OPTIMIZED ANN MODEL FOR ULTRASONICATION WASTEWATER TREATMENT PROCESS

Mallikarjuna Huggi and S.R. Mise
V.T.U, Belgaum, India

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

Cite this Article: Mallikarjuna Huggi and S.R. Mise, Optimized ANN Model for Ultrasonication Wastewater Treatment Process, International Journal of Advanced Research in Engineering and Technology, 10(3), 2019, pp. 94-102.

http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=10&IType=3

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 as 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 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 is 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 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.

![Generalized Feed Forward Neural Network - Predictive](image1)

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

![Generalized Feed Forward Neural Network - Optimized](image2)

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

Fig. 1 shows a typical multi perceptron model with X1, X2, X3, X4 and X5 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 Xs.

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 X1 can take three values, X2 with 4 values, and X3 with 3 values, X4 with 5 values and X5 with 3 values. Then Y can be predicted with different combinations of the X1, X2, X3, X4 and X5. For each of these combinations, Y can be predicted with ANN. The combination of Xs 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 waste 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  | 251  | 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.

| 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 OUS 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](https://ssrn.com/abstract=3527481)
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.

![SAMPLE 5 graph](https://ssrn.com/abstract=3527481)

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 OUS 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](image)

**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.

**REFERENCES**

[1] Ackah M, Agyemang O, Anim AK, et al. 2011. Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(3-4): 186-194.

[2] Ambashta RD, Sillanpaa M. 2010. Water purification using magnetic assistance: A review. Journal of Hazardous Materials, 180: 38-49.

[3] Allen MB, Arnon DI. 1995. Studies on nitrogen-fixing blue-green algae. I. Growth and nitrogen fixation by *Anabaena cylindrica* lem. Plant Physiology, 30(4): 366-372.
Bello ARC, Angelis DF, Domingos RN. 2005. Ultrasound Efficiency in Relation to Sodium Hypochlorite and Filtration Adsorption in Microbial Elimination in a Water Treatment Plant. Brazilian Archives of Biology and Technology, 48: 739-745.

Chong MN, Jin B, Chow CWK, et al. 2010. Recent developments in photocatalytic water treatment technology: A review. Water Research, 44: 2997-3027.

Chua SY, Adul Latif P, Ibrahim Sh, et al. 2010. Effect of ultrasonic irradiation on COD and TSS in raw rubber mill effluent. Environment Asia, 3(special issue): 32-35.

Deymier PA, Vasseur JO, Khelif A. 2004. Second-order sound field during megasonic cleaning of patterned silicon wafers: Application to ridges and trenches. Journal of Applied Physics 90, 4211-4218

Ferguson CM, Charles K, Deere D. 2009. Quantification of microbial sources in drinking-water catchments. Critical Review in Environmental Science and Technology, 39(1): 1-40.

Gaya UI, Abdullah AH. 2008. Heterogeneous photocatalytic degradation of organic contaminants over titanium dioxide: a review of fundamentals, progress and problems. Journal of Photochemistry and Photobiology C: Photochemistry Reviews, 9: 1-12.

Gomez-Lopez MD, Bayo J, García-Cascales MS, et al. 2009. Decision support in disinfection technologies for treated wastewater reuse. Journal of Cleaner Production, 17(16): 1504-1511.

Haarhoff J, Edzwald JK. 2004. Dissolved air flotation modelling: Insights and shortcomings. Journal of Water Supply Research and Technology - AQUA, 53: 127-150.

Huang X, Sillanpaa M, Duo B, et al. 2008. Water quality in Tibetan Plateau: metal contents of four selected rivers. Environmental Pollution, 156(2): 270-277.

Kim BR, Anderson JE, Mueller SA, et al. 2002. Literature review - efficacy of various disinfectants against Legionella in water systems. Water Resources, 36: 4433-4444.

Kommineni S, Amante K, Karnik B. 2009. Strategies for Controlling and Mitigating Algal Growth within Water Treatment Plants. Water Research Foundation, Denver, Colorado, USA.

Kyllonen HM, Pirkonen P, Nystrom M. 2005. Membrane filtration enhanced by ultrasound: a review. Desalination, 181: 319-335.

Lamminen MO. 2004. Ultrasonic Cleaning of Latex Particle Fouled Membranes. PhD Thesis. The Ohio State University, USA.

Liang H, Nan J, He W, et al. 2009. Algae removal by ultrasonic irradiation-coagulation. Desalination, 239: 191-197.

Pavithra and Lokesh K.S (2014), Selection of Wastewater Treatment Process Based on Analytical Hierarchy Process, International Journal of Civil Engineering and Technology (IJCIET), Volume 5, Issue 9, pp. 27-33

Liu HL, Chiou YR. 2005. Optimal decolorization efficiency of Reactive Red 239 by UV/TiO2 photocatalytic process coupled with response surface methodology. Chemical Engineering Journal, 112: 173-179.

Lu JU, Du X, Lipscomb G. 2009. Cleaning Membranes with Focused Ultrasound Beams for Drinking Water Treatment. 2009 IEEE International Ultrasonics Symposium Proceedings.

Mahvi AH, Dehghani MH. 2005. Evaluation of ultrasonic technology in removal of algae from surface waters. Pakistan Journal of Biological Science, 8: 1457-14.

Mutiarani, Irsyad M, Trisnobudi A. 2009. Ultrasonic Irradiation in Decreasing Water Turbidity. http://www.ftsl.itb.ac.id/.../PE-EM3-MUTIARANI-15305035-EDIT.pdf.

Pilli S, Bhunia P, Yan S, et al. 2011. Ultrasonic pretreatment of sludge: A review. Ultrasonics Sonochemistry, 18: 1-18.

Pirkonen P, Gronroos A, Heikkinen J, et al. 2010. Ultrasound assisted cleaning of ceramic capillary filter. Ultrasonics Sonochemistry, 17: 1060-1065.

Pozos N, Scow K, Wuertz S, et al. 2004. UV disinfection in a model distribution system: biofilm growth and microbial community. Water Resources, 38: 3083-3091.
Mallikarjuna Huggi and S.R. Mise

[26] Qiu YJ, Yang F, Rong F, et al. 2011. Degradation of Microcystins by UV in the Presence of Low Frequency and Power Ultrasonic Irradiation. Measuring Technology and Mechatronics Automation (ICMTMA), 2011 Third International Conference.

[27] Sayyed MRG, Wagh GS. 2011. An assessment of groundwater quality for agricultural use: a case study from solid waste disposal site SE of Pune, India. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(3-4): 195-201.

[28] Mahvi AH, Dehghani MH. 2005. Evaluation of ultrasonic technology in removal of algae from surface waters. Pakistan Journal of Biological Science, 8: 1457-14.

[29] Mallikarjuna Huggi and S.R. Mise. 2019. ANN model of Wastewater Treatment Process, International Journal of Advanced Research in Engineering and Technology (IJARET), Volume 10, Issue 3,

[30] Stefan A, Balan G. 2011. The Chemistry of the Raw Water Treated by Air-Jet Ultrasound Generator. Rev. Roum. Sci. Tech. Mec. Appl., 56(1): 85-92.

[31] Tansel B. 2008. New technologies for water and wastewater treatment: A survey of recent patents. Recent Patents on Chemical Engineering, 1: 17–26.

[32] Tiwari RN. 2011. Assessment of groundwater quality and pollution potential of Jawa Block Rewa District, Madhya Pradesh, India. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(3-4): 202-212.

[33] Toor R, Mohseni M. 2007. UV-H2O2 based AOP and its integration with biological activated carbon treatment for DBP reduction in drinking water. Chemosphere, 66(11): 2087-2095.

[34] Wong KYK. 2002. Ultrasound as A Sole or Synergistic Disinfectant in Drinking Water. Master Thesis. Worcester Polytechnic Institute, USA.

[35] Zhang M, Li C, Benjamin MM, Chang Y. 2003. Fouling and natural organic matter removal in adsorbent/membrane systems for drinking water treatment. Environmental Science and Technology, 37(8): 1663–1669.

[36] Zhang Y, Love N, Edwards M. 2009. Nitrification in drinking water systems. Critical Review in Environmental Science and Technology, 39(3): 153-208.

[37] Zhang WJ, Jiang FB, Ou JF. 2011. Global pesticide consumption and pollution: with China as a focus. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(2): 125-144.

http://www.iaeme.com/IJARET/index.asp 102  editor@iaeme.com

Electronic copy available at: https://ssrn.com/abstract=3527481