Effect of Forced Convection on the Rate of Diffusion Controlled Corrosion of Horizontal Tubes Embedded in Fixed Bed of Sphere

Yousra Hamdy
Alexandria Higher Inisitute for engineering and technology,
Basic Science Depatement,
Alexandria, Egypt.

Abstract:- copper is utilized in essentially each industry. Its corrosion resistance has noteworthy benefits. Copper is incredible for channeling since it isn't very as overwhel ming as other applications, and it is profoundly safe to corrosion. In the event that the encompassing medium is destructive, the Copper tubes of the heat-Exchangers will uncovered to diffusion controlled corrosion, or tubes of catalyst embedded in settled bed to upgrade rate of mass transfer. The impact of constrained convection on the rate of diffusion controlled corrosion of an cluster of level copper tubes inserted in an dormant settled bed of circular pressing was explored. The rate of diffusion controlled corrrosion was decided utilizing diffusion controlled dissolution of copper within the acidic $K_2Cr_2O_7$. Solution speed, copper tubes diameter and solution physical properties (D, ρ, μ) were considered in this inquire about. It is taken note that the increment within the tube diameter, solution speed and sulfuric acid concentration cause an increments in the rate of mass transfer. The results show that It was found that the information are connected to the equation: $\mathbf{Sh= 2.1\ Sc^{0.33}\ Re^{0.51}}$ (850<Sc<1048, 1751 < Re <17684)

Keywords—Packed bed, Fixed bed, Copper Corrosion, Mass transfer,

I. Introduction

Environmental security is focused on three major global issues, carbon, water and climate. Enough resources to maintain a fair standard of life, safe drinking water and safe breathing air. The ability to control corrosion is essential to the effective and efficient use of materials to address these challenges. For example, oil and natural gas are transferred through steel pipe lines. The factors governing the rate of corrosion are broadly divided into those relating to metal and the environment, the nature of the environment and the reactions that occur at the interface between metal and the environment. [1]

Metal corrosion is a major problem for the chemical and petrochemical industry in particular. It results in huge financial losses due to the following factors:1-Corrosion decreases equipment efficiency, for instance, the thermal efficiency of heat exchangers decreases because of the deposition of low thermal conductivity corrosion products on the heat exchanger tubes 2-Corrosion decrease the safety considerations in handling hazardous materials such as toxic gases, concentrated acids, ammonia, explosive and flammable materials or hydrocarbon compound, 3- Plant shut downs because of equipment failure, 4- Cost of repair and replacement of the corroded equipment, 5- Maintenance cost 6- Loss of valuable products such as foodstuff, dyestuff and drugs because of contamination with corrosion products, 7- In extreme cases loss of life may be take place as a result of corrosion causing equipment failure with catastrophic consequences e.g. pressure vessels, boilers, metallic container for toxic chemicals, turbine blades and oil rig failure. [2]

Copper's Erosion (Cuprosolvency) shapes a patina in a response with water. This starting patina erosion secures channels against assist er osion and harm. Copper isn't inclined to breaking since of its flexibility and isn't harmed by strongly cold work, so copper channels are used extensively within the refrigeration industry. In the presence of corrosive medium copper can corrode. [3]

In view of its economic significance, corrosion work will continue to enhance understanding of its process and to look for new methods to prevent and mitigate the effect of corrosion and to counter it in line with this trend.

Abdel-Aziz et al. [4] and Hikmet et al. [5] Abdel-Aziz et al. [4] and Hikmet et al. [5] have studied the dissolution properties of colemanite and gypsum formation in sulphuric acid by calculating the distribution of particles in the reaction cell over time.

Amer et al. [6] examined Rates of mass transfer controlled Fe/Cu galvanic corrosion at the divider coating of a barrel shaped unsettled vessel in various manure electrolytic media. Jagadeesan et al.[7] examined The synergistic activity brought about by halide particles (Cl^-, Brand I^-) and surfactants (cetyltrimethyl ammonium bromide and sodiumlaurylsulphate) on the corrosion restraint of mellow steel in 1M H_2SO_4 . The outcomes show that the improved hindrance proficiency of the inhibitor brought about by the expansion of halides and surfactants is because of synergism.

Sulpis et al. [8], Slaimana et al. [9] and Hasan et al. [10] investigated the effect of rotation velocity and time on corrosion of mild steel cylinder in different concentration of NaCl. They found an increase in the rate of corrosion with speed of rotation with increace of salt content. For all metals investigated a marked increase in the corrosion rate at the transition from laminar to turbulent flow was observed. Heitz et al. [11],Poulson and Robinson et al. [12] and Abouzeid et al. [13] made a robotic approach and talked about the nature of stream actuated corrosion and created a unused procedure f or measuring mass exchange coefficients and tried by this framework. These frameworks studied the effect of Reynolds number temperature on the corrosion rate is also studied and discussed.

Sedahmed et al. [14] considered the rate of dissemination controlled erosion of copper tube in turbulently streaming 8 M H_3PO_4 (Sc = 49860) by measuring the restricting current of the anodic disintegration of the tube divider in two position: In a brief pipe segment beneath completely created stream and downstream of a sudden withdrawal.

Riggs et al. [15], Behpour et al. [16] made a potentiostatic ponder on the electrochemical conduct as inhibitors for corrosion of copper. Results of electrochemical impedance and Tafel polarization measurements consistently identify both compounds as good inhibitors. Results have shown that the slow transfer of cuprous chloride complexes to the bulk is the rate that determines the step across the polarization range.Sedahmed et al. [3] , Abdel-Aziz et al [4],Zahran et al. [17] , Nosier et al. [18] , Shehata et al. [19] , El-Shazly et al [20], Abdel-Aziz et al. (a) [21], and Soliman et al. [22] contemplated the pace of diffusion controlled disintegration of a section by choosing the pace of dispersion controlled breaking down of the segment divider (copper) in matured chromate plan. The effect of polyox drag diminishing polymer on the pace of corrosion underneath fierce stream conditions was attempted. Drag diminishing polymers were found to decrease the pace of disintegration, contingent upon polymer focus and Reynolds number.

Oldfield et al. [23], Atef et al [24], Scheiner et al. [25] Chen J. et al [26] and El-Naggar et al. [27] worked out on electrochemical hypothesis of galvanic erosion. They found that galvanic erosion can be characterized basically as that erosion that happens since of one metal being in electrical contact with another in a conducting destructive environment. The erosion is fortified by the potential distinction that exists between the two metals, the more respectable fabric acting as a cathode where a few oxidizing species is decreased, the more dynamic metal, which erodes, acted as the anode. Chernov et al. [28], Al-Zahrani et al. [29] and Stevan et al. [30] studied corrosion in sea water on the basis of an analysis of the factors responsible for the initial, maximum possible corrosion rate with subsequent adjustment for its reduction with time. The discharge current of dissolved oxygen was used as the determining parameter in the study. Asymptotic smoothing of corrosion rates with time was caused by the formation of slightly soluble oxides on the metal, which determine the resistance to oxygen transport.

Hasan. et al (a)[31] , Naoki Tangiuchi et al [32] and Guangming Jiang et al [33] corrosion trials of carbon steel (CS) in two stage stream of gas-fluid solution were completed utilizing electrochemical polarization procedure.

Al-Sumail, et al [34], Wu-Shung Fu et al [35] Abdel-Aziz et al. (b) [36] analyzed time subordinate compelled convection warm trade from a solitary round barrel embedded in a level squeezed bed of roundabout particles underneath neighborhood warm non-balance condition numerically using the awful segment system. The dispersal of warm trade rates on the warm surface of the reacting twisted channel is or perhaps non-uniform that successfully purposes a warm mischief to demolish the channel. A technique of using the porous medium to redesign warm trade paces of the channel is by then made to unwind the warm damage. The self-emphatic Lagrangian–Eulerian methodology is right off the bat adjusted for rewarding a moving limit issue of the permeable medium.

Nosier et al. [37] Benari et al [38], Anees et al. [39] Khaled [40] Introduced a present study addresses the relationship between the presence of extracts from crude oil and the corrosion of metallic equipment in the context of the petroleum refining industry.The mechanisms were elucidated by rotating disc methods.

The target of the current work is to contemplate the effect of the one-phase flow and fluid composition of the Cu tube on the single-phase diffusion regulated corrosion rate. Analysis of the risk of corrosion in pipelines and barrel shaped sections and reactors. The high shear worry of the liquid in the channel zone evacuates the defensive oxide layer, especially on account of copper and copper combinations to the arrangement and that of disintegrated oxygen from the answer for the steel surface. [41]

II. EXPERIMENTAL PART

This work pointed to consider the impact of constrained convection on the rate of diffusion controlled corrosion of level copper-tubes cluster embedded in an idle settled bed of round pressing. The diffusion controlled rate of corrosion will be decided in acidic K_2Cr_2O7 solution. Factors considered were:

1. Solution velocity "0.15, 0.31, 0.56, 0.71, 1.03, 1.19, 1.34, and 1.57 cm/s".
2. Diameter of copper tubes "1, 1.5, and 2.2 cm".
3. Physical properties of the solution (D, ρ, μ).

The study assists following technical purposes:

- Design and operation of heat exchanges which use horizontal tubes embedded in fixed bed reactors to absorb excess heat generated by exothermic reactions taking place in the fixed bed reactor.
- Prediction of the rate of the diffusion controlled corosion of flat tubes implanted in settled beds beneath distinctive stream condition. This would make it conceivable to calculate the erosion remittance of the warm exchanger tubes in plan arrange.
- To recreate commonsense diffusion controlled erosion i n quickened framework to be specific the dissemination controlled erosion of copper particles in fermented dichromate solution was chosen to conduct the display ponder in see of its effortlessness and exactness. [42, 43]

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A. *Chemicals used*

Potassium dichromate, Sulfuric acid (98%) pure, Ferrous ammonium sulfate, Diphenyl amine barium salt, Copper tubes (commercial) are used as (A.R) grade and purched from local market.

B. *Apparatus*

Figure (1) appears the exploratory setup utilized within the display consider. It comprised primarily of a vertical column and stream circuit. The conduit column comprises (15×15 × 50 cm height) was packed with plastic spherical packing (0.8 cm diameter). Pattern of copper tubes were embedded in the center of the fixed bed, the tubes were laid out in a square pattern with pitch range from 1.25 to 1.5 times the tube breadth and clearance not less than one-fourth of the tube breadth. Three distinctive tube breadths of "1, 1.5, 2.2 cm "were utilized. The stream circuit comprised of "20 liter "capacity tank, "1/3 hp" plastic head pump,"1 inche" channels and a bypass to control the solution stream rate.

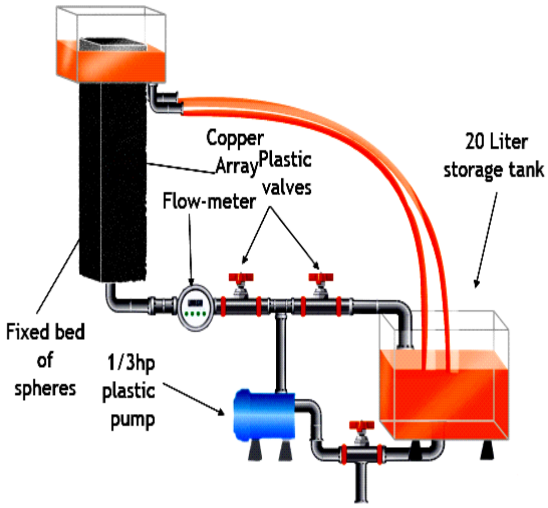

Fig.1. Experimental Setup

C. *Procedure:*

Before each run 20 L of newly arranged acidified dichromate solution were set in the capacity tank. The strong fluid mass trade coefficient of the dispersion controlled crumbling of copper in fermented dichromate arrangement was used to explicit the pace of dissemination controlled corrosion of an cluster of tubes implanted within the settled bed beneath different conditions agreeing to the condition:

$$3Cu+7H_2SO_4+K_2Cr_2O_7 \rightarrow 3CuSO_4+Cr_2(SO_4)_3+K_2SO_4+7H_2O \quad (1)$$

The mass transfer coefficient was determined by plotting ln (C0/C) versus time according to the following equation:

$$Q \ln(Co/C) = K A t \qquad (2)$$

Where C_o is the initial concentration of potassium dichromate, C is the concentration of potassium dichromate at time (t), Q is the solution volume, A is the surface area of the copper tubes (equal to πdLn; where d is the copper tube diameter, L is the length of the copper tubes and n is the number of copper tubes). The slant of the subsequent straight line is equivalent to KA/Q and the mass transfer coefficient (K) can be reasoned from it. [44]

The centralization of the dichromate solutiont was estimated whenever between time by pulling back trial of 5 cm^3 of the arrangement every 10 min and titrating it using standard plan of ferrous ammonium sulfate and diphenyl amine barium salt as a pointer.

Three various beginning centralizations of acidified potassium dichromate solution were used explicitly:
0.003 M $K_2Cr_2O_7$ + 0.5 M H_2SO_4, 0.003 M $K_2Cr_2O_7$ +1 M H_2SO_4 and 0.003 M $K_2Cr_2O_7$ + 2 M H_2SO_4

All tests were completed at room temperature (25±2 °C). The physical properties: solution viscosity (μ), solution density (ρ) and mass diffusivity (D) were taken from the composition .The deliberate physical properties are recorded in Table 1. [45]

Table 1: Values of Solution Physical Properties According to their Composition

Solution composition	Density ρ (Kg/m^3)	Viscosity μ (Kg/m.sec)	Diffusivity D (m^2/sec) $\times 10^{10}$	Sc
0.003M $K_2Cr_2O_7$ + 0.5M H_2SO_4	1023.4	0.0009273	10.654	850.476
0.003M $K_2Cr_2O_7$ +1M H_2SO_4	1059.662	0.001035	9.5458	1023.2003
0.003M $K_2Cr_2O_7$ + 2M H_2SO_4	1116.374	0.0012077	8.1807	1322.38796

III. RESULTS AND DISCUSSION

For a variety of level cylinders implanted in a fixed bed of circular pressing with distance across of 8mm.the controlled dispersion pace of consumption was estimated.

A linear plotting of ln(C0/C) vs. time done to determine the mass transfer coefficient according to equation(2).

A. *Effect of solution velocity*

Figure (2) shows the effect of solution speed on the rate of corrosion. The rate of consumption increases, as the pace of solution course augments. As the pace of course increases the thickness of the dispersion layer decreases thus growing the pace of mass exchange. [45, 46]

It can likewise be explained that by extending the delta speed the pace of mass transfer increases as the fixation incline augments along these lines growing the main impetus and thusly the rate of corrosion increases. [28-32]

Which implies that the expanding in speed will build the measure of oxygen showing up to the surface and consequently the consumption rate to increase [47-49].

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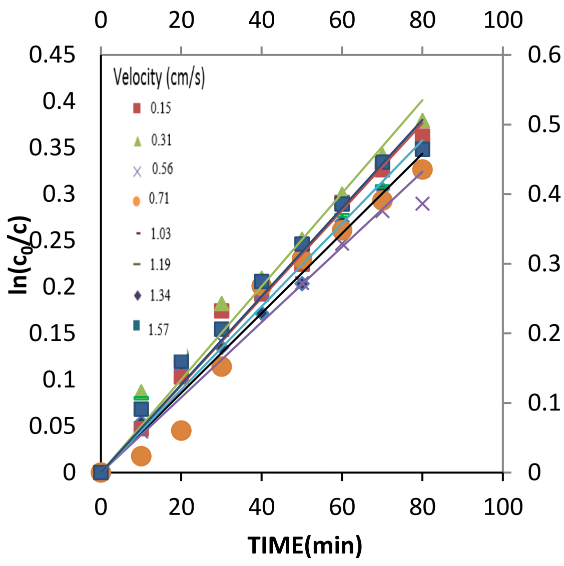

Fig.2. plot of ln C_0/C versus time at different solution velocities (Solution composition 0.003 M $K_2Cr_2O_7$ + 1M H_2SO_4; Tube diameter =1 cm)

B. Effect of copper tube diameter

With refering to Figures (3 to 5) appear the impact of copper tubes diameter within the corrosion rate with Tube diameters values of (1cm, 1.5 cm, and 2.2 cm) separately.

Figure (6) shows the impact of the cylinder measurement at various solution speeds on the pace of mass transfer effect of copper tube distance across.

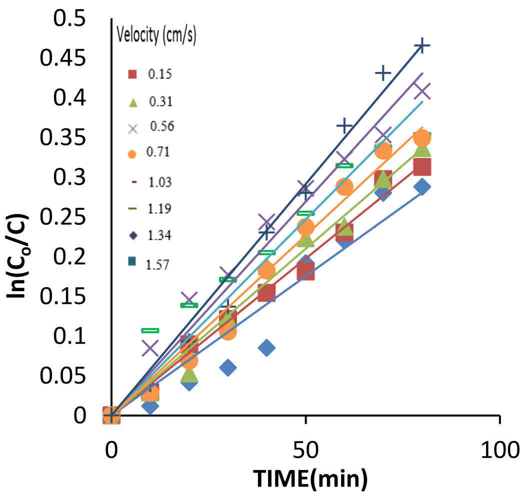

Fig.3. plot of ln C_0/C versus time at different solution velocities (solution composition 0.003 M $K_2Cr_2O_7$ + 1M H_2SO_4; Tube diameter =1 cm)

It is observed that the addition inside the cylinder measurement and solution speed cause an augmentations in the pace of mass transfer because of the development of vortexes inside the spaces between the cylinders. [4, 46]

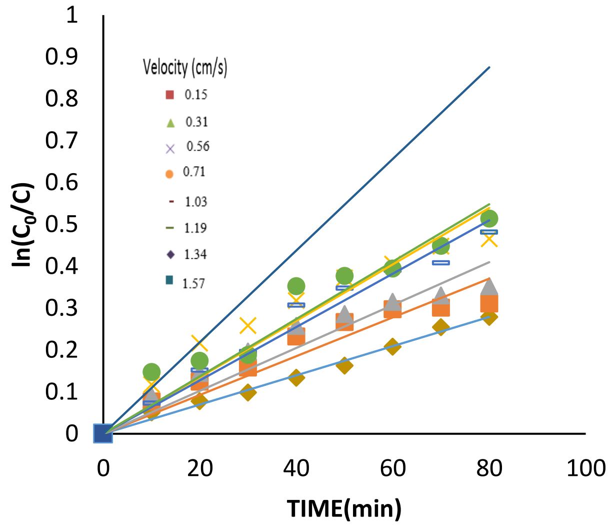

Fig.4. Plot of ln C_0/C versus time at different solution velocities (solution composition 0.003 M$K_2Cr_2O_7$ +1M H_2SO_4; Tube diameter =1.5 cm)

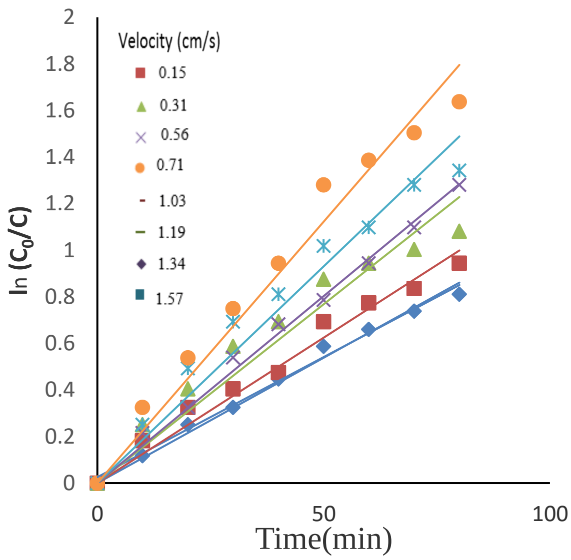

Fig.5. Plot of ln C_0/C versus time at different solution velocities (solution composition 0.003 M $K_2Cr_2O_7$ + 1 M H_2SO_4; Tube diameter =2.2cm)

C. Effect of physical properties of solution

With referring to Figures (7, 3and 8) which show the effect of using initial solution concentration of: 0.003M $K_2Cr_2O_7$ +0.5M H_2SO_4, 0.003 M $K_2Cr_2O_7$ + 1M H_2SO_4 and 0.003 M $K_2Cr_2O_7$ + 2 M H_2SO_4 respectively.

Figure (9) shows the impact of H_2SO_4 focus (0.003 M $K_2Cr_2O_7$ Tube width =1 cm) at distinctive soluion speeds on the pace of mass transfer. These figures showed that by expanding the concentration of sulfuric acid, the rate of corrosion of copper increments. [50, 51]

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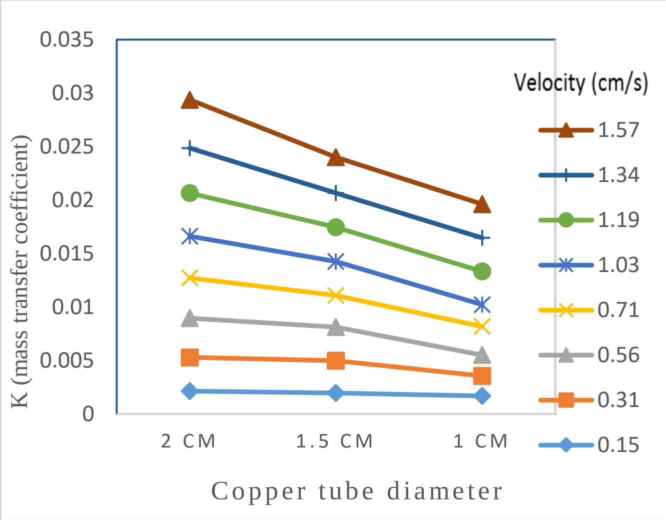
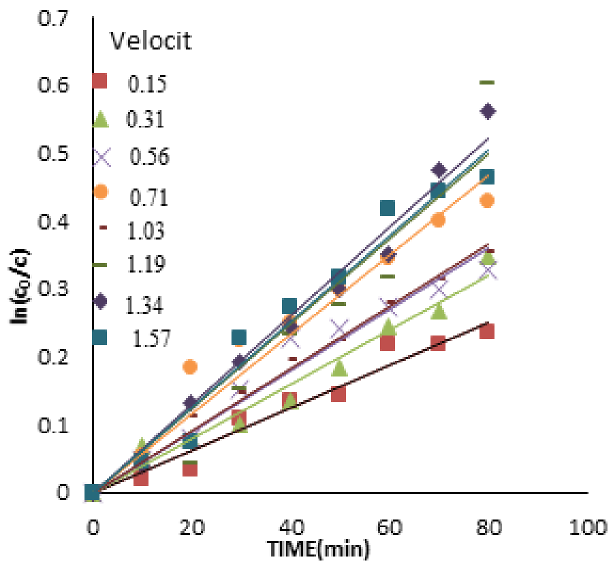


Fig.6. Plot of copper tube diameter versus mass transfer coefficient at different solution velocities (solution composition 0.003 M $K_2Cr_2O_7$ + 1 M H_2SO_4)

Expanding the centralization of active particles in an electrolyte prompts the expansion in the conductivity of the solution which prompts an expansion the rate of corrosion



[52].

Fig.7. plot of ln C_0/C versus time at different solution velocities (solution composition 0.003M $K_2Cr_2O_7$ +0.5M H_2SO_4; Tube diameter =1 cm)

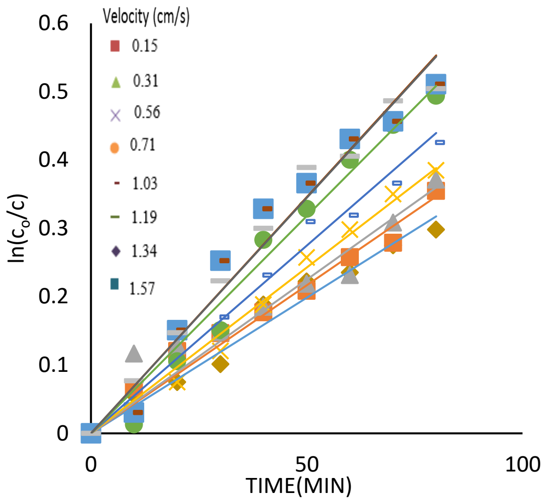


Fig.8. Plot of ln C_0/C versus time at different solution velocities (0.003 M $K_2Cr_2O_7$ + 2 M H_2SO_4; Tube diameter =1 cm)

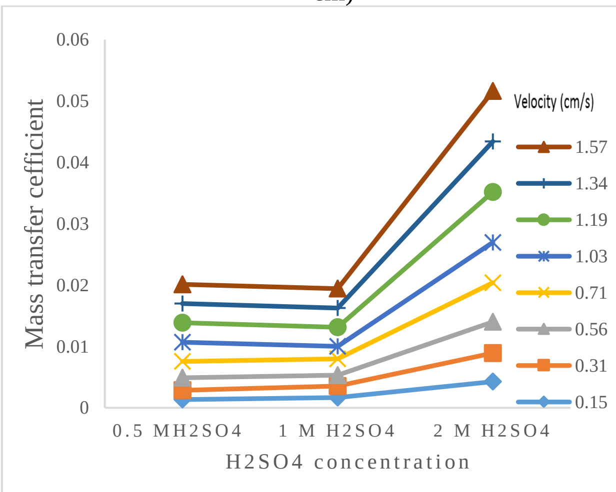


Fig.9. Plot of H_2SO_4 concentration versus mass transfer coefficient at different solution velocities (0.003 M $K_2Cr_2O_7$, Tube diameter =1 cm)

D. Data correlation

The display information were related utilizing dimensional investigation strategy. For constrained convection mass transfer in settled bed pressed column beneath distinc tive stream conditions, the mass transfer coefficient can be related to the overseeing factors by the useful condition:

K= *f* (D, ρ, μ, V, d, dc) Dimensional analysis leads to the equation:

$$Sh = \alpha Sc^{0.33} Re^{\beta} \quad (3)$$

By plotting log Sh versus log Re at different Sc Figure (10) gives a straight lines with slope equal 0.51 and the was obtained from literature of value 0.49 [5]

Thus the overall correlation found to be:

$$Sh = 2.1 Sc^{0.33} Re^{0.51} \quad (4)$$

850<Sc<1048, 1751 < Re < 17684 with deviation ±15%

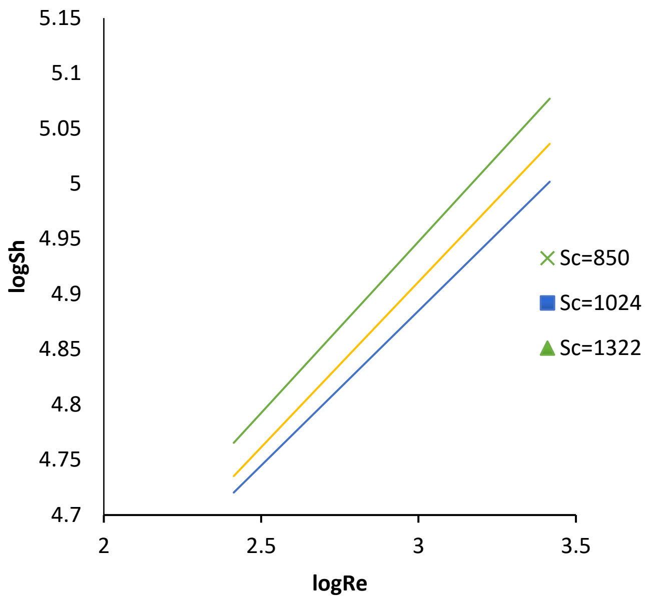


Fig.10. log Sh versus log Re at different conditions

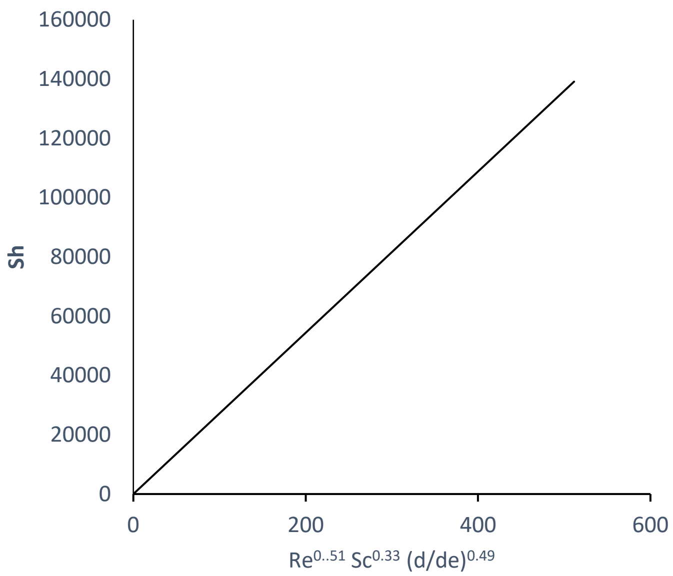


Fig.11. overall correlation

The gotten relationship concurs with Abel-Aziz et al. [21] who considered corrosion of copper with potassium dichromate acidified with sulfuric acid for helical coil. And El-Shazly et al. [20] who considered the corrosion of copper with acidified potassium dichromate for funnel shaped conical bottom of copper as appeared in Figure (11).

Thus the by and large relationship found to be:

$$Sh = 2.1 Sc^{0.33} Re^{0.51} \left(\frac{d}{d_e}\right)^{0.49} \quad (5)$$

850<Sc<1048, 1751 < Re < 17684

IV. CONCLUSIONS

The diffusion controlled corrosion of horizontal copper tubes embedded in fixed bed was examined in terms of the mass transfer coefficient for different conditions. The dimensionless mass transfer equation obtained can be used to assess the rate of corrosion and the corrosion allowance needed in the design of annular flow equipment.

From the results before we can conclude that the corrosion rate can be increased by the following factors:

- Increasing of solution velocity.
- Increasing copper tube diameter.
- Increasing acid concentration.

The dimensionless mass transfer correlation developed in this work under different condition serve the following technical purposes:

$Sh = 2.1\ Sc^{0.33}\ Re^{0.51}$

850<Sc<1048, 1751 < Re < 17684 with deviation ±15%

Nomenclature

Symbols

a	Constant	dimensionless
A	Surface area of copper tube	m^2
C	Dichromate concentration at time *t*	gmol/l
C_o	Initial dichromate concentration	gmol/l
d	Copper disc diameter	Cm
D	Diffusivity	m2/ sec
K	Mass transfer coefficient	cm/s
T	*Temperature*	*ºC*
Q	*Solution volume*	*Liter*
V_n	Liquid velocity	cm/s
t	time	s

Greek Symbols

μ	Solution viscosity	g/cm.sec
ρ	Solution density	g/cm^3
α	Constant	dimensionless
β	Constant	dimensionless

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