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Prediction of the Scale Removal Rate in Heat Exchanger Piping System Using the Analogies between Mass and Momentum Transfer

Najwa S. Majeed
Department of Chemical Engineering/ College of Engineering/ University of Baghdad

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Abstract

The possibility of predicting the mass transfer controlled $CaCO_3$ scale removal rate has been investigated. Experiments were carried out using chelating agents as a cleaning solution at different time and Reynolds's number. The results of $CaCO_3$ scale removal or (mass transfer rate) (as it is the controlling process) are compared with proposed model of prandtl's and Taylor particularly based on the concept of analogy among momentum and mass transfer.

Correlation for the variation of Sherwood number (or mass transfer rate) with Reynolds's number have been obtained .

Keywords: *Scale removal, chemical cleaning, chelating agents, calcium carbonate scale deposition, heat exchanger piping systems*

1. Introduction

Scale is a term generally used in industry refers to any deposit on equipment surfaces. These deposits may form in distribution line, heater treaters, boilers, condensers, heat exchanger, or on nearly any surface which water contacts.

Usually, the deposition of scale is undesirable because it is uncontrolled. The heat transfer properties of scale are much less than those for metals.

A build – up of scale on metal surfaces may act as insulation causing decreased efficiency. scale build-up in boilers can cause hot spots , in which the temperature of the metal will exceed the safe operating temperature and cause equipment failure .

Uneven scale deposition may cause pitting corrosion. If the deposited scale is particularly impermeable and the system contains dissolved O_2, It is possible that an oxygen concentration cell may form between the scale-coverd iron and the uncovered iron , resulting in pitting type corrosion beneath the scale [1].

The fouling may be minimized by the treatment of water to reduce the total solids content of the incoming water and by blowing down boilers to reduce the total solids of water in the boiler.

With all these precautions, some sludge or scale accumulates in boilers [2].

Scale normally results from naturally occurring minerals that are dissolved in the water. These minerals are concentrated by evaporation when concentrated or heated some of the minerals do not stay in solution and precipitate forming the scale. The mineral responsible for forming amajority of the scale present is calcium carbonate $CaCO_3$ [3].

Various cleaning methods have been used; mechanical, chemical and thermal or a combination of them. Cleaning up by chemicals is the widely adopted procedure [4].

There are three fundamental criteria for restoring fouled equipment chemically;

1- The chemical solvent must react, or otherwise dissolve, the solid phases.
2- The solvent must not damage the equipment or be hazardous to use because of flammability or toxicity.
3- The cost of solvent and means of using it must be economically acceptable.

Scaling can be removed effectively by the use of chelating agents which are capable of forming soluble complexes with the metal ions. The precipitation of these complexs are not the same as those of metal ion of particular intrest are the systems in which the dissolved complexing ligands interact with the solid substrats in contact with the solution.

As a consequence, the surface and interfacial characteristics such as the charge, the degree of solvation, solubility of solids and selective adsorptivity of suspended matter, can be altered by the effect of chelating agents.

Ethylene diamine tetraacetic acid (EDTA) is a crystalline organic acid having the formula $C_2H_4N_2\ (CH_2COOH)_4$.

EDTA forms soluble complexes with Mg, Ca, Sr, Ba, and other divalent metals [5] chelating agents function by an adsorption mechanism [9]. Cleaning solution usually passed in turbutent flow through the system, during cleaning process. When turbulent flow occurs in circular tubes, momentum is transferred between layers of fluid, this momentum transfer manfests itself as a frictional resistance which is equivalent to the time rate of momentum transfer per unit area [6].

Mass transfer may occur during turbulent flow. Most of the experimental studies showed that there is a relation exists between mass transfer and skin friction, knowledge of such relationship would allow prediction of the rate of mass transfer from friction loss data.

The present investigation of the problem of scale removal is being studied mainly on tubes of heat exchanger obtained from Dura Refinery using chemical solution (chelating agent).

A special flow system has been designed where parts of these piping were being fixing in exposed to the treatment solution.

Rate of scale removal was studied as a function of time and Reynolds's number of the system.
Furthermore a mathematical model to describe the solution mechanism was attempted and presented in this investigation.

2. Experimental Work

Cupper alloy heat exchanger tubes with chemical composition listed in table (1) from Dura Refinery was used. The tubing was of (10cm long, 25mm O.D and 2mm in thickness).

The large thickness (2-4mm) scale used has a mixed type composition as shown in table (2).
Disodium ethylene diaminetetra aciticacid (EDTA) was used.

Table 1,
Chemical Composition of Heat Exchanger Tubes.

Copm.	copper	Tin	Lead Max.	Iron Max.	Zinc	Arsenic
Wt%	70-73	1.2	0.7	0.06	0.09	0.1

Table 2,
Complete Analysis of Scale AL-Dora Refinery Water Deposit from Heat Exchange r Tubes.

Element analysis	wt%
Iron (Fe2O3)	3.6
Aluminum Al2O3)	1.04
Calcium Carbonate ($CaCO_3$)	60
Magnesium (Mg O)	7.0
Chlorine (Cl)	0.009
Copper (Cu O)	9.14
Zinc (Zn O)	3.7
I.R (Insoluble residue)	6.3
L.O.T (Loss on inition)	9.2

The dynamic system for descaling investigation was all made of Q.V.F glass. it consisted of 5 liter round bottom container with four necks , the container was connected from the bottom with tubing through which hot solution circulated .

A controlled heating tapes were rapped around the insulated Q.V.F glass tubing for heating the circulating solution.

The circulation of the chemical solution was effected using centrifugal pump (0.25kw) and total flow rate was measured by a rotameter which ranged from 0-1000 liter/hour. The flowing liquid then passed the scaled metal specimen, and returned to the round bottom container as shown in figure (1).

The pressure drop though the speciment was measured using U- tube manometer.

The temperature of the test solution was measured by means of thermometer.

The concentration of calcium ion in the acid solution was measured by using shimadiza UV-160by determining the absorbance of calcium ions.

The amount of the scale deposits which has been removed at each run was calculated by weight difference of the scaled tube before and after the tests.

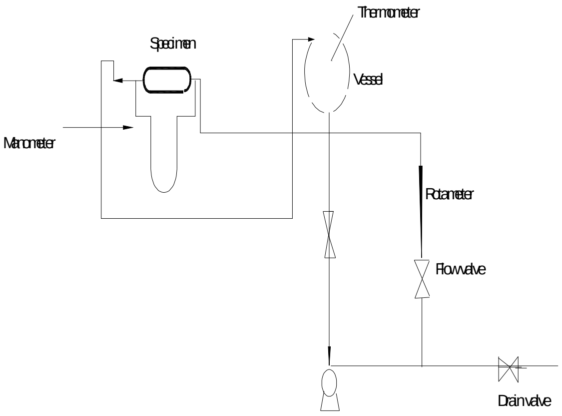

Fig.1. Schematic Diagram of Experimental System

3. Results and Discussion

From the analysis of scale composition table (1) it was clear that the most fraction of scale composition is ($CaCO_3$) then the most important reaction is the reaction of $CaCO_3$ scale with the chelating agent solution. This reaction has been studied by Schmidt (3) he found that the reaction is first order reaction.

The stoichiometry of the reaction is:

$$2Ca^{+2} + EDTA^{-4} \rightleftharpoons EDTA\ Ca_2$$

In the present work mass transfer coefficient was calculated by estimating the mass flux of Ca^{+2} ions using the following equations [7]:

$$NA = \frac{M}{t.A} \qquad ...(1)$$

$$NA = kc\,\Delta C \qquad ...(2)$$

A complete formulation of the scale removal rate equation must take into account both the mass transfer and chemical reaction rates some instances one of the rates , mass transfer or reaction , is so much smaller than the other that it becomes the controlling one (5) .

In the case of $CaCO_3$ scale removal using chelating agent it was found by Schmidt et.al. [6] for $CaCO_3$ scale removal in sugar evaporatos which have almost the same composition as the present work , that the process is mass transfer controlling process , and by the observed fact that the rate of desolution increased by increasing the rate of liquid past the scale [7].

3.1. Effect of Reynolds's Number on the Rate of Scale Removal

Figures (2) & (3) show the variation of mass transfer ceafficient (kc) and Sherwood number (Sh) with Reynolds's number (Re) at different time intervals.

It is clear that the valves of (kc) and (sh) increase with increasing (Re).

The increase in (kc) with increasing (Re) can be explained according to the following equation [8, 9].

$$kc = D + \epsilon_D / \delta_d \qquad ...(3)$$

As Reynolds's number increases the convective mass transport of Ca^{+2} ion will increase (i.e. mass transfer by diffusion due to the increased turbulence.

Increasing turbulence leads to decrease the thickness of viscous sub layer and the diffusion layer that represents the main residence to momentum and mass transport respectively [6, 9]. Increasing the mass transfer coefficient with Reynolds's number leads to increase Sherwood number.

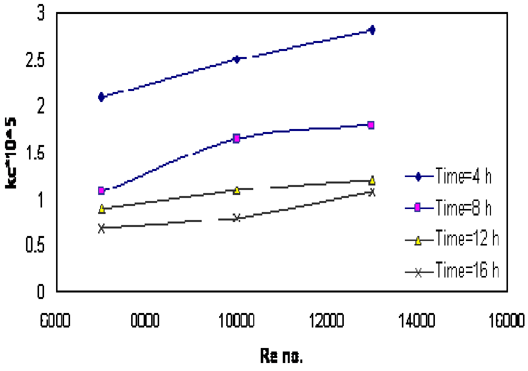

Fig.2. Variation of Mass Transfer Coefficient with Reynolds Number at Different Time Intervals.

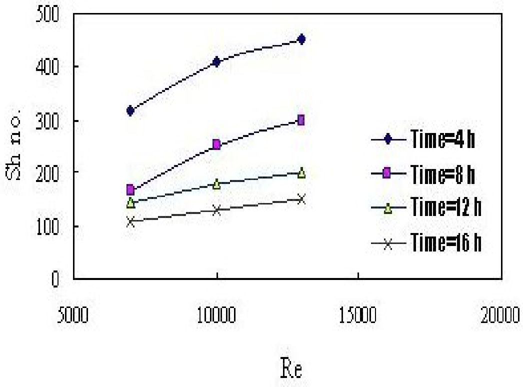

Fig.3. Variation of Sherwood Number with Reynolds Number at Different Time Intervals.

3.2. Effect of Time

Figure (4) & (5) shows the variation of (k) and (Sh) with time at various Re. these figures indicate that, the time causes a significant decrease in (k) or (Sh) for all (Re) rang. This can be explained by the decrease of roughness as the time increases due to the scale removal, hence decreasing the mass transfer rate due to decreasing mass transfer area [9, 10, 11].

Also formation of the chemical reaction product of the scale with the solution influence the mass transfer rate by influencing the Ca^{+2} ion diffusion from the surface to the bulk of the solution [12].

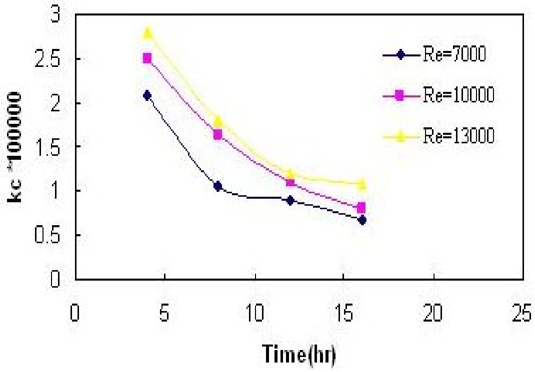

Fig.4. Variation of the Mass Transfer Coefficient with Time at Different Reynolds Number.

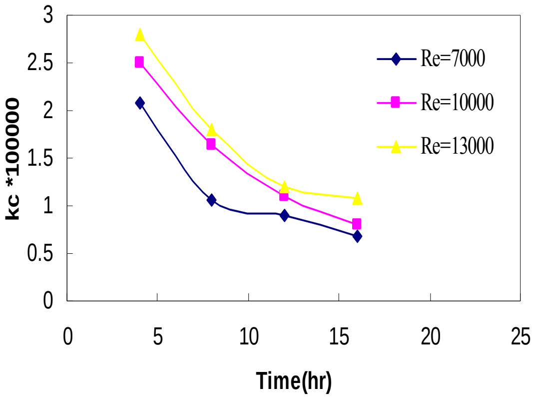

Fig.5. Variation of Sherwood Number with Time at differEnt Reynolds Number.

3.3. Comparison with a Reported in the literatures Model

In this section it is aimed to compare the experimental results of mass transfer with the proposed correlations particularly those which are based on the concept of analogies among momentum and mass transfer.

The comparison serves to investigate how far is the present correlation deviate from the proposed model.
Making a comparison enable to adapt if the scale removal rate can be well represented by this analogy .

The experimental mass transfer results were compard with Prandtl and Taylor Equation [12].

$$Sh = \frac{(f/2)\ Re\ .\ Sc}{1 + 5\,(f/2)^{0.5}\,(Sc - 1)} \qquad \ldots(4)$$

The friction factor for rough surface was abtained by measuring the pressure drop across the test section for each value of Re and time with applying the following equation.

$$F = \frac{\Delta h\ pg}{2u^2 L}$$

Figure (6) show the variation of theoretical Sherwood number with time at different Reynolds's number.

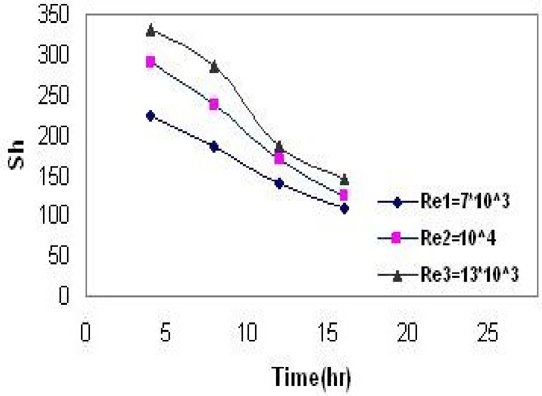

Fig.6. Variation of Theoretical Sherwood Number with Time at Different Reynolds Number.

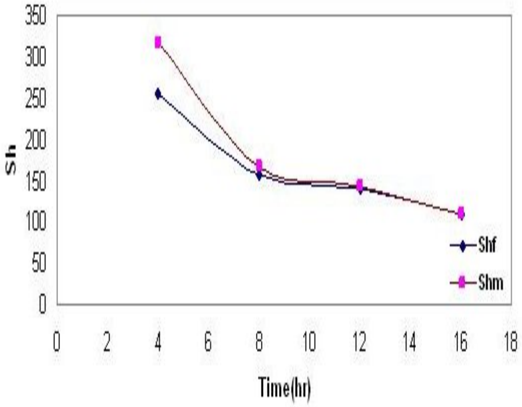

Fig.7 Graphical Comparison of the Theoretical and Experimental Sherwood Number.

Graphical comparison is shown in figure (7) good agreement was found with this equation with differences due to the assumption that the calculated friction factor from the experimental work is equal to the friction factor of $CaCo_3$ scale removal.

It was found that time causes to reduce the differences between the experimental mass transfer coefficient and that obtained from Prandtl and Taylor analogy, that was explained by the decrease of roughness as the time increases and that the Prandtl and Taylor equation was used in a smooth pipe .

According to above conclusions, the analogy model of Prandtl and Taylor can be employed to estimate the mass transfer controlled $CaCO_3$ .scale removal rate (for the scale type used in this work) by determining the friction factor experimentally.

Table (3) lists the values of (Sh) estimated from Prandtl and Taylor analogy using the friction factor besides experimental values obtained by concentration difference of Ca^{+2} ion for all ranges of Re .

Using statistical analysis the following correlation for the variation of (sh or mass transfer rate) with Re have been obtained it is:

$$Sh = 0.23\ Re^{0.558}\ Sc^{1/3}$$

Table 3,
Comparison of Theoretical and Experimental Sherwood Number.

Time(hr)	Sh_f	Sh_m
4	255	316
8	158	166
12	141	144
16	109	110

4. Conclusions

1- Scale removal by means of chelating agents is increases as the rate of solution circulation increases and the time causes more scale removal.
2- The analogy model of Prandtle and Taylor gives a close results to the rate of $CaCo_3$ scale removal.
3- Correlation for the variation of (Sh or mass transfer rate) with Re have been obtained it is:

$$Sh = 0.23\ Re^{0.558}\ Sc^{1/3}$$

Nomenclature

M	the no. of Ca^{+2} ion (removal) (mole)
t	descaling time (sec)
A	the area of mass transfer (m^2)
kc	mass transfer coefficient of Ca^{+2} ion (m/s)
ΔC	the bulk concentration of Ca^{+2} in the solution
D	diffusivity (m/s)
δ_d	viscous sub-layer thickness (m)
ϵ_D	eddy diffusivity for mass transfer (m^2/sec)
Sh	Sherwood number
Re	Reynoldss number
Sc	Schmidt number
F	Friction factor
Δ h	Manometer reading
ρ	the fluid density (leg / m^3)
g	gravitential acceleration (m / s^2)
u	the fluid velocity (m / s)
L	pipe length (m)
Sh_f	theoretical Sherwood number
Sh_m	experimental Sherwood number

5. Refernces

[1] Ostroff , A .G.,Introduction to oilfield water technology , Prentice-hall(1979).
[2] Wasco, J.L, and F.N. Al qurst , Ind.Eng.Chem.38,4, 394 (1946).
[3] Cowan , J.C., and D J. Weintritt , Water-formed scal deposits, Gulf publishing (1976).
[4] Powell ,s.t, " Water conditioning for industry " 1st ed .,Mc Graw –Hill (1954)
[5] Dr.Prakash R.Kota "Principles of reactive interfacial chemical cleaning"(Internet document)(2003) .
[6] Schmidt , N.O. and W .S. Wise, Ind. .Eng. cleaning 50,5,811 (1958).
[7] Philip J.W. Roberts and Donald R. Webster " Turbulent Diffusion " school of Civil and Environmental Engineering , Georgia, Institute of Technology , Atlantes . (2002)(Internet document).
[8] Najwa S. Majeed , PhD Thesis , Dept.of Chem. Eng. University of Baghdad , Iraq. October (2004).
[9] Bradley , G . W . and J . A . smith , Mtls prot . p. 391 , (1983).
[10] Coulson ,J . M . and J. F . Richardson , Chemical engineering , 3rd edition (1977).

[11] Knudsen , J . G . and D . L . Katz , “ Fluid dynamics and heat transfer “ MC Graw Hill , New York , (1958).

[12] Petukhov , B . S ., Heat transfer and friction in turulent pipe flow with variable physical properties, Advances in heat trans , Vol. 6 , $So_{3\,(}$ (1970) .

[13] Brodkey, R . S . and HC. Hershey, Transport phenomena, Anified approach, Mc Graw Hill (1988) .

تخمين معدل ازالة التكلسات المترسبة في انابيب اجهزة المبادلات الحرارية باستخدام علاقات التناظر بين الكتلة والزخم

نجوى صابر مجيد
قسم الهندسة الكيميائية/ كلية الهندسة/ جامعة بغداد

الخلاصة

يهدف البحث الى امكانية تخمين معدل ازالة التكلسات المترسبة في انابيب اجهزة المبادلات الحرارية والممثلة بعملية انتقال المادة لكونها الميكانيكية المسيطرة في عملية الازالة.

اجريت عدة تجارب عملية باستخدام املاح الحوامض العضوية كمحاليل لازالة التكلسات عند ازمان مختلفة وقيم مختلفة لرقم رينولدز. معدل ازالة تكلسات $CaCO_3$ تمت مقارنتها مع موديلات موجودة في الادبيات مثل علاقة برانتل وتيلر وبالاعتماد على علاقات التناظر بين الكتلة والزخم. تم استنباط علاقة بين قيم معدل انتقال المادة (رقم شيروود) مع رقم رينولد.