RESULTS AND DISCUSSION

A pilot-scale Zero Discharge System facility has already been constructed in ATIRA, Ahmedabad. Process flow diagram of the existing Zero Discharge System for the batch and continuous operation is shown in fig. 3.1.1 and fig. 3.1.2. Several experiments were conducted using synthetic textile effluent prepared using two types of dyes i.e. Procean Brill Red HE-7B and Procean Brill Yellow HE-7R of 0.1, 0.3 & 0.5 % w/v each on batch and continuous mode. The influent characterization of synthetic textile effluent was done which is shown in table 4.1 and calculation was done as per Appendix A, B, C, &D.

Table 4.1: Influent characterization of Synthetic Textile Effluent

Sr. No.	Characteristics	Procean Brill Red HE-7B			Procean Brill Yellow HE-7R		
		0.1% w/v	0.3% w/v	0.5% w/v	0.1% w/v	0.3 % w/v	0.5 % w/v
1	pH	8.78	9.10	9.25	6.03	5.25	5.04
2	Color, Co-pt scale	51111	148148	244814	9259	30000	49629
3	COD, mg/l	688.69	2114.28	3675	757.14	2529.73	4186.66
4	TDS, mg/l	908	2656	4402	918	2676	4416
5	TSS, mg/l	10	19	29	6	44	84
6	TS, mg/l	918	2675	4431	924	2720	4500

4.1 BATCH OPERATION:

The Process flow diagram of the existing Zero Discharge System for the batch operation is shown in fig 3.1.1. Experiments were conducted by varying pressure in the pump (P1) and the duration of batch operation was of 1 hour. The system does not depend on the composition of the effluent. The results of batch operation are shown from table 4.1.1 to table 4.1.12 in terms of Water consumption in Storage tank (ST1), Inlet (I) to the pump (P1), Bypass (B) from pump (P1), Outlet (O) from pump (P1), Recollect (R) from the rectangular duct (D1), Net Water Evaporated, Pump (P1) power unit consumed, Air Blower (AB1) power unit consumed, Total Power unit consumed and Operating cost of the system. The temperature and relative humidity were measure with the help of digital thermo hygrometer at the bottom and top of the duct respectively. Besides this the calculation was done for the evaporation of 1000 ltr of wastewater, the power unit consumed and operating cost for 1000 ltr are as shown from table 4.1.1 to table 4.1.12**.** The calculation steps are shown in Appendix E.

Table 4.1.1: Results of Batch Operation for 1 hr. at 300 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump unit KWH	Blower unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
300	21	20	45	67	26.8	69.06	47.2	21.86	16.47	5.39	0.25	0.55	0.8	4.40	148.37	816.05	24.66
300	23	21	43	62	26.9	69.32	46.1	23.22	17.77	5.45	0.255	0.55	0.805	4.43	147.72	812.46	23.47
300	21	20	44	68	27	69.58	45.6	23.98	18.6	5.38	0.26	0.55	0.81	4.46	150.64	828.50	22.43
300	22	21	41	55	27.1	69.83	45.1	24.73	19.33	5.40	0.26	0.55	0.81	4.46	149.86	824.26	21.85
300	24	23	36	54	26.8	69.06	47.2	21.86	16.4	5.46	0.27	0.55	0.82	4.51	150.13	825.73	24.98
300	23	22	42	59	26.8	69.06	46.5	22.56	17.11	5.45	0.25	0.55	0.8	4.40	146.74	807.07	24.16
300	23	22	43	58	26.6	68.55	44.5	24.05	18.61	5.44	0.25	0.55	0.8	4.40	147.16	809.36	22.61
300	25	24	34	52	26.7	68.80	45.1	23.70	18.23	5.47	0.265	0.55	0.815	4.48	148.88	818.85	23.09

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.2: Results of Batch Operation for 1 hr. at 400 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
400	21	20	39	68	26.9	69.32	40.56	28.76	22.16	6.60	0.3	0.55	0.85	4.68	128.80	708.39	22.95
400	24	23	33	63	26.9	69.32	39.1	30.22	23.58	6.64	0.31	0.55	0.86	4.73	129.53	712.40	21.97
400	23	22	35	70	26.8	69.06	37.85	31.21	24.59	6.62	0.32	0.55	0.87	4.79	131.38	722.61	21.22
400	22	21	34	67	27	69.58	39.1	30.48	23.87	6.61	0.315	0.55	0.865	4.76	130.92	720.05	21.68
400	25	24	31	60	26.8	69.06	40.5	28.56	21.91	6.65	0.325	0.55	0.875	4.81	131.54	723.49	23.29
400	21	20	37	71	27	69.58	39.5	30.08	23.48	6.60	0.35	0.55	0.9	4.95	136.42	750.32	21.93
400	24	23	33	63	26.8	69.06	38.5	30.56	23.94	6.62	0.32	0.55	0.87	4.79	131.38	722.61	21.67

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.3: Results of Batch Operation for 1 hr. at 500 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
500	22	21	37	62	27	69.58	35.85	33.73	26.03	7.70	0.39	0.55	0.94	5.17	122.12	671.67	22.82
500	24	23	33	54	27.1	69.83	36.1	33.73	26	7.73	0.4	0.55	0.95	5.23	122.82	675.51	22.93
500	21	20	41	65	27	69.58	35.92	33.66	25.97	7.69	0.41	0.55	0.96	5.28	124.88	686.86	22.84
500	23	22	32	56	26.8	69.06	36.2	32.86	25.14	7.72	0.39	0.55	0.94	5.17	121.73	669.53	23.50
500	23	22	33	58	27.2	70.09	36.15	33.94	26.22	7.72	0.41	0.55	0.96	5.28	124.31	683.71	22.75
500	25	23	30	55	27.1	69.83	36.35	33.48	25.74	7.74	0.39	0.55	0.94	5.17	121.37	667.54	23.13

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.4: Results of Batch Operation for 1 hr. at 700 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
700	23	21	33	64	27.8	71.64	30.86	40.78	32.52	8.26	0.43	0.55	0.98	5.39	118.66	652.64	20.25
700	25	24	31	49	26.8	69.06	31.04	38.02	29.72	8.30	0.42	0.55	0.97	5.34	116.84	642.63	21.83
700	22	21	42	63	27.2	70.09	32	38.09	29.84	8.25	0.43	0.55	0.98	5.39	118.75	653.13	21.66
700	20	20	47	71	27.6	71.12	31.05	40.07	31.86	8.21	0.43	0.55	0.98	5.39	119.32	656.25	20.50
700	21	20	43	69	26.9	69.32	30.04	39.28	31.04	8.24	0.41	0.55	0.96	5.28	116.51	640.82	20.98
700	24	23	34	53	27.1	69.83	30.92	38.91	30.64	8.27	0.4	0.55	0.95	5.23	114.81	631.43	21.26
700	23	22	32	56	26.8	69.06	29.9	39.16	30.9	8.26	0.41	0.55	0.96	5.28	116.20	639.09	21.10

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.5: Results of Batch Operation for 1 hr. at 800 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
800	24	23	37	53	27.3	70.35	24	46.35	37.36	8.99	0.45	0.55	1	5.50	111.23	611.77	19.40
800	22	21	41	62	26.9	69.32	23.4	45.92	37.01	8.91	0.445	0.55	0.995	5.47	111.68	614.23	19.40
800	23	22	35	56	27.1	69.83	24.1	45.73	36.78	8.95	0.44	0.55	0.99	5.45	110.55	608.05	19.58
800	26	24	30	45	27.2	70.09	25.2	44.89	35.88	9.01	0.435	0.55	0.985	5.42	109.29	601.10	20.08
800	25	24	32	49	27.1	69.83	24.2	45.63	36.63	9.00	0.43	0.55	0.98	5.39	108.83	598.56	19.73

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.6: Results of Batch Operation for 1 hr. at 900 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
900	24	23	33	62	27.4	70.61	20.44	50.17	41.05	9.12	0.47	0.55	1.02	5.61	111.87	615.27	18.17
900	23	22	39	70	27.7	71.38	21.27	50.11	41.01	9.10	0.455	0.55	1.005	5.53	110.43	607.35	18.16
900	25	24	33	60	26.8	69.06	22.6	46.46	37.31	9.15	0.45	0.55	1	5.50	109.27	600.97	19.70
900	27	26	30	55	27.4	70.61	22.2	48.41	39.23	9.18	0.45	0.55	1	5.50	108.96	599.26	18.96

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.7: Results of Batch Operation for 1 hr. at 1000 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
1000	25	24	35	62	27.6	71.12	18.7	52.42	43.07	9.35	0.465	0.55	1.015	5.58	108.52	596.85	17.84
1000	21	19	51	70	27.1	69.83	18.9	50.93	41.62	9.31	0.47	0.55	1.02	5.61	109.50	602.26	18.29
1000	22	21	46	67	27.1	69.83	18.8	51.03	41.7	9.33	0.46	0.55	1.01	5.56	108.20	595.08	18.29
1000	26	25	32	57	26.9	69.32	18.6	50.72	41.34	9.38	0.47	0.55	1.02	5.61	108.75	598.11	18.49
1000	24	22	41	63	26.9	69.32	18.51	50.81	41.455	9.35	0.47	0.55	1.02	5.61	109.04	599.71	18.41

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.8: Results of Batch Operation for 1 hr. at 1100 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
1100	25	23	38	60	27.4	70.61	16.55	54.06	44.54	9.52	0.47	0.55	1.02	5.61	107.17	589.41	17.61
1100	23	21	40	69	27.6	71.12	15.22	55.90	46.41	9.49	0.48	0.55	1.03	5.67	108.50	596.73	16.98
1100	21	20	43	70	27	69.58	17.82	51.76	42.29	9.47	0.47	0.55	1.02	5.61	107.74	592.57	18.29
1100	25	23	37	62	27.4	70.61	17.435	53.17	43.65	9.52	0.475	0.55	1.025	5.64	107.63	591.99	17.91
1100	24	22	39	65	27	69.58	16.64	52.94	43.44	9.50	0.48	0.55	1.03	5.67	108.45	596.49	17.94
1100	26	25	37	53	27.1	69.83	15.78	54.05	44.5	9.55	0.48	0.55	1.03	5.67	107.80	592.89	17.68

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.9: Results of Batch Operation for 1 hr. at 1200 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
1200	23	22	37	78	26.9	69.32	11.56	57.76	48.06	9.70	0.52	0.55	1.07	5.89	110.32	606.73	16.79
1200	22	21	47	81	26.8	69.06	11.67	57.39	47.7	9.69	0.51	0.55	1.06	5.83	109.37	601.54	16.89
1200	25	24	35	67	26.9	69.32	11.54	57.78	48.04	9.74	0.51	0.55	1.06	5.83	108.84	598.59	16.86
1200	24	22	39	76	27.1	69.83	11.32	58.51	48.8	9.71	0.52	0.55	1.07	5.89	110.14	605.77	16.60
1200	21	20	52	85	27.2	70.09	12.5	57.59	47.91	9.68	0.515	0.55	1.065	5.86	109.99	604.95	16.81
1200	27	26	31	65	27	69.58	11.38	58.20	48.42	9.78	0.52	0.55	1.07	5.89	109.44	601.91	16.80

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.10: Results of Batch Operation for 1 hr. at 1300 psig

P psig	Temp °C		RH %		Water consmp. cm	Inlet ltr	Bypass ltr	Outlet ltr	Recollect ltr	Water Evaporated ltr	Pump Unit KWH	Blower Unit KWH	Power Unit Consumed KWH	Cost Rs.	Power Unit Consumed for 1000 ltr KWH	Cost for 1000ltr Rs.	Eff. %
	B_D	T_D	B_D	T_D													
1300	27	25	32	60	27.4	70.61	6.21	64.40	54.22	10.18	0.53	0.55	1.08	5.94	106.11	583.61	15.80
1300	23	22	51	78	26.9	69.32	7.26	62.06	52.08	9.98	0.525	0.55	1.075	5.91	107.72	592.46	16.08
1300	24	23	44	70	27	69.58	5.25	64.33	54.31	10.02	0.52	0.55	1.07	5.89	106.82	587.49	15.57
1300	26	24	34	63	26.8	69.06	7.51	61.55	51.44	10.11	0.525	0.55	1.075	5.91	106.31	584.71	16.43
1300	22	21	47	73	26.9	69.32	6.52	62.80	52.85	9.95	0.52	0.55	1.07	5.89	107.54	591.49	15.84
1300	25	24	38	65	27.2	70.09	6.86	63.23	53.18	10.05	0.53	0.55	1.08	5.94	107.44	590.89	15.90

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.11: Results of Batch Operation for 1 hr. at 1400 psig

P psig	**Temp °C**		**RH %**		**Water consmp. cm**	**Inlet ltr**	**Bypass ltr**	**Outlet ltr**	**Recollect ltr**	**Water Evaporated ltr**	**Pump Unit KWH**	**Blower Unit KWH**	**Power Unit Consumed KWH**	**Cost Rs.**	**Power Unit Consumed for 1000 ltr KWH**	**Cost for 1000ltr Rs.**	**Eff. %**
	B_D	**T_D**	**B_D**	**T_D**													
1400	31	28	41	60	27.1	69.83	3.85	65.98	55.1	10.88	0.555	0.55	1.105	6.08	101.52	558.34	16.50
1400	25	24	57	68	26.8	69.06	3.99	65.07	54.28	10.79	0.56	0.55	1.11	6.11	102.86	565.71	16.58
1400	27	25	51	65	26.8	69.06	5.1	63.96	53.15	10.81	0.575	0.55	1.125	6.19	104.05	572.29	16.90
1400	29	27	49	61	27.2	70.09	3.81	66.28	55.43	10.85	0.57	0.55	1.12	6.16	103.20	567.61	16.37
1400	28	27	50	62	27	69.58	3.1	66.48	55.66	10.82	0.565	0.55	1.115	6.13	103.08	566.92	16.27
1400	30	29	44	58	26.9	69.32	4.2	65.12	54.26	10.86	0.575	0.55	1.125	6.19	103.60	569.78	16.68
1400	26	22	55	76	26.4	68.03	3.4	64.63	53.83	10.80	0.57	0.55	1.12	6.16	103.69	570.32	16.71

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

Table 4.1.12: Results of Batch Operation for 1 hr. at 1500 psig

P psig	**Temp °C**		**RH %**		**Water consmp. cm**	**Inlet ltr**	**Bypass ltr**	**Outlet ltr**	**Recollect ltr**	**Water Evaporated ltr**	**Pump Unit KWH**	**Blower Unit KWH**	**Power Unit Consumed KWH**	**Cost Rs.**	**Power Unit Consumed for 1000 ltr KWH**	**Cost for 1000ltr Rs.**	**Eff. %**
	B_D	**T_D**	**B_D**	**T_D**													
1500	26	24	38	71	26.6	68.55	0	68.55	56.77	11.78	0.59	0.55	1.14	6.27	96.80	532.42	17.18
1500	27	26	35	68	26.6	68.55	0	68.55	56.75	11.80	0.58	0.55	1.13	6.22	95.79	526.86	17.21
1500	28	25	32	70	26.6	68.55	0	68.55	56.65	11.90	0.6	0.55	1.15	6.33	96.67	531.67	17.36
1500	27	25	34	71	26	67.00	0	67.00	55.19	11.81	0.57	0.55	1.12	6.16	94.83	521.58	17.63
1500	24	23	47	76	26.6	68.55	0	68.55	56.87	11.68	0.58	0.55	1.13	6.22	96.78	532.27	17.03
1500	26	25	40	70	26.6	68.55	0	68.55	56.78	11.77	0.55	0.55	1.1	6.05	93.49	514.18	17.17
1500	25	24	45	72	26.8	69.06	0	69.06	57.32	11.74	0.585	0.55	1.135	6.24	96.66	531.65	17.00

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct

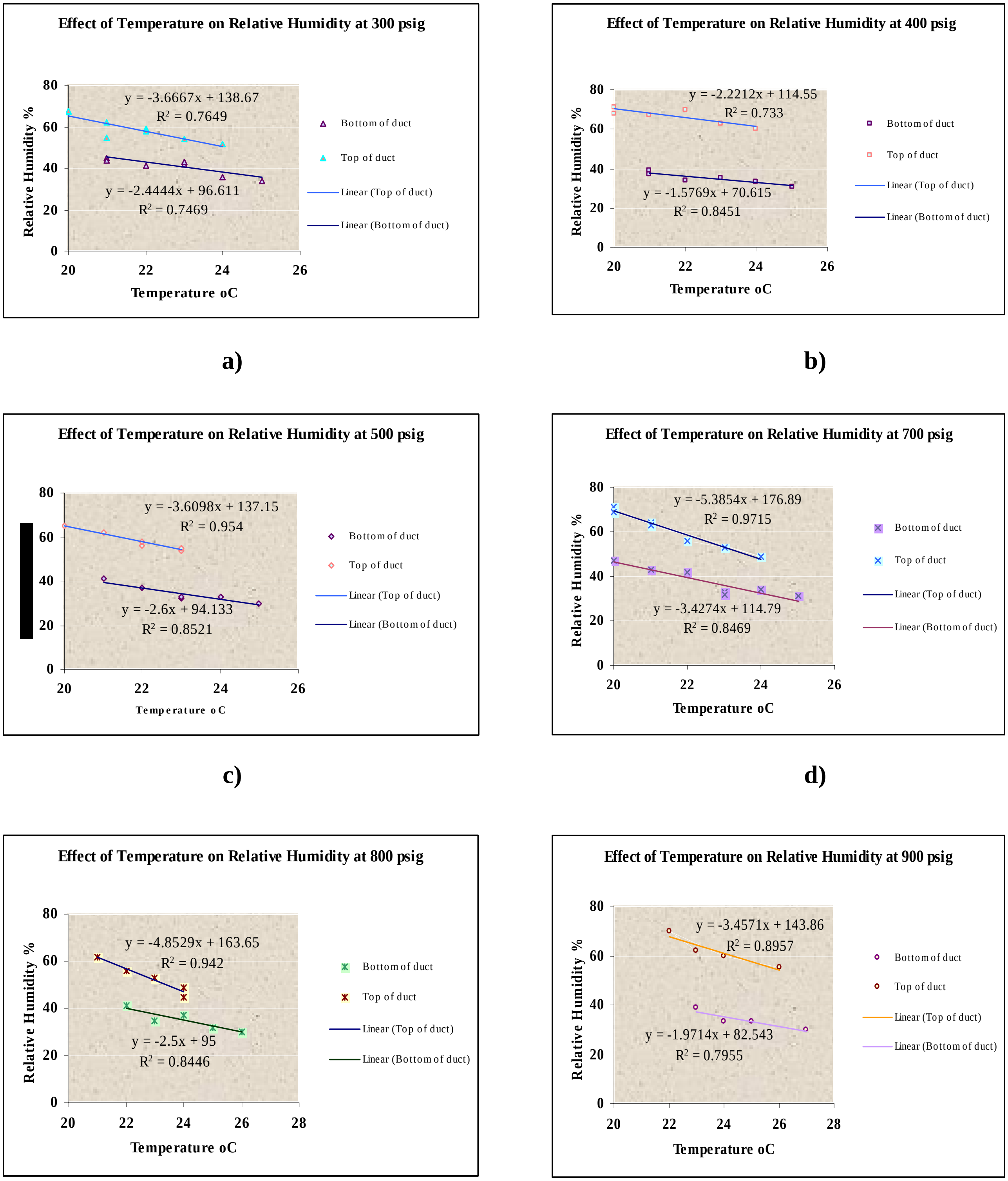
4.1.1 Effect of Temperature on Relative Humidity:

Fig. 4.1.1.1 and fig. 4.1.1.2 shows the plot of temperature vs. relative humidity at different pressures for batch operation which is measured with the help of digital thermo hygrometer. The temperature and relative humidity were measured at the top and bottom of the duct (D1). From all the graphs, it can be seen that with the increase in temperature, the relative humidity decreases i.e. it is lower at higher temperature and higher at lower temperature. This is due to the reason that at higher temperature, the moisture content in the air is lower and at lower temperature, the moisture content in the air is higher.

It can also be observed that the temperature at the bottom of the duct is slightly higher than that at the top of the duct and the relative humidity at the bottom of the duct is lower than that at the top of the duct. The difference in the temperature is of 1-3^{o} C. This is due to the reason that the dry air when fed from the bottom of the duct gets humidified when comes out from the duct. Due to this the temperature and relative humidity at the top of the duct are lower and higher respectively.

It can also be observed from all the graphs that the average relative humidity at the top of the duct at lower pressure i.e. 300 psig is 59.4% whereas by increasing pressure it increases and at the higher pressure i.e. 1500 psig it increases to 71.1%. This is due to the reason that with increasing the pressure, the size of the water droplets decreases. Therefore more surface area of the water droplets will be exposed to air, leading to increase in relative humidity nearer to saturation point.

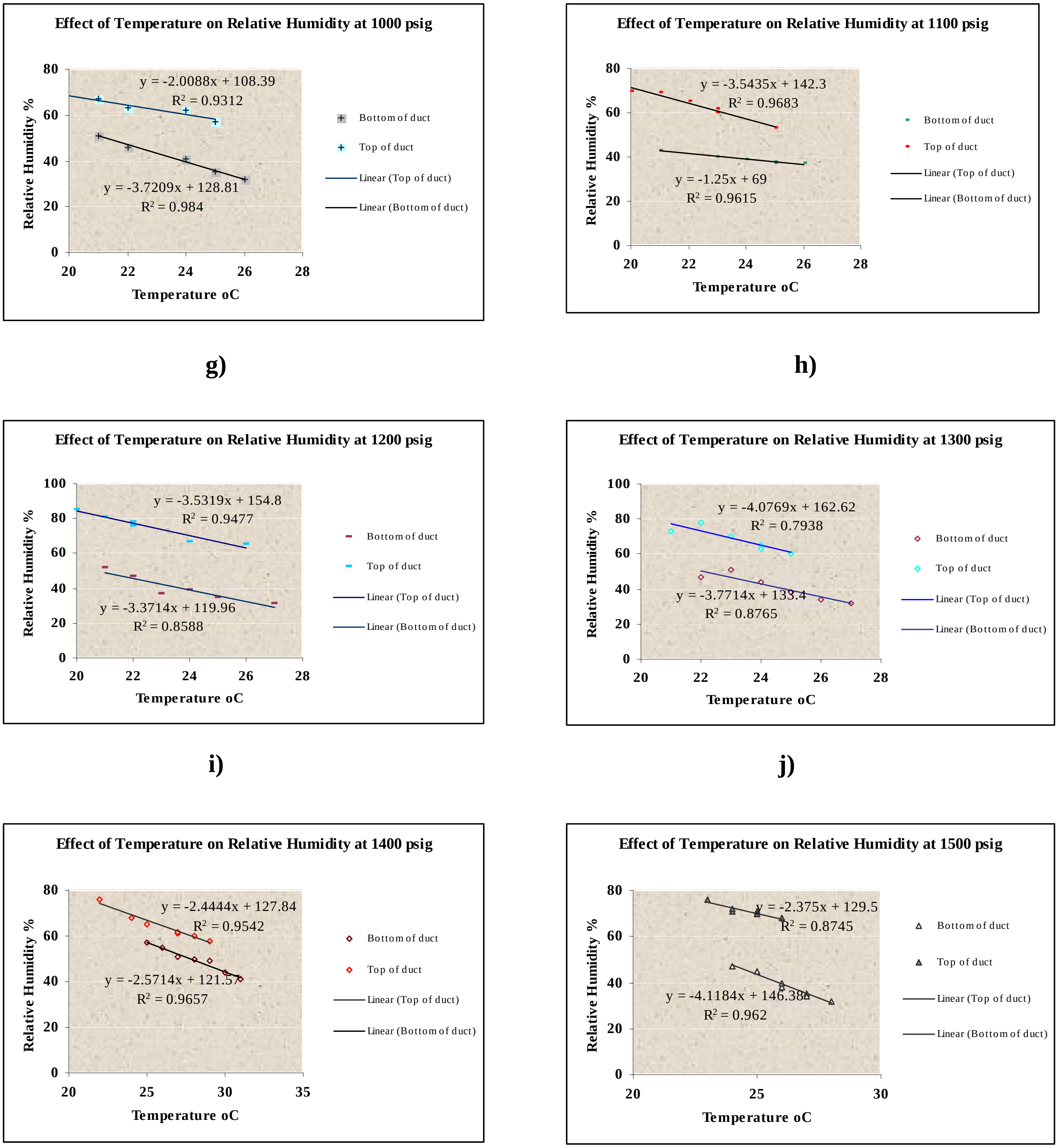
Plots of Temperature vs. Relative Humidity



a) b) c) d) e) f)

Figure 4.1.1.1: Plots of Temperature vs. Relative Humidity at a) 300 psig b) 400 psig c) 500 psig d) 700 psig e) 800 psig f) 900 psig

Plots of Temperature vs. Relative Humidity



g) h) i) j) k) l)

Figure 4.1.1.2: Plots of Temperature vs. Relative Humidity at g) 1000 psig h) 1100 psig i) 1200 psig j) 1300 psig k) 1400 psig l) 1500 psig

4.1.2 Effect of Temperature and Pressure on Evaporation:

Fig. 4.1.2.1 and fig. 4.1.2.2 shows the plot of Temperature vs. Net water evaporated for batch operation at different pressures. It can be seen from the plots at unique pressure that with the increase in the temperature, the rate of evaporation of the water droplets increases. The research shows that a 100 micron water particle requires a little over 5 seconds to free-fall 5 feet if no evaporation occurs. However if this droplet is allowed to fall free in the region of high temperature, the water droplet will quickly lose water by evaporation and become half its original diameter while falling only 2.5 feet. Therefore it can be said that evaporation is effected by the temperature, humidity and wind conditions. The higher the temperature, the lower will be the humidity and greater the wind conditions (which lengthen hang time), the greater the amount of evaporation.

Fig. 4.1.2.3 gives the exact idea of the effect of temperature and pressure on the net water evaporated. From the plot it can be seen that with the increasing temperature and pressure, the net evaporation of the water increases. This is due to the reason that by increasing the pressure, the size of the water droplets coming out of the high pressure system decreases. Due to this, more surface area of the water droplets will be exposed to air and at the same time if the weather is dry, more evaporation will take place.

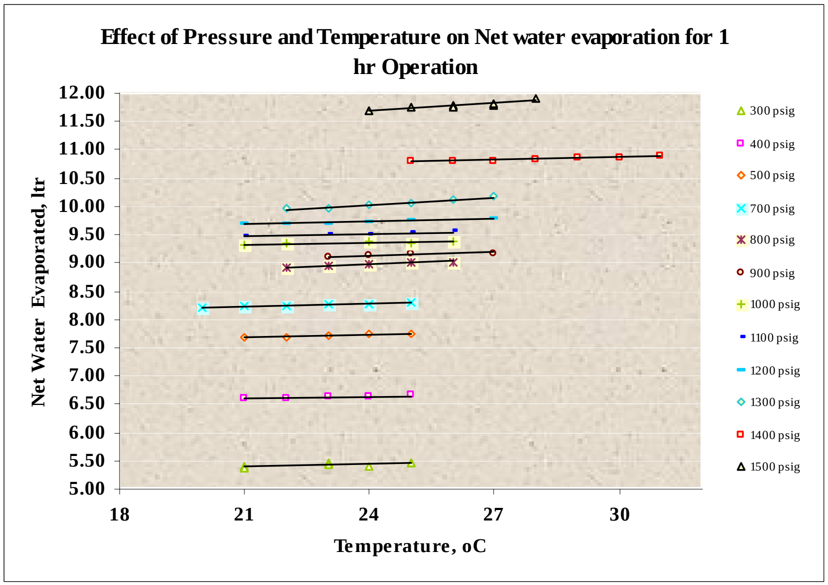
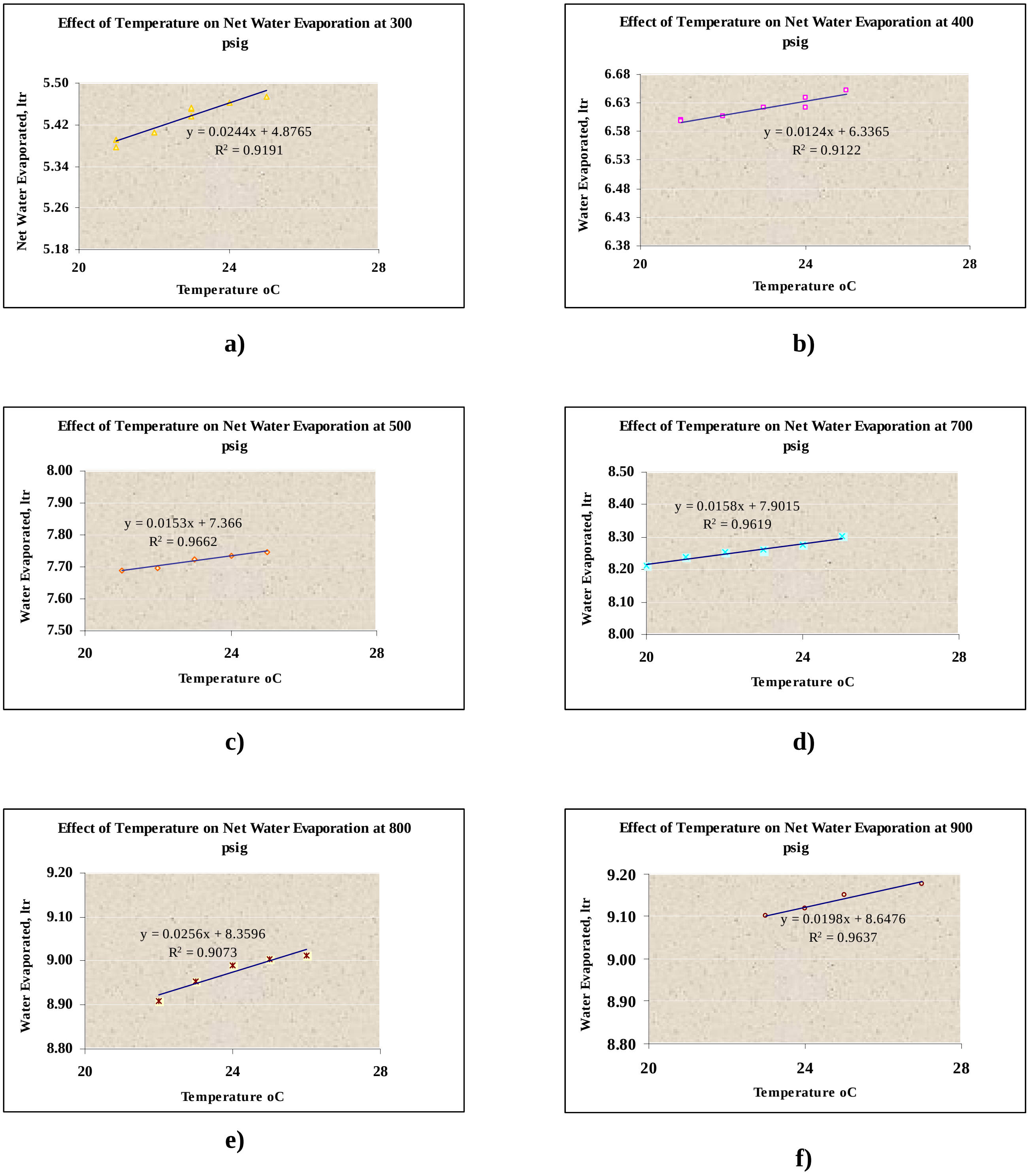


Figure 4.1.2.3: Plot of Pressure and Temperature vs. Net Water Evaporated in 1 hr. Operation

Plots of Temperature vs. Net Water Evaporated



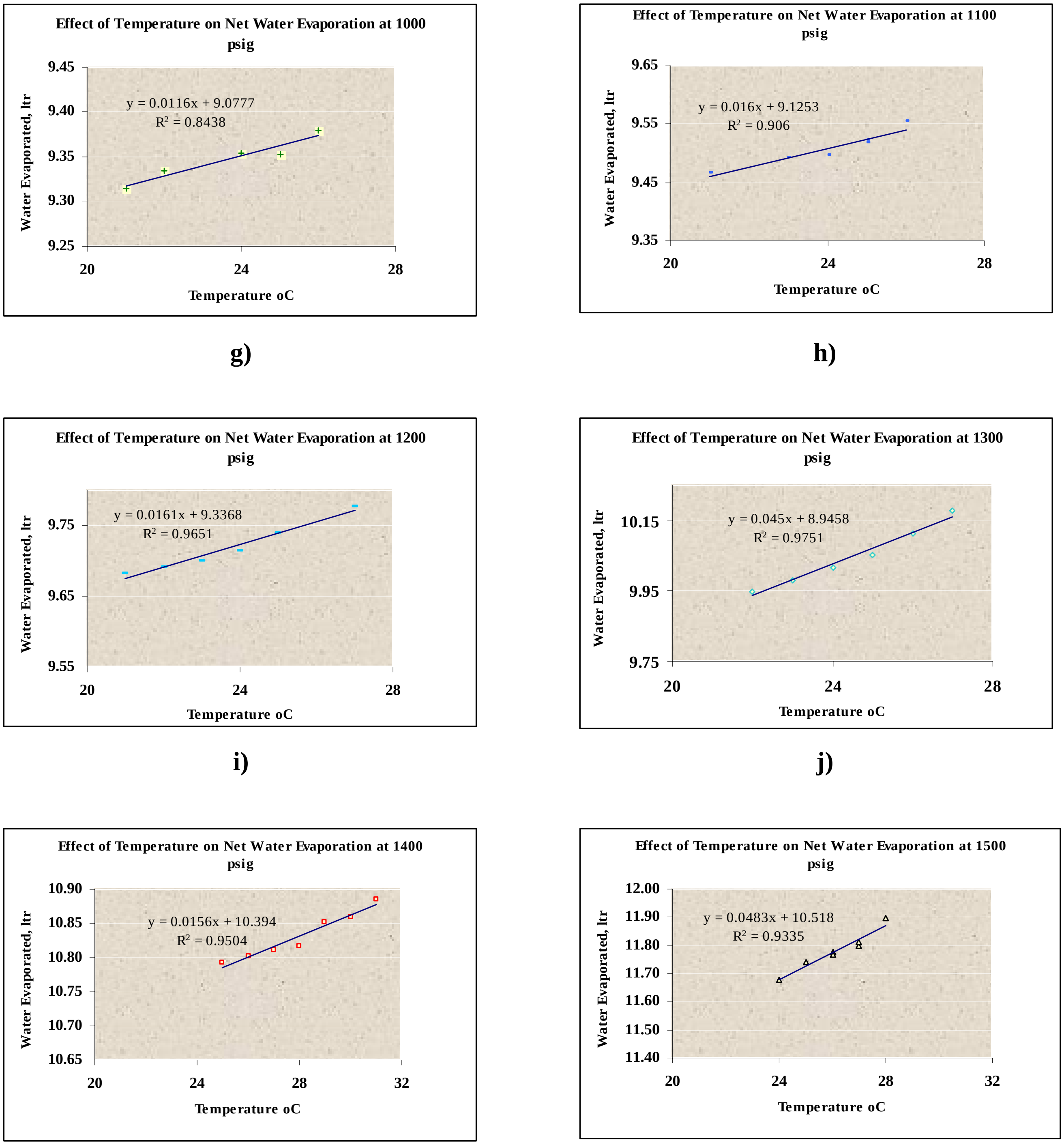
a) b)

c) d)

e) f)

Figure 4.1.2.1: Plots of Temperature vs. Net Water Evaporated at a) 300 psig b) 400 psig c) 500 psig d) 700 psig e) 800 psig f) 900 psig

Plots of Temperature vs. Net Water Evaporated



g) **h)**

i) **j)**

k) **l)**

Figure 4.1.2.2: Plots of Temperature vs. Net Water evaporated at g) 1000 psig h) 1100 psig i) 1200 psig j) 1300 psig k) 1400 psig l) 1500 psig

4.1.3 Effect of Pressure on Power Unit Consumption and operating cost of the system:

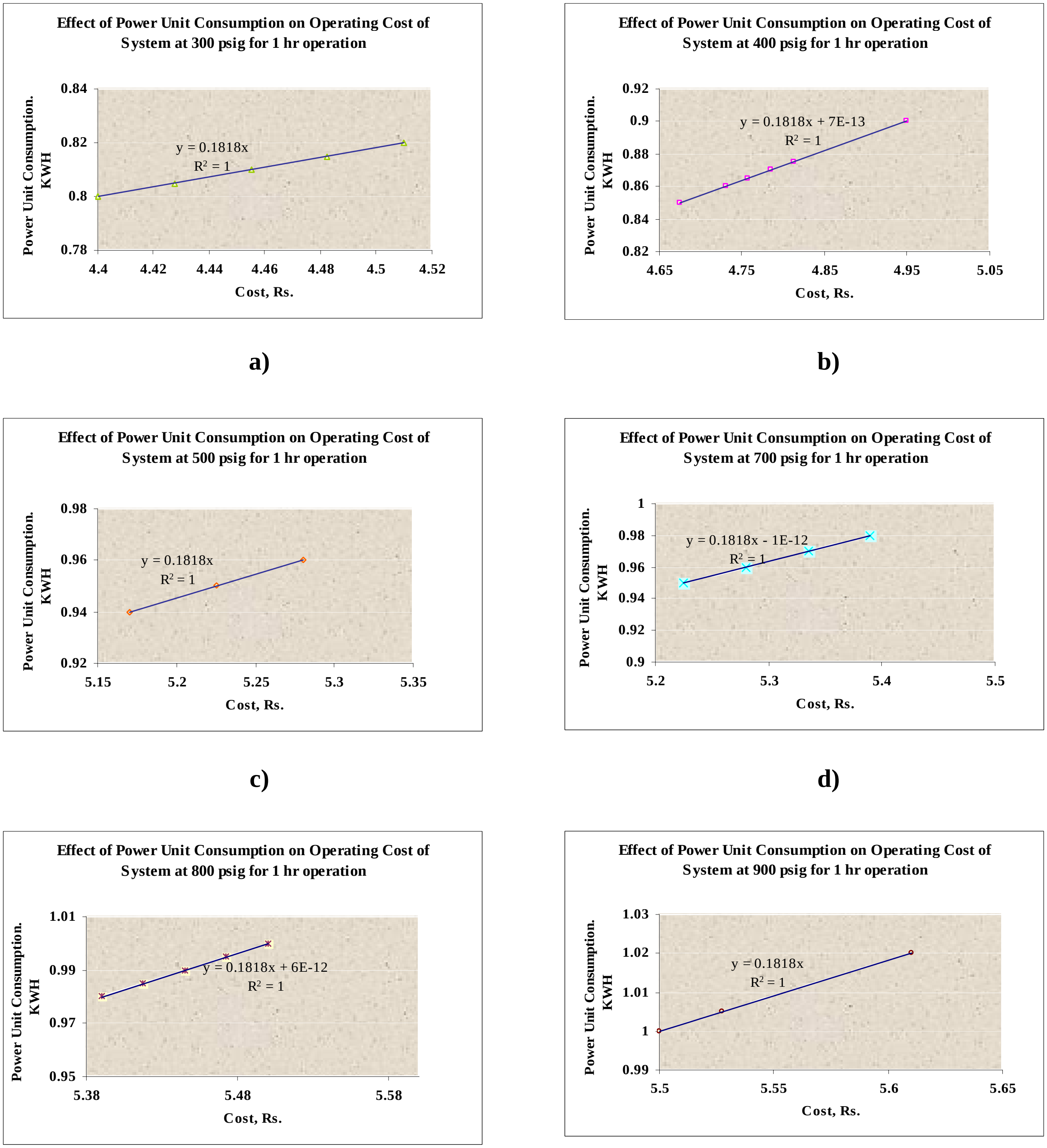
Fig. 4.1.3.1 and fig. 4.1.3.2 are the plots showing the effect of pressure on power unit consumption and operating cost for 1 hour operation. From the plots, it can be seen that with increasing pressure in the pump, the power unit consumption and operating cost of the system increases. This is due to the reason that with increasing the pressure in the pump will put extra load on transmitting media (belt & pulley) as a result the motor will consume more horse power. So the power unit consumption will increase with increasing in the pressure. Operating cost also increases with increase in pressure in the pump as such the only input into the system is electricity. The cost for 1 unit consumed comes out to be Rs 5.5. Therefore, the operating cost of the system is directly proportional to the power unit consumed.

The more clear results can be seen in the plot of power unit consumption vs. operating cost of the system at different pressures for 1 hour operation as shown in fig. 4.1.3.3.

Similarly fig. 4.1.3.4 and fig. 4.1.3.5 are the plots showing the effect of pressure on power unit consumption and operating cost for 1000 ltr of water evaporation. From the plot, it can be seen that with increasing the pressure, the power unit consumption and the operating cost of the system decreases. This is due to the reason that for 1 hour operation amount of water evaporated at different pressures was varying and in this case the amount of water evaporated is fixed i.e. 1000 ltr. From the calculation steps shown in appendix E, for the evaporation of 1000 ltr of wastewater, it can be seen that the power unit consumed for 1000 ltr is inversely proportional to the water evaporated in 1 hr at different pressures. From the effect of pressure on evaporation it can be seen that the evaporation increases with increase in pressure. So the increase in pressure will increase the amount evaporation and simultaneously the power unit consumption and operating cost of system for 1000 ltr water evaporation decreases.

The more clear results can be seen in the plots of power unit consumption vs. operating cost of the system at different pressures for 1000 ltr of water evaporation as shown in fig. 4.1.3.6.

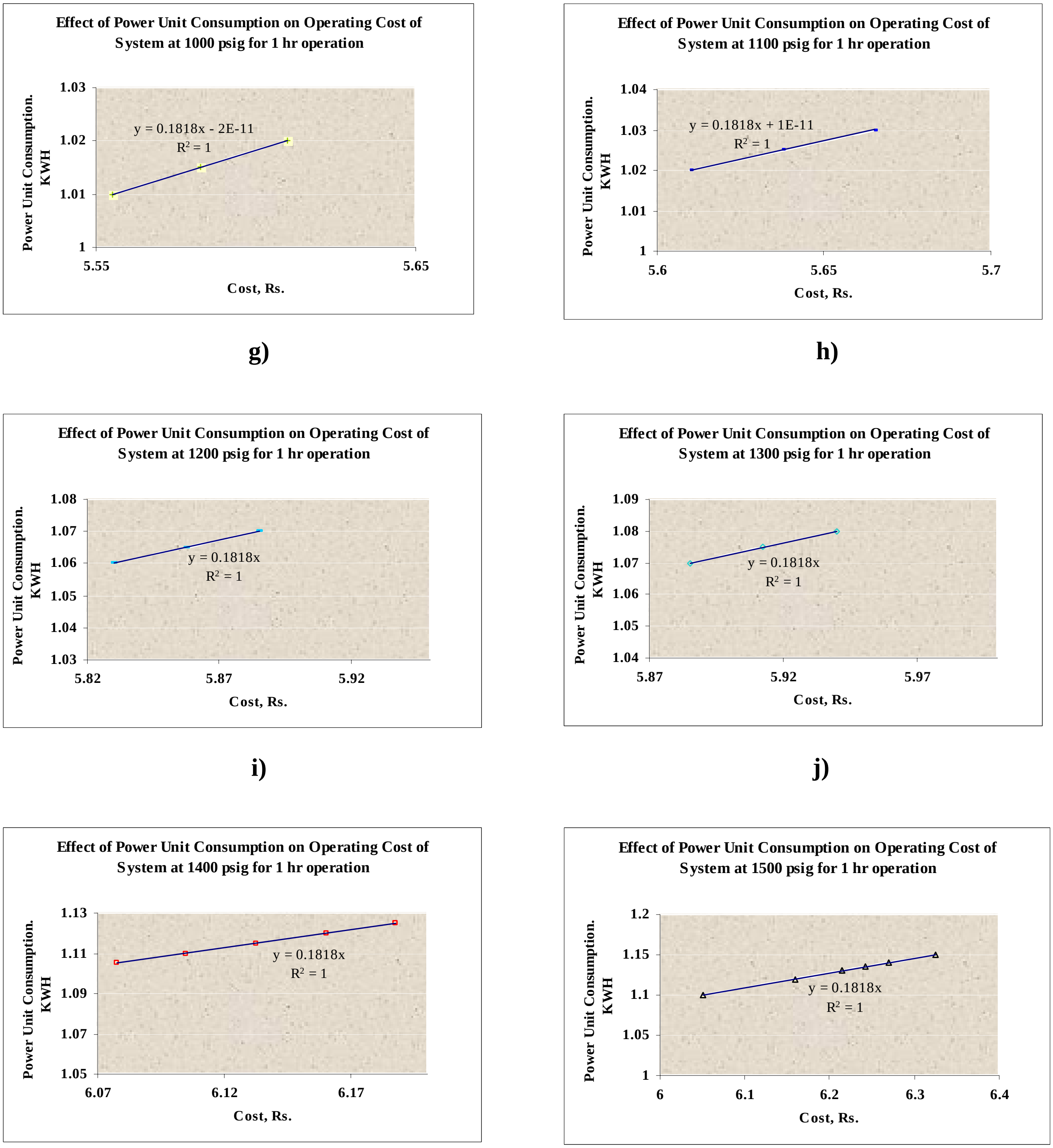
Plots of Power unit consumed vs. Operating Cost for 1hr Operation



a) b) c) d) e) f)

Figure 4.1.3.1: Plots of Power unit consumed vs. operating cost for 1 hr. at a) 300 psig b) 400 psig c) 500 psig d) 700 psig e) 800 psig f) 900 psig

Plots of Power unit consumed vs. Operating Cost for 1hr Operation



g) **h)**

i) **j)**

k) **l)**

Figure 4.1.3.2: Plots of Power unit consumed vs. operating cost for 1 hr. at g) 1000 psig h) 1100 psig i) 1200 psig j) 1300 psig k) 1400 psig l) 1500 psig

Plots of Power unit consumed vs. Operating Cost for 1000 ltr water evaporation

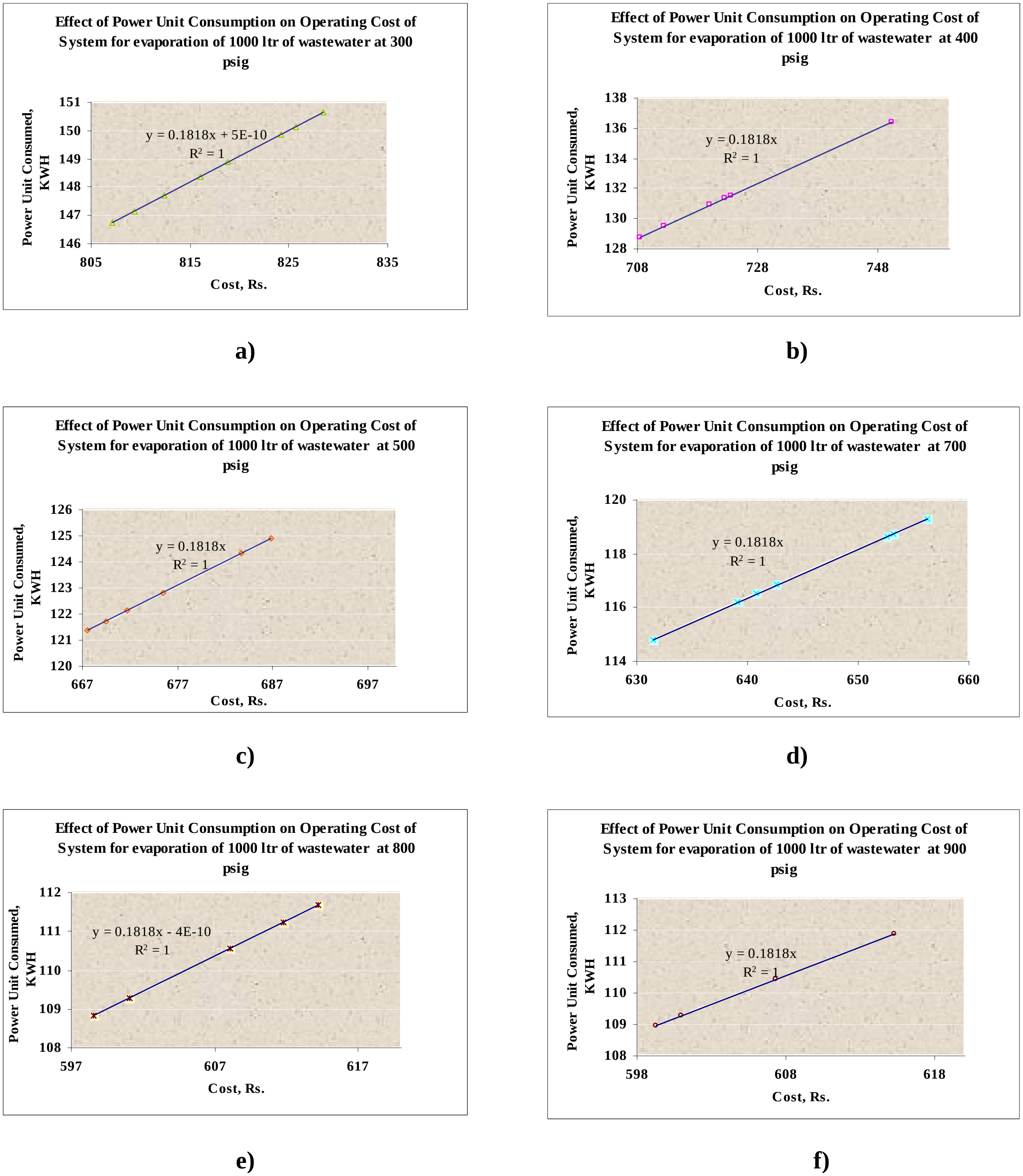


Figure 4.1.3.4: Plots of Power unit consumed vs. operating cost for1000 ltr of water evaporation at a) 300 psig b) 400 psig c) 500 psig d) 700 psig e) 800 psig f) 900 psig

Plots of Power unit consumed vs. Operating Cost for 1000 ltr water evaporation

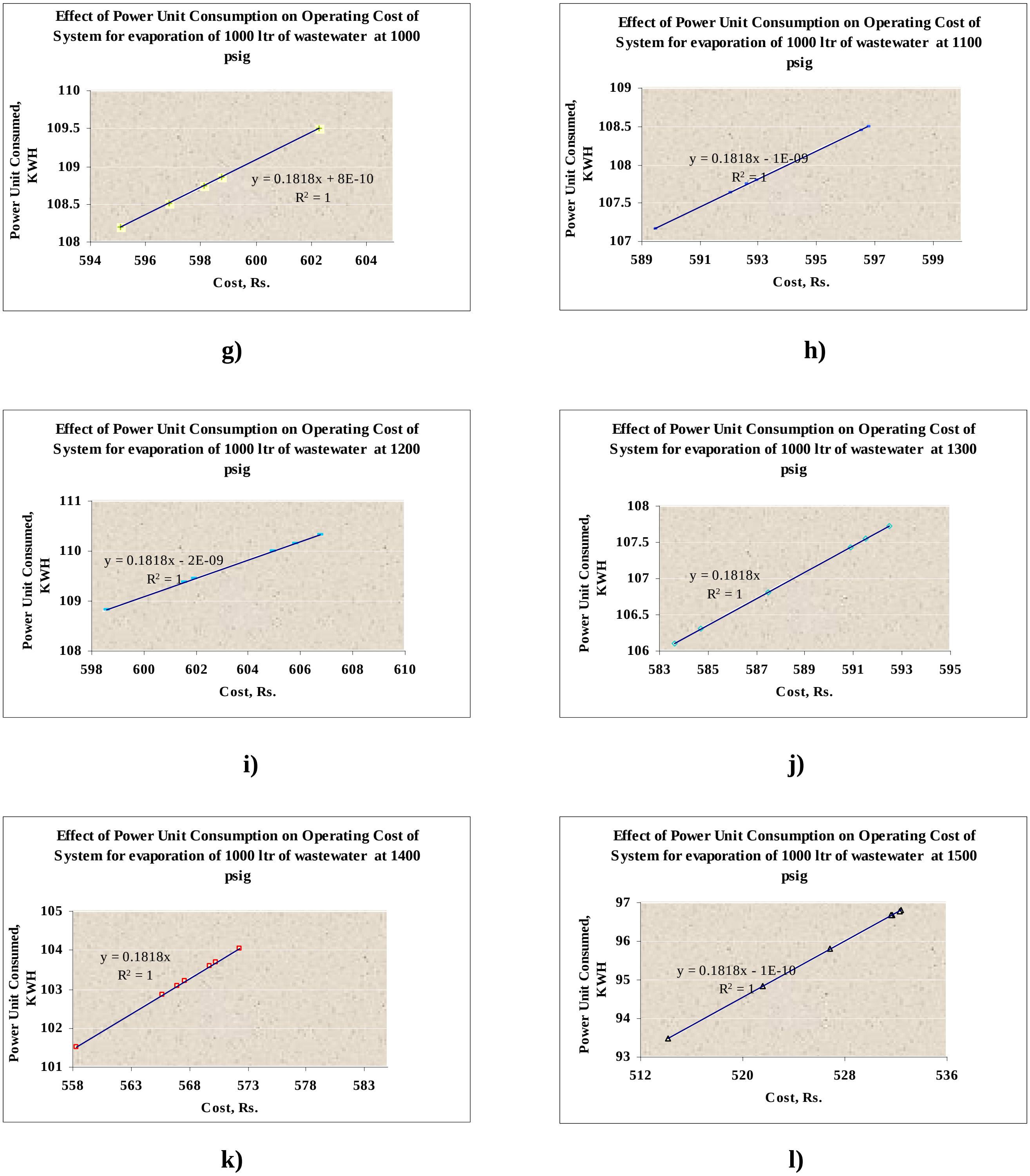


Figure 4.1.3.5: Plots of Power unit consumed vs. operating cost for 1000 ltr. of water evaporation at g) 1000 psig h) 1100 psig i) 1200 psig j) 1300 psig k) 1400 psig l) 1500 psig

Plots of Pressure vs. Power unit consumed & Operating Cost

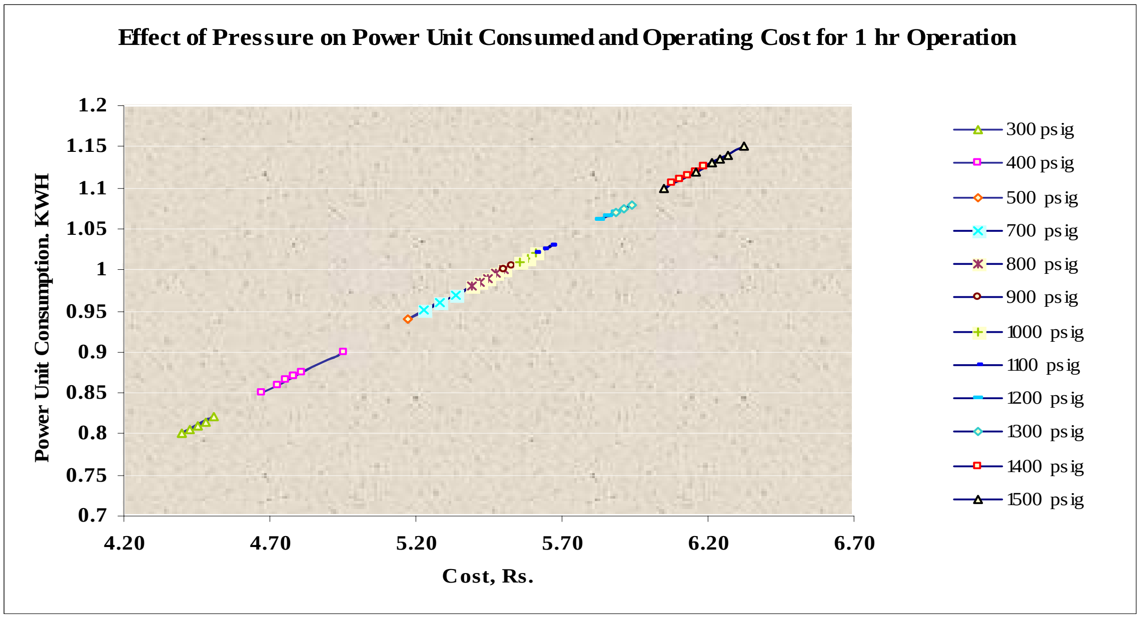


Figure 4.1.3.3: Graphs showing behavior of power unit consumed & Operating cost at different pressures for 1 hr. operation

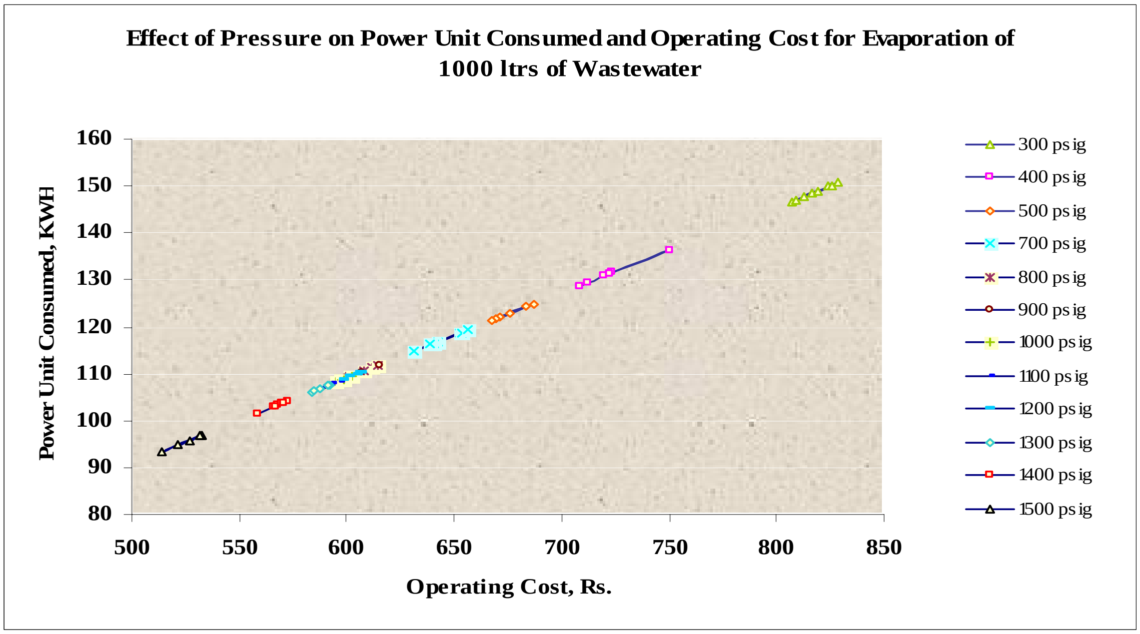


Figure 4.1.3.6: Graphs showing behavior of power unit consumed & Operating cost at different pressures for 1000 ltr. of waste water evaporation

4.1.4 Plots of Average Results of Batch Operation for 1 hour:

The results as shown in table 4.1.1 to table 4.1.12 at different pressures were averaged and are shown in table 4.1.4.1.

Figure 4.1.4.1(a) shows plot of the effect of pressure on the inlet (I) to the pump, bypass from the pump, outlet from the pump and recollect coming out from the bottom of the duct. The plot shows that the inlet to the pump remains constant with increasing pressure because the total amount of wastewater intake by the pump is the capacity of the pump and it does not vary with varying pressure. The plot also shows that bypass from the pump decreases with increasing pressure. At lower pressure it is at a higher side and at a higher pressure it is at a lower side. The outlet from the pump increases with increasing pressure because it is the difference between the inlet to the pump and bypass from the pump as shown in Appendix E and as the bypass decreases with increasing pressure, the outlet will definitely increase**.** The recollect coming out from the bottom of the duct increases with increasing in the pressure because with increasing pressure, the size of the water droplet decreases and the droplets coming out from the high pressure system will be in large amount, as a result the collision between this fine water droplets increases which leads to the combination of this fine droplets to form large droplets. The large droplets formed are unable to remain suspended in air and fall down into the duct, which comes out from the bottom of the duct.

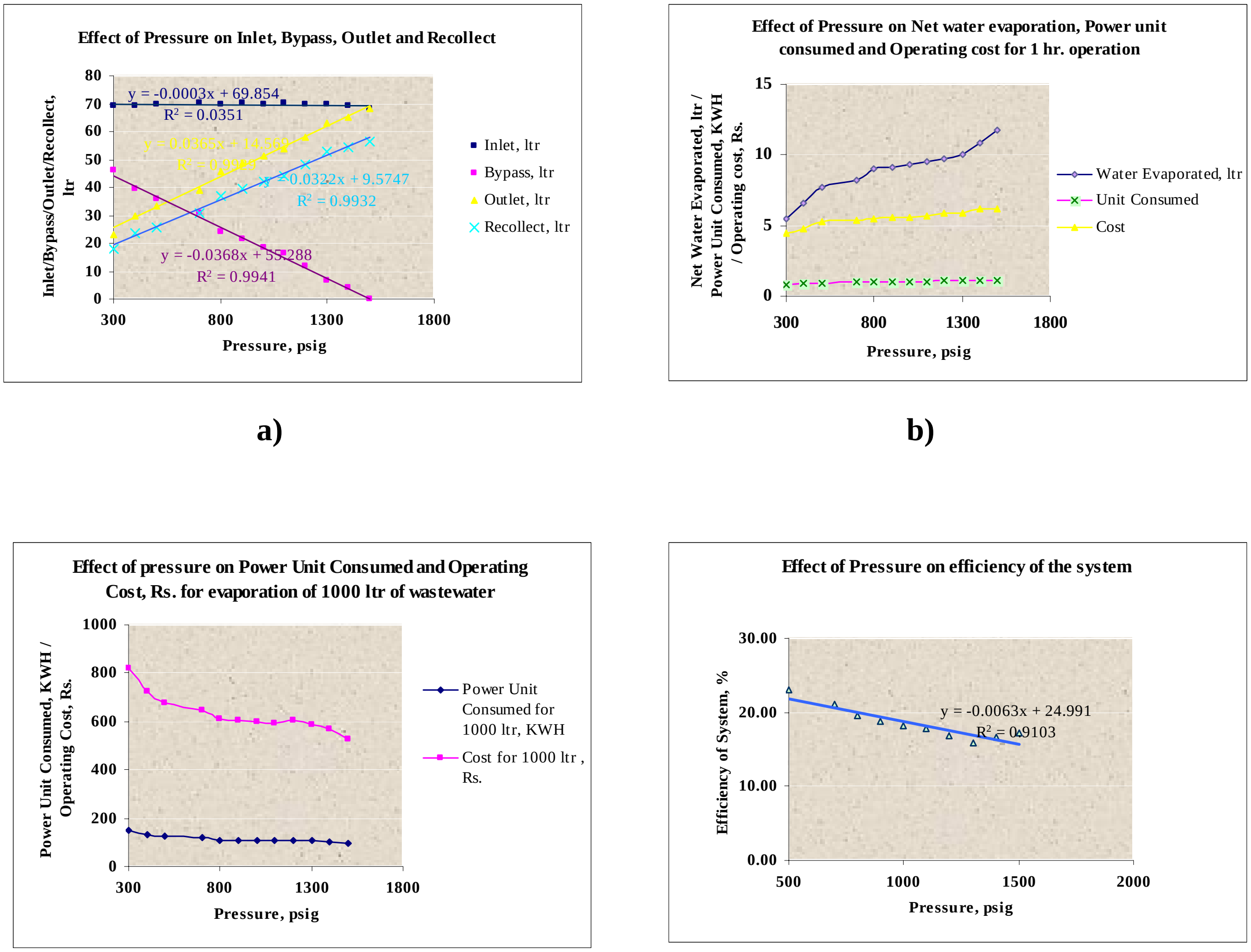
Fig. 4.1.4.1(b) & (c) shows plot of the effect of pressure on the net water evaporation, power unit consumed and the operating cost of the system for 1 hr operation and for 1000 ltr water evaporation respectively. The plots are similar to the former plots described for this effect.

Fig. 4.1.4.1(d) shows plot of the effect of the pressure on the efficiency of the system in terms of % evaporation and is calculated as per Appendix E. It can be seen that it decreases with increasing pressure due to the reason that the net water evaporation increases with increasing pressure with a very small difference compared to the increase in the outlet from the pump with a large difference.

Table 4.1.4.1: Average Results: For 1 hr Batch Operation

Pressure, psig	Inlet, ltr	Bypass, ltr	Outlet, ltr	Recollect, ltr	Water Evaporated, ltr	Power Unit Consumed, KWH	Cost, Rs.	Power Unit Consumed for 1000 ltr, KWH	Cost for 1000 ltr , Rs.	Efficiency %
300	69.16	45.91	23.25	17.82	5.43	0.81	4.44	148.69	817.79	23.35
400	69.28	39.3	29.98	23.36	6.62	0.87	4.79	131.43	722.84	22.08
500	69.66	36.1	33.57	25.85	7.72	0.95	5.22	122.87	675.80	23.00
700	70.02	30.83	39.19	30.93	8.26	0.97	5.33	117.3	645.14	21.08
800	69.89	24.18	45.71	36.73	8.97	0.99	5.45	110.32	608.79	19.62
900	70.41	21.63	48.79	39.65	9.14	1.01	5.53	110.13	605.71	18.73
1000	69.89	18.7	51.18	41.83	9.35	1.02	5.59	108.77	598.21	18.27
1100	70.22	16.57	53.65	44.14	9.51	1.03	5.64	107.88	593.35	17.73
1200	69.53	11.66	57.87	48.16	9.72	1.07	5.86	109.68	603.25	16.80
1300	69.66	6.6	63.06	53.01	10.05	1.08	5.91	106.99	588.44	15.94
1400	69.28	3.92	65.36	54.53	10.83	1.12	6.14	103.14	567.28	16.57
1500	68.4	0	68.4	56.62	11.78	1.13	6.21	95.86	527.23	17.22

Plots of Average Results



a)

b)

d)

Figure 4.1.4.1: a) Plot showing effect of pressure on inlet, bypass, outlet and recollect for average results.

b) Plot showing effect of pressure on net water evaporated, power unit consumed and operating cost of the system for average results.

c) Plot showing effect of pressure on power unit consumed and operating cost for evaporation of 1000 ltr of wastewater for average results.

d) Plot showing the effect of pressure on efficiency of the system for average results.

4.2 CONTINUOUS OPERATION:

The Process flow diagram of the existing Zero Discharge System for the continuous operation is shown in fig 3.1.2. Experiments were conducted with the fixed amount of initial volume of wastewater taken in the collection tank (T1) and the pump bypass line and recollect line were continuously recycled to see at the time required to evaporate fixed amount of wastewater at varying pressure.

The results of the continuous operation are shown in table 4.2.1. Fig. 4.2.1(a) shows the plot of effect of the temperature on relative humidity measured at the top and bottom of the duct respectively. It shows similar behavior as described in the batch operation.

Fig. 4.2.1(b) shows the plot of effect of the pressure on the time required for evaporation. The fixed amount of initial volume i.e. 18.4 ltr. of wastewater was taken in continuous operation. It can be seen that with increasing pressure the time required to evaporate 18.4 ltr wastewater decreases due to the reason that with increasing pressure more water droplets will be formed of smaller size compared to that at lower pressure benefiting the advantage of exposure of higher surface area of water droplets into the air. This leads to the higher evaporation in lesser time.

Fig 4.2.1(c), (d) & (e) shows the plot of effect of the pressure on net water evaporation, power unit consumed & operating cost for 1 hour, the effect of the power unit consumed on operating cost for 1 hour and the effect of the pressure on net water evaporation, power unit consumed & operating cost for 1000 ltr of water evaporation. The plot shows the similar effect as the batch operation.

Table 4.2.1: Results of Continuous Operation

P psig	**Temp ^{o}C**		**RH %**		**V_I ltr**	**V_F ltr**	**Water Evaporated, ltr**	**Time required for evaporation hr**	**Water Evaporated in 1 hr., ltr**	**Pump unit, KW**	**Blower Unit, KW**	**Total Power Unit Consumed, KW**	**Total Power Unit Consumed, KWH**	**Cost, Rs. for 1 hr**	**Power Unit Consumed for 1000 ltr, KW**	**Cost for 1000ltr, Rs.**
	B_D	**T_D**	**B_D**	**T_D**												
300	34	31	21	36	18.4	1.62	16.78	3.27	5.13	0.89	1.8	2.69	0.82	4.52	160.31	881.70
400	36	34	17	31	18.4	1.8	16.60	2.65	6.26	0.901	1.45	2.351	0.89	4.88	141.63	778.95
500	29	27	33	47	18.4	1.45	16.95	2.32	7.31	0.95	1.27	2.22	0.96	5.26	130.97	720.35
700	31	28	30	44	18.4	1.6	16.80	2.10	8.00	0.88	1.15	2.03	0.97	5.32	120.83	664.58
800	33	32	24	34	18.4	1.76	16.64	1.96	8.49	0.882	1.08	1.962	1.00	5.51	117.91	648.50
900	29	28	32	45	18.4	1.4	17.00	1.92	8.85	0.89	1.056	1.946	1.01	5.57	114.47	629.59
1000	32	31	26	37	18.4	1.65	16.75	1.84	9.10	0.892	1.012	1.904	1.03	5.69	113.67	625.19
1100	32	30	26	39	18.4	1.63	16.77	1.82	9.21	0.89	1.001	1.891	1.04	5.71	112.76	620.18
1200	31	28	28	44	18.4	1.71	16.69	1.74	9.59	0.92	0.96	1.88	1.08	5.94	112.64	619.53
1300	33	31	24	38	18.4	1.58	16.82	1.73	9.72	0.94	0.95	1.89	1.09	6.01	112.37	618.01
1400	34	32	21	35	18.4	1.46	16.94	1.69	10.02	0.97	0.93	1.9	1.12	6.18	112.16	616.88
1500	35	33	19	33	18.4	1.7	16.70	1.59	10.50	0.94	0.87	1.81	1.14	6.26	108.38	596.11

P = Pressure, B_D = Bottom of the Duct, T_D = Top of the Duct, V_I = Initial Volume, V_F = Final Volume

CHAPTER – 4

RESULTS AND DISCUSSION

A pilot-scale Zero Discharge System facility has already been constructed in ATIRA, Ahmedabad. Process flow diagram of the existing Zero Discharge System for the batch and continuous operation is shown in fig. 3.1.1 and fig. 3.1.2. Several experiments were conducted using synthetic textile effluent prepared using two types of dyes i.e. Procean Brill Red HE-7B and Procean Brill Yellow HE-7R of 0.1, 0.3 & 0.5 % w/v each on batch and continuous mode. The influent characterization of synthetic textile effluent was done which is shown in table 4.1 and calculation was done as per Appendix A, B, C, &D.

Table 4.1: Influent characterization of Synthetic Textile Effluent

Sr. No.	Characteristics	Procean Brill Red HE-7B			Procean Brill Yellow HE-7R		
		0.1% w/v	**0.3% w/v**	**0.5% w/v**	**0.1% w/v**	**0.3 % w/v**	**0.5 % w/v**
1	pH	8.78	9.10	9.25	6.03	5.25	5.04
2	Color, Co-pt scale	51111	148148	244814	9259	30000	49629
3	COD, mg/l	688.69	2114.28	3675	757.14	2529.73	4186.66
4	TDS, mg/l	908	2656	4402	918	2676	4416
5	TSS, mg/l	10	19	29	6	44	84
6	TS, mg/l	918	2675	4431	924	2720	4500

4.1 BATCH OPERATION:

The Process flow diagram of the existing Zero Discharge System for the batch operation is shown in fig 3.1.1. Experiments were conducted by varying pressure in the pump (P1) and the duration of batch operation was of 1 hour. The system does not depend on the composition of the effluent. The results of batch operation are shown from table 4.1.1 to table 4.1.12 in terms of Water consumption in Storage tank (ST1), Inlet (I) to the pump (P1), Bypass (B) from pump (P1), Outlet (O) from pump (P1), Recollect (R) from the rectangular duct (D1), Net Water Evaporated, Pump (P1) power unit consumed, Air Blower (AB1) power unit consumed, Total Power unit consumed and Operating cost of the system. The temperature and relative humidity were measure with the help of digital thermo hygrometer at the bottom and top of the duct respectively. Besides this the calculation was done for the evaporation of 1000 ltr of wastewater, the power unit consumed and operating cost for 1000 ltr are as shown from table 4.1.1 to table 4.1.12**.** The calculation steps are shown in Appendix E.

4.3 COMPARATIVE STUDY FOR BATCH AND CONTINUOUS OPERATION:

Fig. 4.3.1 shows the comparative study of the batch and continuous operation for the net evaporation with respect to pressure. It can be seen that the continuous and batch operation gives almost similar results but there is a minor difference in the amount of net water evaporated at different pressure. The water evaporated in batch operation is about 5-10 % higher than that of the continuous operation. This is due to the reason that in case of batch operation there may be some error in the measurement of the bypass and recollect.

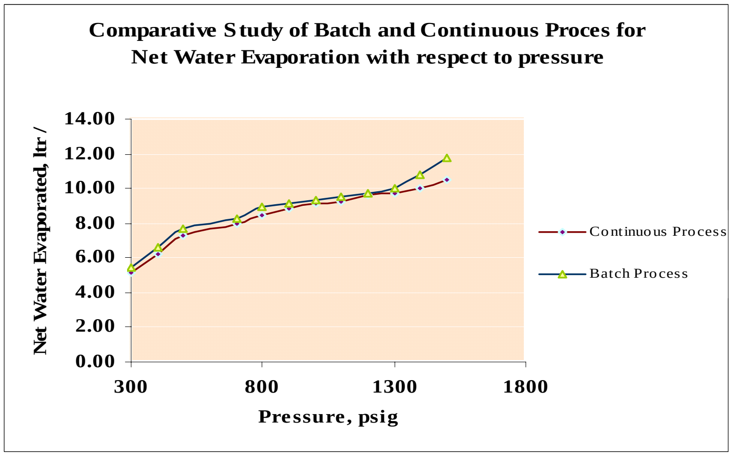


Figure 4.3.1: Plot showing the comparative study of batch and continuous operation for net water evaporation with respect to pressure

CHAPTER – 5
CONCLUSION

The main aim of the project is to achieve sustained, genuine and techno-economically viable ‘Zero Discharge’ compliance requirement of the textile industry by the regulatory body.

Several experiments were conducted at pilot scale in two modes: batch and continuous which consists of the characterization of the textile effluent, determination of the temperature and relative humidity, net water evaporated in 1 hr, power unit consumed in 1 hr and for 1 KL of waste water evaporation and the operating cost of the system for 1 hr and for 1 KL of waste water evaporation at different pressures. The result shows that the evaporation is effected by temperature, humidity, wind conditions and the water droplet size. At higher temperature, the relative humidity will be lower, higher will be the wind conditions and greater will be evaporation rate. Besides this with increasing pressure in the pump, the fine water droplets are formed benefiting the advantage of higher surface area associated with the fine water droplets. Therefore with increasing pressure, evaporation rate increases at the same time power unit consumption and operating cost also increases which comes out in the range of Rs. 400 – 800/KL of wastewater evaporation, which is too high from techno-economic point view point. These operating costs have to be maintained in the range of Rs. 20-60/KL in order to be techno-economically viable. For that, few modification in the existing design of the system are required to keep water to air ratio 1:10 instead of existing 1:1.3 ratio.

The results achieved at pilot scale are promising and if these results are scaled up appropriately for industrial scale, then it will be a great success and ‘Zero Discharge’ will no longer considered a myth!!!!

CHAPTER – 6
SCOPE FOR FUTURE WORK

In this project, ‘Zero Discharge’ have been achieved for textile effluent in a sustained and genuine manner, but it can be seen from the results that the operating cost for 1 KL of water evaporation comes in the range of Rs. 400 to Rs. 800. The higher cost comes due to the reason that the net water evaporation is much less i.e. in the range of 17 to 24 % of the outlet from the pump which is the input to the high pressure system. The rest 76 to 83 % comes out in the form of recollect due to the reason that in the present system, the water to air ratio is only 1:1.3. Therefore in future, if water to air ratio is kept as 1:10, then the 76 to 83 % recollect coming out of the duct reduces significantly thereby increasing the net water evaporation and reducing the operating cost for evaporation of 1 KL of wastewater. The project can be extended for the above mentioned modification in the existing design of the system to achieve the operating cost in the range of Rs. 20 – 60 / KL of evaporation.

As the ‘Zero Discharge’ system pilot plant at ATIRA can handle any type of effluent having TDS of up to 160,000 mg/L Therefore in addition to textile industry effluent, project can be extended for any other industrial effluent.

At present the project deals with the pilot scale trials, it can be extended to industrial scale.

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APPENDIX: A

CHEMICAL OXYGEN DEMAND (COD)

A.1 General:

Chemical Oxygen Demand (COD) test determines the oxygen required for chemical oxidation of most organic matter and oxidizable inorganic substances with the help of strong chemical oxidant. The test can be employed for the same purpose as the BOD tests taking into account its limitations. The intrinsic limitation of the test lies in its inability to differentiate between the biologically oxidizable and biologically inert material.

COD determination has an advantage over BOD determination in that the result can be obtained in about 3 hours, as compared to 5 days required for BOD test. Further the test is relatively easy, gives reproducible results and is not affected by interference's as the BOD test.

A.2 Application of COD data:

- ✓ Extensively used in the analysis of domestic and industrial wastewater.
- ✓ In conjunction with BOD test, COD test is helpful in indicating toxic conditions and the presence of biologically resistant organic substances.
- ✓ COD test is used widely in the operation of treatment facilities because of the speed with which results can be obtained.

A.3 Principle:

Reflux digestion method:

The organic matter and oxidizable inorganic substances present in water or wastewater get oxidized completely by standard potassium dichromate ($K_2Cr_2O_7$) in the presence of H_2SO_4 to produce $CO_2 + H_2O$. The excess $K_2Cr_2O_7$ remaining after the reaction is titrated with ferrous ammonium sulfate [$Fe(NH_4)_2(SO_4)_2$]. The dichromate consumed gives the O_2 required for the oxidation of organic matter. The contents are refluxed for 2 hours. Reactions are as under:

$$\mathbf{2\,K_2Cr_2O_7 + 8\,H_2SO_4 \longrightarrow 2\,K_2SO_4 + 2\,Cr_2\,(SO_4)_3 + 8\,H_2O + 3O_2}$$

$$\mathbf{C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6CO_2 + 6H_2O}$$

In order for $K_2Cr_2O_7$ to oxidize organic matter, the solution is made acidic. An excess of $K_2Cr_2O_7$ must be present in COD analysis. Hence excess is added and actual amount reduced is determined. Ferrous ammonium sulfate is used for back titration.

The test is based on the principle that all organic compounds can be oxidized by strong oxidizing agents in acidic media. Hence:

- ✓ COD values are always greater than BOD values. COD values are too large, if greater amounts of biologically resistant organic matter are present, i.e. lignin.
- ✓ COD values do not provide any information on the rate at which actual biodegradation will take place.
- ✓ Reflux condensers are used to prevent loss of volatile organic compounds.

A.4 Interferences:

1. Fe(II) and hydrogen sulfide exert COD of 0.14 mg/mg Fe^{2+} and 0.47 mg/mg H_2S respectively.
2. The chlorides interference is eliminated by addition of mercury salt (mercury sulfate), which precipitates chlorides as $HgCl_2$: $Hg^{2+} + 2Cl^- = HgCl_2$. Although 1 g $HgSO_4$ is specified for 50mL sample, a lesser amount may be used where sample chloride concentration is known to be less than 2000 mg/L or as long as a 10:1 ratio of $HgSO_4$: Cl^- is maintained.
3. Addition of Ag_2SO_4 to concentrated H_2SO_4 acts as a catalyst to stimulate the oxidation of straight chain aliphatic and aromatic compounds.
4. Nitrite (NO^{2-}) exerts a COD of 1.1 mg/mg NO_2-N. Sulfamic acid is added at 10 mg sulfamic acid for every 1 mg of NO_2-N in the refluxing flask. Add sulfamic acid to the standard $K_2Cr_2O_7$, since it must be included in the distilled water blank.

A.5 Sample Handling:

Natural, not very heavily polluted water should be analyzed on the same day or at least within 24 hours. If there is to be a delay before analysis, the sample may be preserved by adding, sulfuric acid, about 2mL H_2SO_4 (d = 1.84) to each 100 mL of sample. If samples are to be stored for longer than 24 hours, deep freezing is recommended.

Safety Precautions:

1. Handling concentrated sulfuric acid, especially at the start of refluxing step requires extreme care.
2. Silver sulfate is poisonous, and hence contact with the chemical and its solution must be avoided.

3. Mercuric sulfate is very toxic and hence contact with the chemical and its solution must be avoided.

A.6 Apparatus:

1. COD Reflux apparatus consisting of a 500-mL capacity flat bottom flask with condenser.
2. A heating mantle

A.7 Chemicals Required:

1. Potassium dichromate ($K_2Cr_2O_7$)
2. Sulfuric acid (H_2SO_4) – Silver sulphate (Ag_2SO_4) solution
3. Mercuric sulphate ($HgSO_4$)
4. Ferrous ammonium sulfate (FAS) [$Fe(NH_4)_2(SO_4)_2$]
5. Ferroin indicator

A.8 Reagents:

1. *Standard potassium dichromate, 0.25 N:* Dissolve 12.259 g of potassium dichromate (dried at 103^{o}C for 24 hr) in distilled water and dilute to 1 L.

2. *Sulphuric acid-silver sulfate reagent:* Add 10 g of silver sulfate to 1000 mL of concentrated sulphuric acid (H_2SO_4) and keep overnight for dissolution.

3. *Ferroin Indicator:* Dissolve 1.485g of 1, 10-phenanthroline monohydrate and 0.695 g of ferrous ammonium sulphate heptahydrate in distilled water and dilute to approximately 100 mL.

4. *Standard ferrous ammonium sulfate (FAS), 0.25 N:* Dissolve 98 g of ferrous ammonium sulphate hexahydrate in about 400 mL distilled water. Add 20mL of concentrated sulphuric acid (H_2SO_4). Cool and dilute to exactly 1L. The ferrous ammonium sulfate (FAS) titrant must be standardized daily by the following procedure:

Dilute 10ml of standard potassium dichromate ($K_2Cr_2O_7$) solution to 100ml with distilled water. Slowly add 30ml of concentrated sulphuric acid and cool to room temperature.

Titrate with ferrous ammonium sulphate titrant, using 2 to 3 drops (0.10 to 0.15 ml) of Ferroin indicator.

Normality of FAS = [(ml $K_2Cr_2O_7$) * 0.25] / (ml of FAS required)

The deterioration of FAS can be decreased if it is stored in a dark bottle.

A.9 Procedure:

1. Take a 500 mL capacity flat-bottom conical flask and add 0.4 g of $HgSO_4$.
2. Add 20 mL of sample or an aliquot of sample diluted to 20 mL with distilled water and mix well.
3. Add few glass beads followed by 10 mL of potassium dichromate depending upon the expected COD.
4. Add slowly 30 mL concentrated sulfuric acid + silver reagent and mix thoroughly. The slow addition along with swirling prevents fatty acids to escape out due to high temperature.
5. Mix well. If the color turns green, take either fresh sample with lesser aliquot or add more dichromate and sulfuric acid. Connect the flask to condenser. Mix the contents before heating. Improper mixing will results in bumping and sample may be blown out.
6. Reflux for a minimum of 2 hours. Cool and then wash down the condenser with distilled water.
7. Dilute for a minimum of 150 mL (about 300 mL), cool to room temperature and titrate potassium dichromate remaining after refluxing with corresponding standard ferrous ammonium sulfate using ferroin as an indicator (8-10 drops). Sharp color change from blue green to wine red indicates end point or completion of the titration.
8. Perform blank in the same manner using distilled water instead of sample.

A.10 Calculation:

$$\text{COD (mg/L)} = \frac{[(A - B) * N * 8 * 1000]}{\text{Sample size (mL)}}$$

Where:

A = mL of $[Fe(NH_4)_2(SO_4)_2]$ used for blank,

B = mL of $[Fe(NH_4)_2(SO_4)_2]$ used for sample,

N = Normality of FAS titrant $[Fe(NH_4)_2(SO_4)_2]$

8 = milliequivalent weight of oxygen.

Sample Calculation: Table….. COD = 688.69 mg/L

$$\text{COD (mg/L)} = \frac{[(A - B) * N * 8 * 1000]}{\text{Sample size (mL)}}$$

A = 24.1 mL, B = 14.2 mL, N = 0.1, Sample size = 11.5 mL

∴ COD = [(24.1 – 14.2) * 0.1 * 8000] / 11.5 = 688.69 mg/L

Source:

⇨ Eaton Andrew D. et.al, “Standard Methods for the Examination of Water & Wastewater”, 1995, Pg. Nos.: 5-12 to 5-15.

⇨ Maiti S. K., “Handbook of methods in Environmental Studies”, Analysis of Water & Wastewater, Vol. 1, 2001, Pg. Nos.: 60-66.

APPENDIX - B

TOTAL DISSOLVED SOLIDS (TDS)

B.1 General:

A large number of solids are found dissolved in natural waters, the common ones are carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates of calcium, magnesium, sodium, potassium, iron, etc. In other words, TDS is simply the sum of the cations and anions concentration expressed in mg/L.

B.2 Environmental significance:

A high content of dissolved solids elevates the density of water, influences osmoregulation of freshwater organisms, reduces solubility of gases (like oxygen) and reduces utility of water for drinking, irrigation and industrial purposes. TDS concentration beyond 500 mg/L, decreases palatability and may cause gastrointestinal irritation.

B.3 Principle:

A well-mixed, measured portion of sample is filtered through a standard glass-fibre filter and the filtrate portion is evaporated at $180 \pm 2\ ^{o}$ C and that gives the amount of total dissolved solids. The reason for higher temperature used is to remove all mechanically occluded water. Where organic matter is generally very low in concentration, the losses due to higher drying temperature will be negligible.

B.4 Apparatus:

1. Evaporating dishes
2. Analytical balance
3. Dessicator
4. Hot air oven
5. Filter paper (Whatman No. 41)

B.5 Procedure:

1. Take an evaporating dish of suitable size, make it clean, dry at 103-105 ^{o} C, cool in desiccator and not the initial weight (W_i).
2. Filter about 100 mL to 250 mL of sample through filter paper (Whatman No. 41) and

take the filtrate in the evaporating dish. Choose the sample volume to yield 10 to 200 mg of dried residue.

3. Evaporate the sample in a hot air oven at 180 ± 2 ^{o} C and after the whole water is evaporated, cool the evaporating dish in a desiccator and take the final weight (W_f).

B.6 Calculation:

$$\text{Total dissolved solids, mg /L} = \frac{(W_f - W_i) * 1000 * 1000}{V}$$

Where:

W_f =Final weight of evaporating dish, g

W_i = Initial weight of evaporating dish, g

V = Volume of the sample taken (mL)

Sample Calculation: Table…. TDS = 908 mg/L

$$\text{Total suspended solids, mg /L} = \frac{(W_f - W_i) * 1000 * 1000}{V, mL}$$

W_f = 50.3214 g, W_i = 50.2760 g, V = 50 mL

$\therefore$ TSS = [(50.3214 – 50.2760) * 1000 * 1000] / 50 = 908 mg/L

Source:

⇨ Maiti S. K., “Handbook of methods in Environmental Studies”, Analysis of Water & Wastewater, Vol. 1, 2001, Pg. Nos.: 144-145.

APPENDIX - C

TOTAL SUSPENDED SOLIDS (TSS)

C.1 General:

The term Total Suspended Solids (TSS) applies to the dry weight of the material that if removed from a measured volume of water sample by filtration through a standard filter. TSS are responsible for the following physical problems:

- They cut down light transmission through the water and so lower the rate of photosynthesis in aquatic flora.
- In less turbulent parts of river, some of the solids may sediment out, smothering life of the river bed.

The TSS determination is extremely valuable in the analysis of polluted water. It is a major parameter used to evaluate the strength of domestic wastewater and to determine the efficiency of treatment unit.

C.2 Precautions:

1. Results may be questionable if the TSS includes oils, grease or other volatile matter.
2. Exclude large floating particles or submerged agglomerates of non-homogenous material from the sample.
3. In case of highly polluted water, sewage or wastewater, excessive residue on the filter paper may form a water-entrapping crust, in such case; limit the sample size so that yielding no more than 200 mg residue.
4. Prolonged filtration times resulting from filter clogging may produce high results owing to increased colloidal materials captured on the clogged filter.

C.3 Apparatus:

1. Evaporating dishes of 100 mL capacity made up of porcelain
2. Desiccator
3. Drying oven or hot air oven, for operation at 103 to 105 ^{o} C.
4. Analytical balance, capable of weighing to 0.1 mg.
5. Glass fiber filter paper
6. Filtration apparatus and suction flask.

C.4 Procedure:

- Assemble filtration apparatus and begin suction. Sufficient sample should be filtered, if possible, to yield an increase in weight of about 10 mg. This often requires filtration of 500 mL or more of sample of biologically treated wastewater or lightly polluted waters. Choose the sample volume to yield 10 to 200 mg of dried residue.
- Carefully remove the filter paper from filtration apparatus. Dry for at least 1 hour at 103 to 105 ^{o} C in a hot air oven, cool in a dessicator and weigh.

C.5 Calculation

$$\textbf{Total suspended solids, mg/L} = \frac{(W_f - W_i) * 1000 * 1000}{\text{Volume of sample, mL}}$$

Where:

W_f =Final weight of filter paper, g

W_i = Initial weight of filter paper, g

Sample Calculation: Table…. TSS = 10 mg/L

$$\text{Total suspended solids, mg/L} = \frac{(W_f - W_i) * 1000 * 1000}{\text{Volume of sample, mL}}$$

$W_f = 0.0945$ g, $W_i = 0.0935$ g, V = 100 mL

$\therefore$ TSS = [(0.0945 - 0.0935) * 1000 * 1000] / 100 = 10 mg/L

Source:

⇨ Maiti S. K., “Handbook of methods in Environmental Studies”, Analysis of Water & Wastewater, Vol. 1, 2001, Pg. Nos.: 144-145.

APPENDIX - D

TOTAL SOLIDS (TS)

D.1 Principle:

Total Solids (TS) is the measure of all kinds of solids i.e. suspended, dissolved and volatile solids. Total solids can be determined as the residue left after evaporation at 103 to 105 ^{o} C of the unfiltered sample. It consists of two parts: Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).

Each fraction is again divided into volatile suspended solids (VSS) and fixed solids after heating at 550 ^{o} C. VSS is the organic fraction that lost as CO_2 and fixed solids are the ash portion that remains.

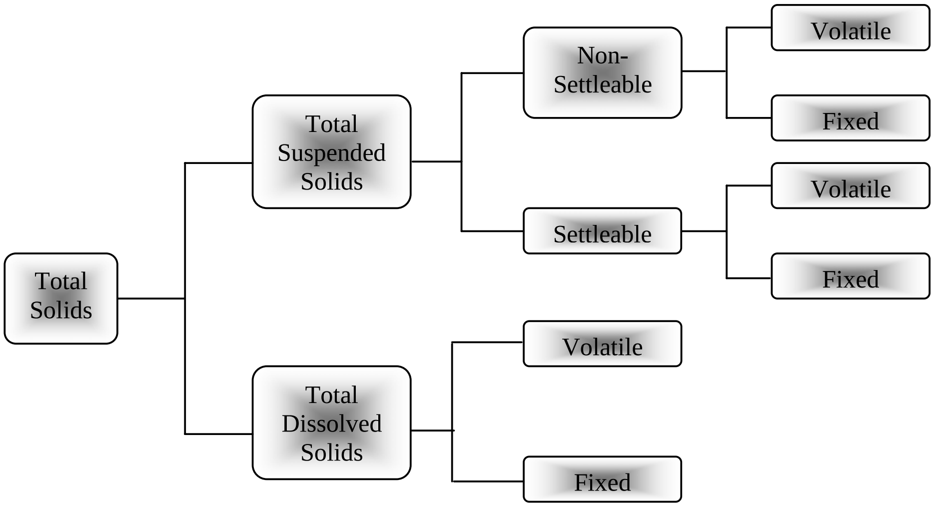

Figure D.1: Classification of Total Solids

D.2 Apparatus:

1. Evaporating dishes: Dishes of 100 mL capacity made up of either porcelain or platinum.
2. Desiccator, provided with a desiccant containing a colour indicator of moisture ($CuSO_4.5H_2O$).
3. Drying Oven or hot air oven, for operation at 103 to 105 ^{o} C.
4. Analytical balance, capable of weighing to 0.1 mg.

D.3 Procedure:

- Take an evaporating dish or clean beaker (400 mL capacity) of suitable size and dry at 103 to 105 ^{o} C for 1h. Store and cool the dish in desiccator until needed. Weigh immediately before use. Note the initial weight (W_i) in mg.

- Put 250-300 mL unfiltered well-mixed sample in it.
- Put in hot air oven at 103 - 105 °C for 2h up to dryness.
- Cool in desiccator and take the final weight (W_f) in mg.
- Repeat cycle of drying, cooling, desiccating and weighing until a constant weight is obtained, or weight change is less than 4 % of previous weight or 0.5 mg, whichever is less. When weighing dried sample, be alert to change in weight due to are exposure and / or sample degradation. Duplicate determination should be within 5% of the average.

D.4 Calculation:

$$\textit{Total solids, mg/L} = \frac{(W_f - W_i) * 1000}{\textit{Volume of sample, mL}}$$

Where:

W_f =Final weight of evaporating dish, mg

W_i = Initial weight of evaporating dish, mg

Or

Total solids, mg /L = Total Dissolved Solids, mg/L + Total Suspended Solids, mg/L

Sample Calculation: Table…. TS = 918 mg/L

Total solids, mg /L = Total Dissolved Solids, mg/L + Total Suspended Solids, mg/L

TDS = 908 mg/L, TSS = 10 mg/L

$\therefore$ TS = 908 + 10 = 918 mg/L

Source:

⇨ Maiti S. K., “Handbook of methods in Environmental Studies”, Analysis of Water & Wastewater, Vol. 1, 2001, Pg. Nos.: 143-144.

APPENDIX - E

RESULTS CALCULATION STEPS

E.1 Water Consumption:

At the start of the experiments, wastewater was injected into the storage tank (ST1) and the initial level of the water was measured. After 1 hour, the final level was measured. The difference in the initial and final level is the amount of wastewater consumed.

Water Consumed, cm = Initial water level, cm + Final water level, cm

Sample calculation: For 300 psig

Initial water level: 76.3 cm, Final water level: 49.5 cm

$\therefore$ ***Water consumed, cm = 76.3-49.5 = 26.8 cm***

E.2 Inlet (I) to Pump (P1):

The capacity of the storage tank (ST1) is 232 m^3 and the diameter & height are 0.57295 and 0.9 m respectively. The inlet to pump is calculated by the following equation:

$$\textbf{Inlet to the pump, ltr} = \left(\frac{\Pi}{4} * D^2 * H\right) * 1000$$

D = Diameter of the Storage Tank, m

H = Water Consumption, m

Sample calculation: For 300 psig

Diameter of Storage Tank = 0.57295 m, Water Consumption = 0.268 m

$\therefore$ ***Inlet to the pump, ltr =*** $\frac{\Pi}{4} * 0.57295^2 * 0.268 * 1000 = 69.06$ ***ltr.***

E.3 Bypass (B):

The Bypass (B) coming out of the pump (P1) was measured with the help of measuring cylinder.

Sample calculation: For 300 psig

$\therefore$ ***Bypass = 47.2 ltr.***

E.4 Outlet (O) from pump (P1):

The outlet (O) from the pump (P1) is the difference between the inlet to the pump and bypass coming out of the pump.

Outlet (O) from the pump (P1) = Inlet (I) to Pump (P1) – Bypass (B) from pump (P1)

Sample calculation: For 300 psig

Inlet to the pump = 69.06 ltr, Bypass from the pump = 47.2 ltr.

∴ ***Outlet from the pump = 69.06 – 47.2 = 21.86 ltr.***

E.5 Recollect (R) from the duct (D1):

The Recollect (R) coming out from the bottom of the duct (D1) was measured with the help of measuring cylinder.

Sample calculation: For 300 psig

∴ ***Recollect (R) = 16.47 ltr.***

E.6 Net Water Evaporated:

The Net water evaporated is the difference between the outlet (O) coming out from the pump (P1) and the recollect (R) collected at the bottom of the duct.

Net water evaporated ltr. = Outlet (O) from pump (P1) – Recollect (R)

Sample calculation: For 300 psig

Outlet (O) from pump (P1) = 21.86 ltr, Recollect (R) = 16.47 ltr

∴ ***Net Water Evaporated = 21.86 – 16.47 = 5.39 ltr.***

E.7 Power Unit Consumed:

The power unit consumed is measured with the help of energy meter provided and it is the sum of the power unit consumed for pump (P1) and blower (AB1).

Power Unit Consumed, KWH = Pump unit, KWH + Blower unit, KWH

Sample calculation: For 300 psig

Pump unit = 0.25 KWH, Blower Unit = 0.55 KWH

∴ ***Power Unit Consumed = 0.25 + 0.55 = 0.8 KWH***

E.8 Operating cost of the system:

Since the input to the system is only electricity, the operating cost of the system have been calculated by keeping the base as Rs. 5.5/Unit power consumed and is calculated by the following formula:

Operating cost of the system, Rs. = 5.5 * Power unit consumed, KWH

Sample calculation: For 300 psig

Power Unit Consumed =0.8 KWH

∴ ***Operating cost of the system, Rs. = 5.5 * 0.8 = Rs. 4.40***

E.9 Power unit consumed for 1000 ltr. of water evaporation:

The power unit consumed for the evaporation of 1000 ltr. of water is calculated as follows:

Power unit consumed for 1000 ltr. of water evaporation, KW = (1000 * power unit consumed for 1 hr., KWH)/ (water evaporated in 1 hr., ltr.)

Sample calculation: For 300 psig

Power unit consumed for 1 hr. = 0.8 KWH, Water evaporated in 1 hr. = 5.39 ltr.

∴ ***Power unit consumed for 1000 ltr. of water evaporation = 1000 * 0.8 / 5.39 = 148.37 KW***

E.10 Operating cost for 1000 ltr. of water evaporation:

The operating cost for the evaporation of 1000 ltr. of water is calculated by keeping base as Rs. 5.5/Unit power consumed and is calculated as follows:

Operating cost for 1000 ltr. of water evaporation = 5.5 * Power Unit consumed for 1000 ltr., KW

Sample calculation: For 300 psig

Power unit consumed for 1000 ltr. of water evaporation = 148.37 KW

∴ ***Operating cost for 1000 ltr. of water evaporation = 5.5 * 148.37 = 816.05 KW***

E.11 Efficiency of the System, %:

The efficiency of the system is calculated based on the % evaporation which is calculated as follows:

Efficiency of the system, % = Water Evaporated in 1 hr, ltr * 100 / Water input (outlet), ltr

Sample calculation: For 300 psig

Water evaporated in 1hr = 5.39 ltr., Outlet = 21.86 ltr

∴ **Efficiency of the system, % = 5.39 *1000 / 21.86 = 24.66**