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Optimization and Control of Acation Exchanger :1- Steady State Optimization

Dr. Ghanim M. Alwan*, Layla A. A. Ahmed*, Ahlam. S. Maroof* & Abeer S. Mahmod*

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Abstract

The effect of process variables on the recovery of hardness from water by acation exchanger was studied. At steady state the process could be represented by second order nonlinear emperical model. Although this model was less accurate than the dynamic model,the results show agreement when compared with the experimental data. The steady state optimization model was used to limit the operating conditions of the system. The static feed forward control could be used with the aid of on – line digital computer.

Keywords: action exchanger, process model, optimization, control

الاختيار الافضل والسيطرة على مبادل كتيوني .1 الاختيار الافضل للمنظومة في ظروف مستقرة

الخلاصة

يتضمن البحث دراسة تأثير متغيرات العملية على مقدار إزالة الأملاح المسببة للعسرة في الماء بواسطة مبادل كاتيوني في ظروف مستقرة. تم تمثيل العملية بموديل رياضي لاخطي ومن الدرجة الثانية .بالرغم من قلة دقة هذا الموديل مقارنة بالموديل الديناميكي الا انه اعطى نتائج مرضية مقارنة بالنتائج العملية .من خلال هذا الموديل تم تحديد الظروف التشغيلية المثلى.. من الممكن استخدام السيطرة الامامية الانية للعملية بمساعدة الحاسوب.

Nomenclature

C: Concentration of salts (hardness) into water (ppm)
C_i: Inlet concentration (ppm)
C_o: Outlet concentration (ppm)
F: Volumetric flow rate of water (liter/s).
T: Temperature of water ($^{\circ}$C).
Y: Objective function (% of salts recovery by ion exchange) (-).

* Chemical Engineering Department, University of Technology/ Baghdad

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Introduction

A water supply which labeled "soft" or "hard" is dependent on the presence of two highly soluble minerals, calcium and magnesium. However, when calcium and magnesium permeate water, they buildup on contact surfaces, possibly plug pipes and damage water heaters. A water softener called an ion exchange unit is effectively used to reduce the hardness level of water. The ion exchange water softening process can nearly remove all calcium and magnesium from source water. Softener may also remove as much as (5 – 10) ppm. Physical and chemical processes filter the water through an exchange media known as resin or zeolite. Negative charged resin is called cation resin and it attracts positive ions. Positively charged resin is called anion resin, and it attracts negative ions. The water softener will need to run on an alternate cycle called regeneration (Kocher, etal, 2004).

It is important to study the effect of process variables on the objective function of the system. So that, it is desirable to develop a mathematical model of the chemical process under consideration. These models are often used for optimum control system design. Ion exchanger process may be controlled precisely to give more uniform and higher quality products by the application of automatic control often leading to higher profiles. The complexities of controlling an ion exchange plant, demand flexibility and robustness in order to optimize the operation of the plant (Mkondwent, Tzoneva and Hendry, 2003).

Experimental Set – up

The use of ion exchange process affords numerous efficient and effective means of conditioning feed water. The proper selection of the specific ion exchange process depends on water quality needs, operating convenience and economic considerations for effective results, the system must be carefully selected , designed operated and maintained (Technifax, 1998). The set – up of the present work Figure (1) was designed and constructed in the best way to collect data. The process system consists mainly of cation ion exchanger with resin type of $R – SO_3 – Na^+$, tape water tank and digital measuring devices (conductivity, temperature and PH meters).

Experimental Procedure

1 The feed tank was filled with tap water; the desired composition of salts in water was adjusted by using well – mixing.

2 The system was operated until steady state conditions (10 seconds).

3 Digital sensors were used to detect the process variables at sampling time of five seconds.

4-The operating conditions of the system are:

a- Flow rate of water at the range of (1 to 9 liter/min)

b- Inlet concentration of salts (hardness) into water (275 to 600 ppm).

c- Temperature of water (12 to 40.0 C°).The ion exchanger was periodically regenerated by using NaCl solution.

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Process Model

The modeling of process systems is often used to optimize investment and operating costs, and achieve automatic control of industrial processes. Steady state model is very useful at the design stage (Jhon, 1981). an empirical model is useful to find the relations between process variables because it depends on actual experimental data. The equations of mass balance for ion exchanger are complex and nonlinear. They can not be solved directly but require computational data (Komarova, Nikashina and Rubinshtien, 1971) and (Kalinitchev and Höll, 2004).

In the present work, the process is represented by a second order nonlinear empirical model (Montagomry, 1997) which is:

$$y = 0.1177 + 0.1463F + 0.6945Ci + 0.5407T - 1.6563F^2 - 0.0001C_i^2 - 0.0304T^2 - 0.1097FCi + 1.2222FT - 0.0096CiT \quad \ldots (1)$$

With correlation coefficient of 98.08% and standard deviation of 0.16.

where:

$$Y = objective\ function = recovery\ \%\ of\ salts = \frac{C_i - C_o}{C_i} \times 100$$

Second order regression analysis for the present experimented data with the statistical software program were used for estimating the coefficients and statistical analysis of this model. Three process variables were considered in this model which affect the recovery of salts by the ion exchanger. They are; (flow rate, inlet concentration and temperature) (Nikkah, 2003). An agreement in results is obtained by this model when they are compared with the experimental data. The optimum conditions and design of control system were obtained. Also the significant effect of each process variable on the objective function could be explained by this model.

Figures (2)and(3) illustrate that the recovery % of ion exchanger decreases as the inlet flow rate and inlet concentration of salts increase above the optimum operating condtion due to the limiting of resin surface area. The water flow rate (F) is highly effective than inlet concentration (C_i) for the recovery percent as explained by equation (1) and Figure (2).

The effect of temperature on efficiency of ion exchanger is low as shown in Figure (4) and equation (1) in the range of temperature of (12–40C$^{\circ}$). This means that the rate of adsorption of ions by the resin is small affected with low operating temperature. In equation (1) the interaction between the process variables is very low and has no significant effect on the objective function in the range of experimental data. However, from previous work, it is desirable to operate with the ion exchanger isothermally in low range of temperature.

Steady State Optimization

(Celikovsky, 1993) and (Tzoneva, 2002) developed the method for design of steady state optimal control of the ion exchange process. The steady state optimization deals with

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the determination of new optimal steady state values of process variables. These values which directly depending on the values of disturbances , are considered constant for some interval time, i.e, until the next disturbance occurs.

In the present work, the optimization process was applied to equation (1) for experimental range of operating variables to find the optimum conditions for operation and control using the analytical technique (Himmelblau, 1970) with the aid of software computer program. The results of optimization technique as shown in the Appendix are:

F = 3.10 liter/min, C_i = 256.25 ppm, C_o = 5.84 ppm and T = 31.30 C°

Under these optimum conditions, the maximum recovery % (Y) is 97.72% , figures (2, 3 & 4) confirm these results. Although the steady state optimization technique is less accurate than the dynamic technique.The results are in agreement when compared with experimental ranges of process variables.

Proposed Control System

In the present work, the design of proposed control system is on line control using single loop of static feed forward control algorithm with the aid of advanced software program. The structure of controller mainly depends on the present model of the process, (Figure 5) . Regarding to (Figures 2 & 3 and equation 1), the logic of controller requires measurement of the critical process variable (input flow concentration, C_i) which proves the main disturbance by conductivity sensor to measure the concentration of salts in each time intervals. The manipulated variable is the flow rate of water (effective variable, F). Then the desired value was the recovery % of salts by ion exchanger ($Y_{set\ value}$). The feed back control is not effective for ion exchanger . The control logic of the system can be developed by connecting the process to the advanced on – line digital computer.

Conclusions

1. The recovery of salts (hardness) from water by a cation exchanger is affected by three process variables. These are, water flow rate, inlet concentration of salts and temperature. The flow rate of water proves the most effective variable while the inlet concentration of salts into the water is the most critical variable.
2. In the present work cation exchanger process can be represented mathematically by second order nonlinear process model. Although the steady state model is less accurate than the dynamic model, it shows agreement when applied to the cation exchanger.
3. The steady state optimization model can be developed with the aid of an on – line digital computer to obtain the optimum operating conditions.
4. On – line feed forward control may be more effective than feed back scheme. The structure of controller can be designed depending on the experimental process model instead of complex mass balance equations which describe the ion exchanger process.

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Appendix

Analytical Optimization Technique

From process model equation (1):

(I)

By analytical optimization technique, the first derivative of equation (I) with respect to F, C_i, & T which equals zero at optimum conditions yields:

$$\frac{\partial Y}{\partial F} = 0.1463 - 2\times 1.6563F - 0.1097C_i + 1.2222T = 0$$

(II)

$$\frac{\partial Y}{\partial C_i} = 0.6945 - 2\times 0.0001C_i - 0.1097F - 0.0096T = 0$$

(III)

$$\frac{\partial Y}{\partial T} = 0.5407 - 2\times 0.0304T + 1.2222F - 0.0096C_i = 0$$

(IV)

Solve the simultaneous equations (II, III and IV) with the aid of computer program yields the optimum operating conditions which are:

F = 3.10 liter/min, C_i = 256.25 ppm, C_o = 5.84 ppm and T = 31.30 C°

And the corresponding optimum recovery % (Y) is 97.72% from equation (I).

The test of the nature of the optimum conditions [3.10 256.25 31.30] where the maximum or minimum is obtained as follows:

By taking the second derivative of equation (I) with respect to F, C_i, and T.

$$\frac{\partial^2 Y}{\partial F^2} = -3.312, \qquad \frac{\partial^2 Y}{\partial C_i^2} = -0.0002$$

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and
$$\frac{\partial^2 Y}{\partial T^2} = -0.0608$$
(V)

Since the signs of the second derivatives are – ve, the optimum operating conditions [3.10 256.25 31.30] give maximum recovery % (Y) of 97.72.

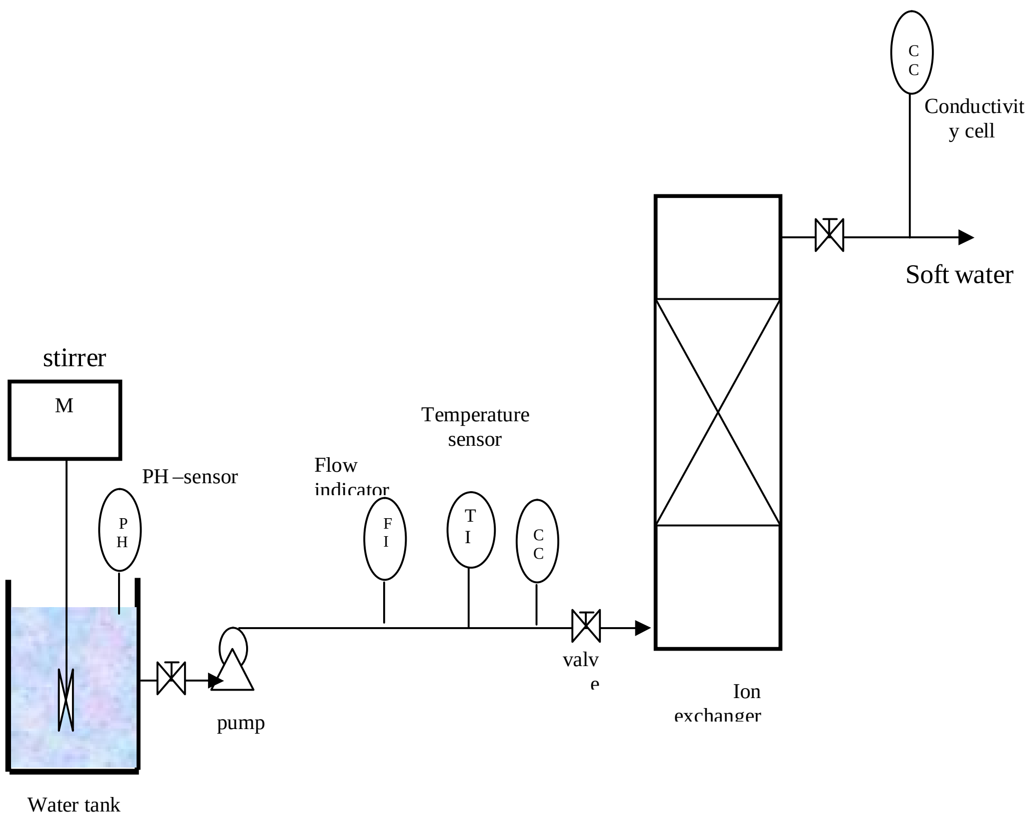

Figure (1) Schematic diagram of experimental set –up

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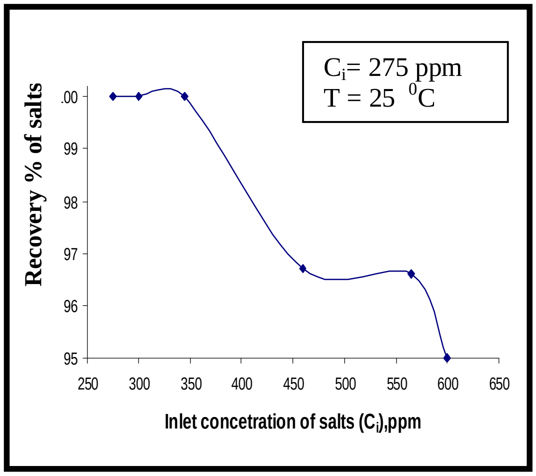

Figure (2) Effect of flow rate of water on recovery % of ion exchanger for constant temperature and inlet concentration of salts

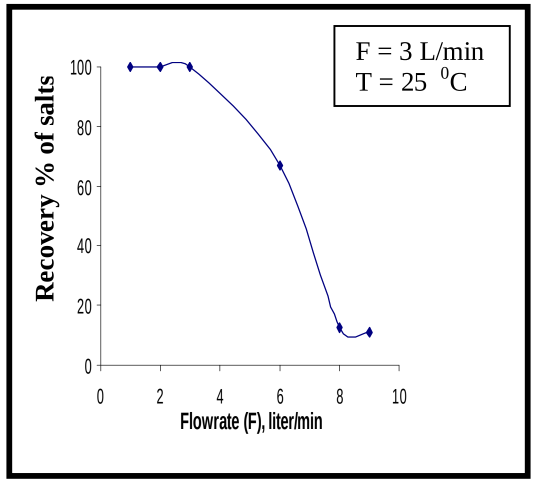

Figure (3) Effect of inlet concentration (C_i) on recovery% of ion exchanger for constant temperature and flow rate of

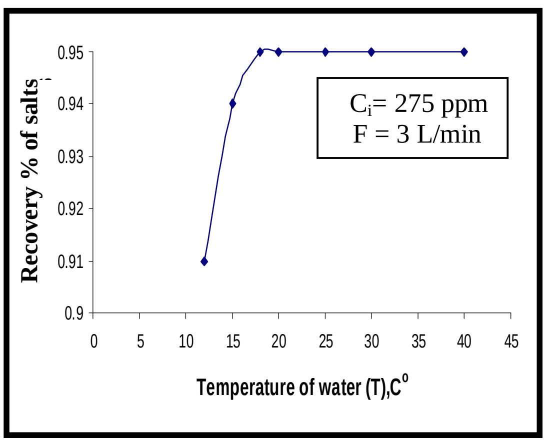

Figure (4) Effect of temperature on recovery% of ion exchanger for constant water flow rate of water and inlet concentration of salts

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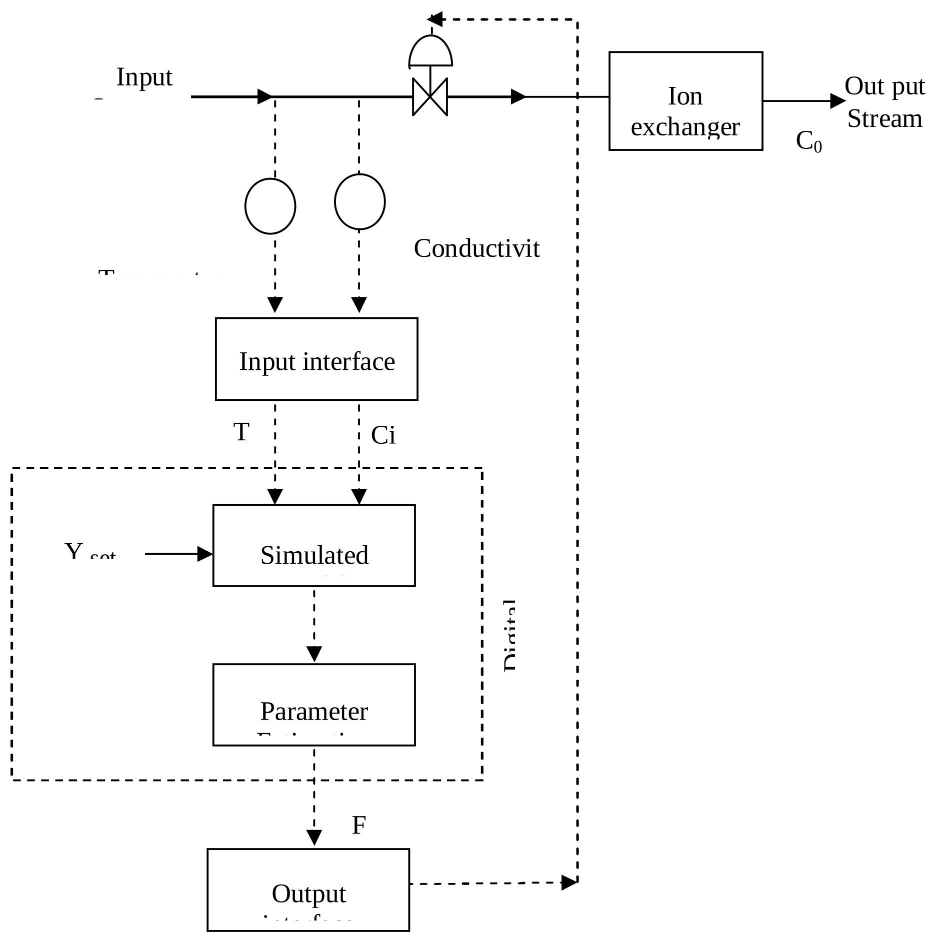

Figure (5) On-line feed forward control of Ion exchanger

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