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Optimum Conditions for Heat Exchanger to Minimize the Production Cost (PC) Ratio by using Taguchi Method and S/N Ratio Analysis

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Abstract: The present study is application of Design of experiment (DOE) method to optimize the cleaning Design methodology, cleaning frequency and production capacity of heat exchanger to minimize the production cost ratio. The optimal value of cleaning frequency, production cost and type of design ensures the least possible production cost (PC) ratio. The PC ratio is ratio of production cost any day to production cost first day which keep on increasing day by day due to fouling of tubes which results in lesser heat transfer. ANOVA analysis is performed on data and it is found that cleaning frequency is most significant factor as compared to design of cleaning methodology and production capacity for minimum response variable production cost ratio.
Keywords: Design of Experiment, cleaning frequency, production capacity, ANOVA Analysis, production cost ratio.

I. INTRODUCTION AND LITERATURE REVIEW

The major challenge in today's industry is to reduce the production cost. Heat exchanger is the important equipment of production and manufacturing industry which is required to transfer heat from one medium to other for process requirements. During the course of continuous operation of heat exchanger, the sludge starts to accumulate inside the heat exchanger tubes which make heat transfer inefficient and subsequently production cost increases [1].

In this research study we will analyze three designs for heat exchanger tubes cleaning from inside.

1) *Mechanical Cleaning:* Mechanical cleaning is offline cleaning method in which Heat exchanger (HE) is cleaned by high pressure water jet once it is shut down [2]. In this method there is no provision of removing the scale deposition inside the tubes during running condition. The tube choking is rapid as compared to online cleaning methods.
2) *Magnetic Ring:* In this design methodology, Magnetic ring fixed on HE inlet pipe generates magnetic field which reduce or eliminate scale formation in pipes [3]. Due to magnetic field oscillations are developed in water flowing inside the pipe. These active oscillations increase the solubility of substance in water and scale formation is reduced.
3) *Automatic Tube Cleaning System:* ATCS is cleaning system developed for keeping shell and tube heat exchangers continuously clean as it online cleaning method [4]. Fouling rate is reduced by ATCS system which occurs along with time and helps to prolong the degradation of Heat Exchanger performance. The elastic sponge/rubber balls are poured into the collector of the ball recirculating unit from where they pass into the tubes of heat exchanger along with the tube side fluid. Transported by the tube side fluid, they pass through all tubes without impairing the operation of the heat exchanger.

By using any of the above method we cannot eliminate the off line cleaning but rate of scale deposition can be reduced to significant level and production capacity will be higher for longer duration as compared to without online tube cleaning method. Cleaning frequency is the time duration after which HE is shut down and taken for cleaning of tubes mechanically.

Rama Rao, et al. [5] studied the Metal removal rate[MRR] by electro chemical machining [ECM]. In his study MRR has to be increased to ma ximum . The parameters which affect the MRR by ECM are voltage, feed rate and electrolyte concentration. The optimum values of parameters were determined by taguchi method, S/N ratio analysis and ANOVA analysis. Three levels were taken for these factors and feed rate is most significant factor for MRR and electrolyte concentration is least significant factor. Bala murugan, et al. [6] studied optimization of process parameter such as cutting speed, feed, depth of cut and width of cut during end milling for hardened steel by S/N ratio and ANOVA analysis with response variable surface finish and tool life. Ting Kong, et al. [7] used taguchi method in experimental design for quality improvement of product and process. Shyam Kumar, et al. [8] studied optimization of process parameter and its affect on quality, productivity and production cost. Sorana D.Bolboaca, et al. [9] studied about useful orthogonal arrays for number of experiments in Design of experiments with maximum number of factors and their respective different levels by developing an algorithm. Srinivas, et al. [10] used taguchi method for optimization of process parameters for improvement of surface roughness during lathe operations.

II. EXPERIMENTAL SET-UP

The analysis is done by taking three set ups as per the cleaning design philosophy. Figure 1 is showing set up for automatic tube cleaning system (ATCS). Along with design factor, cleaning frequency and production capacity are also taken as factor and their respective different levels. The response variable is Production Cost (PC) ratio which we have to minimize to reduce the production cost. This study is conducted by design of experiment (DOE) taguchi method.

Figure 1: ATCS unit used for experimentation

Table 1: Process Parameters and their Levels

Factor	Parameter Name	Levels			
		I	II	III	unit
A	Design	Off line cleaning	Magnetic Ring Cleaning	ACTS Cleaning	NA
B	Clean Time	10	15	20	Days
C	Production Capacity	1	0.9	0.8	in %

Table 1 shows the process parameters and their levels. Total three parameters and three levels are taken and accordingly orthogonal array has been made.

III. RESULTS AND DISCUSSION

Experiments are carried out for all the three design set ups and PC ratio was calculated by using formula

$$PC_{ratio} = \frac{\text{Production}_{\text{cost}-anyday}}{\text{Production}_{\text{cost}-firstday}}$$

The value of PC ratio for all factors and their level is shown in table 2. This ratio is useful to analyze that how much production cost is increased as compared to first day because once the tubes of heat exchanger starts choking by scale formation inside tube the production cost starts increasing due to inefficient heat transfer.

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Table 2: Experimental value of PC ratio

Design type	Day after cleaning	dp(kpa)	dt(^{o}C)	Injection water flow rate (Kg/hr)	Steam flow rate (Kg/hr)	Elect Power/hr	Production Cost (HE only)	PC increment ratio
3	1	40.05	24.09	1476407	97770	889.35	533610.00	1.00
3	10	45.71	22.98	1476401	97774	1346.50	807900.00	1.51
3	15	48.97	22.37	1476405	97772	1422.22	853332.96	1.60
3	20	52.22	21.75	1476395	97774	1563.70	938220.00	1.76
2	1	40.15	23.89	1476407	97770	1086.35	651810.00	1.00
2	10	48.71	20.98	1476401	97774	1468.50	881100.00	1.35
2	15	53.47	19.37	1476405	97772	1947.22	1168332.96	1.79
2	20	58.22	17.75	1476395	97774	2113.70	1268220.00	1.95
1	1	42	24	1476407	97770	1290.64	774383.68	1.00
1	10	49	19.8	1476401	97774	2024.05	1214427.87	1.57
1	15	56.2	17.7	1476405	97772	2366.22	1419732.96	1.83
1	20	66.2	14.3	1476395	97774	2809.02	1685412.70	2.18

There is combination of 9 different sets of cleaning design methodology, cleaning frequency and production capacity which is prepared by taguchi design for three factors and their three levels. By taguchi method L9 orthogonal array has been made to know S/N ratio of each combination.

Table 3: Experimental result of PC ratio

Sr No	Design	CT	P.Cap	PC ratio	S/N ratio
1	1	10	1.0	1.57	-3.91799
2	1	15	0.9	1.83	-5.24902
3	1	20	0.8	2.18	-6.76913
4	2	10	0.9	1.35	-2.60668
5	2	15	0.8	1.79	-5.05706
6	2	20	1.0	1.95	-5.80069
7	3	10	0.8	1.51	-3.57954
8	3	15	1.0	1.60	-4.0824
9	3	20	0.9	1.76	-4.91025

In order to know the significance of parameters on PC ratio, ANOVA analysis [10] was performed and it was observed that cleaning frequency is the most significant factor and least significant factor is production capacity.

Table 4 Rank identification for response variable PC ratio (S/N ratio based)

Level	Design	CT	P.Cap
1	-5.312	-3.368	-5.135
2	-4.488	-4.796	-4.255
3	-4.191	-5.827	-4.6
Delta	1.121	2.459	0.88
Rank	2	1	3

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Table 5 Rank identification for response variable PC ratio (mean data)

Level	Design	CT	P.Cap
1	1.86	1.477	1.827
2	1.697	1.74	1.647
3	1.623	1.963	1.707
Delta	0.237	0.487	0.18
Rank	2	1	3

Table 4 & 5 Represents the rank identification of the factors according to their significance for response variable PC ratio. Table 4 is S/N ratio based and table 5 is mean data based. Both table s have given similar results in terms of rank of the factors which clearly defines that cleaning frequency is most significant factor for response variable PC ratio.

Figure 2 &3 shows the mean analysis and signal to noise analysis of PC ratio response variable. it is clear that factors which are ranked higher are having peak profile and factors which are having lower ranks are having low profiles in Signal to noise ratio analysis . Our objective is to always have higher value of S/N ratio which can be achieved by the peak point of the factors in S/N ratio analysis which will give the optimal case for PC ratio as shown in table 6.

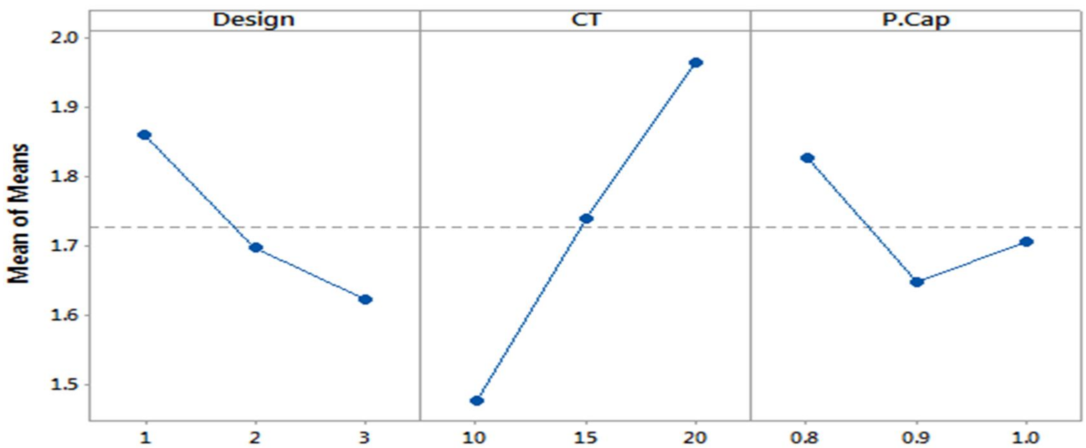

Figure 2 Mean analysis for PC ratio response

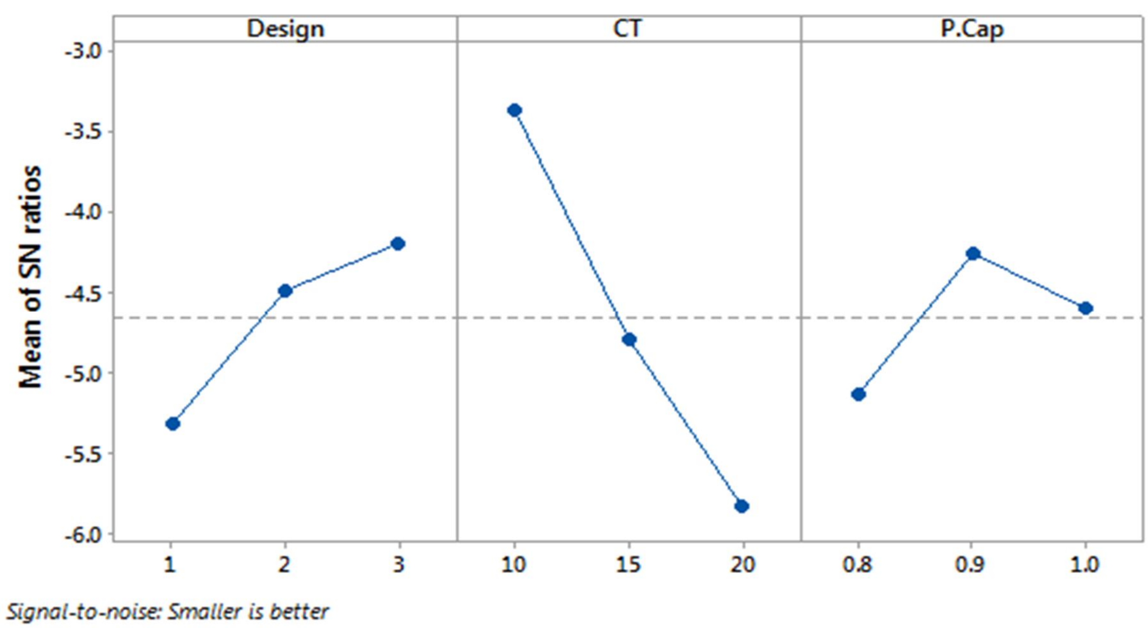

Figure 3: Signal to noise ratio analysis for PC ratio response

A. Optimal Solution for PC Ratio

Table 6 Optimal solution for PC ratio

Response	Design	Cleaning Time	Production capacity
	A	B	C
PC ratio (real value)	3	10	0.9
PC ratio (coded)	3	1	2

Table 6 shows the optimal solution for given factors and their respective variables which we got from S/N ratio analysis. The real value indicates the exact value for given factor and coded value represents the level of that individual factor.

IV. CONCLUSION

Study on influence of different conditions on heat exchanger production cost was studied in this research. As fouling occurs in heat exchanger, more energy is required to transfer the heat to production fluid and therefore production cost increases. Taguchi method is applied to get the solution in terms of optimum value of factors. Three factors were selected in this research namely design philosophy of cleaning heat exchanger tubes, cleaning frequency of heat exchanger tubes and production capacity from that particular heat exchanger. Response variable is production cost (PC) ratio which our objective is to minimize. Result shows that most significant variable affecting PC ratio is cleaning frequency and least significant variable is production capacity. The optimum solution for minimum PC ratio is that design philosophy of cleaning heat exchanger tubes should be ATCS , Cleaning frequency 10 days and production capacity of 90%.

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