PERFORMANCE ANALYSIS OF PERISTALTIC PUMP WITH NEWTONIAN FLUID: AN EXPERIMENTAL INVESTIGATION

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ABSTRACT

The present paper focus on performance of peristaltic pump to determine the optimal influential process parameters with newtonian fluids. Because it plays a vital role in the fields of applications such as food processing industries, chemical handling, water related industries, engineering and manufacturing sectors and many other places for pumping fluids without contamination. In the present work Taguchi method has been selected to analyze the optimal influential process parameters such as speeds, number of rollers, and diameter of tubes in varying levels for conducting the experiments. Based on the parameters levels and factors, L₂₅ orthogonal array is considered from orthogonal selector table in design of experiments to predict the peristaltic pump performances in terms of experimental outputs. These responses such as pressure, wave length, amplitude and discharge are analyzed using Taguchi method under higher the better condition formula and the optimal influential process parameter settings have been proposed for each and every performance measures.

KEYWORDS: Design of Experiments, Higher The Better Characteristics, Peristaltic Pump Fabrication, S/N Ratio Analysis of Performance Measures: Pressure, Wave Length, Amplitude and Discharge

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INTRODUCTION

Now a day's pumps are used for pumping varieties of fluids from various sources to destinations, there is a special place occupied pump is Peristaltic Pump (PP). Because it plays a vital role in the fields of manufacturing and biological applications but there is a lot of conflicts between them to identify the optimal influential process parameters for particular application because the optimal influential parameters selection differs from application to application employed. In these aspects, it requires a new set of influential process parameters which depends on application and design of peristaltic pump. In order to avoid these conflicts in any application while pumping the newtonian fluid, the present work has been carried out with Taguchi analysis. In the very beginning a heart surgeon Dr. Michael Debakey developed a peristaltic pump in 1932 for blood transmission [1]. Thereafter, Bernard Refson developed non-occlusive roller pump by using soft flat tubing in 1992. Watson Marlow fluid group Technology later invented Peristaltic pumps for outside laboratory applications. The schematic diagram of peristaltic pump drawn with solid works software as shown in Figure 1. Generally, all the peristaltic pumps are comes under the category of positive displacement pump only where a constant volume of fluid discharged per each revolution. According to the Greek word peristaltikos, the working principle of positive displacement pump is defined as clasping and compressing the tube by using rollers/cams for drawing the fluid into the tube. So it can be used for designing a liquid dispenser system by using this peristaltic pump. Based on the pressure rating two types of pumps

can be used in the peristaltic pump those are tube pumps and hose pumps. Tube pumps are low pressure rating pumps can be used up to 5 bar pressure, hose pumps are high pressure rating pumps can be used up to 16 bar pressure. The mechanical and biological point of view the peristalsis mechanism subject played a key role for scientific researches and the peristaltic flow of viscous fluid has been attracted many researchers so far since the first investigation carried out [2] to understand the peristaltic action in different situation such as the problems related to mechanism of peristaltic pump, effect of slip on MHD flow of various fluids and different waveforms of peristaltic pump, wavelengths [3-13] and also the theoretical and experimental attempts have been made for observing peristaltic motion in biological and physiological systems.

Figure 1: Schematic Diagram of Peristaltic Pump.

On the other hand, Taguchi method is a single objective optimization method and it is widely used in several industrial sectors to design a product or a process with single quality characteristics. Over decades, number of reports have been recognized on the application of Taguchi analysis to optimizing the several process and quality characteristics. [14,15] and succeed to get the effective responses [16-18]. Taguchi analysis is applied to examine the effect of cutting parameters on surface roughness and stated that Taguchi method is a best and an effective tool for optimizing the single quality characteristics [19]. So far most of the researchers have been studied about the theoretical aspect of fluid behavior in peristaltic pump of Newtonian and non-Newtonian fluids [20]. Therefore; there is noticeable research gaps are identified to analyze the peristaltic pump performance with Newtonian and non-Newtonian fluids by using Taguchi analysis. In order to accomplish the research gaps have been noticed in literature, an attempt has been made to design and fabricate the rotary peristaltic pump for performance analysis by using Newtonian fluids. In this regard, a rotary peristaltic pump has been modeled and fabricated in which the process parameters setting can be varied as required level to analyze the pump performance in pumping of Newtonian fluid i.e., Water. In Taguchi analysis, S/N ratio analysis has been used with higher the better condition formulas for normalizing the experimental outputs by eradicate the errors.

EXPERIMENTAL SETUP

In the present work, water has been used as working fluid with density of 1000 kg/m^3 and viscosity of 0.00095 Ns/m^2 . The input process parameters which have been selected in varying levels for determining the performance of peristaltic pump with water is tabulated in Table 1. the main reason for selecting the water for pumping through the peristaltic pump is easy availability, based on this, the performance analysis of pump can be evaluated and also can be identified the optimal influential process parameters with water. This data is useful for pumping same kind of sensitive, aggressive and many other fluids. The experimental studies were performed on fabricated peristaltic pump (Figure 2) as per the Taguchi

orthogonal array design and it is used to determine the minimum number of experiments to be conducted for predicting the outputs.

Figure 2: Peristaltic Pump for Experimentations.

In the present analysis, based on the levels and factors, the corresponding orthogonal array L_{25} has been selected from orthogonal selector table for conducting the peristaltic pump experiments with water. The layout of peristaltic pump experimental design is shown in Table 2.

Table 1: Peristaltic Pump Parameters with their Levels

Factors	Parameters	Levels				
		L1	L2	L3	L4	L5
A	Speeds of rotor (rpm)	10	15	20	25	30
B	Diameter of tubes (mm)	6.4	9.5	12.7	19	25.4
C	Number of rollers	2	3	4	5	6

RESULTS AND DISCUSSIONS

The peristaltic pump experiments data (Table 3) is analyzed by using higher the better condition formula as shown in Eq. (1).

$$S/N \text{ ratio } (\eta) = -10 \log_{10} \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \quad (1)$$

Where, y = obtained response value and n = number of experimental run.

The effects of optimal influential process parameters on each and every individual response such as pressure, wavelength, amplitude and discharge have been selected. From the experimental outputs the average value and S/N ratios of the response characteristics for each parameter for different levels have been calculated and their S/N ratios are given in the Table 4.

Table 2: Peristaltic Pump Experimental Design

Exp. No.	Speed (rpm)	Diameter of Tube (mm)	Number. of Rollers
1	10	6.4	2
2	10	9.5	3
3	10	12.7	4
4	10	19	5
5	10	25.4	6
6	15	6.4	3
7	15	9.5	4
8	15	12.7	5
9	15	19	6
10	15	25.4	2
11	20	6.4	4
12	20	9.5	5
13	20	12.7	6
14	20	19	2
15	20	25.4	3
16	25	6.4	5
17	25	9.5	6
18	25	12.7	2
19	25	19	3
20	25	25.4	4
21	30	6.4	6
22	30	9.5	2
23	30	12.7	3
24	30	19	4
25	30	25.4	5

Table 3: Peristaltic Pump Responses

Exp. No.	Pressure (N/mm ²)*10 ⁻⁶	Wavelength (mm)	Amplitude (mm)	Discharge (mm ³ /min.)*10 ³
1	0.143	9.667	1.667	136.667
2	0.157	12.667	3.333	463.333
3	0.183	16.000	5.000	871.667
4	0.19	16.667	5.333	893.333
5	0.213	24.000	7.000	1445.000
6	0.153	12.000	3.000	445.000
7	0.17	14.333	4.000	590.000
8	0.203	18.667	6.000	1176.667
9	0.22	28.000	7.667	1495.000
10	0.233	36.667	9.000	2738.333
11	0.147	10.667	2.333	255.000
12	0.15	11.333	2.667	385.000
13	0.177	15.667	4.667	845.000
14	0.227	33.333	8.333	1741.667
15	0.26	42.000	10.00	2958.333
16	0.163	13.333	3.667	588.333
17	0.2	17.667	5.667	1015.000
18	0.217	26.667	7.333	1453.333
19	0.223	29.667	8.000	1635.000
20	0.23	35.000	8.667	2285.000
21	0.173	15.000	4.333	685.000
22	0.21	22.667	6.667	1440.000
23	0.237	38.333	9.333	2810.000
24	0.207	20.000	6.333	1420.000
25	0.243	40.667	9.667	2890.000

In order to determine the effects of optimal influential process parameters on experimental outputs, S/N ratios analysis has been used. From the main effect plots S/N ratios response are identified for each parameter at each level and S/N ratios response are plotted from Figures 3 to Figure 6. From the Figure 3 it is observed that the optimal influential process parameter settings for pressure response of peristaltic pump with water are as follow:

- Speed is at level 5, Diameter of tube is at level 5 and Number of rollers is at level 1.

These optimal influential process parameter settings give better pressure response for any application when peristaltic pump is used. Moreover, this obtained optimal influential process parameter settings are best suited for higher the better characteristics response in the required field. Similarly, to observe the effect of process parameters on wavelength, amplitude and discharge, the S/N ratio's data are plotted from Figure 4 to Figure 6. From the Figure 4 and Figure 6, it is observed that the optimal influential process parameter settings for wavelength, amplitude and discharge response of peristaltic pump with water are as follow:

- Speed is at level 5, Diameter of tube is at level 5 and Number of rollers is at level 2.

Table 4: S/N Ratios of PP Experimental Results

Exp. No.	Pressure	Wavelength	Amplitude	Discharge
1	-16.893	-40.294	-55.561	-77.286
2	-16.082	-37.946	-49.543	-66.682
3	-14.751	-35.917	-46.020	-61.193
4	-14.429	-35.562	-45.460	-60.979
5	-13.432	-32.395	-43.098	-56.802
6	-16.306	-38.416	-50.457	-67.032
7	-15.391	-36.873	-47.958	-64.583
8	-13.850	-34.578	-44.437	-58.586
9	-13.151	-31.056	-42.307	-56.507
10	-12.652	-28.714	-40.915	-51.250
11	-16.653	-39.439	-52.641	-71.869
12	-16.478	-38.913	-51.479	-68.290
13	-15.040	-36.100	-46.619	-61.462
14	-12.879	-29.542	-41.584	-55.180
15	-11.700	-27.535	-40.000	-50.579
16	-15.756	-37.501	-48.713	-64.607
17	-13.979	-35.056	-44.932	-59.870
18	-13.270	-31.480	-42.694	-56.752
19	-13.033	-30.554	-41.938	-55.729
20	-12.765	-29.118	-41.242	-52.822
21	-15.239	-36.478	-47.264	-63.286
22	-13.555	-32.892	-43.521	-56.832
23	-12.505	-28.328	-40.599	-51.025
24	-13.681	-33.979	-43.967	-56.954
25	-12.287	-27.815	-40.294	-50.782

Figure 3: Main Effects of Plots for S/N Ratios of Pressure.

Figure 4: Main Effects of Plots for S/N Ratios of Wavelength.

Figure 5: Main Effects of Plots for S/N Ratios of Amplitude.

Figure 6: Main Effects of Plots for S/N Ratios of Discharge.

Table 5: S/N Ratios Table of all Response

S/N Ratios Ranking Table for Pressure			
Level	Speed	Dia. of Tube	No. of Rollers
1	-15.12	-16.17	-13.85
2	-14.27	-15.10	-13.93
3	-14.55	-13.88	-14.65
4	-13.76	-13.43	-14.56
5	-13.45	-12.57	-14.17
Delta	1.66	3.60	0.80
Rank	2	1	3
S/N Ratios Ranking Table for Wavelength			
Level	Speed	Dia. of Tube	No. of Rollers
1	-36.42	-38.43	-32.58
2	-33.93	-36.34	-32.56
3	-34.31	-33.28	-35.07
4	-32.74	-32.14	-34.87
5	-31.90	-29.12	-34.22
Delta	4.52	9.31	2.51
Rank	2	1	3
S/N Ratios Ranking Table for Amplitude			
Level	Speed	Dia. of Tube	No. of Rollers
1	-47.94	-50.93	-44.86
2	-45.22	-47.49	-44.51
3	-46.46	-44.07	-46.37
4	-43.90	-43.05	-46.08
5	-43.13	-41.11	-44.84
Delta	4.81	9.82	1.86
Rank	2	1	3
S/N Ratios Ranking Table for Discharge			
Level	Speed	Dia. of Tube	No. of Rollers
1	-64.59	-68.82	-59.46
2	-59.59	-63.25	-58.21
3	-61.48	-57.80	-61.48
4	-57.96	-57.07	-60.65
5	-55.78	-52.45	-59.59
Delta	8.81	16.37	3.27
Rank	2	1	3

This obtained optimal influential process parameter settings give better wavelength, amplitude and discharge response for any application and these are best suited for higher the better characteristics response in the required field. The number of rollers only changes in the influential process parameters on all the responses. When the number of rollers increases by keeping speed and diameters of tube are constant, it leads to increase the number of squeezes on tube by the rollers, which tends to transfer the fluid pillow within short period of time. This phenomenon is helped to attain the higher amplitude and discharge response in peristaltic pump with water. From the Table 5, it is noticed that the only diameter of tube is the most influential process parameter on all experimental outputs. According to this analysis, it is observed that slight change in diameter of tube tends to change in output results of peristaltic pump with water.

CONFIRMATION RESULTS

A validation procedure is the most important aspect for any sort engineering jobs after assessing the optimal influential process parameter combinations using any statistical tools and stochastic processes. Therefore in this work following formula (Eq.2) has been used to predict the peristaltic pump performance.

$$M_R = M_A + M_B + M_C - 2M_m \quad (2)$$

Where, M_R = Mean of response, M_A = Mean of optimal level of "A", M_B = Mean of optimal level of "B", M_C = Mean of optimal level of "C" and M_m = Total mean of corresponding parameter.

Table 6: Confirmation Results

PP Responses	Pressure	Wavelength	Amplitude	Discharge
Initial settings	$A_1B_1C_1$			
	0.143	9.667	1.667	136.667
Optimal settings	$A_5B_5C_2$			
	0.2533	46.67	9.33	3355.67
Predicted Values	0.2607	45.076	10.893	3361.366

From the Table 6, it is observed that the responses obtained with optimal influential process parameter settings are quite closer to predicted experimental responses of peristaltic pump and this optimal setting gives better responses improvement than initial values.

CONCLUSIONS

Based on the Taguchi's S/N ratio analysis with water under higher the better condition the following conclusions have been drawn

- For better pressure response, the optimal process parameter settings are speed at 30 rpm, diameter of tube at 25.4 mm and number of rollers at 02.
- For better wavelength, amplitude and discharge responses, the optimal process parameter settings are speed at 30 rpm, diameter of tube at 25.4 mm and number of rollers at 03.
- Through this analysis, it is concluded that diameter of tube is the most influencing factor for all responses when water equivalent density fluid is pumped with peristaltic pump.
- From the confirmation results, it is concluded that the Taguchi analysis is the most prominent and effective technique for optimizing the peristaltic pump performance.

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