Conductivity of series mechanism for Spherical Pellets (Kser) in Fixed Bed Reactor at High Pressure

Abdualnaser M. Almagrbi[1], Walid A. Alaswad[2] Hana O. Ben Oun[3] ,Zainab A. Aldali[4],
[1,2,3,4]Chemical And Petroleum Engineering, Elmergib University, Alkhmos, Libya

الملخص:

مفاعل الحفاز ذو القاعدة المعبأة عبارة عن مجموعة من الكريات ذات الحجم الموحد (المحفز) التي يتم ترتيبها عشوائيًا وتثبيتها بثبات في مكانها داخل وعاء أو أنبوب، يتم إمداد المواد المتفاعلة إلى المفاعل مع تدفق الجزء الأكبر من السائل عبر الطبقة المعبأة، عند ملامسة الجسيم النشط تحفيزيًا ، يخضع المتفاعل لتحولات كيميائية ، والتي عادة ما تكون مصحوبة بتقليل الحرارة أو استهلاك الحرارة، إذا لزم الأمر ، تتم إزالة الحرارة أو إمدادها من خلال جدار الأنبوب.

تم تطوير نماذج رياضية جديدة للتحقيق في العوامل التي تؤثر على موصلية آلية السلسلة في مفاعل طبقة ثابتة بما في ذلك التوصيل الحراري لمرحلة المائع (kf) والطور الصلب المشتت (ks) مسامية الطبقة (ε) ، الشكل وتوجه الأطراف وكذلك كثافتها، هناك عوامل إضافية بجانب هذه العوامل التي تساهم بشكل كبير في الخلط النصف قطري في طبقة معبأة ومهمة في المفاعلات الكيميائية وكذلك في عمليات فصل kc المخصصة للمعدات.

غالبًا ما يكون الخلط نصف القطري مرغوبًا لأنه يقلل من التدرج غير المرغوب فيه لدرجة حرارة النصف قطرية في المفاعلات، يعتمد مدى الخلط على عدد رينولدز ، والانتشار الجزيئي لحساسية السوائل للمكونات الفردية وعلى هندسة التعبئة.

الكلمات المفتاحية: سرير معبأ ، مفاعل ، محفز ، جسيم ، مسامية الطبقة

Abstract

Packed bed catalytic reactor is an assembly of usually uniformly sized pellets (catalyst) which are randomly arranged and firmly held in position within a vessel or tube. The reactants are supplied to the reactor with the bulk of the fluid flowing through the packed bed. Contacting with catalytically active particle, reactant undergo chemical transformations, which are usually accompanied with

heat reduce or heat consumption. If necessary, the heat is removed or supplied through the tube wall.
A new mathematical models is developed to investigate the parameters that influence the Conductivity of Series Mechanism in a fixed bed reactor including the thermal conductivity of the fluid phase (kf) and solid dispersed phase (ks) the porosity of bed (ε), the shape and orientation of the partied and as well as its density. There are additional parameters beside these parameters that contribute significantly radial mixing in packed bed and important in chemical reactors as well as well as in equipment devoted kc separation processes are considered.
Radial mixing is often desirable since it reduce undesirable radial temperature gradient in reactors. The extent of mixing depends on Reynolds number, molecular diffusion of fluid sensitivity of individual constituents and upon the geometry of the packing.
Keywords: Packed bed, reactor, catalyst, particle, bed porosit

1. Introduction

In packed-bed reactor design, the study of radial heat transfer-mechanism of flowing fluid through packing materials in a single wall tube forms an important aspect of the design of fixed bed reactors. The rational design of packed-bed reactors must satisfy optimum conditions for the reaction through the determination of temperature distribution within the reactor and the operational parameters such as the diameter of the reactor-tube and size of the packing-pellets.

The parameters include the thermal conductivity of continues fluid phase (kf), the conductivity solid dispelled phase (ks) and the porosity of the bed (ε) (usually the porosity depends upon the pellet particle-size, particle-shape, particle orientation and its density).Besides these parameters, additional parameters that affected the radial thermal conductivity in packed beds reactors with gaseous fluid flow. The parameters are classified as:

- Fluid Phase Redial Peclet Group
- Turbulent Diffusion
- Effect of Radiation
- Effect of the Pellet Size
- Effect Of high pressure

Argo and smith method had been modified to evaluate the series mechanism (kser) in an uniform packed bed reactor for cylindrical and spherical and hollow cylindrical pellets for radial heat transfer through the pellet solution [1] [2].

- The following assumptions have been made:
- i-Heat transfer through the particle occurs only in the radial direction.
- ii-A constant temperature gradient exist in the solid particle.
- iii-Heat transfer occurs by conduction and convection.
- iv-The mean temperature of the particle is equal to the temperature of the surrounding fluid at the center line of the particle.
- v-An average heat transfer coefficient may be considered applicable to the cylindrical particles is assumed to occur over elements normal to the direction of flow.

2. Methodology

2-1- Theoretical Development

At steady state conditions, the heat transferred through a cylindrical plane parallel to the center line of a packed cylindrical bed will be the sum of the part passing through the void space and the part passing through the solid material. If q is the total rate of heat flow per unit area of the plane and the effective thermal conductivity ker, then the total rate can be expressed as:

$$q = -k_{er}\frac{\partial t}{\partial r} = q_{void} + q_{solid} \qquad (1)$$

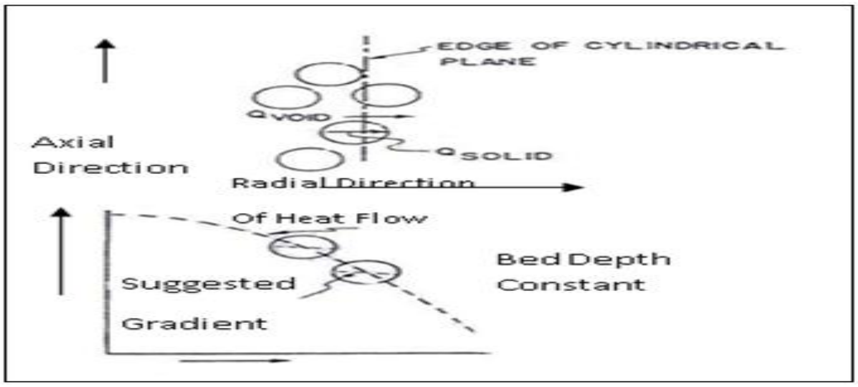

Figure1: Heat flow through Packed-Bed.

This concept is illustrated in the upper half of Figure (1) the temperature gradient in Equation (1) applies to the bed as a whole and deserves some explanation because of the possibility of temperature differences between solid and fluid phases in a packed bed. Bunnel in 1949 measured temperatures at the same radial position in both the gas and in the center of the solid particle and found no significant difference [6]. The solid particles were activated alumina (relatively low conductivity). On the basis of these data it will be assumed that the average temperature of the particle is the same as that of the gas at the same radial position. This does not require that the temperature gradient within a single solid particle coincide with that of the fluid phase.

As shown in Figure (1), there may existed a considerable temperature difference between gas and particle for the transfer of heat to the particle side and from the particle back to the gas stream. The temperature gradient within the particle would be sufficient to transfer heat from one side to another.

The heat passing across the plane in the void space is the sum of that due to molecular conduction, turbulent diffusion, and radiation. Since these paths are in parallel.

$$q_{void} = -\varepsilon(k'_{rf}(p) + k'_{m}(cp_f(p), \mu_f(p), \rho_f(p)) + k'_{td}(cp_f(p), \mu_f(p),$$
$$\rho_f(p) + K'_{rd})\frac{\partial T}{\partial r} \qquad (2)$$

Where ε is the void fraction and the prime superscript indicates that the conductivity is based upon the total void and non-void area; i.e., $k_{rf} = \varepsilon k'_{rf}$ etc

The precise evaluation of the heat transfer through the particle presents a mathematically complex problem. This complexity arises both from the geometry of the bed and the several mechanisms by which heat can enter and leave the pellet. To solve this problem, no simplification will be made concerning the heat-transfer mechanisms, but an ideal model of the packed bed will be employed in order to avoid unsolvable geometrical difficulties. The methods by which heat can enter a particle from its inner side are radiation, convection from the gas stream, and conduction through point contacts and stagnant fillets as indicated in Figure (2) heat is transferred through the particle and leaves the other side by the same three mechanisms. The three processes are in series and hence the whole will be designated as the series mechanism. Hence

$$q_{solid} = -k'_{series}(1-\varepsilon)\frac{\partial T}{\partial R} \qquad (3)$$

Combining Equations (1, 2 and 3) gives an expression for the point effective thermal conductivity in terms of contributions for each mechanism responsible for radial heat transfer.

$$k_{er} = \varepsilon(k'_{rf}(p) + k'_{m}(cp_f(p), \mu_f(p), \rho_f(p)) + k'_{td}(cp_f(p), \mu_f(p),$$

$$\rho_f(p)) + k_{rd}) + (1-\varepsilon)k'_{series} = k_{rf}(p) + k_m((cp_f(p), \mu_f(p), \rho_f(p)) +$$
$$k_{td}(cp_f(p), \mu_f(p), \rho_f(p)) + k_{rd} + k_{series}$$

$$k_{er} = \varepsilon(k'_{rf}(p) + k'_m(cp_f(p), \mu_f(p), \rho_f(p)) + k'_{td}(cp_f(p), \mu_f(p),$$
$$\rho_f(p)) + k_{rd}) + (1-\varepsilon)k'_{series} \qquad (4)$$

$$= k_{rf}(p) + k_m(cp_f(p), \mu_f(p), \rho_f(p)) + k_{td}(cp_f(p), \rho_f(p) + k_{rd} + k_{series} \qquad (5)$$

k'_{series} = conductivity of series mechanism based upon non void area.

Where $k_{series} = (1-\varepsilon)k'_{series}$ where k_{series} is based upon void and non-void area.

2.3 Molecular Conductivity

The molecular conductivity (Km) of the fluid makes little contribution. At high Reynolds numbers, it becomes significantly on the radial heat transfer.

The molecular conductivity may be represented by

$$k_m = D_p.C_p.G / R_{ep}.P_r \qquad (6)$$

2.4 Fluids-Phase Conduction

The value of $K_{rf}'(P)$ in equation (5) is the molecular conductivity of the fluid, its value will change with radial position because of the temperature and pressure variation in the bed. For gases krf(P) is so low and not an important contribution to ker while for liquids this is not true.

2.6 Turbulent Diffusion

The contribution of turbulent diffusion ktd is a measure of heat transfer as a result of turbulent mixing of portions of the gas stream at different temperatures. Singer and Wilhelm have pointed out that its value can be advantageously estimated from measurements of mass transfer radially by the same mechanism. The advantage of using mass transfer data is due to the fact that the transfer of mass radially in a packed bed does not involve the series or radiation mechanisms, but is caused only by molecular conduction and turbulent diffusion and the former contribution is small. On this basis:

$$K_{td}' = \frac{\rho c_p D_P}{\varepsilon} \qquad (7)$$

$$\left(Pe_m = \frac{d_{p^u}}{D_e} \right) \qquad (8)$$

Determined from mass-transfer data,

$$K_{td}{}' = \rho c_p \left(\frac{d_{p^u}}{\varepsilon Pe_m} \right) = \frac{d_p c_p G}{Pe_m \varepsilon} \qquad (9)$$

2.7 Evaluation of Series Mechanism (kser)

Argo and smith method had been modified to evaluate the series mechanism (kser) in an uniform packed bed reactor for cylindrical and spherical and hollow cylindrical pellets for radial heat transfer through the pellet solution [1].

The following assumptions have been made:

i- Heat transfer through the particle occurs only in the radial direction.

ii- A constant temperature gradient exists in the solid particle.

iii- Heat transfer occurs by conduction and convection.

iv- The mean temperature of the particle is equal to the temperature of the surrounding fluid at the center line of the particle.

v- An average heat transfer coefficient may be considered applicable to the cylindrical particles is assumed to occur over elements normal to the direction of flow.

2.7.1. Conductivity of Series Mechanism for Spherical Pellets (kser)

The mathematical problems encountered the evaluating series mechanism in an actual packed bed with its non-uniform arrangement of the solid particles have been mentioned. In order to obtain a useful solution to the problem of radial heat transfer through the spherical pellet same assumptions of the cylindrical pellets mentioned above can be used.

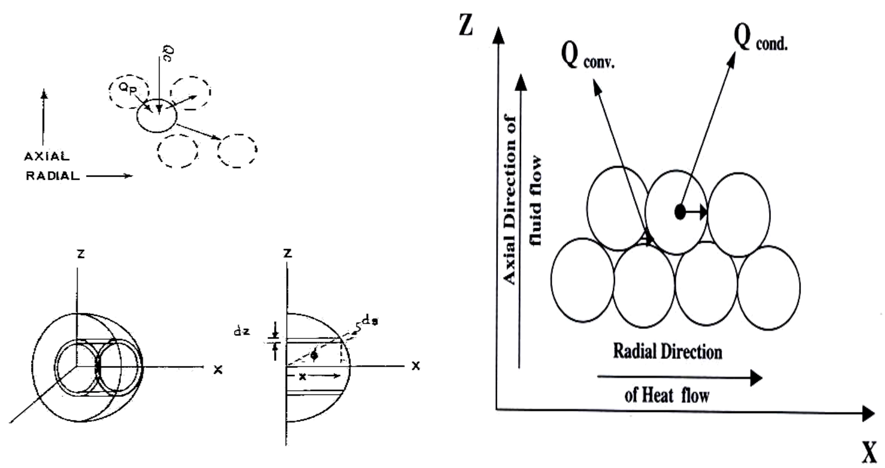

Figure 2: Heat Transfer in a Single Spherical Particle.

The permits heat transfer in the particle to be summed over elements normal to the direction of flow. One half of such a spherical particle with the normal element is illustrated in the lower half of Figure (2) an element leads to the expression.

$$dq' = k_g (2\pi z dz)\left(\frac{T - T_b}{x}\right) \quad (10)$$

$$= h 2\pi\, z (T_s - T_b) ds \quad (11)$$

Where:

$dq' =$ rate of heat flow through the element.

Ks = molecular thermal conductivity of solid particle

Z = coordinate normal to heat flow (parallel to axis of bed).

X = coordinate in direction of heat flow

T = temperature at the center plane of the particle = temperature of fluid phase at the same radial position

Ts = temperature of surface of the particle at a distance x

Tb = T + x = temperature of the fluid at a distance x.

Ds = element of surface through which heat is transferred to the gas stream or to other particles

h = total heat transfer coefficient from the surface of the particle to the fluid or to other particles

The element of surface area available for heat transfer to the gas stream may be related to dz as follows:

$$dz = \frac{dz}{\cos\phi} = \frac{rdz}{x} \quad (12)$$

Elimination of Ts from Equation (11) and integration to obtain the total heat flow through the central plane of the particle yields:

$$q' = -\frac{hk_\delta \pi}{(k_\delta + hr)} (r^3) \left(\frac{dT}{dx}\right) \quad (13)$$

At any distance x from the central plane the total heat flow in the particle

$$q' = -\frac{hk_\delta r}{k_\delta + hr} (\pi z^2) \left(\frac{dT}{dx}\right) \quad (14)$$

Since πz^2 is the cross-sectional area of the solid at this point, and dT/dx is the radial temperature gradient in the fluid phase. Equation (14) may be written as:

$$q' = -\left(\frac{hk_\delta r}{k_g + hr}\right) A \frac{dT}{dr} \quad (15)$$

= heat transferred through the solid, based upon the temperature gradient of the bed

Since qsolid is based upon unit area of normal plane including both void and non-void surface,

$$q_{solid} = \frac{q'}{A}(1-\varepsilon) = -\left(\frac{hk_\delta r}{k_\delta + hr}\right)(1-\varepsilon)\frac{\partial T}{\partial r} \qquad (16)$$

Comparison of Equation (3) and (16) gives the desired expression for k'_{series}

$$k'_{series} = \frac{hk_\delta r}{k_\delta + hr} = \frac{hk_\delta d_p}{2k_s + hd_p} \qquad (17)$$

The above equation can be rearranged in the following form

$$k_{ser} = k_{s,r}\left\{\frac{N'u}{2k_{s,r}/k_f + N'u}\right\} \qquad (18)$$

where :

$$N'u = (h' * D_p)/k_f \qquad (19)$$

Dixon and Cresswell in 1979 and Sixon in 1988 suggested new formula for Bif in a fixed bed reactor packed with both cylindrical and spherical particles, [8][9] which can be written as:

$$B_{if} = N_{nwf}\left(\frac{d_t}{2d_p}\right)(P_{erf}/R_{ep}P_r) \qquad (20)$$

Where:

$$N_{uwf} = 0.523(1 - d_p/d_t)P_r^{0.33}R_e^{0.738} \qquad (21)$$

$$\frac{1}{P_{erf}} = \frac{1}{P_{erf}(\infty)} + \frac{0.74\varepsilon}{\operatorname{Re} P_r} \qquad (22)$$

$$P_{erf}(\infty) = \begin{cases} 12 & \text{spheres} \\ 7 & \text{cylinders} \\ 6 & \text{hollow cylinders} \end{cases}$$

$$Bif = r/D_P \frac{N'u}{\ker} * \frac{C_P * G * D_P}{R_{ep} * P_r} \qquad (23)$$

or $N'u = Bif\ (D_P / r)\ (R_{ep} * P_r) / P_{er}$ (24)

Where:

Per : is the effective radial Peclet number.
Wellauer proposed an equation for Per which can be written as [10][11]:

$$1/P_{er} = 1/P_{erf} + (k_{s,r}/k_f)/(R_{ep} * P_r) * \left\{ \frac{1 + 4/Bif}{8/N_s + 1} \right\} \quad (25)$$

Equation (29) can be expressed as:

$$N'u = 2\,Bif\,(D_p / D_t).\gamma.\left\{ \frac{1 + 4/Bif}{8/N_s + 1} \right\} \quad (26)$$

where $\gamma = (k_{s,r} * R_{ep} + R_{ep} * P_r) / P_{erf}$

Ns = inter phaseheat transfer group
= a r2 h/ks,r
a = specific interfacial surface area
= 4 / Dp (1-ε) (for cylindrical packing)
h = fluid to packing heat transfer coefficient
The fluid to packing heat transfer coefficient has been regarded by Stuke [1948] as a lumped parameter which includes the true fluid-solid film heat transfer coefficient (hfs) and the particle conductivity (kP). The appropriate lumping was show to be

$$\frac{1}{h} = \frac{1}{h_{fs}} + D_p / \beta K_p \quad (27)$$

Where β = 10 , 8 and 6 for spheres , cylinders and slabs respectively.
Substituting for h from equation (27) and eliminating h in terms of (Nufs = hfs DP/kf) we obtained.
The inter phase heat transfer group (NS) is correlated by the relation made by Dixon and Cresswell and Dixon:

$$N_S = \frac{0.25(1-\varepsilon)\left(\frac{AP}{VP}\right)\left(\frac{d^2t}{dp}\right)}{\frac{k_{rs}}{k_f}\left[\frac{1}{Nu_{fs}} + \left(\frac{1}{\beta}\right)\left(\frac{kf}{ks}\right)\right]} \quad (28)$$

Where :

$$\frac{k_{rs}}{k_f} = \sqrt{1-\varepsilon} * \frac{2}{M}\left[\frac{B(k_S-1)}{M^2 k} Ln\left(\frac{k}{B}\right) - \left(\frac{B+1}{2}\right) - \left(\frac{B-1}{M}\right)\right] \qquad (29)$$

Where :

$$M = \frac{K-B}{K} \quad , \quad K = \frac{K_s}{K_f} = \frac{K_P}{K_f}$$

$$B = C\left(\frac{1-\varepsilon}{\varepsilon}\right)^{10/9}$$

$$\beta = \begin{cases} 10 & \text{spherical particle} \\ 8 & \text{spherical particle} \end{cases}$$

$$N_{Uf_s} = 2.0 + 1.1 P_r^{1/3} . \mathrm{Re}\, p^{0.6}$$

$$C = \begin{cases} 1.25 & \text{for spherical particle} \\ 2.5 & \text{for cylindrical particle} \end{cases}$$

The viscosity of a gas is a strong function of pressure as proposed by Reichenberg method [1971, 1975 and 1979] and the viscosity ratio μ/μ^{o} can be written as the following equation:

$$\frac{\mu_f}{\mu^{o}} = 1 + Q\frac{A.P_r^{3/2}}{\beta P_r + \left(1 + C\ P_r^{D}\right)^{-1}} \qquad (30)$$

The constants A, B, C and D are functions of the reduced temperature (Tr) and can be evaluated from the following equations.

$$A = \frac{\alpha_1}{T_r}\exp \alpha_2 T_r^{a} \quad \& \quad B = A(\beta_1 T_r - \beta_2)$$

$$C = \frac{\gamma_1}{T_r}\exp \gamma_2 T_r^{C} \quad \& \quad D = \frac{\delta_1}{T_r}\exp \delta T_r^{d}$$

$$Q = (1 - 5.665\mu_r)$$

Where:

$$\mu_r = 52.46\frac{\mu^2 P_c}{T_c}$$

$\alpha_1 = 1.9824\times10^{-3}$ $\alpha_2 = 5.2683$ $a = -0.5767$ $\beta_1 = 1.6552$

$\beta_2 = 1.2760$ $\gamma_1 = 0.1319$ $\gamma_2 = 3.7035$ $C = -79.8678$

$\delta_1 = 2.9496$ $\delta_2 = 2.9190$ $d = -16.16169$

$$\mu_f = \mu^o\left[1 + Q\frac{A.P_r^{3/2}}{BP_r + (1 + CP_r^{D})^{-1}}\right] \quad (31)$$

The relation thermal conductivities of all gases with pressure can be evaluated by the following equations:

$$k_f = \frac{1.22\times10^{-2}[\exp(0.535\rho_r - 1)]}{\Gamma Z_c^5} - K_f^0 \qquad \rho_r > 0.5 \quad (32)$$

$$k_f = \frac{1.14\times10^{-2}[\exp(0.67\rho_r) - 1.069]}{\Gamma Z_c^5} - k_f^o \qquad 2.0 > \rho_r > 0.5 \quad (33)$$

$$k_f = \frac{2.60\times10^{-3}[\exp(1.55\rho_r) + 2016]}{r Z_c^5} - k_f^o \qquad 2.8 > \rho_r > 2.0 \quad (34)$$

and

$$\Gamma = 210\left(\frac{T_c M^3}{P_c^4}\right)^{1/6}$$

(35)

The effect of pressure on the density of gases can be calculated by the following equation:

$$\rho_f = \frac{P.M_{wt}}{Z.R.T} \quad (36)$$

Where:

$$Z = 1 + (B^0 + wB^1)\frac{P_r}{T_r} \quad (37)$$

Where:

$$B^0 = 0.083 - \frac{0.422}{T_r^{1.6}} \quad , \quad B' = 0.139 - \frac{0.172}{T_r^{4.2}}$$

The departure function for Cp is obtained by the following equation

$$C_{P_f} = \frac{k_f}{\mu_f * 1000} - \frac{10.4}{M^{W.t}} \quad (38)$$

Substituting in equation (26) using equation (18) the series mechanism (kser) for spherical pellets can be written as in the following form:

$$K_{ser(c,s)} = k_{s,r}\left[\frac{Bif\,(D_p/D_t).\gamma.\left[\dfrac{1+4/Bif}{8/N_s+1}\right]}{k_{s,r}/k_f + Bif\,(D_p/D_t).\gamma\left[\dfrac{1+4/Bif}{8/N_s+1}\right]}\right] \quad (39)$$

3. Results and Discussion

In this work three different mathematical models were conducted to investigate the parameters that affected the radial thermal conductivity in packed bed heat exchanger under high pressure up to 25 bars. These models provide a comprehensive relation in predicting the radial Peclet number for a heat transfer through a packed bed with random packing of solid particles.

The catalyst-shape of pellet was considered in the mathematical models (sphere) for evaluation of radial thermal conductivity in the packed bed reactor. Attention is focused on the theoretical model describing the behavior of high pressure on a radial thermal conductivity in fixed bed reactor packed with catalyst pellets, where the reactants fluid flows through the packed bed specially at high pressure a varies of physical and chemical phenomena occur in the reactors. Moreover, many elementary processes taking place in the reactor, which more parameters are involve due the complexity of these phenomena. These required where details to be include in the mathematical model, which need more parameters it will be contain. The best model is selected on the basis of the properties of the particular system under consideration and assumption. The availability of the model equation includes the description behavior of the packed bed reactors packed with different size of the pellets using the gas flowing through the bed catalysts.

3.1 Effect of Reynolds Number upon the conductivity of Serious Mechanism (Kser):

The values of conductivity of serious mechanism (Kser) were predicted at different Reynolds number and pressure and plotted in figures 2 and 3. As seen in Figures 2 and 3, the values of Kser increase greatly with the increase of Reynolds number at the same pressure. Also, for the same Reynolds number Kser value increase with increase of pressure. However, for low Reynolds number the difference in Kser value with the variation of pressure is smaller than that at higher Reynolds number. This can be explained due to the variation of gas properties and flow pattern with the pressure and Reynolds number.

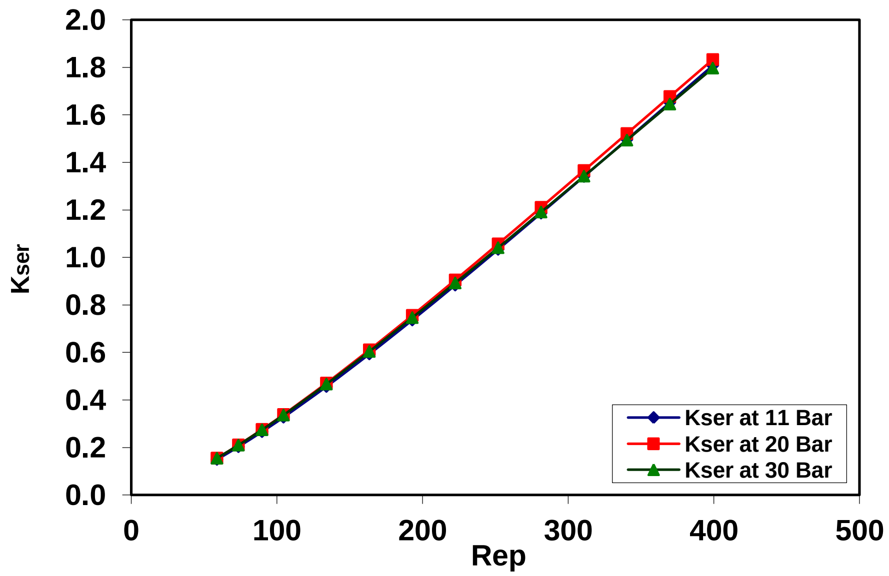

Figure 2: Effect of Column Pressure on K_{ser} for Spherical Pellets (with 3.175 mm diam.)

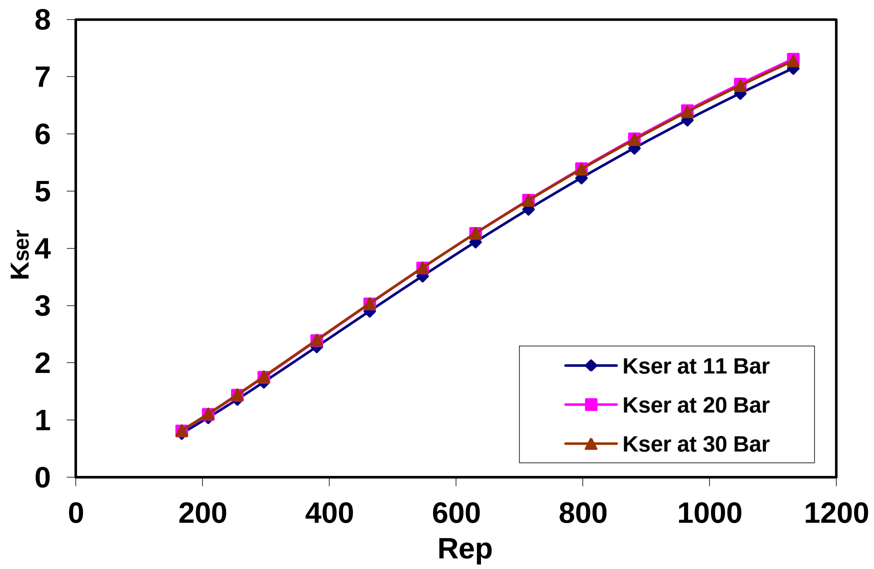

Figure 3: Effect of Column Pressure on Kser for Spherical Pellets (with 9.00 mm diam.)

The same trend was seen in Figures 1 and 2. But the variation in Kser-value with pressure at the same Reynolds number was smaller and the can be found in the following manner:

Kser at 11bar > Kser at 20bar > Kser at 30bar.

3.2. Effect of Pellet Size on Kser for Cylindrical Pellets.

A comparison between Kser-value for different particle size of Spherical pellets was shown in figures 4 and 5 at a pressure of 11 and 20 bar. From Figures, the size of pellet affected greatly Kser and it was clearly that the greater the size the greater the value of Kser. However, At low Reynolds numbers the variation is smaller than that at high once.

An explanation for this effect is that the Conductivity of Series Mechanism for cylindrical pellets (kser) depends on the structure and irregular interconnections between the solid particles in the bed. The void fraction (€) is a major factor affecting at transfer through the fixed bed. Higher voidages would give rise to lower solid-to-solid contact areas and less solid media for heat transfer. Lower void fractions in packed beds are expected to result in higher Conductivities of Series Mechanism for large Dt/Dp ratios. Moreover, for fixed beds of high Dt/Dp ratio the extra resistance to heat transfers at the wall region is caused by the ordering of the packing by the wall.

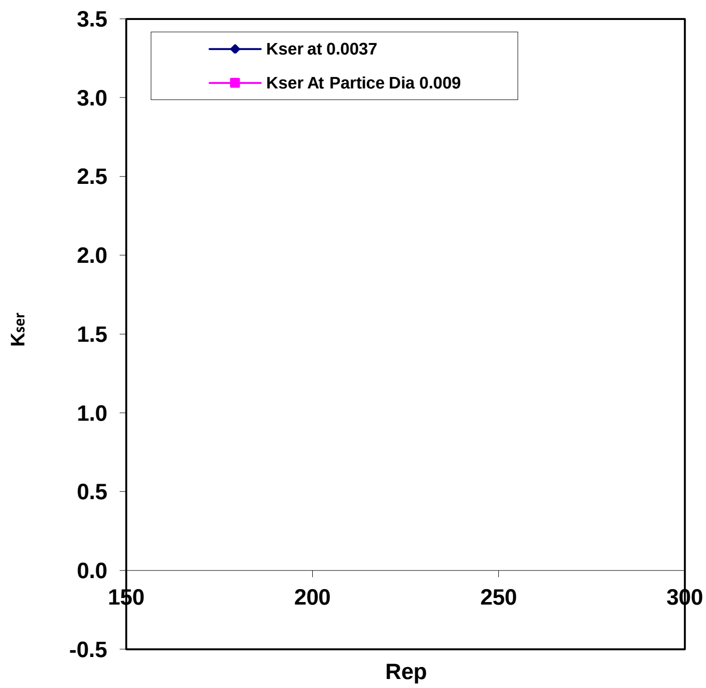

Figure 4: Effect of Pellet Size on Kser for Spherical Pellets at 11 Bar.

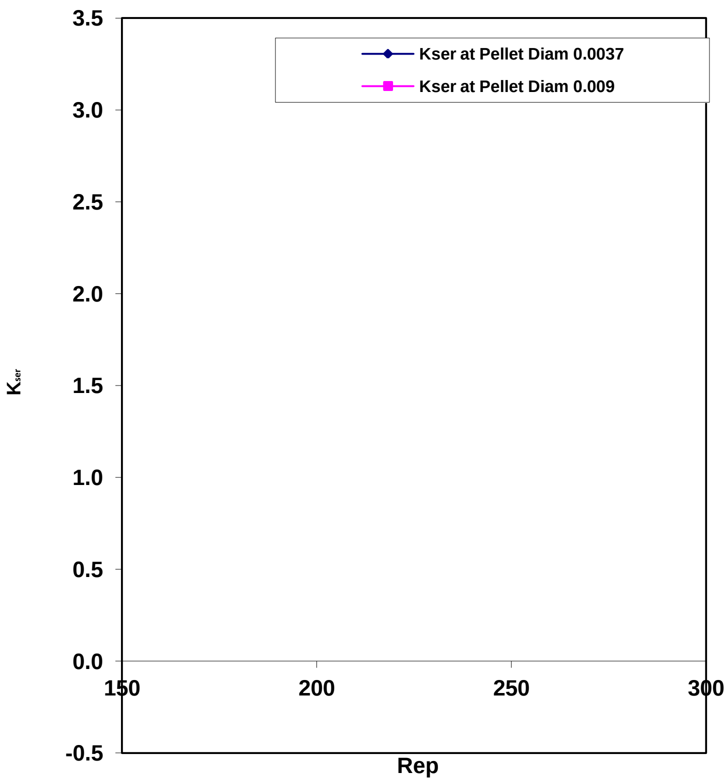

Figure 5: Effect of Pellet Size on Kser for Spherical Pellets at 20 Bar.

4. Conclusion

The model for the prediction of Conductivity of series mechanism in packed-bed reactor has been developed. Parameters that affect the Conductivity of series mechanism under high pressure (up to 30 bars) are considered in the models. Noting that, the catalyst-shape of pellets were considered in the mathematical models (Spherical) for evaluation of Conductivity of series mechanism in the packed bed reactor, from the results, man can conclude that:

- At all pressure (11 and 20 bar), it is observed that the Conductivity of series mechanism was a strong function of pressures at the same Reynolds number and it increased linearly with the increase of pressure.
- The difference between the Conductivity of series mechanism at 20 bar and those of 11 bar can be up to 60% .
- The Conductivity of series mechanism was affected by the pellet size on cylindrical pellets were used.
- For solid pellets Independent of shape and size a small variation in Conductivity of series mechanism under the same pressure and Reynolds number were observed. However for Spherical pellets, a large difference

between the small and large pellets was very pronounced.

- The size of pellet affected greatly Kser and it was clearly that the greater the size the greater the value of Kser.

5. References

1. Argo, W,B and Smith, J.M. Chem, Eng, Prog, 49, 443, (1953).
2. Al-Meshragi, M, Ph. Dr. Thesis, Salford University, (1989).
3. Agnew, J.B., Potter, O.E., ‘Heat transfer properties of packed tubes of small diameter’, Trans, Instn.Chem.Engs., 48, T15, (1970).
4. Ahmed, M. and fahien, R.W. Chem, Eng, Sci, 35, 889, (1980).
5. Alan, J. Slavin; Frank, A.L.; Londry, J.H.: "A new model for the effective thermal conductivity of packed beds of solid spheroids: alumina in helium between 100 and 500 oC", Inter. J. of Heat & Mass Transfer, V. 43, pp. 2059-2073, (2000)
6. Alder, B.J: Prediction of Thransport properties of dense Gases and Liquids, UCRL 14891-T, university of California, Berkeley calif., May, (1966).
7. Al-Meshragi, M. and Hughes, R. 51st chemical eng.. Conference, Canada, Halifax (2001).
8. Andersson, K.E.B. Trans, Roy, Inst, Tech, Stockholm, 34, 316, (1963).
9. Azevedo, S.F. de, Romero-Ogawa, M.A., Wardle, A.P., ‘modeling of tubular fixed-bed catalytic reactors: a brief review’, Trans. IchemE 68, part A, 483, (1990).
10. Baddour, R.F. and Yoon, C.F Chem, Eng, prog, Symp. Ser 57, 35, (1962).
11. Balakrishnan, A.R. and Pei, D.C. Ind. Eng. Chm. Proc. Des.Dev. 18, 40, (1979).