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A Topsis-Based Taguchi Optimization to Determine the Reverse Osmosis Process Parameter for Distillery Effluent in ZLD Process

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Abstract: In general, the optimization problems contain more than one response, which often conflict with each other. This paper proposes the TOPSIS-based Taguchi optimization approach to determine the optimization of reverse osmosis process parameters for improving recovery and quality of permeate. The performance criteria are identified for Permeate are COD, Total Solids, Conductivity and Hardness in reverse osmosis process. They are dependent on process parameters Operating Pressure (OP), Potential Hydrogen, Oxidation Reduction Potential and Anti Scaling Agent. Four factors having three control levels and one factor having three control levels are identified for performance criteria. The temperature is taken as noise factor. The data for permeate, recovery and quality of permeate obtained by running scenario that combines factor levels in Taguchi design while signal to noise (S/N) ratios are calculated for the data. After a decision matrix is generated by the S/N ratios, the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method is then used to transform the multi-response problem into a single- response problem. The anticipated improvement rate is also determined by finding the levels of the factors in order to optimize the system which uses Taguchi's single response optimization methodology.

Keywords: ANOVA, Reverse Osmosis Parameters, Design of Experiment, Multi Response, Orthogonal Array, Taguchi method, TOPSIS.

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 liters/year (M. Lit/year) of alcohol and generating 45945 M. Lit/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

Yusuf Tansel et.al [1] this study presents a simulation design and analysis case study of a flexible manufacturing system (FMS) considering a multi-response simulation optimization using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) based Taguchi approach. While in order to reduce expensive simulation experiments with the Taguchi design, the TOPSIS procedure is used to combine the multiple FMS responses (performance measures) into a single response in the optimization processes. Majid Behzadian ET. al. [2] among numerous MCDA/MCDM methods developed to solve real-world decision problems, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) continues to work satisfactorily across different application areas. In this paper, we conduct a state-of-the-art literature survey to taxo nomize the research on TOPSIS applications and methodologies. Barış Şimşek. Al. [3] In general, the optimization problems contain more than one response, which often conflict with each other. This paper proposes the TOPSIS-based Taguchi optimization approach to determine the optimal mixture proportions of the high strength self-compacting concrete (HSSCC) in a ready-mixed concrete plant. Gokhan Torlak ET. Al. [4] the article uses fuzzy TOPSIS multi-methodological approach in the Turkish domestic airline industry. It starts by describing exceedingly complex nature of competition in the sector. Then, it deals with the constituent parts of the research methodology and the eclectic approach itself. Ting-Yu Chen ET. Al. [5] Interval-valued fuzzy sets involve more uncertainties than ordinary fuzzy sets and can be used to capture imprecise or uncertain decision information in fields that require multiple-criteria decision analysis (MCDA). Saeed Rouhani ET. Al. [6] Evaluation of business intelligence for enterprise systems before buying and deploying them is of vital importance to create decision support environment for managers in organizations. On this basis, organizations will be able to select, assess and purchase enterprise systems which make possible better decision support environment in their work systems. Renato A. Krohling ET. Al. [7] The selection of the best combat responses to oil spill in the sea when several alternatives have to be evaluated with different weights for each criterion consist of a multi criteria decision making (MCDM) problem. The results show the feasibility of the fuzzy TOPSIS framework to find out the best combat responses in case of accidents with oil spill in the sea. Rautenbach ET. Al. [8] Contrary to seawater desalination where water recovery rates of about 50% are optimal, waste water treatment processes must achieve very high water recovery rates since all disposal methods for the concentrate are very cost intensive. For the treatment of dumpsite leachate, the process has been in operation since September 1994, achieving water recovery rates of >97%. Meea Kang ET. Al.[9] Increasing attention has been focused on the health effects associated with ingestion of low levels of arsenic and antimony in drinking water. Consequently, it is assumed that the removal of antimony in drinking water by RO membranes has a higher efficiency than that of arsenic compounds, regardless of pH changes. R.J. Xie ET. Al. [10] Chlorination and dechlorination are required in most saline water (brackish and seawater) reverse osmosis membrane desalination processes, regardless of whether a membrane or conventional chemical conditioning is employed as a pre-treatment. Sarayu Mohana et. Al. [11] Distillery spent wash is the unwanted residual liquid waste generated during alcohol production and pollution caused by it is one of the most critical environmental issue. Despite standards imposed on effluent quality, untreated or partially treated effluent very often finds access to watercourses. Lilian Malaeb ET. Al. [12] This paper presents a review of recent advances in reverse osmosis technology as related to the major issues of concern in this rapidly growing desalination method. These issues include membrane fouling studies and control techniques, membrane characterization methods as well as applications to different water types and constituents present in the feed water. Verma Chhaya ET. Al [13] Distilleries are largest polluter discharging a huge amount of waste water called spent wash, which are difficult and costly to treat and dispose. Quality and the characteristics of molasses spent wash were depending on the method of processing.

III. TOPSIS BASED DESIGN OF EXPERIMENTS

TOPSIS has been developed by Hwang and Yoon (1981) for solving the MADM problems. It is based on the idea that an alternative, which is chosen, should have the farthest distance from the negative ideal solution and on the other side, the shortest distance from the positive ideal solution. TOPSIS procedure is rational and understandable. The computation process of the TOPSIS method is depicted in a simple mathematical form and the importance weights can be obtained by direct assignation. For these reasons, the TOPSIS method is highly stable for decision making studies (Sen and Yang 1998). TOPSIS based Taguchi optimization follows the Taguchi optimization (Yang and Chou 2005) and is used to combine the multiple FMS performance characteristics into a single value that can then be used as the single optimization function.

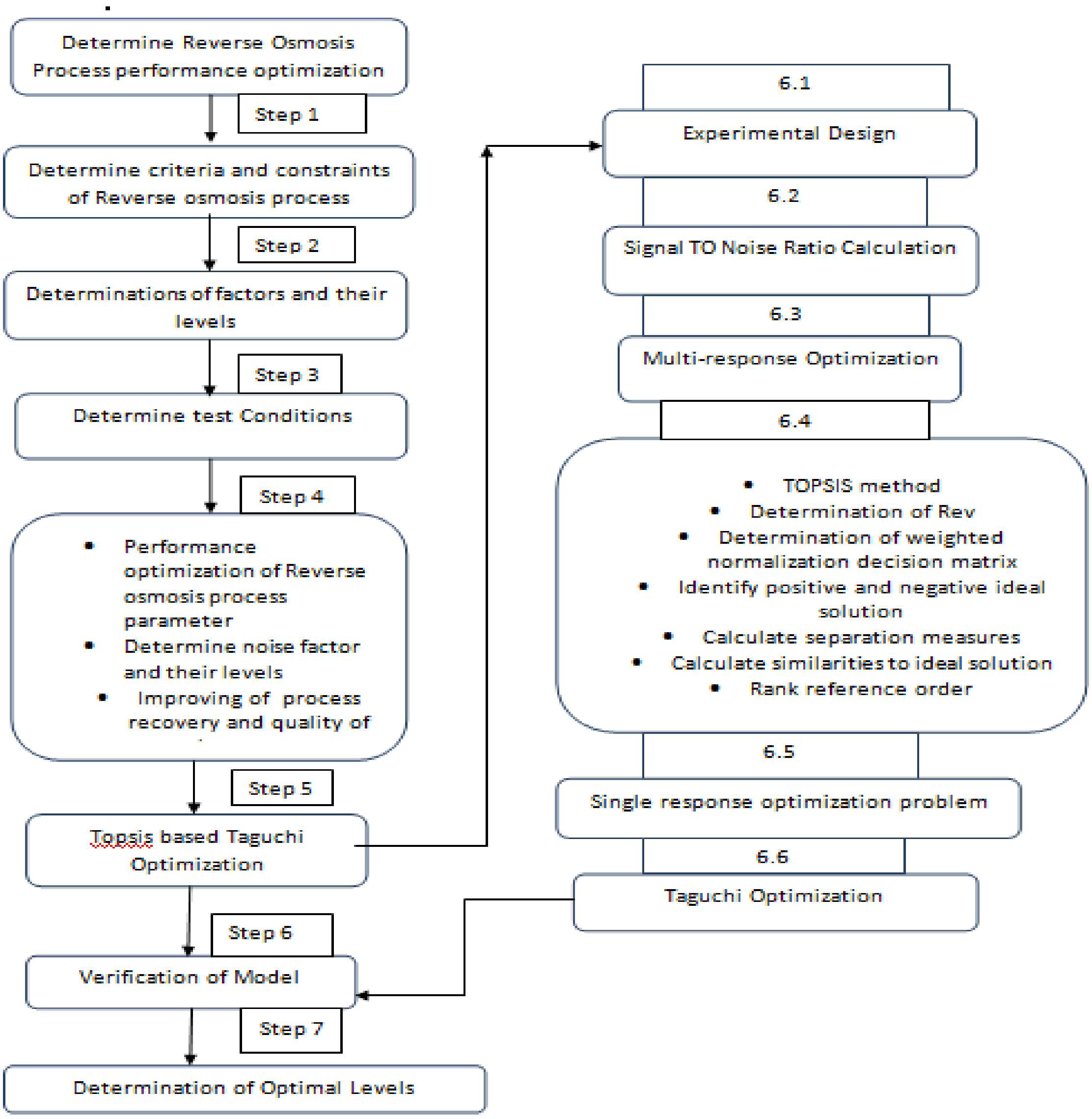


Fig. III Flowchart of Processing RO by TOPSIS method

The first step is to make simulation runs which are executed by following the experimental structure of the selected orthogonal array. The signal-to-noise ratio (S/N ratio, η) is an effective way to find significant factors by evaluating minimum variance (Yang and Chou 2005; Kuo et al. 2008). The S/N ratios can then be defined as shown in Eq. (1-2). While Eq.(1) is used for "smaller-the-better" responses, Eq.(2) is applied for "larger-the-better" responses (Kuo et al. 2008).

$$n_{ij} = -10\log\left(\frac{1}{n}\sum_{k=1}^{n} y_{ij}^{2}\right) \qquad (1)$$

$$n_{ij} = -10\log\left(\frac{1}{n}\sum_{k=1}^{n} \frac{1}{y_{ijk}^{2}}\right) \qquad (2)$$

IV. MULTI RESPONSE SIMULATION OPTIMIZATION

After computation of the S/N ratios for each response of the system for all scenarios, the TOPSIS method is applied. The modification of Yang and Chou's (2005) TOPSIS-based Taguchi approach for multi response simulation optimization of Reverse Osmosis Process is shown below:

Step 1: Determine the factors that affect specified performance measures for the RO problem.

Step 2: Formulate the experimental design matrix using orthogonal array.

Step 3: Make simulation runs of RO simulation model according to the orthogonal array.

Step 4: Compute the S/N ratios for all scenarios, $(\eta)m\times r$ using Eq. (1-2).
Step 5: Enter characteristic values of S/N ratios at responses (ηij; *i=1, 2… m "number of scenarios," j=1,2,….,r "number of responses"*) as inputs in matrix as shown in Eq. (3).

$$D = \begin{bmatrix} n_{11} & n_{12} & \cdots & n_{1r} \\ n_{21} & n_{22} & \cdots & n_{2r} \\ \cdots & & & \\ n_{m1} & n_{m2} & \cdots & m_{mr} \end{bmatrix} \quad (3)$$

Step 6: Prepare normalized decision matrix using Eq. (4).

$$n_{ij}^{*} = \frac{n_{ij}}{\sqrt{\sum_{i=1}^{m} n_{ij}^{2}}} \quad i = 1,2,\ldots\ldots,mj = 1,2,\ldots\ldots,r \quad (4)$$

Step 7: Construct the weighted normalized decision matrix using Eq. (5-7).

$$v = \left[x_{ij}\right]_{mxr} \quad i = 1,2,\ldots\ldots,mj = 1,2,\ldots.,r \quad (5)$$

$$x_{ij} = n_{ij}^{*}\, w_{j} \quad (6)$$

$$w = \left[w_{1,}w_{2},\ldots,w_{r}\right] \quad (7)$$

Step 8: Determine the ideal and negative-ideal solutions: The ideal solution (A*) and negative-ideal solution (A−), representing the maximum and minimum S/N ratios, respectively, are as follows:

$$A^{*} = (x_{1}^{*}, x_{2}^{*}, \ldots., x_{r}^{*}) \quad (8)$$

$$x_{1}^{*} = \left\{\left(\frac{max}{i}\, x_{ij}\middle| j \in J\right) i = 1,\ldots m\right\} \quad (9)$$

$$A- = (x_{1}^{-}, x_{2}^{-}, \ldots, x_{3}^{-}) \quad (10)$$

$$x_{1}^{*} = \left\{\left(\frac{min}{i}\, x_{ij}\middle| j \in J\right) i = 1,\ldots m\right\} \quad (11)$$

The ideal solution, (A*), is made of all the best values (maximum S/N ratio) and the negative-ideal solution, (A-), is made of all the worst values (minimum S/N ratio) at the responses in the weighted normalized decision matrix (Sen and Yang 1998) (Eq.5).

Step 9: Calculate the distance of scenario into the ideal solution (di*), and from the negative ideal solution (di-) using Eq. (12-13).

$$d_{1}^{*} = \sqrt{\sum_{j=1}^{r} \left(x_{ij} - x_{j}\right) x^{2}} \quad i = 1,2,\ldots m; \; j = 1,2,\ldots,r \quad (12)$$

$$d_{1}^{-} = \sqrt{\sum_{j=1}^{r} \left(x_{ij} - x_{j}\right) x^{2}} \quad i = 1,2,\ldots m; \; j = 1,2,\ldots,r \quad (13)$$

Step 10: Calculate the ranking score (Ci*) using Eq. (14).

$$\mathrm{c}_{\mathrm{i}}^{*} = \frac{\mathrm{d}_{\mathrm{i}}^{-}}{(\mathrm{d}_{\mathrm{i}}^{-} + \mathrm{d}_{\mathrm{i}}^{*})}, \mathrm{i} = 1,2,\ldots,\mathrm{m}; \mathrm{j} = 1,2,\ldots,\mathrm{r} \quad (14)$$

Step 11: Determine the optimal parametric combination to maximize S/N: The optimal combination of factor-levels is finally determined, in view of the fact that a larger TOPSIS value indicates better quality. Taguchi method is to be applied finally to evaluate this optimal setting (by maximizing the TOPSIS index).

V. 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.

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) (Σ (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 (ŷ/s2y)………………….1, S/N = -10 log ((l/n) (Σy2))…………..……2

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.

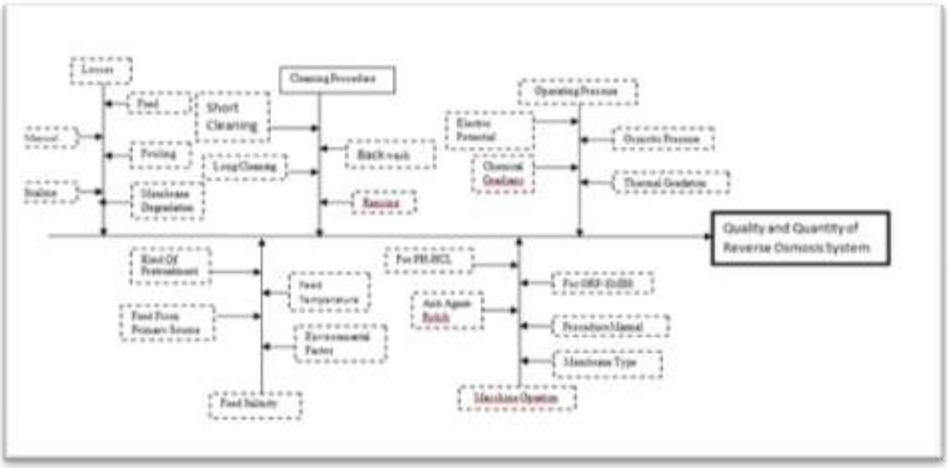
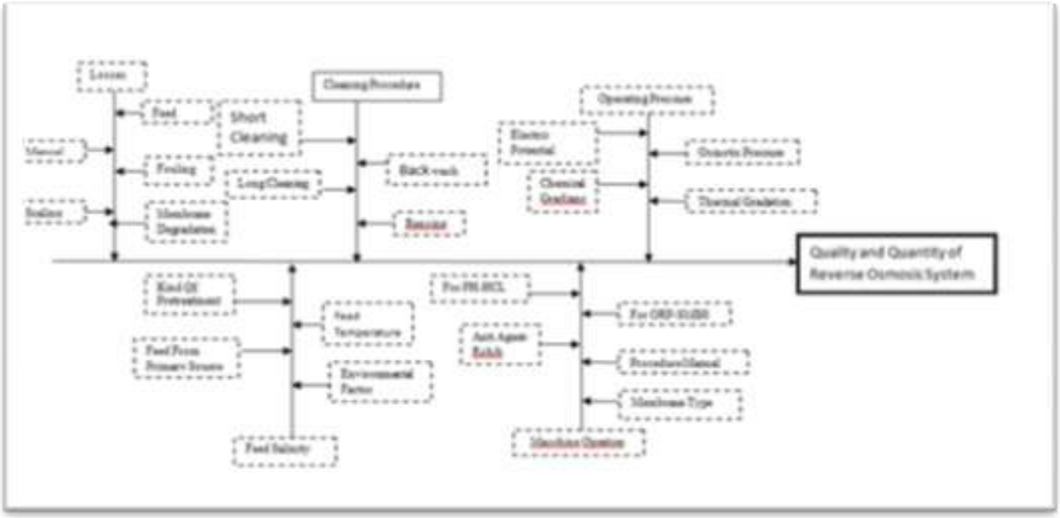


Figure IV Fishbone diagram of cause of effect



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 literature of 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)

Available literature on 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 major loss to the RO processes 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).

VI. EXPERIMENTATION

The experiment was performed on **RO 8100 PHARM ST8 PT44400W** machine. The experimental set 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 antiscalant 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 5.1 Control Panel

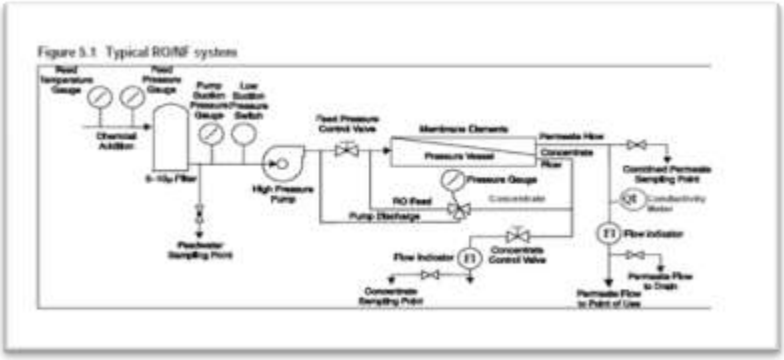


Figure5.2 Meter

VII. 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.

VIII. 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 shows the S/N response graph for TOPSIS respectively.

Table. Response Table for Signal to Noise Ratios (TOPSIS) Higher is better

Level	OP	PH	ORP	ASA
1	-22.64	-20.88	-22.05	-21.00
2	-22.01	-24.41	-21.60	-21.49
3	-20.39	-19.75	-21.39	-22.55
Delta	2.25	4.66	0.66	1.56
Rank	2	1	4	3

IX. 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 Analysis Of Variance for (TOPSIS) Higher is better

Source	DF	SS Adj	MS	F	% contribution
OP	2	24.312	12.1558	41.80	14%
PH	2	106.337	53.1685	182.83	63%
ORP	2	2.047	1.0237	3.52	13%
ASA	2	11.407	5.7035	19.61	03%
OP+PH	4	20.869	5.2173	17.94	05%
OP+ORP	4	0.649	0.1622	0.56	001%
OP+ASA	4	0.497	0.1243	0.43	003%
Residual Error	6	1.745	0.2908		
Total	26	167.863			

X. RESULTS AND DISCUSSION

For TOPSIS 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 63% at B3 .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 (A3B3C3D1) shown in fig. 7.1 i.e. Operating Pressure = 14%, potential of hydrogen = 63%, Oxidation reduction potential; = 13%, Anti Agent = 03%.

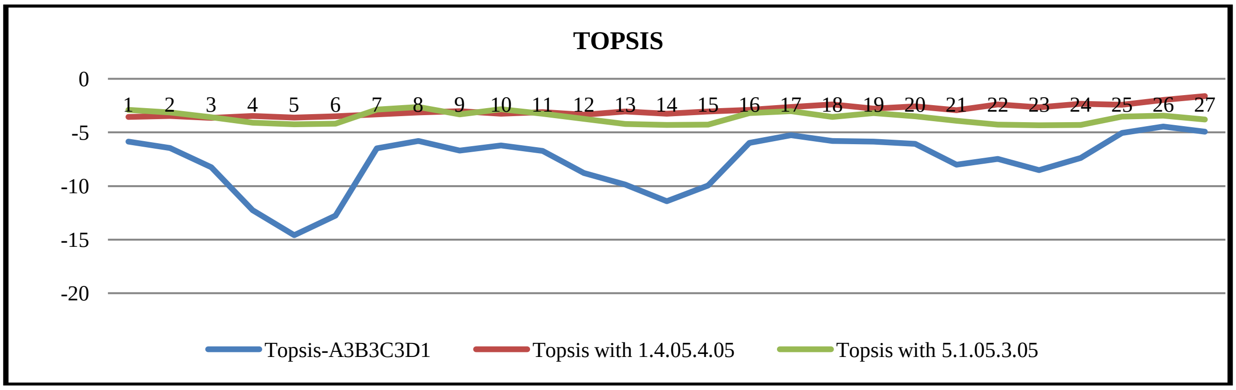


Fig IX.I. Line chart for TOPSIS

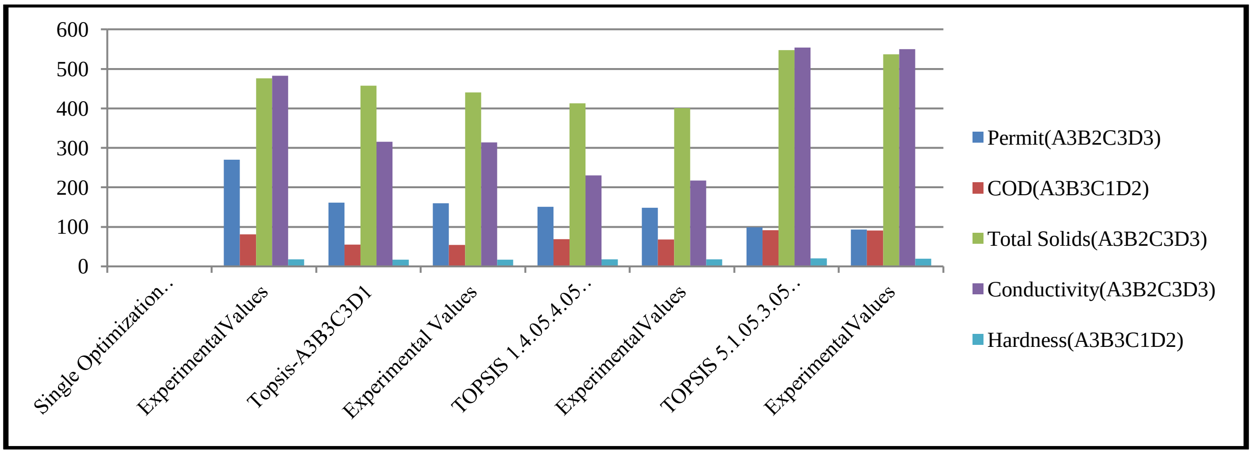


Fig IX.II. Bar chart for TOPSIS

Figure 9.1Main effect plot for Permeate

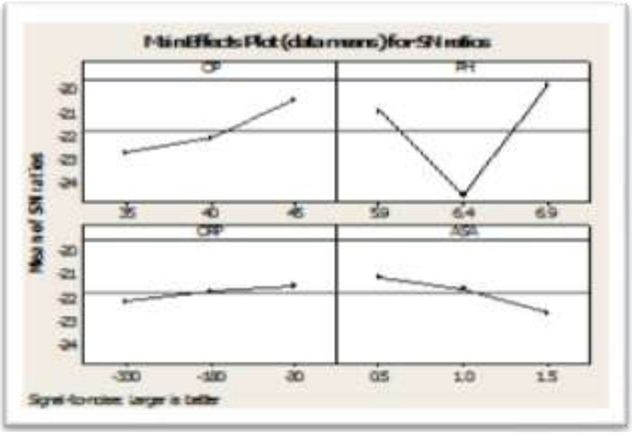
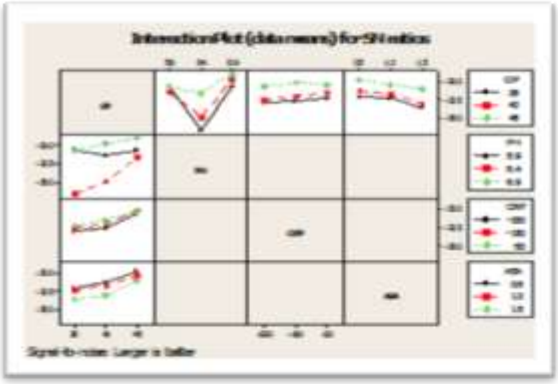


Figure 9.2 Interaction plot Permeate



CONCLUSION

The following are conclusions drawn based on the tests conducted on reverse osmosis process.
1) From the ANOVA, Table 7.4 and the P value, the Potential of Hydrogen is the most significant factor which contributes to the TOPSIS i.e. 63% contributed by the PH on TOPSIS.
2) The second factor which contributes to TOPSIS is the Operating pressure (OP) having 13%.
3) The third factor which contributes to TOPSIS is the ORP having 5.4%.
4) The Fourth factor which contributes to Permeate is the Anti Agent (ASA) having 3.6%.

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