

# OPTIMIZED ANN MODEL FOR ULTRASONICATION WASTEWATER TREATMENT PROCESS

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## ABSTRACT

*In this work, ANN model has been used to optimize the input factors in the ultrasonication process. The required parameters for the ultrasonication process to achieve the maximum percentage of solids reduction are derived using the optimization methods. Experiments are conducted to verify the optimum parameters achieved. Eight samples of untreated water have been subjected to five treatment methods. The treatment methods like STP, RZT, TWP, Ultrasonication and Optimized ultrasonication treatment methods are used to treat the water and the values of parameters like pH, TSS, TDS, COD and BOD are measured for all the five methods. The improvement in each method is analyzed. It has been determined that Optimized ultrasonication treatment method yielded the best performance over all other four methods.*

**Keywords:** Waste water treatment process, artificial neural networks, ultrasonication, sludge treatment, environmental protection

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## 1. INTRODUCTION

Water is essential substance for the survival of life on the earth (Tansel, 2008; Ambashta and Sillanpaa, 2010). Sources of water on the earth are ground water, rain water, water in lake, ponds, reservoirs, sea water etc. Quality of water is very important if the water is to be consumed by human beings or animals. However, the water may get contaminated with various types of pollutants (Ferguson et al., 2009; Huang et al., 2008; Zhang et al., 2009; Ackah et al., 2011; Sayyed and Wagh, 2011; Tiwari, 2011; Zhang et al., 2011). In order to make the polluted water fit for drinking purposes, it has to be treated properly so that the harmful components of the contaminated water are free from toxic elements. There are many stages involved in the treatment of contaminated water like reduction of dissolved solids, suspended solids, microbial pollutants etc.

Colloidal and suspended solids can be removed with stages of flocculation, sedimentation and media filtration. Dissolved solids can be removed with carbon adsorption, ion exchange and membrane processes. Inactivation of Microbial pollutants can be achieved Chlorination,

Ozonation and Ultraviolet Radiation (UV) (Tansel, 2008). However, some of these processes are costly, slow and ineffective. More importantly, these processes produce secondary pollutants (Gaya and Abdullah, 2008) as a byproduct which is again toxic in nature (Liu et al., 2005). There were many experiments conducted to reduce the toxic secondary pollutant byproducts like advanced oxidation process, magnetic purification, semiconductor catalysts, forward osmoses etc (Chong et al., 2010; Ambashta and Sillanpaa, 2010). All these methods could only reduce the secondary pollutants production only marginally. One of the innovative methods adopted to reduce the solids in the water is passing the high frequency sound wave, known as ultrasound waves with a frequency of 20,000 Hz or beyond, so that dissolved and suspended solids are separated. This process is known as sonication and since the ultrasound is used in this process, it is also known as ultrasonication.

Ultrasound frequency range is beyond the range that humans can hear, that is beyond 20-20,000Hz range and below 600kHz (Deymier et al., 2004; Wong, 2002). Ultrasound is the energy passed on the water molecules where the molecules are subjected to vibration (Bello et al., 2005). The Ultrasound can be produced with two methods. In the first method, a magnetic coil and vibrating part like nickel and Terfenol-D converts the electrical energy into vibration or mechanical energy. In second method, the electrical energy is converted into high frequency mechanical energy with the help of piezoelectric material (Pilli et al., 2011). The piezoelectric material is attached to a vibrating part thus it imparts the high frequency vibrations to the water molecules.

Ultrasound was used for membrane filtration in several investigations (Zhang et al., 2003, Lamminen, 2004, Kyllonen et al., 2005, Lu et al., 2009, Pirkonen et al., 2010). Treatment to Turbidity as well as total suspended solid (TSS) reduction was achieved with ultrasound in methods proposed by (Mutiarani et al., 2009, Liang et al., 2009, Chua et al., 2010, Stefan and Balan, 2011). Algae removal with ultrasound technique was also addressed by several researchers as the algae growth is one of major concern in the water treatment efficiency. Several research methods were developed to address the algae growth (Allen and Arnon, 1995; Haarhoff and Edzwald, 2004; Mahvi and Dehghani, 2005; Kommineni et al., 2009; Sayadi et al., 2011; Qiu et al., 2011) Similarly water disinfection was carried by some researchers like (Kim et al., 2002; Pozos et al., 2004; Gomez-Lopez et al., 2009; Toor et al., 2007).

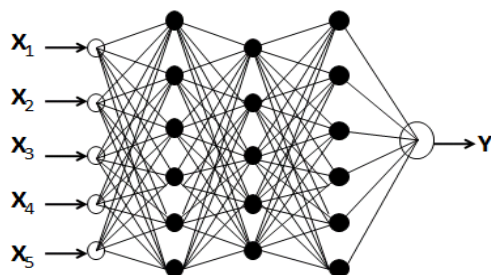
In this work, ultrasonication treatment has been optimized for the process parameters. The process parameters like amplitude of ultrasonic wave and time of activity for solids present are tuned for highest percentage of solids reduction. In next section, the ANN procedure adopted for the optimization is laid out. In sec. III, the experimental results are presented and finally important conclusions are drawn.

## 2. MATHEMATICAL FORMULATION

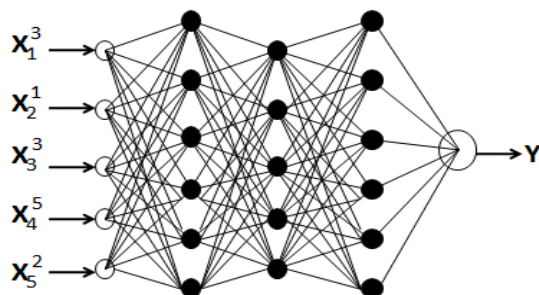
In ultrasonication method, three factors are important to determine the percentage reduction. They are amplitude, time of excitation and total solids present in the slurry. Based on the experimental data [Mallikarjuna Huggi and S.R. Mise 2019], an ANN model was developed by the authors. The ANN model has taken amplitude, time and solids present in the slurry as the input and it predicted the percentage reduction in solids. The ANN model is complex unexplainable black box model. The relationship between different inputs to the output is complex in nature. Sometimes, it is possible to treat it as a linear model, non-linear model and complex unexplainable mathematical model. As the number of layers and neurons increase in the model, the explainability becomes more and more difficult.

An ANN model can be predictive model or an optimization model. The model here is known as a surrogate model since it can be used for both prediction and optimization. A surrogate model is the one that is developed based on certain experimental data. Surrogate model is the statistical

representation of the physical model. In the present case, the surrogate model was built with experimental data collected as part of the research work presented in [Mallikarjuna Huggi and S.R. Mise 2019]. In the present work, the model was optimized. Optimization requires the combinations of various factors to be input into the surrogate model and keep predicting the output from ANN. The ANN predicted output will also be varying as the combinations of input factors keep varying. At certain combinations of the input factors, the output becomes maximum. These are known as local optima. There will be a maximum among the local optima and that value may be considered as the global maxima in the experimental search space.



**Figure 1** Generalized Feed Forward Neural Network - Predictive



**Figure 2** Generalized Feed Forward Neural Network - Optimized

Fig. 1 shows a typical multi perceptron model with  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$  and  $X_5$  as the inputs and  $Y$  as the output. The ANN model has 3 hidden layers and the output layer has sigmoid activation function. The activation functions for the neurons in the hidden layers are Rectilinear activation functions (ReLU). Once the optimum weights for each of the neurons are determined by training the ANN with experimental data, the  $Y$  can be predicted for any new set of  $X_s$ .

In Fig. 2, the optimized ANN model is shown. Each input, that is  $X$ , can take multiple values depending upon the experimental setting. Assume that  $X_1$  can take three values,  $X_2$  with 4 values, and  $X_3$  with 3 values,  $X_4$  with 5 values and  $X_5$  with 3 values. Then  $Y$  can be predicted with different combinations of the  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$  and  $X_5$ . For each of these combinations,  $Y$  can be predicted with ANN. The combination of  $X_s$  that gives the maximum values for  $Y$  is the optimized set of process parameters.

In the current problem, the optimized values of Amplitude, time and total solids were found to be 45 Setting, 50 min and 23 g/L that maximized the percentage reduction in solids. The ultrasonication process with these values as factors is known as Ultrasonication-Optimized (OUS) process. The process with Amplitude, time and total solids of 40 Setting, 43 min and 10 g/L is known as Ultrasonication-Standard (US) process.

### 3. THE SIMULATION RESULTS

In the experimentation, eight samples of waste water were collected at different points of time in a week. Each of the eight samples has different parameters. The parameters measure for

characterizing the waste water were pH Value of the wastewater, Biochemical Oxygen Demand (BOD) in mg/L, Chemical Oxygen Demand (COD) in mg/L, Total Suspended Solids (TSS) in mg/L and Total Dissolved Solids (TDS) in mg/L. Table 1 shows the measured parameters for these eight samples. It can be notice that sample 7 has got highest pH value of 8.0, whereas the sample 3 has got lowest pH value of 7.2. TSS is highest in sample 7 with 348 mg/L and lowest in sample 4 with 126 mg/L. Similarly, the TDS is highest in sample 7 with 806 mg/L and lowest in sample 3 with 261 mg/L BOD is highest in sample 8 with 300 mg/L and lowest in sample 1 with 98 mg/L. COD is highest in sample 7 with 662 mg/L and lowest in sample 5 with 306 mg/L. With this data, it can be concluded that there is no correlation between the parameters since all the samples were collected randomly.

**Table 1** Concentrations of various parameters Before Treatment

SAMPLES	1	2	3	4	5	6	7	8
pH	7.8	7.4	7.2	7.4	7.6	7.3	8.0	7.3
TSS in mg/L	327	176	216	126	338	287	348	128
TDS in mg/L	281	350	261	859	303	613	806	702
BOD in mg/L	98	270	146	278	158	275	252	300
COD in mg/L	496	389	421	332	306	599	662	470

The collected 8 samples were subjected to treatment. Five different methods were chosen for the purpose of reducing the solids in waste water sample. The treatment methods are Sewage plant treatment (STP), Root Zone Technology (RZT), Treatment without Plants (TWP), Ultrasonication – Standard and Ultrasonication – Optimized. The five parameters, that were measured before treatment, were also measured after the treating the sample waste water with five methods. One liter of waster was taken from the sample for each of the treatments. Table 2 shows the measured values of five parameters after treatment with Ultrasonication-standard method.

**Table 2** Concentrations of various parameters after Ultrasonication-Standard (US) Treatment

SAMPLES	1	2	3	4	5	6	7	8
pH	7.8	7.1	7.1	7.3	7.3	7.1	7.2	7.1
TSS in mg/L	312	102	177	115	149	228	139	104
TDS in mg/L	260	319	251	591	260	470	654	277
BOD in mg/L	81	220	71	254	98	274	90	180
COD in mg/L	468	342	430	279	297	269	270	329

Similarly, when the sample water was treated with Ultrasonication-Optimized (OUS) method, there was a drastic reduction in the values of parameters. Table 3 shows the values of parameters after treating 8 samples of waste water with OUS method. While there were other methods like STP, RZT and TWP, the reduction in the values of parameters for these methods are shown in Figures for dew samples.

**Table 3** Concentrations of various parameters after Ultrasonication-Optimized (OUS) Treatment

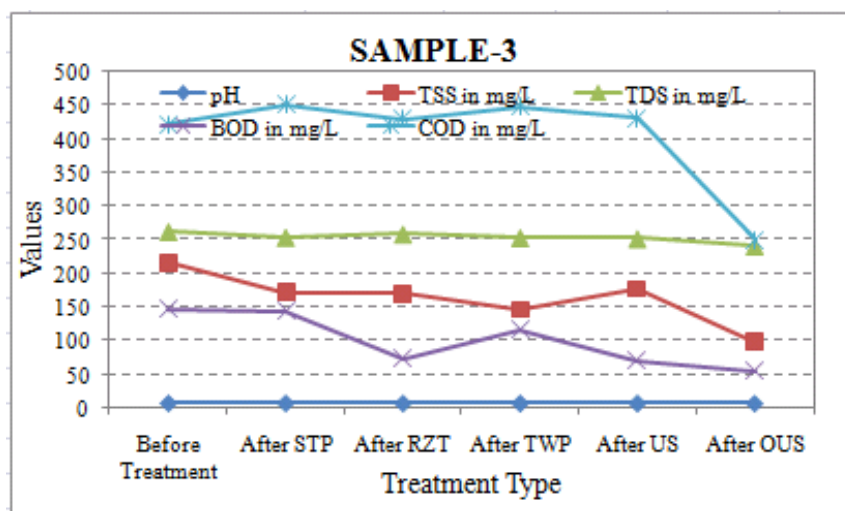
SAMPLES	1	2	3	4	5	6	7	8
pH	7.5	7.1	7.0	7.2	7.2	7.0	7.1	7.1
TSS in mg/L	218	100	118	110	134	162	136	101
TDS in mg/L	257	317	250	511	251	391	284	272
BOD in mg/L	65	200	63	58	54	115	87	78
COD in mg/L	363	253	282	267	286	264	254	267

In Table 4, for sample 3, the values of measured parameters after treating with 5 different methods, is shown. One liter of sample 3 is subjected to each of the five treatment processes. A fresh un-treated sample was used for each treatment process. It can be noticed that the reduction in value from untreated condition to treated condition varied randomly among five treatment methods.

**Table 4** Concentrations of various parameters after 5 different treatments on sample 3

SAMPLE 3	Before Treatment	After STP	After RZT	After TWP	After US	After OUS
pH	7.2	7.2	7.1	7.1	7.1	6.8
TSS in mg/L	215.8	171.3	170.3	146.1	176.8	98
TDS in mg/L	261.3	253.1	257.7	252.5	250.9	240
BOD in mg/L	146.0	142.8	72.6	114.1	70.8	54
COD in mg/L	421.0	450.0	428.3	447.6	430.0	249

Fig. 3 shows the change in parameter values after treating the wastewater sample with five different treatment methods. It can be noticed that COD did not change much when STP, RZT, TWP and US treatment methods were used. But when OSU was used on a fresh sample, the COD got drastically reduced from 421 mg/L to 249 mg/L. Similarly, there is almost not much reduction in the concentration of TDS. There is a slight drop in the TDS in OUS method from 261.3 mg/L to 240 mg/L. TSS has dropped marginally with STP, RZT and TWP methods, but the US method did not show much improvement as expected in an US method. When OUS was used in place of US, there was significant drop in the TSS concentration. The TSS reduced from 215.8 mg/L to 98 mg/L. With OUS, the BOD and pH got reduced to 54 mg/L and 6.8 respectively. For all five parameters, only OUS method yielded better results than other methods for sample 3.



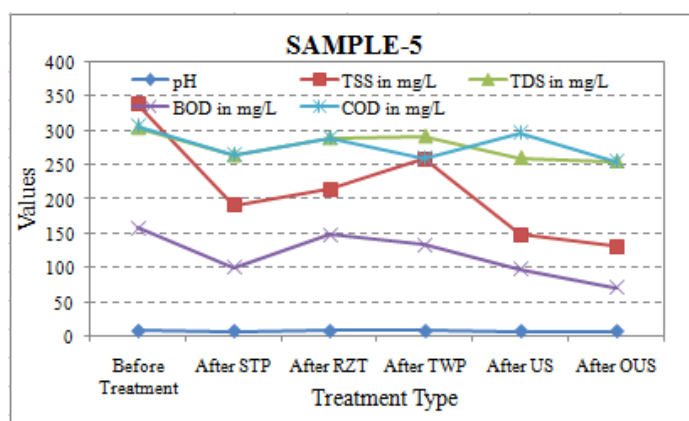
**Figure 3** Variation in concentrations of various parameters after 5 different treatments on sample 3

Similarly, in Table 5, the values of measured parameters are shown that were measured after treating with 5 different methods, for sample 5. Again, one liter of sample 5 was treated with five treatment methods. A fresh un-treated one liter of sample 5 was used for each treatment process. It can be noticed that the reduction in value from untreated condition to treated condition varied randomly among five treatment methods in the case of sample 5 also.

**Table 5** Concentrations of various parameters after 5 different treatments on sample 5

SAMPLE 5	Before Treatment	After STP	After RZT	After TWP	After US	After OUS
pH	7.6	7.3	7.5	7.5	7.3	7.2
TSS in mg/L	338.3	190.8	214.8	258.7	148.7	131
TDS in mg/L	303.3	263.6	288.3	291.2	260.0	255
BOD in mg/L	158.1	100.4	148.1	133.7	97.9	71
COD in mg/L	306.4	264.9	289.2	258.8	297.3	254

Fig. 4 shows the change in parameter values after treating the wastewater sample with five different treatment methods. It can be noticed that COD did not change much when RZT and US treatment methods were used. But when STP, TWP and OSU were used on a fresh sample, the COD got drastically reduced from 306.4 mg/L to 264.9 mg/L, 258.8 and 254 mg/L respectively. Similarly, there is reduction in the concentration of TDS for STP, US and OUS methods only. There is a slight drop in the TDS in OUS method from 303.3 mg/L to 255 mg/L. TSS has dropped marginally with RZT and TWP methods. When STP, US and OUS were used, there was significant drop in the TSS concentration. The TSS reduced from 338.3 mg/L to 190.8 mg/L, 148.7 mg/L and 131 mg/L respectively. With OUS, the BOD and pH got reduced to 71 mg/L and 7.2 respectively. For all five parameters, STP and OUS methods yielded better results than other methods for sample 5.



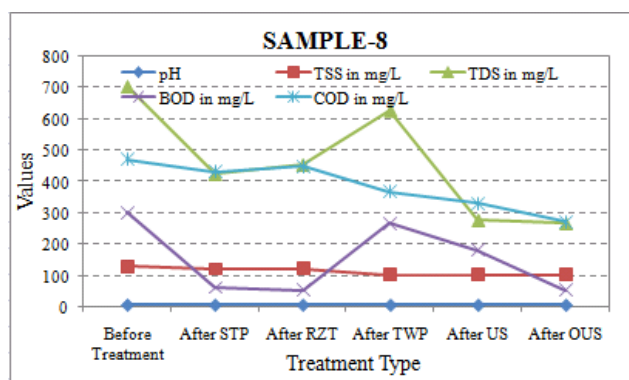
**Figure 4** Variation in concentrations of various parameters after 5 different treatments on sample 5

Similarly, another sample is taken measuring the performance the five treatment methods. Sample 8 is taken this time for experimentation. Table 6 shows the values of measured parameters that were measured after treating the sample 8 with 5 different methods. Again, one liter of sample 8 was treated with five treatment methods. Like samples 3 and 5, a fresh untreated sample 8 was used for each treatment process.

**Table 6** Concentrations of various parameters after 5 different treatments on sample 8

SAMPLE 8	Before Treatment	After STP	After RZT	After TWP	After US	After OUS
pH	7.3	7.1	7.2	7.1	7.1	6.8
TSS in mg/L	128.3	120.2	121.4	102.7	103.7	102
TDS in mg/L	702.1	423.9	452.7	625.3	276.7	266
BOD in mg/L	300.2	59.9	53.0	265.6	180.3	52
COD in mg/L	469.7	431.4	447.6	366.2	329.0	270

Fig. 5 shows the change in parameter values after treating the wastewater sample with five different treatment methods. It can be noticed that COD did not change much when STP and RZT treatment methods were used. But when TWP, US and OSU treatment methods were used on a fresh sample, the COD got drastically reduced from 469.7 mg/L to 366.2 mg/L, 329 mg/L and 270 mg/L respectively. Similarly, there is much fluctuation in the concentration of TDS. There is a significant drop in the TDS in OUS method from 702.1 mg/L to 266 mg/L. TSS has not changed much with any of the five treatment methods, When OUS was used, there was drop in the TSS concentration. The TSS reduced from 128.3 mg/L to 102 mg/L, which is the largest drop among all methods. With OUS, the BOD and pH got reduced to 52 mg/L and 6.8 respectively. For all five parameters, only OUS method yielded better results than other methods for sample 3.



**Figure 5** Variation in concentrations of various parameters after 5 different treatments on sample 8

#### 4. CONCLUSION

In this work, optimized parameters were derived for ultrasonication treatment method. To obtain the optimum parameters for the ultrasonication, an ANN model was developed and model was run with various combinations of the factors to achieve the best output. In order to validate the ANN model, experiments were conducted. Five different treatment methods were used in experimentation. The optimized ANN factors were used along with ultrasonication method and that method is named as Ultrasonication-Optimized method (OUS). Eight samples of wastewater were collected and were treated with five treatment methods, namely, STP, RZT, TWP, US and OUS. Of all the five treatment methods, OUS showed consistent results. The reduction in the concentration of all parameters, namely, pH, TSS, TDS, COD and BOD, were significant. Other methods had shown either significant, marginal or almost no reduction in different samples. Hence it is concluded that OUS method is the best method among all the five treatment processes for the samples treated since it has yielded consistent results. As future work, the OUS can further be optimized with heuristic algorithms like ACO, Harmony search or simulated annealing.

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