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Research Paper

Optimizing the Reverse Osmosis Process Parameters by Maximizing Recovery by Taguchi Method

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ABSTRACT: *In this study, the effects of Operating Pressure, Potential Hydrogen, Oxidation Reduction Potential and Anti Scaling Agent on multi responses like Permeate, COD, Total Solids, Conductivity and Hardness in the Reverse Osmosis Process were experimentally investigated on RO 8100 ST8 PT44 400Wl machine. The settings of RO parameters were determined by using Taguchi's experimental design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA) are employed to find the optimal levels and to analyze the effect of the RO parameters. Results show that potential of hydrogen, operating pressure, oxidation reduction potential and anti scaling agent are the four Parameters that influence the Permit more effectively and COD, Total Solids, Conductivity and Hardness respectively. Improvement in recovery of RO process is achieved with optimize setting. Finally, the ranges for best RO conditions are proposed for ZLD process.*

Keywords: *ANOVA, reverse osmosis parameters, design of experiment, multi response, orthogonal array, Taguchi method. Permeate, Recovery, Reject*

I. INTRODUCTION

One of the most important environmental problems faced by the world is the pollution that is mostly generated by industries. India is the most sugar producing country in world in recent time and integrated with distilleries and distillery waste have hazardous effects. Molasses based distilleries are classified as a 'Red' category Industry by the Central Pollution Control Board. With the amount of highly polluting, spent wash being generated at 10 to 15 times the volume of spirit produced, it is an area of major environmental concern. A recent report suggests that there are 325 molasses based distilleries in the country producing 3063 million litres/year (M.Ltr/year) of alcohol and generating 45945 M.Ltr/year of spent wash as waste annually. A Spent wash goes through different phases like pretreatment in digester then lagooning for settling of solids and then major process of reverse osmosis separating clean water from effluent and make the spent wash concentrate for agriculture Bio-composting and clean water again used in industry. In this paper the RO processes parameters are complete study and how to improve the clean water call permeate with quality in that again used in industry and study. The RO Parameters are pressure ph, ORP and anti scaling which more affect the process of RO by Taguchi Array set of representation in done so that effective utilization in resources to get the maximum quality output.

II. LITERATURE REVIEW

Lingyung Hung et.al [1] this paper states that objective of this study is to remove salt from high salinity wastewater and recycle a purified stream using an RO process. It was found that high operating pressure and temperature were beneficial for wastewater treatment using the RO process. R Gunther et al [2] states that the paper some aspect of engineering plant designs and economics of high pressure reverse osmosis system will be discussed. S. Velikova ET. Al. [3] The effects of operating pressure and feed concentration on the solute transport parameter (D,,/KS) and mass transfer coefficient (k) with respect to aqueous sodium chloride solutions for different cellulose acetate membranes have been studied. Payel Sarkar ET. Al. [4] Small scale brackish water desalination units are used in remote areas and their sustenance depend on the twin factors of consistency of product water quality and availability of raw water resources. Jongs up Hong eP. Al. [5] Pressurized oxy-fuel combustion power cycles have been investigated as alternatives. In this paper, as the extended work of our previous study, we perform a pressure sensitivity analysis to determine the optimal combustor operating pressure for the pressurized oxy-fuel combustion power cycle. R.Rauntenbach ET. Al. [6] this Paper discussed a simpler and more-energy efficient process the combination of RO, operating at 16, 120 and 200 bar, with nano filtration ad crystallizer/filtration. Jolanta Bohdziewicz ET. Al. [7] this paper review an attempt at removal of nitrate ions from tap water by means of the compound reverse osmosis process and nono filtration. In the first stage water was filtered from Nano filtration membranes which resultant in the absence of bivalent ions in the obtained permeates. Vidyadhar V. Gedam ET. Al. [8] this paper examines the influence of different operating parameters such as pressure, temperature, pH on the performance of polyamide reverse osmosis membrane. Thus, proper control of these factors is essential for successful operation and maintenance. B. A. WINFIELD et. Al. [9] states that Investigations have been made into techniques of removing sewage fouling from cellulose acetate membranes using a pilot scale reverse osmosis unit. It has been found that reductions in the pH of solutions surrounding the membrane when not pressurized are effective in loosening the fouling: Hoang ET. Al. [10] states that conversely, calcium rejection improves in the presence of even small quantities of alginate foulant at all pH values. The concentration of foulant, the feed pH and the presence of calcium are all shown to impact upon this performance. Pham Thanh Hai et. Al.[11]This project aims to investigate the effect of pH in order to improve the efficiency of the RO desalination process. Based on the primary knowledge, decreasing the pH of the solution to a certain extent can create several improvements to both the plant and the product. Bogdan C. Donose et. Al.[12]In this study, three types of commercially available RO membranes were statically exposed to hypochlorite solutions and analyzed by Fourier transform infrared spectroscopy (FTIR), Scanning Electron Microscopy (SEM) and Atomic Force Microscopy(AFM) in conjunction with performance tests.) Hiroaki Ozaki et. Al.[13] states that the investigation was conducted for synthetic wastewater and wastewater from the heavy metal industry. L. Y. Dudley ET. Al. [14] this paper highlights how the selection of appropriate proprietary chemicals and their use in conjunction with good pre-treatment design can ensure cost-effective and efficient operation. Yuelian Peng ET. Al. [15] in this work, effects of four anti-scaling and five cleaning agents on calcium sulfate scaling in direct contact membrane. C.Saleh Al-Zahrani ET. Al. [16] states that the purpose of this paper is to review the results of using different types of anti-sealant chemicals at the Al-Jubail Desalination Plant. This paper will compare the results experienced using the above chemicals. This paper will also discuss the necessity of anti-sealant selection for every operating mode in MSF evaporators. A Mubarak. ET. Al. [17] meanwhile, In this paper, a) the reaction mechanism leading to $CaCO_3$ crystallization is presented, b) the rates of the individual steps at this operational temperature are reported; and c) the inhibiting effects of antiscalants on all of the rates involved are quantified and discussed. S.A. Al-Saleh ET. Al. [18] states that in the past three decades a great deal of research activity has focus& on the development and testing of anti-scale agents. Three basic methods are commonly applied in inhibition of scale formation. The first method involves the prevention of scale deposition through pH adjustment by acid addition. The second method controls scale precipitation through the addition of special chemicals either alone or coupled with sponge ball cleaning. The third method is a combination of additive and acid addition. R.J. Xie et. Al.[19] states that changes in reduction and oxidation potential (ORP) were studied with variations in chlorine doses (0–5 mg L^{-1} NaOCl) and salinities. As expected, the ORP values were greater at higher than at lower chlorine doses for any given water.

III. TAGUCHI BASED DESIGN OF EXPERIMENTS:

Among the available methods, Taguchi design is one of the most powerful DOE methods for analyzing of experiments. It is widely recognized in many fields particularly in the development of new products and processes in quality control. The salient features of the method are as follows: a. a simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost. b. Help arrive at the best parameters for the optimal conditions with the least number of analytical investigations. c. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment’s and facilities. d. Can include the noise factor and make the design robust. e. Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists. [20] Sharda R. Nayse ET. Al. The machining processes generate a wide variety of surface textures. Surface texture consists of the repetitive and random deviations from the ideal smooth surface. These deviations are Roughness: small, finely spaced surface irregularities (micro irregularities) Waviness: surface irregularities of greater spacing (macro irregularities) lay: predominant direction of surface texture [21] Ani Idris ET. Al. states that cellulose acetate hollow fiber membranes for reverse osmosis (RO) were spun using a forced convection technique. In this study, a systematic experimental design based on Taguchi’s method (which is a fractional factorial method) has been employed for discussing the relationship between the rejection rate coefficient, permeation rate and the dry–wet spinning conditions for

making cellulose acetate hollow fibers for RO. The factors considered in the experimental design included the polymer contents (PCs), the ratio of the solvent (acetone) to swelling agents (form amide) in the dope solution, the dope extrusion rate (DER), the type of bore fluid (BF), the residence time (RT) and the nitrogen gas flushing rate (GR). The results indicate that the BF and the DER are the two most important factors in determining the performance of the RO membranes.
Taguchi defines three quality characteristics in terms of signal to noise (S/N) ratio which can be formulated for different categories which are as follows:

a. Larger is best characteristics
Data sequence for maximizing the permeate, which is higher-the-better performance characteristics, is preprocessed as per equation 3. $S/N = -10 \log ((1/n) (\Sigma (1/y2)))$……..…3, Where, y is value of response variables and n is the number of observations in the experiments.

b. Nominal and small are best characteristics
Data sequence for Chemical oxygen demand, Total Solids, Conductivity and hardness, which are lower-the-better performance characteristics, are preprocessed as per equations. $S/N = -10 \log (\hat{y}/s2y)$………………….1, $S/N = -10 \log ((l/n) (\Sigma y2))$…………..……2

2.1 Taguchi method- based design of experiments involved following steps,
a. Definition of the problem
b. Identification of noise factors
c. Selection of response variables
d. Selection of control parameters and their levels
e. Identification of control factor interactions
f. Selection of the orthogonal array
g. Conducting the matrix experiments (experimental procedure and set-ups)
h. Analysis of the data and prediction of optimum level

a. Definition of the problem

A brief statement of the problem under investigation is "To optimize the Reverse Osmosis Process parameters to minimize COD, Total solids, Conductivity and hardness and maximize the Recovery."

b. Identification of noise factors

The environment in which experiments are performed is the main external source of temperature of performance of Reverse Osmosis process. Some examples of the environmental noise factors are temperature, Feed Salinity, Cleaning Procedure and human error in operating the process.

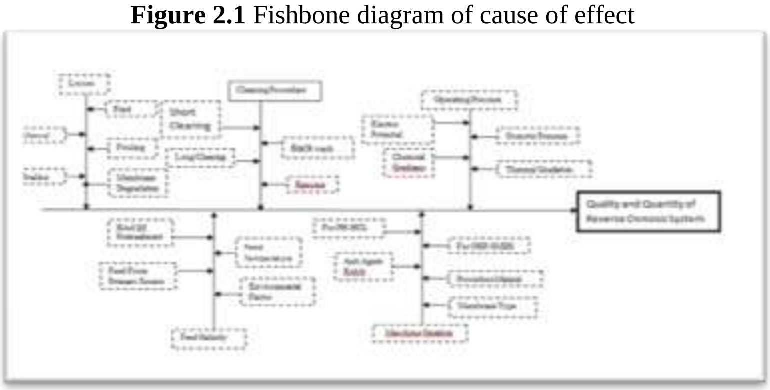
c. Selection of response variables

In any process, the response variables need to be chosen so that they provide useful information about the performance of the process under study. Various parameters used while designing the experiments. By considering all parameters given below and by taking literature review as technical base Permeate, COD, TS, COND and Hardness are chosen as response variables.

D. Selection of control parameters and their levels:

The process parameters affecting the functioning of Machine Related Parameters: Operating Pressure and Process Related parameters are - Potential of Hydrogen by HCL adding, ORP by SMBS adding and Anti scaling agent by ROHIB adding.

Figure 2.1 Fishbone diagram of cause of effect



a. selection of Operating Pressure (OP)

It is known from the fundamental of R.O process on operations pressure plays a vital role for maximizing the permeate and quality of the permeate in R.O Process note that by increasing OP the quantity of output increases with quality. Further by more increase in pressure lead to damaging the system and quality of output. Which then lead to deterioration the membrane such as quality and integrity of the system. So with destiny specification from manufacturer the range of OP is determined the effect is analyzed on output.

b. Selection of Potential of Hydrogen (PH)

RO process include that the influence of PH on output of RO on membrane efficiency. Then proper control of ph is essential for successful operation and maintenance. The changing physicochemical property of effluent produce an explanation of the modes, action of the PH effect feed PH presence of calcium impact upon the performance of RO Process. Performance test shown a reduction of de-ionized water and blackish water permeability

c. Selection of Oxidation Reduction Potential (ORP)

It is known that ORP of the feed greatly affect permeate as move the negative the ORP the better the result we get in permeate. Some quality parameter gets affected by the ORP changing. The surface of membrane get less gel formation (Concentration Polarization) paper suggests that. ORP plays a vital role in it came to smooth operation and efficiency of RO process.

d. Selection of Quantity of Anti Scaling Agent (ASA)

It is found that scaling and fouling is a major loss to the RO process by which the permeate is affected and is the qualities of permeate also. Facedown of anti-scalant is given according with the feed and avoids the machine failure. Consulting the literature review and available anti scalant is to be managed. Considering the literature review and the available machine settings following process parameters were selected for the present work:

a) Operating Pressure (OP), b)Potential OF Hydrogen (PH), c)Oxidation Reduction Potential (ORP) ,d)Anti Scaling agent (ASA)

d. Selection of orthogonal array-

Selection of particular orthogonal array from the standard O.A depends on the number of factors, levels of each factor and the total degrees of freedom.

- Number of control factors = 4
- Number of levels for control factors = 3
- Degree of freedom of each factor= number of level-1=3-1=2
- Degree of freedom of interaction of A*B= (2*2)=4
- Degree of freedom of interaction of A*C= (2*2)=4
- Degree of freedom of interaction A*D= (2*2)=4
- Total Degree of freedom of control factors = 4*2=8
- Total Degree of freedom of interaction = 4+4+4=12
- Total degree of freedom-8+12=20
- Minimum number of experiments to be conducted =20+1=21

Based on these values and the required minimum number of experiments to be conducted is 21, the nearest O.A. fulfilling this condition is L27.Therefore, Number of trials =27. The Experimental design has been shown with coded and actual values of input parameters are shown in Table 1

Table1. Methodology used for termination of reverse osmosis process

Response Variables	**In-process**	**Quantity- Permeate**	**Quality- COD, Total Solids, Conductivity, Hardness**	
Control Variables	**Process related**	Potential of Hydrogen (PH)	Oxidation Reduction Potential (ORP)	Anti Scaling Agent (ASA)
	Machine Related	Operating Pressure		
Design of Experiments		**Taguchi Method**	L27(45) Orthogonal array	
Tools & Equipments		**Machine**	**RO 8100 PHARM ST8 PT44400W**	
Membrane Type		Spiral	Plate and Frame	
Reverse Osmosis Process Component		Filter Pump, Sand Filters, Dosing Systems, Cartridge Filters, High pressure Pump, ST Modules, Inline Booster Pump, PT Modules, Servo Motor Control Valve, Diverter Valves, Cleaning System, Control Panel, Measuring Equipments Instruments, Intermediate Tank, Intermediate pump, Degasser, Permeate transfer pump, Permeate tank		
Assessment of response variables		COND Meter, (COD, Total Solids and Hardness) according to Procedure Manual of test		
Method of effect analysis		MINTAB-15 software ANOVA	Quantitative analysis of Reverse Osmosis Machine	
Criteria for analysis		Smaller the better	COD, Total Solids, Conductivity, Hardness	
Larger the better		Permeate		

IV. EXPERIMENTATION

The experiment was performed on RO 8100 ST8 PT44400W machine. The experimental set figure 4.2 consists of list of attachment and steps of different quality sensors, sense the parameter like temperature, ph, ORP, Conductivity of the feed. Some of them can be control through the different attachment given to the system such as HCL feed pump with HCL tank provide the level of ph control. Sodium Meta Bisulfate (SMBS) tank with pump that it can control ORP level of the feed anti scalant tank and pump control the scaling and fouling as per the need of the feed given. The temperature is noise factor can't be control its total depend on the environmental factor but for experimentation a small lagoon is made so that the define degree can be achieved. The four parameter and noise factor have different setting and adjustment such as Ph-HCL adding, ORP- SMBS adding, Anti Scalant- ROHIB adding and Operating Pressure- By HP pump adjustment by control this four factor over year and with whether support the experimentation are conducted. The sensors are well calibrated with six month duration. After the different setting given by taguchi array experimentation are conducted and water sample as permeate is taken to ORIPAL Lab pvt. Ltd. For COD, Conductivity, Total Solids and Hardness by a procedure manual with calibrated equipment and the result are taken out. The results are feed to MINITAB software to get the interaction and result.

Fig, IV.I Experimentation of RO Process

Parameters	TSS	COND	TDS	TH $CACO_3$	CH $CACO_3$	MH $CACO_3$	M-alkalinity as $caco_3$
Values	3000max	33600max	24000max	800max	450-500max	300max	2000max
Parameters	P-alkalinity as $caco_3$	Chlorides as Cl	Sulphates as SO4	Iron as Fe	Oil &Grease	Free chlorine	Phosphates
Values	Nil	3000-5000max	1000 – 1500max	0.5max	Nil	Nil	600 - 700max
Parameters	Sodium as Na	Potassium as K	Nitrogen	Fluoride	Total Silica as SiO2*	COD	BOD
Values	4000max	8000 - 10000max	1000 – 1100max	0.5max	30max.	27000 - 29000max	4500 – 5500max

Fig. 2 Chemical composition of spent washes

V. EXPERIMENTAL DATA ANALYSIS

Minitab 14 software was used as it provides an effortless method to create, edit and update graphs. Also it provides a dynamic link between a graph and its worksheet that helps in updating the graph automatically whenever the data is changed. Its appearance and easy to use enhancements further add to its advantages. Data analysis has been carried out by the procedural hierarchy as shown below.

1. Computation of (Signal-to-Noise Ratio) S/N ratio of experimental data. For calculating S/N ratio of Permeate, Total Solids, Conductivity and hardness, formula of S/N ratio has been selected from equation 1, 2 &3 according to the objective of optimization.
2. ANOVA is carried out to find out the contribution of each parameter on the reverse osmosis process.
3. The predicted optimal setting has been evaluated from Mean Response.
4. Finally optimal setting has been verified by confirmatory test.

VI. TAGUCHI ANALYSIS (SIGNAL TO NOISE RATIO)

The Mean S/N Ratio is used to find out Optimal Level for Each Parameter and Rank of the parameter. The Rank of the parameter shows that which parameter is most effective. The mean S/N ratio for each factor at levels 1, 2, 3and 4 can be calculated by averaging the S/N ratios for the experiments. Fig. 6.1, Fig. 6.3, fig. 6.5 shows the S/N response graph for Permeate, COD, Total Solids, Conductivity and Hardness and respectively.

Table 6.1 Response Table for Signal to Noise Ratios (Permeate) Higher is better

Level	OP	PH	ORP	ASA
1	40.69	40.23	43.99	41.98
2	43.10	46.62	46.62	43.18
3	44.88	41.82	42.11	43.51
Delta	4.19	6.39	1.88	1.53
Rank	2	1	3	4

Table 6.2 Response Table for Signal to Noise Ratios (Recovery) Larger is better

Level	OP	PH	ORP	ASA
1	28.65	28.19	31.95	29.94
2	31.06	34.58	30.53	31.14
3	32.84	29.78	30.07	31.47
Delta	4.19	6.39	1.88	1.53
Rank	2	1	3	4

VII. ANALYSIS OF VARIANCE (ANOVA)

The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output performance characteristics. In the analysis, the sum of squares and variance are calculated. F-test value at 95 % confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated.

Table 7.1 Analysis Of Variance for (Permeate) Higher is better

Source	DF	SS Adj	MS	F	% contribution
Op	2	**79.72387**	**39.861937**	195.2102	24%
Ph	2	199.4341	99.717094	488.3305	62%
Orp	2	17.45676	8.7283843	42.74429	054%
Asa	2	11.81435	5.9071779	28.92839	036%
Op+Ph	4	9.386	2.3464	11.49	22%
Op+Orp	4	0.735	0.1837	0.90	25%
Op+Asa	4	0.627	0.1568	0.77	15%
Residual Error	6	1.225	0.2042		
Total	26	319.68			

Table 7.2 Analysis of Variance for Recovery Higher is better

Source	DF	SS Adj	MS	F	% contribution
OP	2	**79.72387**	**39.86194**	195.2102	0.24
PH	2	199.4342	99.71709	488.3305	0.62
ORP	2	17.45677	8.728384	42.74429	0.05
ASA	2	11.81436	5.907178	28.92839	0.03
OP+PH	4	9.386	2.3464	11.49	0.45
OP+ORP	4	0.735	0.1568	0.90	0.45
OP+ASA	4	0.627	0.1568	0.77	0.55
Residual Error	6	1.225	0.0452		
Total	26	319.683			

VIII. RESULTS AND DISCUSSION

For Permeate the objective is to maximize it, therefore for calculating the S/N ratio larger the better S/N ratio is used and S/N ratio is calculated for each experiment and mean of S/N ratio is also calculated for each parameter. The mean of S/N ratio is calculated to find the rank of parameter and rank of parameter shows that which parameter is most effective to the reverse osmosis process. From the mean S/N ratio at each level, maximum S/N ratio is selected which indicates the optimal level for that parameter. For potential of hydrogen (PH) the maximum S/N ratio is 62% at B2 .This indicates the optimal level for PH. Similarly for OP, ORP and anti agent the minimum S/N ratio is at A3, C1, and D3. Therefore, optimal parameter for maximum permeate is at level (A3B2C1D3) shown in fig. 7.1 i.e. Operating Pressure = 24%, potential of hydrogen = 62%, Oxidation reduction potential; = 054%, Anti Agent = 036%.

For Recovery the objective is to maximize it, therefore for calculating the S/N ratio larger the better S/N ratio is used and S/N ratio is calculated for each experiment and mean of S/N ratio is also calculated for each parameter. The mean of S/N ratio is calculated to find the rank of parameter and rank of parameter shows that which parameter is most effective to the reverse osmosis process. From the mean S/N ratio at each level select the maximum S/N ratio and this S/N ratio indicate the optimal level for the parameter. Therefore for PH the maximum S/N ratio is 62% at B2 .This indicates the optimal level for PH. Similarly for Operating Pressure (OP), Oxidation reduction potential (ORP) and anti agent (ASA) the maximum S/N ratio is at B2, C1, and D3. Therefore, optimal parameter for maximum Recovery is at level (A3 B2 C1 D3) shown in the fig. 7.3.i.e at Operating Pressure (OP) = 24%, potential of Hydrogen (PH) =62%, Oxidation Reduction Potential (ORP) =0 05%, Anti Agent (ASA) = 03%.

Figure 9.1 Main effect plot for Permeate **Figure 9.2** Interaction plot Permeate

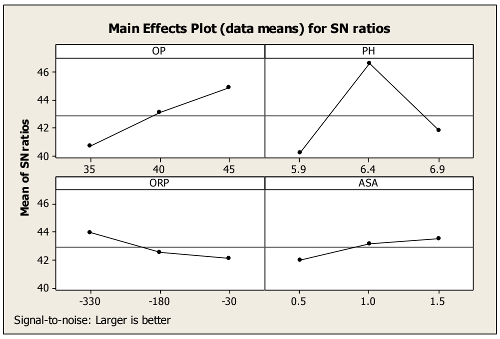
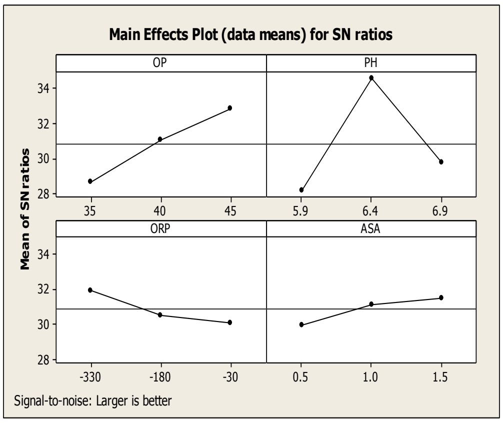
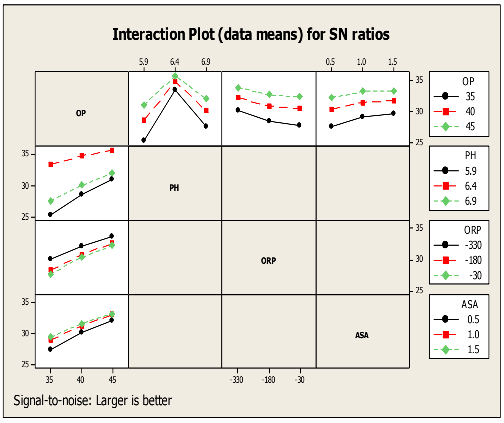


Figure 9.3 Main effect plot for Recovery **Figure 9.4** Interaction plot for Recovery





IX. CONCLUSION

The following are conclusions drawn based on the tests conducted on reverse osmosis process.

I] For Permeate:-

1) From the ANOVA, Table 7.4 and the P value, the noise radius is the most significant factor which contributes to the permeate i.e. 52% contributed by the PH on Permeate

2) The second factor which contributes to permeate is the Operating pressure (OP) having 24%.

3) The third factor which contributes to Permeate is the ORP having 054%.

4) The Fourth factor which contributes to Permeate is the Anti Agent (ASA) having 036%.

Ii] For Recovery:-

1) From the ANOVA, Table 7.5 and the P value, the noise radius is the most significant factor which contributes to the Recovery i.e. 62% contributed by the PH on COD.

2) The second factor which contributes to Recovery is the Operating Pressure (OP) having 24%.

3) The third factor which contributes to Recovery is the ORP having 05%.

4) The Fourth factor which contributes to Recovery is the Anti Agent (ASA) having 03%.

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