# EFFECT OF PARTICLE SIZE,FLOW VELOCITY AND HEAT FLUX ON HEAT TRANSFER COFFICENT IN FLUIDIZED BED COLUMN

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**ABSTRACT:**

An experimental study to investigate the effect of the particle size ($d_p$) and Reynolds number (Re) for different values of heat flux on the heat transfer coefficient (h) in gas-solid fluidized bed was done.

In this work three different sizes of sand particles were employed (525,725 and 925 $\mu$ $m$). The fluidizing medium was air at different velocities in the range of (1.9-2.9 m/s). The rig provided with a horizontal heating tube with outer diameter of (3.175cm) was heated eclectically with different power supplies (69,90,120 and 150 W) .

The fluidized bed temperature profiles were evaluated axially in the fluidized bed for different positions. The recording and the monitoring of these measurements were done by an interface system connected with PC computer.

The results show that the temperature distribution decreases with increase particle size and the heat flux represents as the temperature increases as the air velocities increase .

A new empirical correlation was suggested in this study .The correlation predicts the value of ($Nu_p$) as a function of both ($Re_p$) and ($Fr_p$). All the dimensionless groups are determined based on particle diameter .

$$Nu_p = \frac{0.0738 \mathrm{Re}_p^{\,0.57} Fr_p^{\,0.48}}{5.23 + 0.0042 \mathrm{Re}_p} \qquad \begin{array}{l} 61 < \mathrm{Re}_p < 168 \\ 406 < Fr_p < 1675 \end{array}$$

**Key words: particle ,gas-sold, two phase flow, fluidized bed ,heat transfer coefficient , Nusselt number , Froud numbers**

**الخلاصة :**

يتضمن البحث دراسة عملية لتأثير كل من حجم الجزيئات الصلبة ، رقم رينولدز ومعدل سريان الحرارة على معامل انتقال الحرارة في الجريان ثنائي الطور(غاز- صلب) في الحالة المستقرة.

لقد تم استخدام الرمل كماده صلبة وبثلاث أقطار مختلفة (525,725 and 925 $\mu$ $m$) واستخدام الهواء كوسط للتميع وبثلاث سرع مختلفة هي( ١,٩و٢,٢،٢,٧ و ٢,٩ م\ثا) وجهز الجهاز بمسخن أنبوبي أفقي ذات قطر خارجي (٣,١٧٥ سم) جهز بقدرات كهربائية مختلفة (٦٩،٩٠،١٢٠،١٥٠ واط).

لقد بينت النتائج بان هنالك توزيع محوري لدرجات الحرارة عند جميع السرع المستخدمة وتزداد هذه الدرجات مع زيادة سرع الهواء وتزداد مع نقصان حجم الجزيئات الصلبة وزيادة معدلات سريان الحرارة.

تم الحصول على معادلات تجريبية جديدة لحساب قيم ($Nu_p$) اعتمادا على كل من ($Fr_p$ , $Re_p$) تمثل بالعلاقة التالية :

$$Nu_p = \frac{0.0738 \mathrm{Re}_p^{0.57} Fr_p^{0.48}}{5.23 + 0.0042 \mathrm{Re}_p} \qquad \begin{array}{l} 61 < \mathrm{Re}_p < 168 \\ 406 < Fr_p < 1675 \end{array}$$

## 1. Introduction:

Fluidization is the operation by which fine solid transferred into a fluid. The two separated phase (solid-gas) in some conditions may be treated as a single (homogeneous) phase. However, one of the most interested application of the gas – fluidized bed techniques in engineering is the catalytic cracking process **(Boherill,1975)**

The fluidized bed techniques in column is one of the most important technological process in industry and hence many publication available in this area. However, **Biyikli et al. (1983),**investigated the heat transfer coefficient in the freeboard. **Basu** and **Nag,(1987)**, studied the factor of the residence time of particle velocities on heat transfer coefficient. **Glicksman,(1988),** found that heat transfer varies as the square root of the cross-section average suspension density. **Furchi et al**., **(1988),** measured local heat transfer coefficient in a (6m) height and(72mm) ID column. **Grace**, **(1990),** reported that thermal equilibrium can be reached very quickly between the gas and solids and the heat transfer just exists in the entrance region of column only. **Zheng et al.,(1991)** studied heat transfer in cold bed. **Bi et al., (1991),** studied of heat transfer in fast fluidized bed made of Plexiglas with (86mm) ID and (8m) in height ,with silica gel particle in experimental work. **Wedermann** and **Werther,(1994)** correlated their results for convection heat transfer on vertical wall in functional relationship between Nusselt number, density of the bed and Reynolds Number which based on the column diameter. **Glicksman et al.,(1997),** measured simultaneous heat and mass transfer in (200 mm) diameter column using glass beds with diameter of (88 $\mu$ $m$ ).

## 2. The Experimental Procedure:

Forty eight experimental set were conducted in this work in order to study and analysis the heat transfer coefficient in the gas-solid (sand-air) fluidized bed.

Each experiments was repeated three times to ensure confidence of the results for each sand particle size the experimental procedure to determine the local temperature through the column, consist of the following steps:

1- Pack the column with about of (100 g) of the select mesh size of the sand.

2- Switch on the air compressor until the pressure inside the air storage tank reaches the operation pressure (a bout 1.5 bar) .

3-Open the regulator valve to feed the air through the tube .The pressure drop through the orifice is measured to determined the air velocity under steady state condition.

4- Switch on the heater and regulator the voltage passage through the heater by voltage regulator.

5- Measure and record the temperature at different positions at steady state, Monitoring these measurements by interface system connected with computer .

6- At the steady state ,the heat transfer coefficient between the gas and the solid particles is determined based on the following set of equations:

$$\dot{m}\, c_p\, dT = h\, dA\, (T - T_\infty) \qquad (1)$$

$$h = \frac{\int \dot{m} c_p \, dT}{\int h \, (T - T_\infty) \, dA} \tag{2}$$

$$Nu_p = \frac{h \, d_p}{k_g} \tag{3}$$

**3. Results and Discussion:**

The experimental equipments and instruments are used to measure the fluidized velocities ,heat flux and the temperature along the column.

The heat flux ,the fluidized velocity and the particle size are examined for (48) experiments with three times of receptions. Figure (2) and (3) show the experimental equipments and measurements system which used in this work.

**3.1 The Temperature Profile:**

**3.1.1 Effect of heat flux:**

**Figures (3)** to **(6)** show the effects of the heat flux on the steady state temperature distribution along the column for different particle size and at different fluidized bed velocities.

For the particle size (512 $\mu$ m) and at fluidized bed velocity (U=1.9 m/s), the temperature increases from (96 $^o$C) to (107 $^o$C) when the heat flux increases form (73 W) to (370 W) at (z=10 cm) of the column height. Whereas for the particle size (725 $\mu$ m) and at the same location the temperature increases from (88 $^o$C) to (102 $^o$C) for the same change in the heat flux ,this is due to increase of amount of the heat which is transferred to the fluidized bed system.

**3.1.2 Effect of fluidized bed velocity:**

**Figure (7)** shows the effect the fluidized bed velocity on the temperature distribution along the column for different particle sizes at heat flux value (q=131 W) at the steady state.

For the particle size (512 $\mu$ m) and at a heat flux of (q=131W) the temperature increases from (97 $^o$C) to (108 $^o$C) when the fluidized bed velocity increases form (U=1.9 m/sec) to (U=2.9 m/sec) at a location of (z=10 cm) of the column height. For the particle size of (725 $\mu$ m) and at same value of the heat flux (q=131W) at the location of (z=10 cm) the temperature increases from (87$^o$C) to (99 $^o$C) at the same range of the velocity change. And at the same conditions and locations but for the particle size, the increase in temperatures become (89$^o$C) and (93 $^o$C) when the fluidized bed velocity increase form (U=1.9 m/sec) to (U=2.9 m/sec) , this is due to increase of the great amount of air with great heat that increase the heat transfer to the solid particle and so increases the temperature.

**3.1.3 Effect of particle size:**

**Figure (8)** shows the effects of the particle size on the temperature distribution along the column for different fluidized bed velocities at heat flux value (q=131 W) at the steady state station

For fluidized bed velocity (U=1.9 m/s) and at heat flux (q=131W) the temperature increases from (89 $^o$C) to (96.1 $^o$C) when the particle size varies form (512 $\mu$ m) to (925 $\mu$ m) at (z=10 cm) of the column height. When the fluidized bed velocity becomes (U=2.2 m/s) at the same value of the heat flux (q=131W), the temperature increases from (90 $^{o}$C) to (99.9$^{o}$C) as the particle size varies form (512$\mu$ $m$) to (925$\mu$ $m$) at the same height of the column. The identical behavior can be found as one examine the other range of the fluidized bed velocity, the temperature increases as the mean solid particle diameter decreases this is due to the finer particle can cause higher heat transfer coefficient due to small thermal conductive resistance of small particle . Moreover the smaller particles can increase the effective heat transfer area covered by particle itself.

**3.2 Nusselt Number:**

In this work, an empirical correlation for the Nu as a function of Reynolds number (Re) and Froude number (Fr) based on particle diameter is proposed.

The statistical software (STATISTICA v6) was used to determine the coefficients of the correlation. The dimensionless groups are evaluated at the same ranges of the experimental data in this work.

The final form of the (Nu) correlation extracted from the experimental data is as follows :

$$Nu_p = \frac{0.0738\,\mathrm{Re}_p^{\;0.57}\,Fr_p^{\;0.48}}{5.23 + 0.0042\,\mathrm{Re}_p} \qquad \begin{matrix} 61 < \mathrm{Re}_p < 168 \\ 406 < Fr_p < 1675 \end{matrix} \qquad (4)$$

**Fig (9)** shows the comparison between the experimental data and the correlated values according to the equation ( 4 ) .The figure shows that there is a good relation between the data .

However, the correlation indicates the Nusselt number depend strongly on both Reynolds and Froud numbers.

As shown in **Fig.(10)** the new correlation of Nu number is close to the **Werdermann & Werther (1994)** rather than **McGraw(1976)** correlation.

## 4. Conclusions:

1. For the values of fluidized bed velocities, the temperature increases as the heat flux (q) increases and this is due to increase of amount of the heat which is transferred to the fluidized bed system .
2. For the value of the heat fluxes, the temperature increases as the fluidized bed velocity increases, this is due to increase of the great amount of air with great heat that increase the heat transfer to the solid particle and so increases the temperature.
3. For certain values of fluidized bed velocity and heat flux, the temperature increases as the mean solid particle diameter decreases this is due to the finer particle can cause higher heat transfer coefficient due to small thermal conductive resistance of small particle . Moreover the smaller particles can increase the effective heat transfer area covered by particle itself.
4. The proposed correlation of the Nusselt number can predict the effect of Reynolds and Froud numbers in separated manner rather in combined one as in the other correlations.

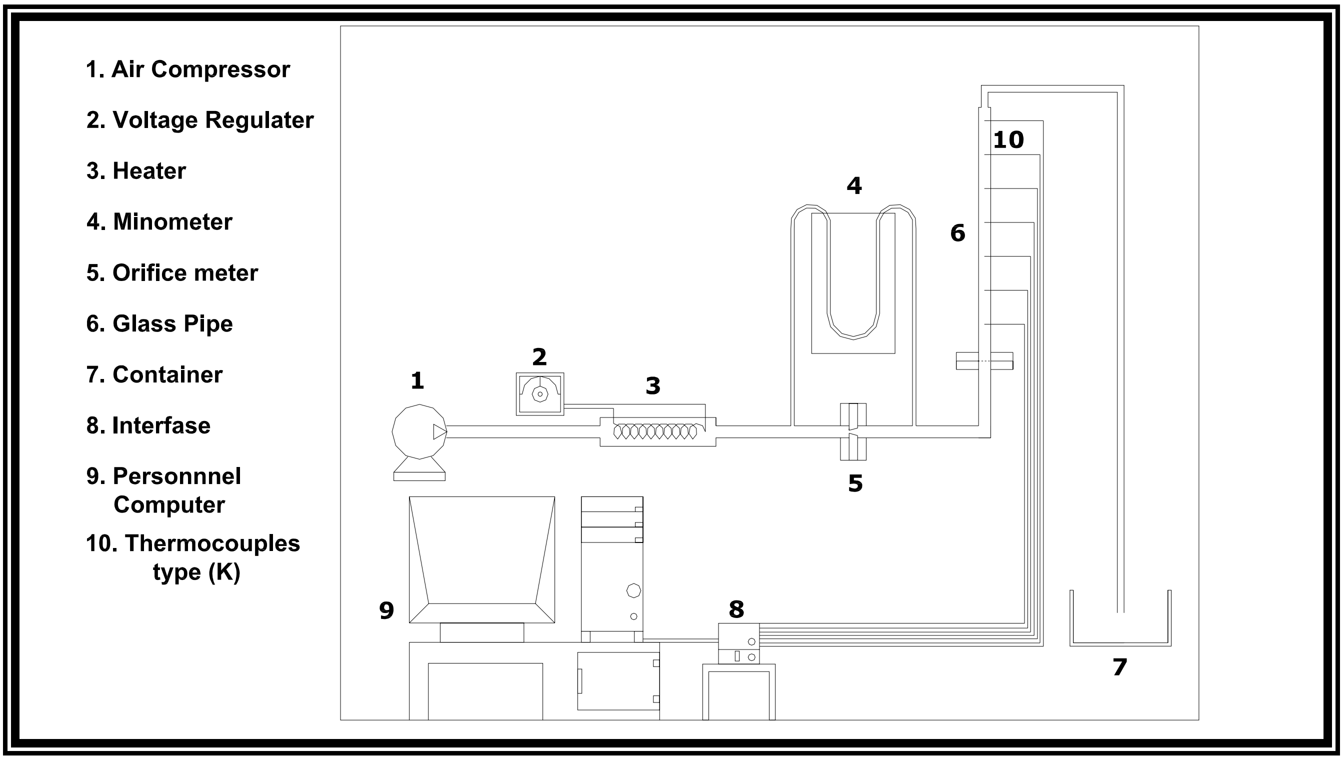


**Figure (1) :The Experimental rig**

**Figure (2): The Experimental equipment and measurements**

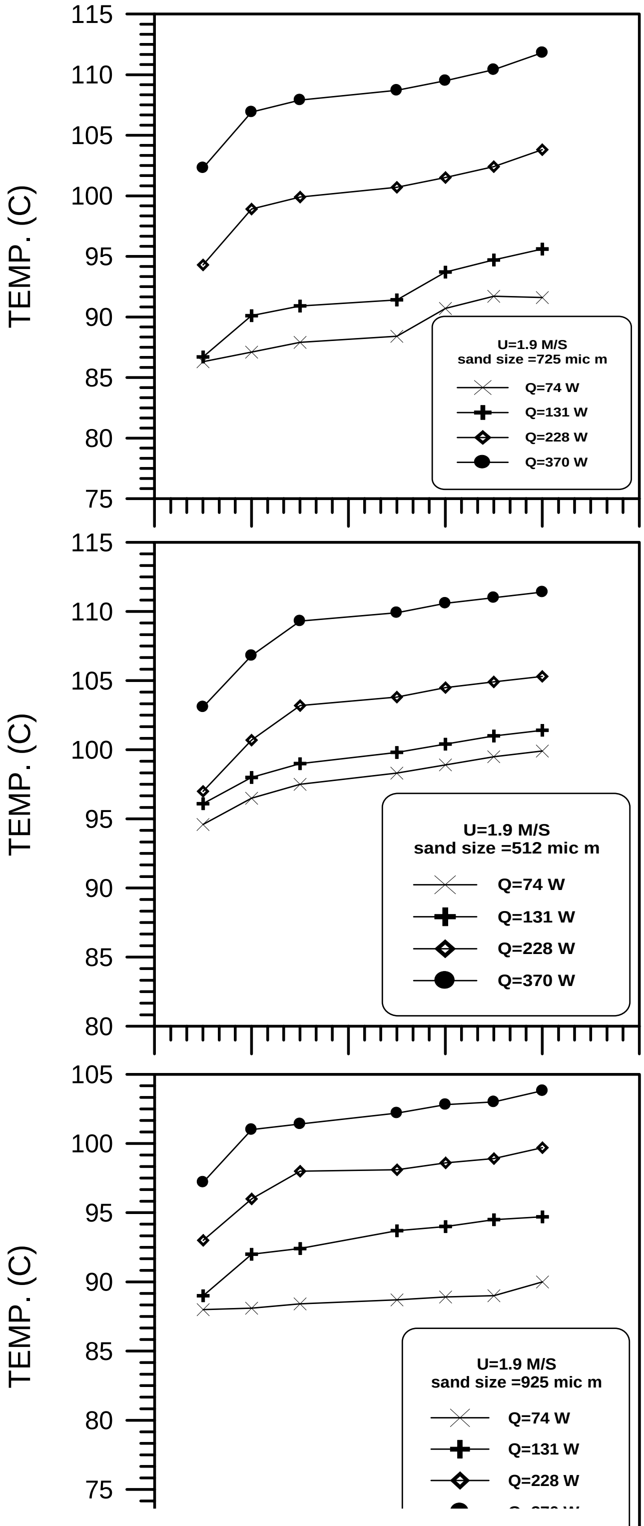


Figure (3): Effect of heat flux on temperature profile at fluidized velocity (1.9 m/s) for different particle sizes

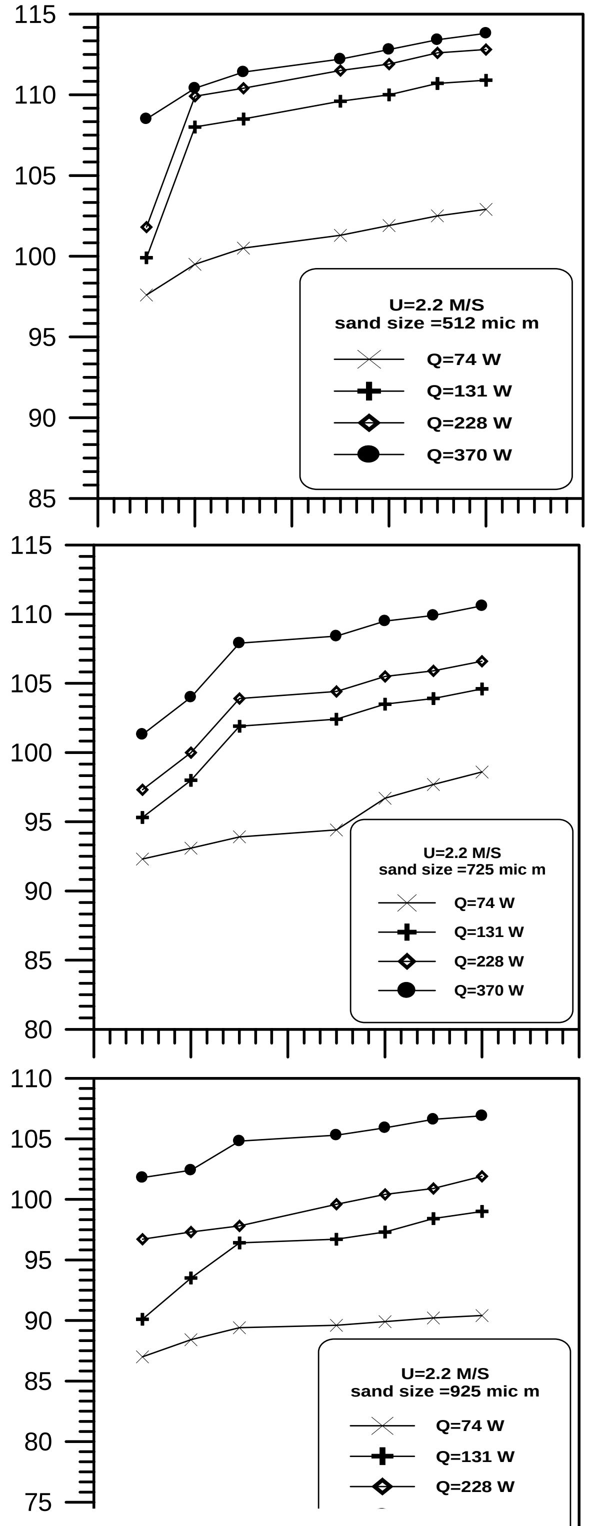


Figure (4): Effect of heat flux on temperature profile at fluidized velocity (2.2 m/s) for different particle sizes

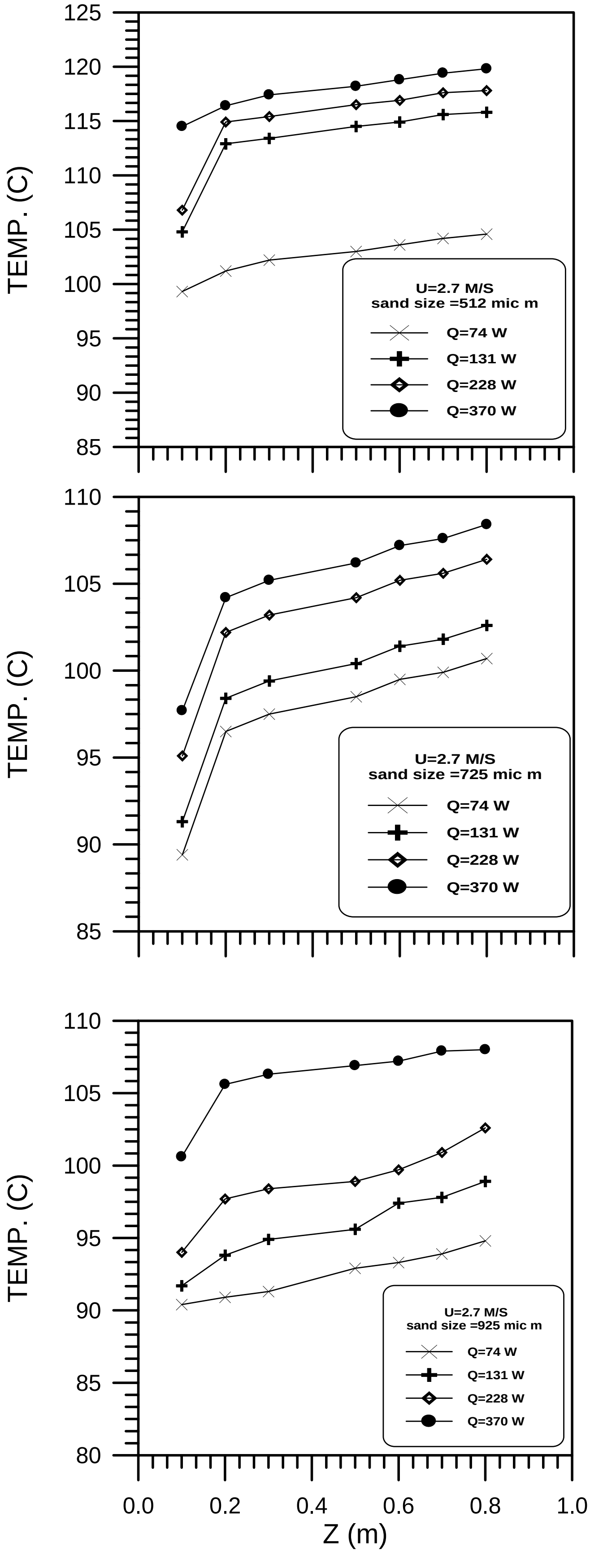


Figure (5): Effect of heat flux on temperature profile at fluidized velocity (2.7 m/s) for different particle sizes

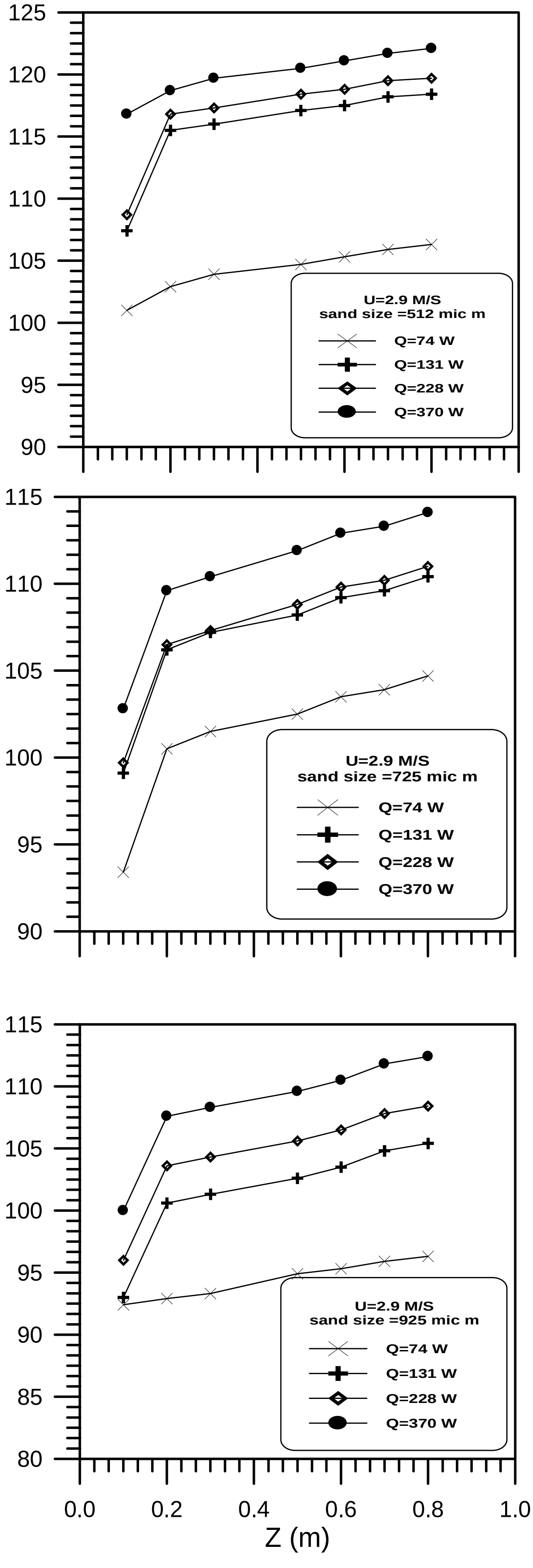


Figure (6): Effect of heat flux on temperature profile at fluidized velocity (2.9 m/s) for different particle sizes

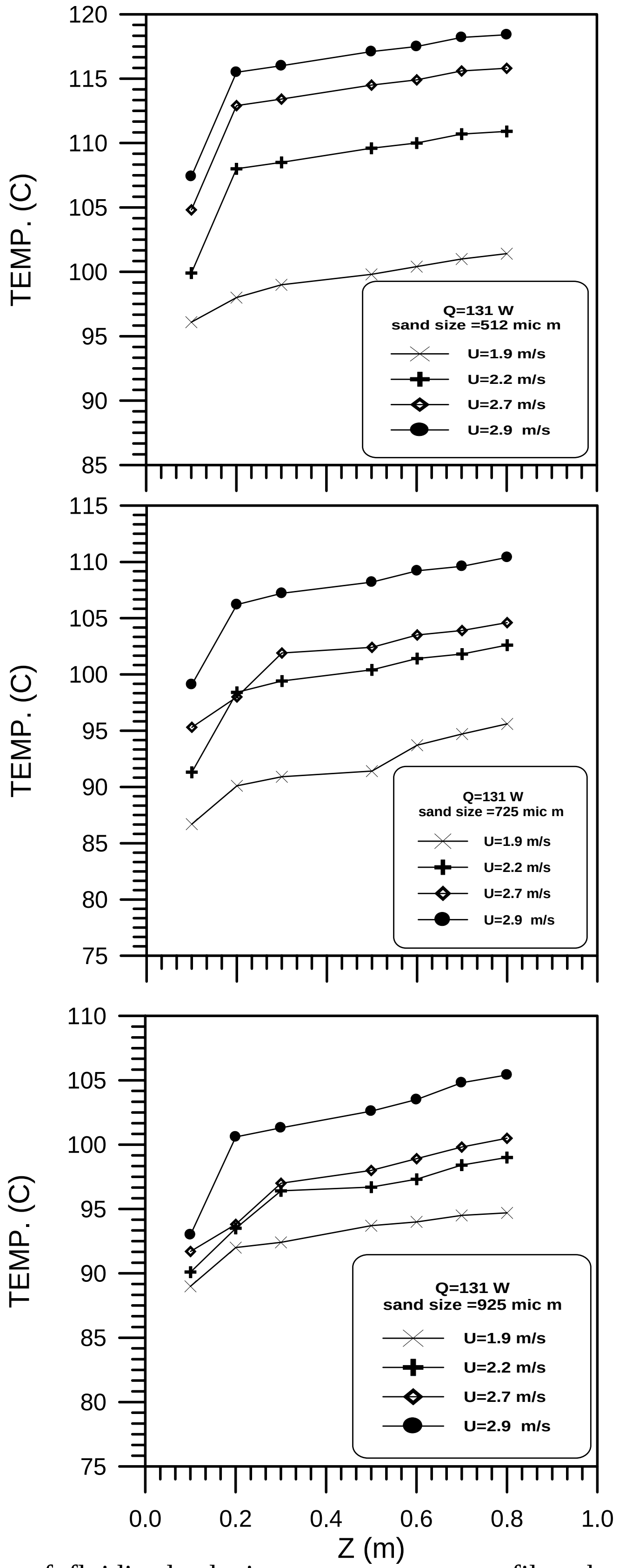


Figure (7) :Effect of fluidized velocity on temperature profile at heat flux (131 W) for different particle sizes

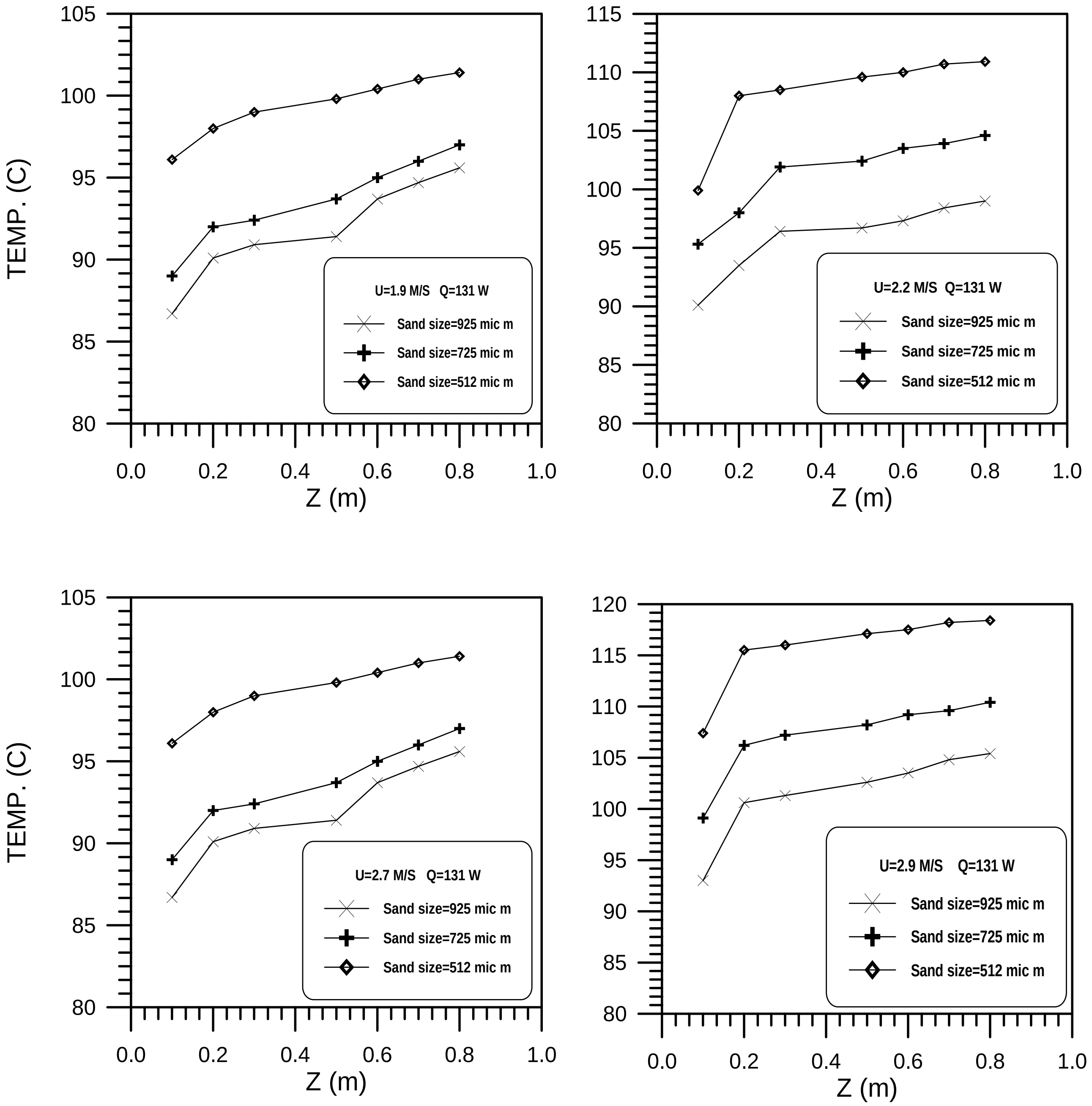


Figure (8):Effect of particle size on temperature profile at heat flux (131 W) for different fluidized velocities

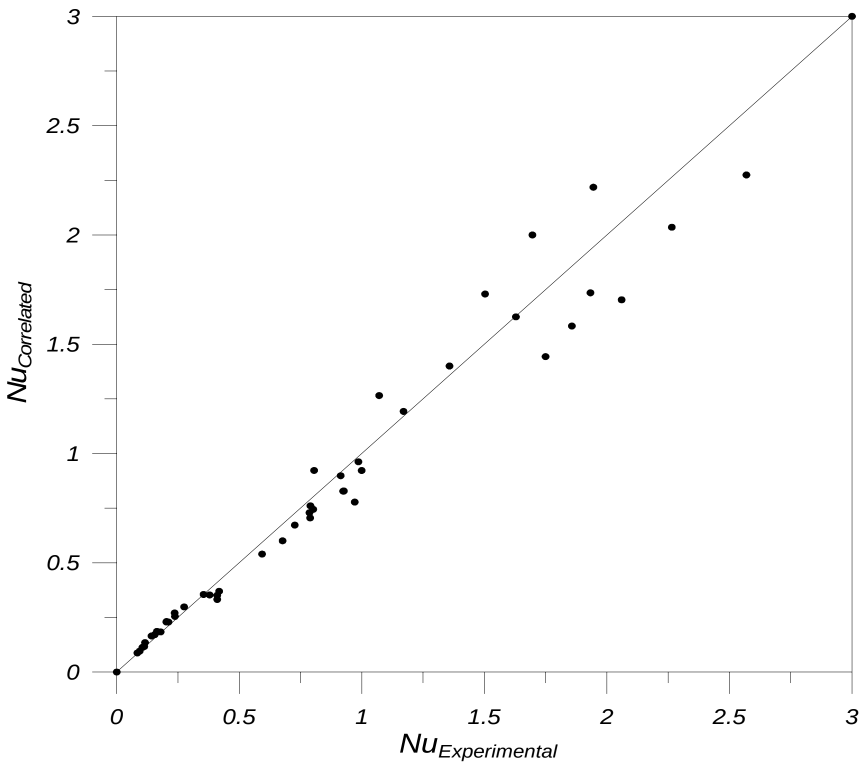


Figure (9): Correlated vs. experimental data of the Nusselnt number

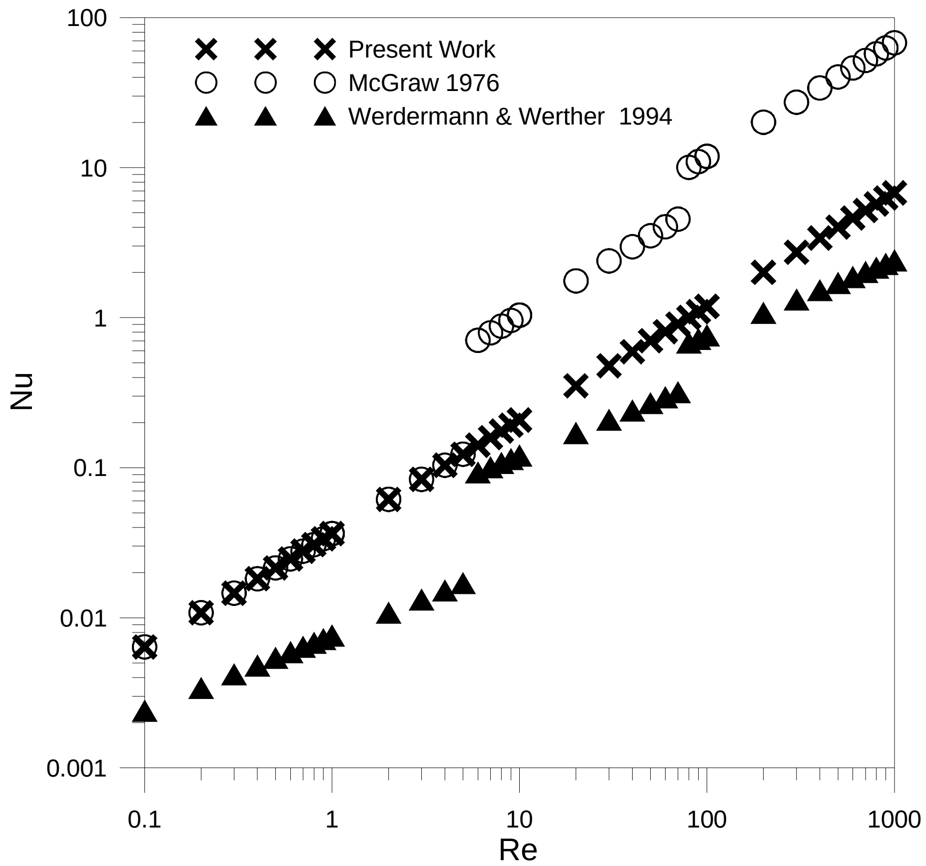


Figure (10): Present work correlation (Nu vs. Re)

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**Nomenclature**

| | | | | | |
|---|---|---|---|---|---|
| **$C_P$** | Specific heat at constant pressure | kJ/kg.$^o$K | **T** | Temperature | $^o$C |
| **D** | Column diameter | m | **$Re_p$** | Reynolds number $(\frac{\rho U d_p}{\mu})$ | |
| **dp** | Diameter of solid particle | m | **U** | Velocity | m/s |
| **$Fr_p$** | Froude number $(\frac{U}{\sqrt{g d_p}})$ | - | **z** | **Axial distance** | m |
| **g** | The acceleration | m/s$^2$ | $\rho_g$ | Density of gas | Kg/m$^3$ |
| **Q** | Power supplied | W | $\rho_s$ | Density of solid | Kg/m$^3$ |
| **$Nu_p$** | Particle Nusselt number $(\frac{h d_p}{k_g})$ | | $\mu$ | Fluidized gas viscosity | Kg/m$^3$ |