Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

OPTIMIZATION DESIGN OF GRANULAR ACTIVAED CARBON USING GENETIC ALGORITHM

Dr. Ahmed Majeed Al-Kadimy
Zohul Abdul Hadi Hamza
University of Basrah/ College of Engineering/ Civil Department
Al.kadhimi@yahoo.com

Received: 26 /1 / 2014 Accepted: 7 / 4/ 2014

Abstract

Integrated advanced wastewater treatment provides important fundamental solutions to problems associated with water scarcity prevailing in arid and semi arid climatic regions.

This was accomplished through treated water with specific specification and characteristics suitable to be used for agricultural, domestic, and industrial purposes. This study is concerned with the use of genetic algorithm procedure for the optimum design of integrated advance wastewater treatment units, with their various types and characteristics. The aim of optimum wastewater treatment units design is to attain optimum values of certain pre defined objective function.

Based on the results of applying genetic algorithm on activated carbon treatment plant, it was found that the optimum values of empty bed contact time, dose of activated carbon, diameter of contractor, and loading rate of multiple hearth furnaces are 10min, 25mg/l, 2.4m, and 30 m/min, respectively.

التصميم الامثل للمعالجة المتقدمة لمياه الصرف الصحي بأستعمال الخوارزميات الجينية

ا.م.د. احمد مجيد حمد الكاظمي
جامعة البصرة – كلية الهندسة

م.زحل عبد الهادي حمزه
جامعة البصرة – كلية الهندسة

الخلاصة

توفر المعالجات المتقدمة المتكاملة لمياه الصرف الصحي حلولا جذرية ومهمة لمشاكل شحة المياه السائدة في العديد من البلدان ذات النظم المناخية الجافه وشبه الجافه ، ويتم ذلك من خلال الحصول على مياه معالجة ذات مواصفات محددة بالإمكان استخدامها لمختلف الأغراض الزراعية والمنزلية والصناعية. يتركز موضوع الدراسة على استخدام طريقة الخوارزميات الجينية في التصميم الأمثل لوحدات المعالجة المتقدمة. وبمختلف أنواعها ومواصفاتها. تهدف مسألة التصميم الأمثل لوحدات المعالجة المتطورة إلى الوصول إلى قيم معايير التصميم المختلفة والتي تعطي اقل قيمة لدالة الهدف وتحقق في الوقت ذاته متغيرات المسألة . وتمثلت دالة الهدف في كلفة وحدات المعالجة بعناصرها المختلفة إضافة لكلفة الصيانة والتشغيل. تمت دراسة المعالجة المتقدمة لمياه الصرف الصحي وتحديد متغيرات التصميم باعتماد وحدة الكاربون المنشط. احتوت المخرجات النظرية في هذه الدراسة على مجموعة المعايير التصميمية المثلى للمعالجة المتقدمة بحيث تحقق هذه المعايير النوعية المطلوبة للمياه المعالجة وبأقل كلفة.

اعتمادا على نتائج الخوارزميات الجينية في تصميم وحدة الكاربون المنشط ان القيم المثلى لزمن التصميم , جرعة الكاربون المنشط , وقطر وحدة المعالجة , ومعدل حمل الفرن المستعمل لاعادة الاستعمال الكاربون المنشط من نتائج الخوارزميات الجينية في تصميم وحدة الكاربون المنشط , هو 10 دقيقة , 25 ملي غرام لكل لتر , 2.4 متر , و30 متر لكل دقيقة على التوالي .

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

1. Introduction

In most Mediterranean countries, the scarcity of water together with the high cost associated with collecting and using the limited surface rainwater for irrigation have become real constraints for our irrigated agriculture. Because of this, particular emphasis is placed on the water use efficiency and the cultivation of crops with high return per square meter and volume of water **(Morrison et al., 2009).**

Drought attributable in significant part to climate change is already causing acute water shortages in large parts of Australia, Asia, Africa, and United States **(Alderfasi, 2009)**.

Reuse of effluents from municipal or sanitary wastewater treatment plant is becoming a matter of great importance as available and economical resources for a variety of applications **(Lin, 2007, Metcalf& Eddy, 2003).** Water reuse figures are basically classified into; Unavoidable water reuse and intentional water reuse. The location of several cities on a single river, stream, or lake leads to unavoidable water reuse when each city uses the water body as a water supply and receiving body for wastewater **(Culp et al., 1979).** Intentional water reuse holds the key to the efficient and effective utilization of the limited freshwater resources by making available a new valuable source of water to augment existing supplies and a major source of supply for the future. It includes the reuse of water for industrial, agricultural, domestic, recreational, and ground water recharge purposes **(Culp et al., 1979).**

1. Activated Carbon Adsorption

Adsorption is the process of collecting soluble substances within a solution on a suitable interface. In AWWT, adsorption with activated carbon-a solid interface, is used principally for the removal of refractory organic compounds, as well as residual amounts of inorganic compounds such as nitrogen, sulfides, and heavy metals **(Benefield, 1989).** The removal of taste and odor compounds from wastewater is another important application, especially in reuse applications.

Activated carbon is produced by heating char to a high temperature and then activating it by exposure to an oxidizing gas at high temperature. The two most common types of activated carbon are granular activated carbon (GAC), which has a diameter greater than 0.1 mm, and powdered activated carbon (PAC), which has a diameter of less than 200 mesh **(Álvarez , et al., 2011).** In this study GAC has been selected over powdered carbon primarily because GAC is normally regenerated and reused, while powdered carbon is discarded after use. Also, GAC has the additional advantage of providing a margin of safety in operation that powdered carbon does not provide. Sudden changes in influent composition are common in wastewater treatment. Granular carbon has the capacity to withstand substantial changes in the influent composition with a much reduced effect on the effluent quality. This aspect and the availability of the regeneration technology were the major factors in the selection of granular carbon.

A bed column is often used to bring the wastewater into contact with the activated carbon. There are three types of activated carbon columns; fixed-bed, expanded-bed, and moving-bed. In fixed-bed columns, the water is applied to the top of the column and withdrawn from the bottom. In expanded bed columns, the influent is introduced at the bottom of the column and is allowed to expand. While, in the moving bed columns, spent carbon is continuously replaced with fresh carbon. Spent granular carbon can be regenerated by removal of the adsorbed organic matter from its surface through oxidation in a furnace. The capacity of the regenerated carbon is slightly less than that of the virgin carbon **(Álvarez et al., 2011).**

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

The design of GAC contactor is based on contact time, hydraulic loading rate, carbon depth and number of contractors. At least two parallel carbon contactors should be used, because then one or more units can remain in operation while one unit is taken out of service for maintenance or for removal and regeneration of spent carbon **(Metcalf & Eddy, 2003).** Based on applying the steady state mass balance equation around the contractor, the adsorbent usage rate can be defined as **(Lin, 2007);**

$$\frac{m_{GAC}}{Q_t}=\frac{C_O-C_e}{q_e} \text{..........................} eq.(1)$$

Where;
Q = flowrate, m^3/min
C_o = initial concentration of adsorbate, mg/l
t = time, min
C_e = final equilibrium concentrate of adsorbate, mg/l
m_{GAC} = mass of adsorbent (GAC), mg
q_e = adsorbent phase concentration after equilibrium, mg adsorbate/g adsorbent.
In Eq.(1), can be neglected if the mass of the adsorbate in the pore space is assumed to be very small compared to the amount adsorbed. Then;

$$\frac{m_{GAC}}{Q_t}=\frac{C_O}{q_e} \text{..........................} eq.(2)$$

The following terms are used commonly when the operational performance of GAC contactors is determined:

Empty-Bed contact time:

$$EBCT=\frac{V_b}{Q} \text{..........................} eq.(3)$$

Where;
EBCT = empty bed contact time, T
V_b = volume of GAC in contactor, L^3
Q = water flow rate, L^3/T

The density of the activated carbon:

$$\rho_{GAC}=\frac{m_{GAC}}{V_b} \text{..........................} eq.(4)$$

Where;
ρ_{GAC} = Density, of GAC Mass/L^3

Specific throughput (m^3 of water treated per gram of carbon):

$$Specific throughput=\frac{t}{EBCT\rho_{GAC}} \text{..........................} eq.(5)$$

where t is the effective contact time, T

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

Carbon usage rate per treated water:

$$CUR = \frac{t}{Specific throughput} \quad ....eq.(6)$$

where CUR is the carbon usage system, M/L^3

Bed life:

$$Bedlife, T = \frac{\text{Volume of water treated for given EBCT}}{Q} \quad ....eq.(7)$$

2. ADVANCED WASTEWATER TREATMENT

Since the objective of this study is to develop a genetic algorithm for the optimum design of advanced wastewater treatment (AWWT) plant, it is necessary to define;

- Water reuses criteria which are the aim of AWWT.
- Required quality of reclaimed water.
- AWWT processes; types and design criteria

3.1 Water Reuse Classifications

Reclamation and reuse of effluents from municipal wastewater treatment plant is becoming a matter of great importance in the available and economical resources for a variety of applications **(Zhang, 2004).** These applications are illustrated in **Figure 1** below:-

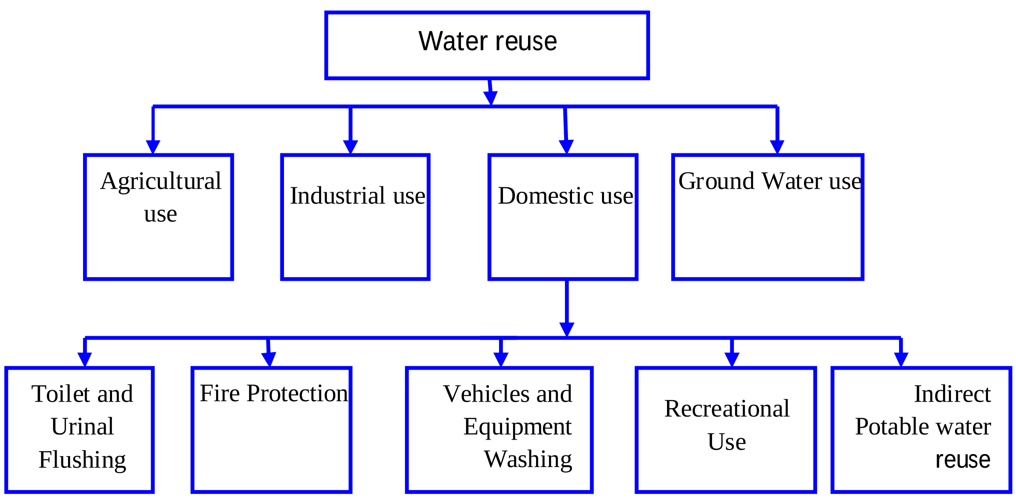

Fig. 1: Water Reuse Classification.

3. Development of Genetic Algorithm for Granular Activated Carbon Treatment Plant Design

The basic steps of genetic algorithms development are namely **(Chambers, 2001):**

1. Selection of model parameters (optimization variables),
2. Parameters encoding,
3. Generation of the initial population,

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

4. Evaluation of the string,
5. Selection of the (chromosomes) strings for reproduction,
6. Crossover of the selected strings, and
7. Mutation of the strings.

The adoption of these steps is dependent on type of genetic algorithm (GA) application. This is particularly true for advanced treatment technologies capable of treating wastewater to a degree of quality appropriate for a specific reuse, making the selection of the most suitable sequence of processes for any potential reuse situation more complex.

4. Formulation of Cost Function

The annual cost of water treatment includes the annualized capital cost, annual operation and maintenance cost, and land requirement cost."Capital costs" refers to the investment required to construct and begin the operation of the plant, principally materials, labor, and interest. Operation and maintenance costs include the costs associated with the labor, material, and energy required to operate and maintain the treatment plant (**Sharma, 2010).** The annual cost function for treatment unit-i can be written as:

$$C_i = ACCi + LC_i + OMC_i \text{..} eq.(8)$$

Where:
ACC_i = annualized capital cost of treatment unit-i, $
LC_i = land cost of treatment unit-i, $
OMC_i = annual operation and maintenance cost of treatment unit-i, $.

The annualized capital cost can be determined by spreading out the capital cost over a given number of years at a specific interest rate, and is defined **as (Sharma, 2010).**

$$ACCi = CC_i + CRF \text{...} eq.(9)$$

$$CRF = \frac{m(1+m)^n}{\left[(1+m)^n - 1\right]} \text{...} eq.(10)$$

Where CC_i is the capital cost of treatment unit-i, CRF is capital recovery factor, m is the interest rate per year, and n is the number of years over which the cost will be spread. In this study, all the capital costs shall be spread over a period of 20 years at a 8 percent annual rate of interest.

5. AWWT of Activated Carbon Processes

This treatment approach incorporates activated carbon unit. For this treatment plant, the objective function can be rewritten as **(Gupta, and Shrivastava, 2006) :**

$$f(X_1, \text{.......} Xj) = Cac \text{..} eq.(11)$$

Where; j=1,…..,4 and $x_j \in \{ EBCT, C_{dose}, D_{ac}, L_{mf} \}$. The cost function of this plant is;

$$C_{ac}. = ACC_{ac} + LC_{ac} + OMC_{ac} \text{..} eq.(12)$$

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

In this study, multiple hearth furnace was used for carbon regeneration. Hence, the capital cost of activated carbon treatment unit includes both the costs of granular activated carbon column and the multiple furnaces (CC_{GAC} and CC_{MF}). Also, the annual operation and maintenance cost of activated carbon unit is the sum of annual operation and maintenance costs of granular activated carbon column and multiple furnace (OMC_{GAC} and OMC_{MF});

$$CC_{ac}. = CC_{GAC} + CC_{MF} \quad \ldots\ldots eq.(13)$$

$$OMC_{ac}. = OMC_{GAC} + OMC_{MF} \quad \ldots\ldots eq.(14)$$

The values of CC_{GAC}, CC_{MF}, OMC_{GAC}, and OMC_{MF} were obtained as **(Clark, 1983);**

$$CC_{GAC}. = 470(Q \times EBCT)^{0.38} \frac{CCI}{100} UN \quad \ldots\ldots eq.(15)$$

$$CC_{MF}. = 60\left(Q / L_{mf}\right)^{0.44} \frac{CCI}{100} UN \quad \ldots\ldots eq.(16)$$

$$OMC_{GAC}. = 100(Q \times EBCT)^{0.78} PP^{0.28} PPI^{0.15} DHR^{0.48} \quad \ldots\ldots eq.(17)$$

$$OMC_{MF}. = 200(Q / L_{mf})^{0.78} Pp^{0.32} PPI^{0.2} DHR^{0.33} \quad \ldots\ldots eq.(18)$$

Where:

Q = treated water flow rate, m^3/min
EBCT = empty bed contact time, min
UN = number of units in the process
L_{mf} = loading rate of multiple hearth furnace, m^3/m^2.min
Pp = unit price of power, $/ kW.hr
PPI = producer price index divided by 100
DHR = directly hourly wage rate, $/hr

The land cost of activated carbon unit (LC_{ac}) was obtained as;

$$LCac. = 1.2PI(UN \times AC + Q/Lmf) \quad \ldots\ldots eq.(19)$$

7. Results and Discussion

The design of AWWT units is illustrated in equations given above. Optimization using genetic algorithm (GA) was applied for the design of granular activated carbon. Two design aspects were considered. The first aspect includes the optimal design criteria for the desired quality of treated water while the second aspect includes the cost of the plant. The cost of plant is considered as the objective function which has to be minimized.

GA was implemented using **MATLAB** program Version 7.10.0.499 (R2010a) with the adoption of roulette wheel selection and single-point crossover **(Goldberg, 1989)**. The crossover probability for single-point crossover was chosen to be 0.6. The population size was selected to be 60. This was done after performing several trains with population sizes of 20, 40, 60, 80 and 100 and it was found that when population size exceeds 60, the effect on results is insignificant.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

7.1 Optimum Design of AWWT

AWWT incorporates granular activated carbon (GAC) process. Here, four design criteria govern the design of this treatments unit; EBCT, C_{dose}, D_{ac}, and L_{mf}. According to GA terminology, the search is for a chromosome, consists of the four elements (genes), that minimizes the objective function along with satisfying all design criteria and effluent quality. During the application of GA in designing AWWT, the effect of varying the concentration of influent and effluent chemical oxygen demand (COD_{in} and COD_{ef}) on optimum design criteria was studied. This was done by taking the minimum, averaged, and maximum values of COD_{in} which are 65, 137, and 225 mg/l, respectively, and by considering COD_{ef} of 5, 8, 11, 14, 17, and 20mg/l. The chosen COD_{in} values where those of secondary effluent of Hamdan Sewage Treatment Plant in Basrah city. The adopted values of COD_{ef} were selected to be within the accepted range of COD in water to be reused for agricultural , domestic, and industrial purposes **(Alderfasi, 2009).**

The effect of COD_{in} and COD_{ef} on activated carbon dose (C_{dose}) and loading rate of multiple hearth furnace (L_{mf}) are shown **in Figures 2** through (7) for maximum, average, and minimum influent flowrates, respectively. The GA was applied for AWWT adopting the maximum, average and minimum values of the influent flow rates of Hamdan Sewage Treatment Plant in Basrah city (1.62, 0.81 and 0.54 m^3/sec). From these figures, the optimum values of C_{dose} and L_{mf} were obtained and they are listed in **Table 1**. The optimum values of empty contact time (EMBT) and Diameter of contractor (D_{ac}) did not change with influent flow rate and they are 10 min and 6.1m, respectively.

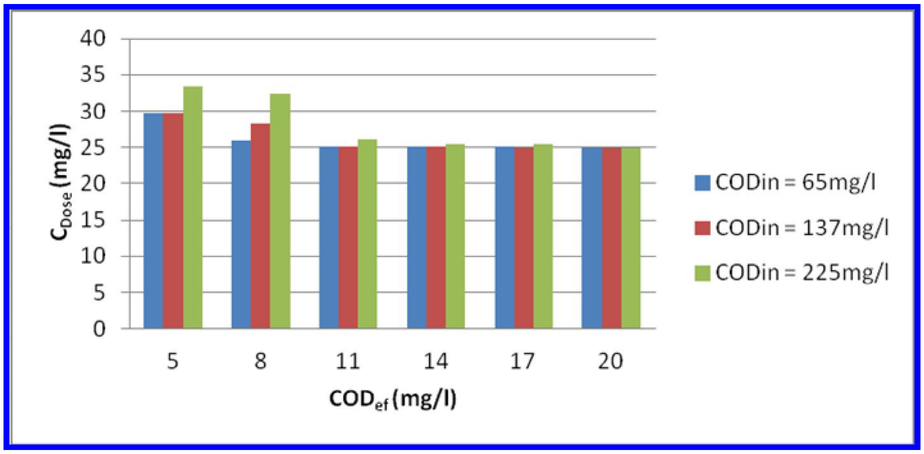

Fig.2: Effect of COD_{in} and COD_{ef} on C_{dose} for Max Influent Flow Rate.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

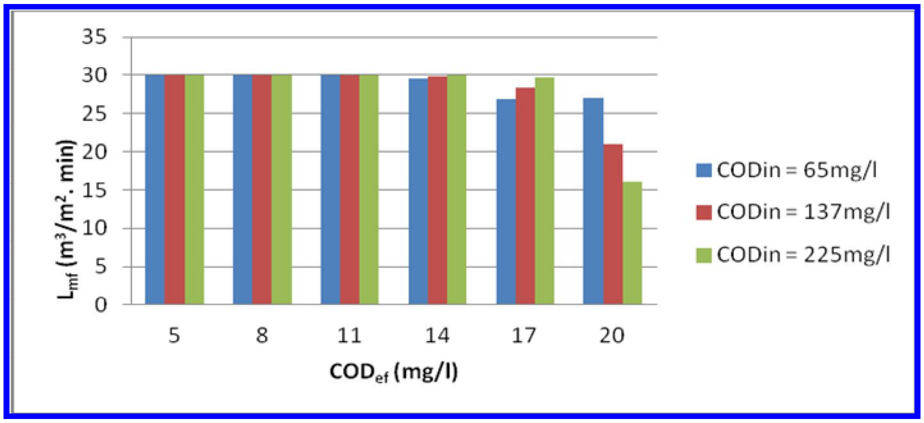

Fig.3: Effect of COD_{in} and COD_{ef} on L_{mf} for Max influent Flow Rate.

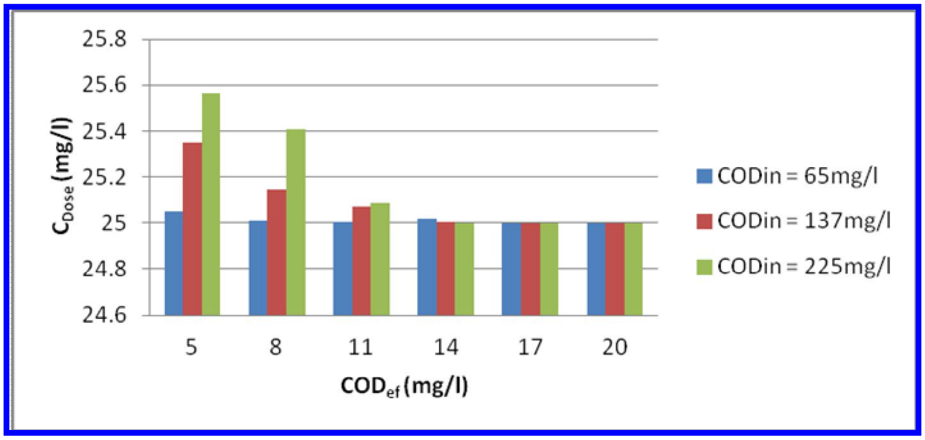

Fig.4 : Effect of COD_{in} and COD_{ef} on C_{dose} for avg. Influent Flow Rate.

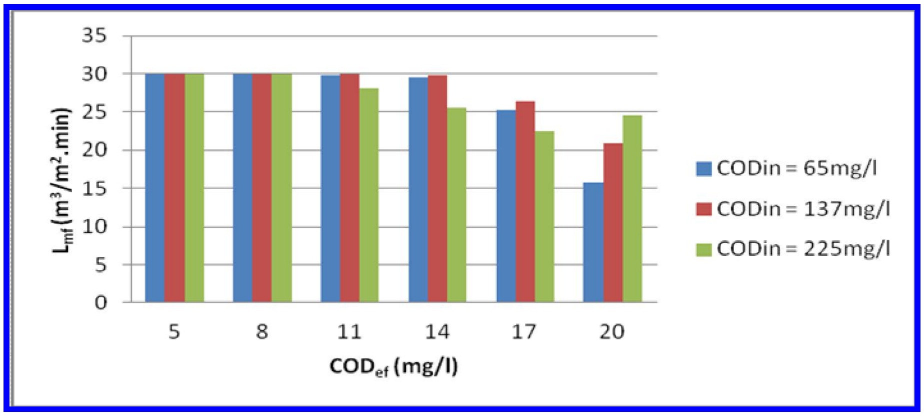

Fig.5 : Effect of COD_{in} and COD_{ef} on L_{mf} for avg. Influent Flow Rate.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

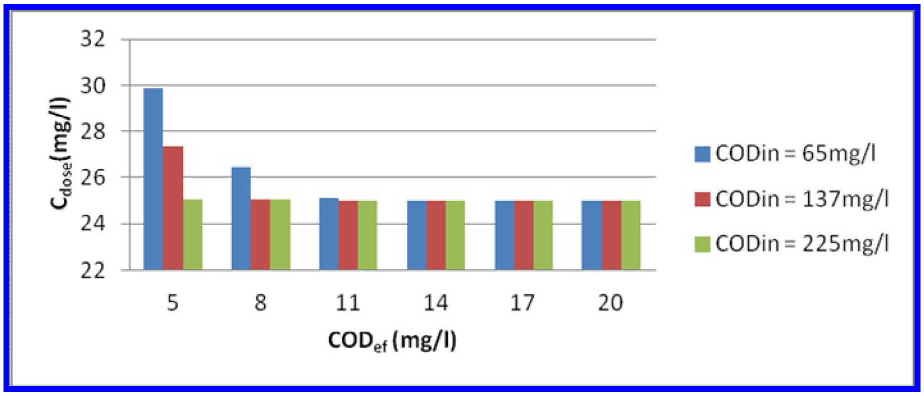

Fig.6: Effect of COD_{in} and COD_{ef} on C_{dose} for min Influent Flow Rate.

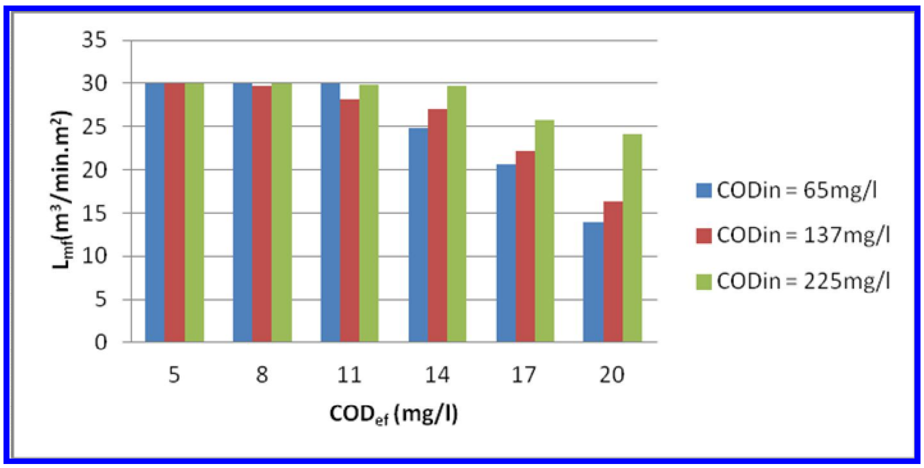

Fig.7 : Effect of COD_{in} and COD_{ef} on L_{mf} for min Influent Flow Rate

Table 1: Optimum Value Ranges of C_{dose} and L_{mf} for Different values of Influent Flow Rates.

Influent flow rate (m^3/sec)	Optimum value ranges	
	C_{dose} (mg/l)	L_{mf} (m^3/min.m^2)
1.62	25-33	16-30
0.81	25-25.5	15-30
0.54	15-30	13-30

The relation between AWWT approach cost and COD_{ef} for different COD_{in} are shown in **Figures 8** through **10** for maximum, average, and minimum influent flow rates,

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 6, Issue 1, December, 2014
Printed in Iraq

respectively. From these figures it is shown that the treatment cost decreases with the decrease of influent flow rate which is a reasonable and logical result.

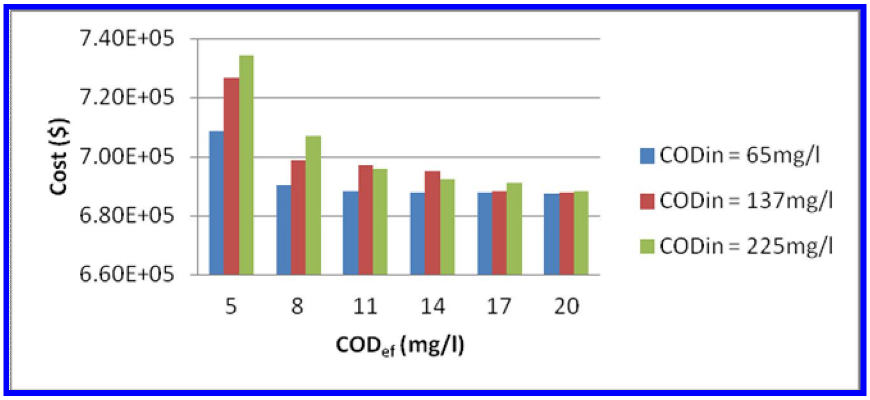

Fig.8: Effect of COD_{in} and COD_{ef} on Cost for Max Influent Flow Rate.

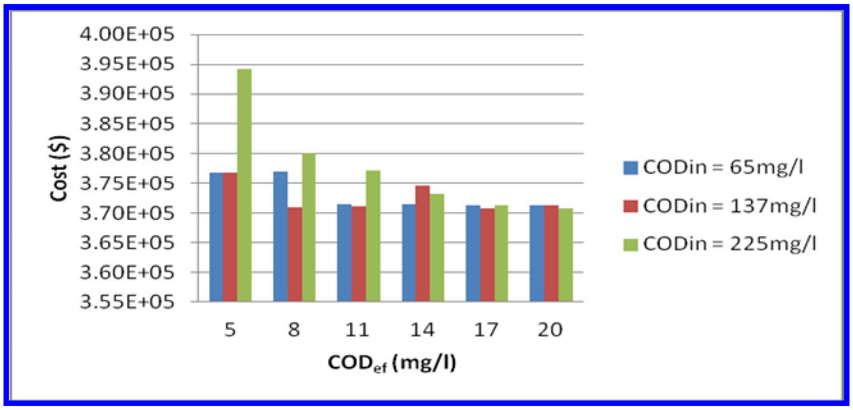

Fig.9 : Effect of COD_{in} and COD_{ef} on Cost for avg. Influent Flow Rate.

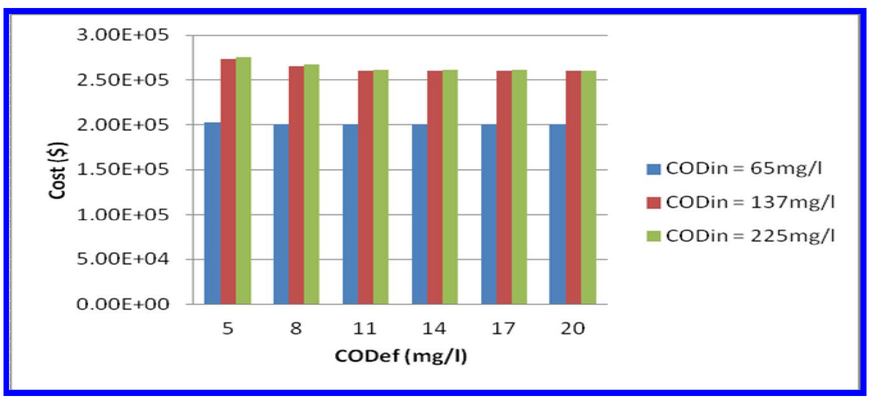

Fig.10: Effect of COD_{in} and COD_{ef} on Cost for min Influent Flow Rate.

8. Conclusions

The development and application of genetic algorithm (GA) for the design of granular activated carbon of advanced wastewater treatment (AWWT) plant, reveal the following conclusions:

1- Genetic Algorithm was found to be powerful technique for operating and defining optimum values of the parameters used in design of the advanced wastewater treatment system.

2- A penalty function can be used to find the global optimum design of constrained problems such as of advanced wastewater treatment design and in conjugation with the genetic algorithm developed in this study.

3- The optimum values of design criteria vary randomly with the increase of influent flow rate.
- The optimum value of empty bed contact time was 10 min.
- Dose of activated carbon was 25 mg/l
- Diameter of contractor was 2.4m, and
- Loading rate of multiple hearth furnaces was 30 m/min.

4- The treatment cost decreases with the decrease of influent flow rate which is a reasonable and logical result. This outcome highlights the importance of applying GA for deciding the design criteria which minimize the treatment cost.

9. References

[1] Alderfasi, A.A. 2009,"Agronomic and Economic Impacts of Reuse Secondary Treated Wastewater in Irrigation under Arid and Semi-Arid Regions" World Journal of Agricultural Science, Vol. 5, No. 3, pp.369-374.

[2] Álvarez , P.M., Beltrán, F.J., Jaramillo, J., Pocostales , P., and Márquez , G. 2011, " Comparison of Various Advanced Treatment Methods for Municipal Wastewater Reclamation" World Academy of Science, Engineering and Technology, Vol. 55.

[3] Chambers, L. 2001,"The Practical Handbook of Genetic Algorithms",Chapman and Hall/CRC, USA.

[4] Clark, R. M. 1983, " Optimizing GAC Systems", Journal of Environmental Engineering, Vol. 109, No. 1.

[5] Culp, R. L., Wesner, G. M. and Culp, G. L. 1978,“ Handbook of Advanced Wastewater Treatment.” 2nd edition, New York, N.Y.: Van Nostrand Reinhold Company.

[6] Goldberg, D.E. 1989,"Genetic Algorithms in Search, Optimization, and Machine Learning", Addison-Wesley: New York, NY, USA.

[7] Gupta, A.K., Shrivastava R. K. 2006,"Integral Water Treatment Plant Design Optimization: A Genetic Algorithm Based Approach" IE(I) Journal-EN, Vol. 87.

[8] Lin S. D. 2007, "Water and Wastewater Calculations Manual" second edition, McGraw Hill Companies, Inc.

[9] Metcalf & Eddy, I., 2003, "Wastewater Engineering: Treatment and Reuse", 4th edition., McGraw Hill Companies, Inc. , New York.

[10] Morrison, J., Morikawa, M., Murphy, M. and Schulte, P. 2009, "Water Scarcity and Climate change" Growing risks for business and investors, Pacific Institute, Oakland, California.

[11] Sharma, J. R. "Development of A Preliminary Cost Estimation Method for Water Treatment Plants" A thesis presented to the University of Texas in fulfillment of the thesis for the degree of Master of Science in Civil Engineering, The University of Texas at Arlington, May, 2010.