Optimization of Sonication Process Using Taguchi Method

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Abstract- DOE is an essential piece of the reliability program pie. It plays an important role in Design for Reliability (DFR) programs, allowing the simultaneous investigation of the effects of various factors and thereby facilitating design optimization. Much of our knowledge about products and processes in the engineering and scientific disciplines is derived from experimentation. An experiment is a series of tests conducted in a systematic manner to increase the understanding of an existing process or to explore a new product or process. Design of Experiments, or DOE, is a tool to develop an experimentation strategy that maximizes learning using a minimum of resources. Design of experiments is widely used in many fields with broad application across all the natural and social sciences. It is extensively used by engineers and scientists involved in the improvement of manufacturing processes to maximize yield and decrease variability. Often times, engineers also work on products or processes where no scientific theory or principles are directly applicable. The taguchi designed experiments have been used in this work to optimize environmental engineering process.

Key Words: Design, Environment, Experiments, Optimization.

I. INTRODUCTION

Ultrasonic waves refer to the sound waves produced by an object vibrating at a frequency higher than the human ear can hear (above 20 kHz). By using modern techniques it has become possible to produce ultrasonic waves of frequency up to 25 billion Hz, which has a wavelength of 10-8 m, comparable with X-ray wavelength. An ultrasonic wave is highly energetic and has extremely short wavelength because of its high frequency and energy. The use of ultrasonics, especially in the field of medicine and various industries is because of its small wavelength and high energy. Due to this it has greater promises in future (Uma Mukherjee, 2003). During the last 20 years we have witnessed an amazing increase in the application of ultrasonic energy in different fields of science. This is especially true for analytical chemistry. The number of manuscript devoted to almost all kinds of analysis dealing with the uses of ultrasonic energy continues to grow year by year (P. R. Gogate 2002, 2007). As the uses of ultrasonication have become increasingly important in analytical chemistry so has the importance of the type of ultrasonic device chosen to work with. Not all devices perform equally and neither all are intended for same applications. Therefore, the first thing to acquire when developing analytical chemistry with the aid of ultrasonication is a knowledge of the differences among the ultrasonic apparatus available, especially of advantages and disadvantages expected for each one (Hugo Miguel Santos, Carlos Lodeiro, and Jos_e-Luis Capelo-Martinez, 2009). When ultrasonic or sonic energy at high power more than 1/3 W/cm2 for water at room temperature is applied to a liquid, a “cold boiling” termed as cavitation takes place. (Yusuf Adeyuwi 2001) Sound, including ultrasound, is transmitted through any physical medium by waves that compress and stretch the molecular spacing of the medium through which it passes. As the Ultrasound crosses the medium the average distance between the molecules will vary as they oscillate about their mean positions. When the negative pressure caused for an ultrasonic wave crossing a liquid is large enough, the distance between the molecules of the liquid exceeds the minimum molecular distance required to hold the liquid intact, and then the liquid breaks down and voids are created. Those voids are the so called cavitation bubbles.

(L.H. Thompson and L. K. Doraiswamy, 1999) have mentioned the chemical and mechanical effects of ultrasound are caused by cavitation bubbles which are generated during the rarefaction, or negative pressure, period of sound waves. During the negative pressure cycle, the liquid is pulled apart at sites containing some gaseous

impurity (nucleation sites), forming a void. Nucleation sites are also known as “weak spots” in the fluid. Nucleation in the absence of ultrasound can be seen every day when drinking a carbonated beverage. The bubbles of carbon dioxide form at scratches in the glass where gaseous impurities, such as air, are harbored and act as nucleation sites. When using ultrasound, the cavitational activity is directly proportional to the number density of particles present in the medium. Chemical effects due to ultrasound are not observed when there are no dissolved gases in the system, when the sound intensity is not greater than the cavitation threshold of the system, or when the reactant is not volatile enough to enter the cavitation bubble during its formation .The physical and chemical effects of ultrasound are the result of both stable and transient cavitational events, which are described in the following sections (T. J. Mason, 1986, 1990, 2002, T.J. Mason and J. P. Lorimer 2002, T. J. Mason, E. Joyce, S. S. Phull, J. P. Lorimer, 2003)

II. PROCESS PARAMETERS

The process parameters may be divided into machine side parameters and sample side parameters. The machine side parameters are those parameters that can be controlled from the machine settings and which affect the output directly. The sample side parameters are directly related with the sample and they can be controlled while preparing the sample both the parameters combine to affect the output from the process.

2.1 Amplitude of Sonication

The Amplitude variation in the setup has been specially designed in such a manner that the amplitude of sonication varies at 10 different levels (10-100 % or A10 – A100) which has been designed particularly to satisfy the experimental requirements. Normally the amplitude varies between 25 to 100 percent i.e. four levels.

2.2 Time of Sonication

The time sonication selected depends on the concentration being used for experimentation. Generally the time of sonication changes with concentration of the sample solution. Higher the concentration of solution higher will be the sonication time. The time for continuous sonication can be varied from few minutes to few hours.

2.3 Temperature of Sonication

The temperature of sonication depends on heat removal from the system. If heat is removed from the reaction system than the temperature of the system will remain constant hence the system will not attain the set point. If heat is not removed from the system then the process of sonication will stop as soon as the system attains the set point.

2.4 Interval for Pulsed Sonication

When the probe sonicator is decided to be operated in a pulsed sonication mode than the time interval for the pulse has to be set. The interval for the pulse has to varied or set through the control panel. If suppose an interval of 2 seconds is set in the control panel than the probe will stop its vibrations for 2 seconds.

III. SAMPLE PARAMETERS

The sample parameters include parameters only related with the sample of the water. These parameters maybe listed as below.

3.1 Concentration of Sample

The concentration of sample can be varied especially in case of synthetic samples in order to study the effect of concentration on the output of the system with the process parameters. Such tests can be helpful for the optimization of both machine side parameters and sample side parameters.

3.2 B pH OF SAMPLE

pH plays a significant role in the treatment of liquids. The pH can affect the treatment process.

IV. SELECTION OF ARRAY

The selection of array depends on the number of parameters chosen to be varied and on the number of levels through which these parameters are to be varied accordingly the L9 array was selected.

TABLE I TAGUCHI ORTHOGONAL ARRAY FOR EXPERIMENTS

Experiment Number	Column 1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

TABLE II DIFFERENT PARAMETERS AT THREE DIFFERENT LEVELS

S. No	Amplitude	Time	Concentration	pH
1	30	15	1	3.1
2	30	30	2	3.2
3	30	45	3	3.3
4	60	15	2	3.3
5	60	30	3	3.1
6	60	45	1	3.2
7	90	15	3	3.2
8	90	30	1	3.3
9	90	45	2	3.1

TABLE III DIFFERENT TRIALS FOR EACH PARAMETER AND THE RESULTS OBTAINED.

S. No	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean Y
1	0.1	0.4	0.3	0.2	0.2	0.24
2	1.1	1.4	1.3	0.9	1.0	1.14
3	2.8	3.1	3.3	3.0	2.9	3.02
4	2.7	3.4	3.0	2.8	3.0	2.98
5	2.2	2.5	2.3	2.0	2.1	2.22
6	0.2	0.8	0.5	0.4	0.3	0.44
7	2.9	2.5	2.2	2.6	3.0	2.64
8	0.1	0.2	0.4	0.6	0.2	0.3
9	0.3	0.2	0.4	0.6	0.5	0.4

TABLE IV SUM OF SQUARES, S/N RATIO & m

S. No	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Sum of Squares Y	Mean Y^2	S/N ratio
1.	0.1	0.4	0.3	0.2	0.2			
S.sq.	.01	0.16	0.09	0.04	0.04	0.34	0.068	11.67 η1
2.	1.1	1.4	1.3	0.9	1.0			
S.sq.	1.21	1.96	1.69	0.81	1	6.67	1.33	-12.38 η2
3.	2.8	3.1	3.3	3.0	2.9			
S.sq.	7.84	9.61	10.89	9.0	8.41	45.75	9.15	-96.42 η3
4.	2.7	3.4	3.0	2.8	3.0			
S.sq.	7.29	11.56	9.0	7.84	9.0	44.69	8.938	-95.12 η4
5.	2.2	2.5	2.3	2.0	2.1			
S.sq.	4.84	6.25	5.29	4.0	4.41	24.79	4.95	-6.94 η5
6.	0.2	0.8	0.5	0.4	0.3			
S.sq.	0.04	0.64	0.25	0.16	0.09	1.18	0.236	6.27 η6
7.	2.9	2.5	2.2	2.6	3.0			
S.sq.	8.41	6.25	4.84	6.76	9.0	35.26	7.052	-8.48 η7
8.	0.1	0.2	0.4	0.6	0.2			
S.sq.	.01	0.04	0.16	0.36	0.04	0.61	0.122	9.13 η8
9.	0.3	0.2	0.4	0.6	0.5			
S.sq.	0.09	0.04	0.16	0.36	0.25	0.9	0.18	7.44 η9
Total								-184.29
m								-20.47

TABLE V CALCULATIONS FOR AVERAGE S/N RATIO

S. No	Parameter	Level	Calculation of average S/N ratio	Average S/N Ratio
1.	Amplitude	A_1	η1+η2+η3/3= 11.67-12.38 - 96.42 /3	-32.37
		A_2	η 4+η 5+ η 6 = - 95.12 - 6.94 + 6.27/3	-31.03
		A_3	η 7+η 8+ η 9 = - 8.48 + 9.13 + 7.44 /3	2.69
2.	Time	B_1	η 1+η 4+ η 7 = 11.67 - 95.12 - 8.48/3	-30.66
		B_2	η 2+η 5+ η 8 = -12.38 - 6.94 + 9.13/3	-3.39
		B_3	η 3+η 6+ η 9 = - 96.42 + 6.27 + 7.44 /3	-27.57
3.	Concentration	C_1	η 1+η 5+ η 9 = 11.67 - 6.94 + 7.44 /3	4.05
		C_2	η 2+η 6+ η 7 = - 12.38 + 6.27 - 8.48/3	-4.86
		C_3	η 3+η 4+ η 8 = - 96.42 - 95.12 + 9.13 /3	-60.80
4.	pH	D_1	η 1+η 6+ η 8 = 11.67+ 6.27 + 9.13 /3	9.023
		D_2	η 2+η 4+ η 9 = -12.38 - 95.12 + 7.44/3	-33.35
		D_3	η 3+η 5+ η 7 = - 96.42 - 6.94 - 8.48/3	-37.28

TABLE VI COMBINED EFFECT OF FACTORS AT DIFFERENT LEVELS

S. No	Factor	Level l ($A_1B_1C_1D_1$)	Level 2 ($A_2B_2C_2D_2$)	Level 3 ($A_3B_3C_3D_3$)
1.	Amplitude of Sonication (A)	-32.37	-31.03	2.69
2.	Time of Sonication (B)	-30.66	-3.39	-27.57
3.	Concentration (C)	4.05	-4.86	-60.80
4.	pH (D)	9.023	-33.35	-37.28
5.	Combined best conditions	$A_2B_2C_2D_2$		

V. OPTIMIZATION USING TAGUCHI METHOD

The optimization was done using the taguchi method (Tables 1-6). The orthogonal array L-9 was selected for the purpose (Table I & II). Fine different sets of readings were taken refer tables (Table III). The parameter wise results from the above set may be discussed as follows (Srinivas Athreya, Dr Y. D. Venkatesh 2012, IIT Mumbai, S. T. Aruna et al., 2011, S. Kamaruddin et al., 2010, Rama Rao S et al., 2012)

VI. RESULTS AND DISCUSSION FOR THE ABOVE TAGUCHI EXPERIMENTS

The results of the different parameter for the first set are as follows

5.1 Effect of Amplitude in the Process

For the above set of experiments for taguchi optimization technique optimized amplitude occurs between level 2 (30-60 amplitude). This though maybe feasible is not in good agreement with the theory. The average S/N ratio for this comes out to be -31.03 for level 2 (Fig 1) & (Tables IV, V, VI).

5.2 Effect of Sonication Time in the Process

For the above set of experiments for taguchi optimization technique the optimized time of sonication occurs between at level 2 (15-30 minutes). This may be feasible for solutions having low concentrations. Solutions having higher concentrations will require greater time. It is their fore difficult to agree completely with this result. The average S/N ratio for this comes out to be -3.39 for level 2 (Fig 2) & (Tables IV, V, VI).

5.3 Effect of Concentration in the Process

For the above set of experiments for taguchi optimization technique, the optimized concentration of sonication occurs at level 2 (1400 mg/lit). At this concentration of solution at least 30 minutes will be required for degradation as observed in the trial runs. The time of sonication agrees with the concentration of sonication. The average S/N ratio for this comes out to be - 4.86 for level 2 (Fig 3) & (Tables IV, V, VI).

5.4 Effect of pH in the Process

From the above set of experiments for taguchi optimization technique, the optimized pH occurs at level 2 (3.2). At this pH of solution faster degradation will take place as observed in the trial runs. It has been observed during experimentation lower pH is favorable for degradation. The average S/N ratio calculated is -33.35 (Fig 4) & (Tables IV, V, VI).

5.5 Best Sonication Conditions from Taguchi Design of Experiments

The best sonication conditions obtained from taguchi design of experiments is A2B2C2D2 all four parameters amplitude, sonication time, concentration and pH respectively should be at level 2 for best experimental results which does not seem impossible as per the results from previous experimentation.

5.6 Optimized Model Developed

In the present example, the identified optimum condition or the optimum level of factors is A2B2C2D2 has been obtained. The value of η under the optimum condition is predicted using the additive model as given below.

N optimization from taguchi = m + m C3-m + m D3- m = -20.49 + [- 4.86 – (-20.49)] + [-33.35 - (- 20.49)] = -17.72

This S/N ratio is very close to the S/N ratio of experiment no 9 in which the factors and levels are closer to the experimental work done.

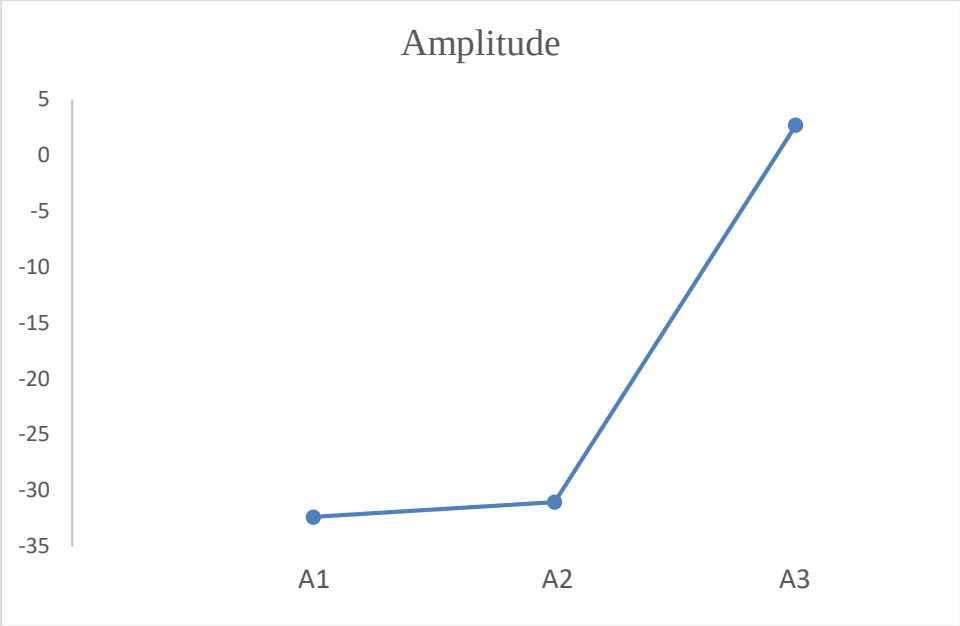

Fig. 1 Average S/N ratio vs. amplitude

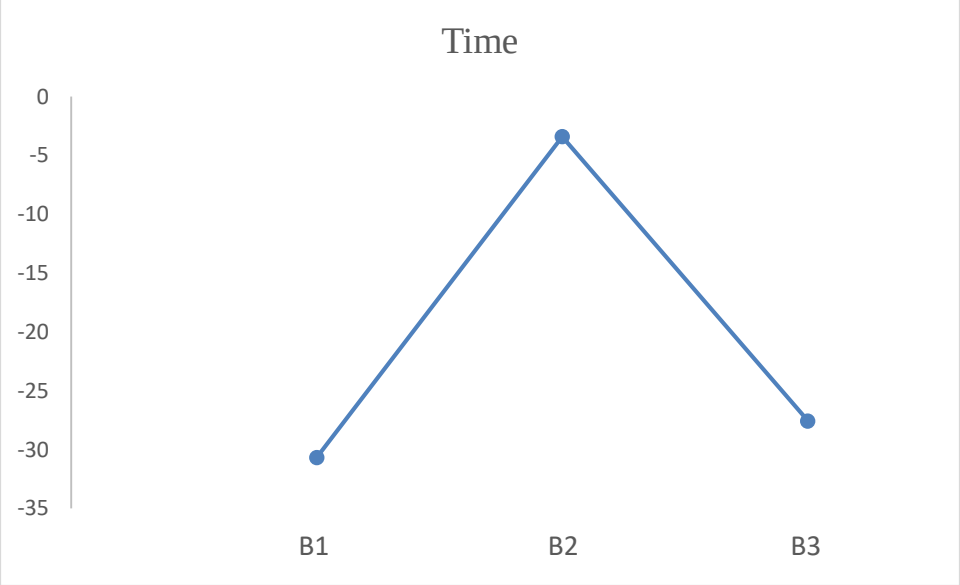

Fig. 2 Average S/N ratio vs. time of sonication

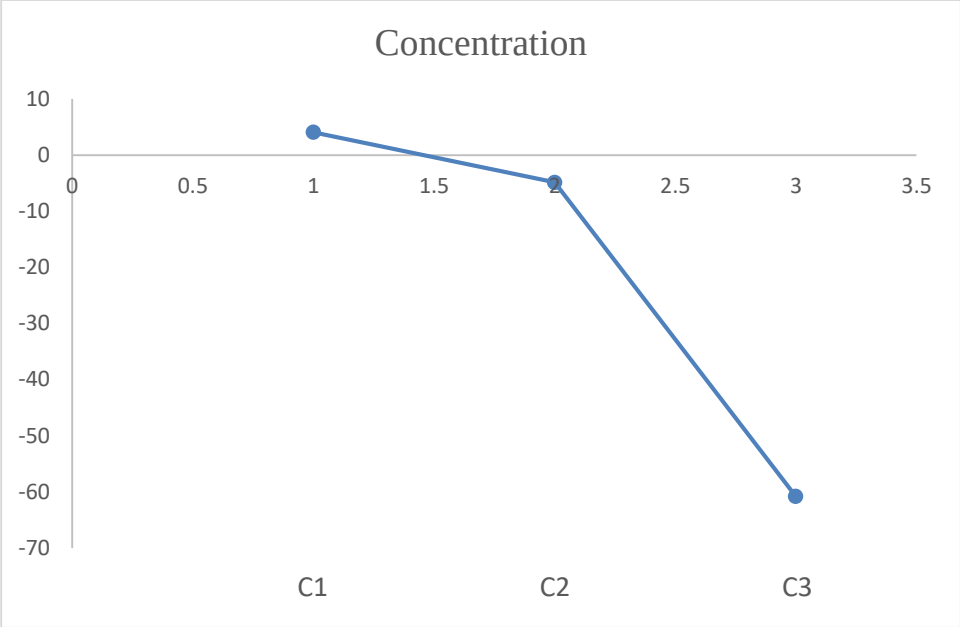

Fig. 3 Average S/N ratio vs. concentration

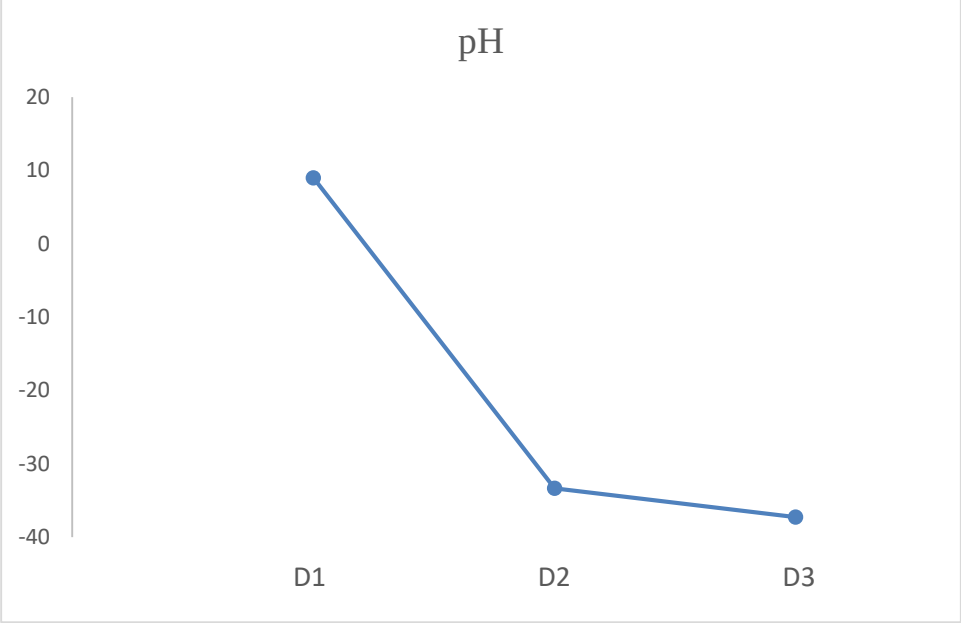

Fig. 4 Average S/N ratio vs. pH

VII. CONCLUSIONS

The degradation process of aspirin using probe type sonication equipment was successfully optimized for both sonication machine parameters as well sample parameters. The optimized results are in confirmation with experiments conducted and theory explained. The best sonication conditions indicate equally influential machine parameters and sample parameters.

ACKNOWLEDGEMENTS

I extend my sincere thanks to Dr. N.W. Ingole for his continuous motivation and guidance during and after execution of this work.

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