The Iraqi Journal For Mechanical And Material Engineering, Vol.12, No.1, 2012

TRANSIENT THERMAL BEHAVIOR OF FLUIDIZED BED COLUMN

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Abstract:

The effect of the particle size (d_p) and the fluidized velocity investigated Experimentally and theoretically for different values of heat flux thermal behavior in gas-solid fluidized bed was done with time.

In this work three different particle size was employed (450,650 and 850 μm). The fluidizing agent was air at different velocities in the range of (2-2.8 m/s). The rig provided with a horizontal heating tube with outer diameter of (3.175cm) was heated eclectically with different power supplies (80,240,350 Watt).

Presented mathematical model one dimensional unsteady includes energy, continuity, and momentum equations for each of two phases. In order to solve the foregoing equations in a numerical way, the discretization method based on control volume procedure has been used the computer code (FLBD) which is written with mathlab 2008.

The results show that the temperature distribution along the packing height decreases with increase particle size and the heat flux represents as the temperature increases as the air velocities increase with time. Compared the experimental and theoretical results and the comparison is a good agreement.

Key words: Particle, gas-sold, two phase flow, fluidized bed, heat transfer coefficient

الملخص:

يتضمن البحث دراسة عملية ونظريه لتأثير كل من حجم الجسيمات الصلبة , وسرعة الجريان وكمية الحرارة المنتقله على توزيع درجات الحراره في الجريان ثنائي الطور(غاز- صلب) مع الزمن .

لقد تم استخدام الرمل كماده صلبة وبثلاثة أقطار مختلفة (450,650 and 850 μm) واستخدام الهواء كوسط للتميع وبثلاث سرع مختلفة هي(2,2.4,2.8 m/sec) وجهز الجهاز بمسخن أنبوبي أفقي ذات قطر خارجي (3.175 cm) جهز بقدرات كهربائية مختلفة (80,240,350 Watt).

لقد تم بناءموديل رياضي احادي الطور مع الزمن يعتمد على معادلات الطاقه والاستمراريه والزخم للطورين الغازي والصلب.لقد تم حل معادلات الموديل الرياضي بطريقة الحجوم المحدده(control volume) باستخدام برنامج (FLBD) والمكتوب ب(Mathlab 2008).

لقد بينت النتائج بان هنالك توزيع لدرجات الحرارة عند جميع السرع المستخدمة وتزداد هذه الدرجات مع زيادة سرع الهواء وتزداد مع نقصان حجم الجزيئات الصلبة وزيادة معدلات سريان الحرارة مع الزمن. لقد قورنت النتائج العمليه والنظريه ولقد وجد هنالك تقارب جيد.

1. Introduction:

The phenomena of gas-to-particle heat transfer accompanied with mass transfer and chemical reaction are present in many technological processes (drying of particulate materials, combustion of coal, thermal treatment of metal products ...) taking place in fluidized bed**. [1]**,The heat transfer problem in fluidized bed especially in column was investigated in numerous experimental studies . However, **Yong Jun cho et al.(1996)**,measured the bed to wall heat transfer coefficients in circulating fluidized bed of particles .Derived a useful cooperating solid loading ratio ,particle size and flow Reynolds number from experimental data. **Sunun et al. (2003)** ,investigated the solid motion in gas –solid fluidized bed via discrete particle simulation**. Winaya et al. (2003)**, investigated the effect of operating parameters on heat transfervfrom bed to U-beam impact separators located in the top region of the riser column. **Karageorgieva et al.(2006)**,presented an information about a low temperature installation ,with which can be investigated the convective heat transfer in circulating fluidized bed . Observed the influence of some factors on the total heat transfer coefficient and also on the convective heat transfer one. **Al- Dabbagh (2006)**, presented an experimental study of heat transfer between a shallow fluidized bed and the surface of a single horizontal tube and a tube bundle, which was immersed in it. **Chang et al.(2008)**, presented a computational modeling study of gas-solid flow in a fluidized bed furnace by means of three-dimensional computational fluid dynamics (CFD). **Mladen et al.(2009)**, described the mathematical model of unsteady one-dimensional gas to particles heat transfer for non-isothermal fluidized bed with periodic heating of solid particles. **Z.O. Opafunso et al.(2009)**, designed the pneumatic and hydraulic systems in coal fluidized bed combustor. **Wankhede(2009)**, Studies related to heat transfer in a sound assisted fluidized bed of fine powders were very limited. Investigated heat transfer in a bubbling fluidized bed of fine powders and immersed heating surface in absence and presence of acoustic waves.

In this paper, the experimental study for unsteady gas - solid particles thermal behavior in fluidized bed is presented. The results obtained for interstitial gas temperature and solid particle temperature on the basis of prediction method are compared to the experimental results given in

2-The Experimental Apparatus and Procedure:

The experimental equipments and instruments are use to measure the temperature along the column heat flux and the fluidized velocities with time.

The fluidized velocity, the heat flux and the particle size are examined. Figure (1) show the experimental equipments and measurements system which used in this work and reference [11]. The fluidization column with about of (150 g), constructed from pipe, having an inner diameter of (3.175 cm) and a height of (125 cm), is placed in a vertical position.

1- Air compressor: Air was used as the gas phase. It was provided by a compressor followed by an accumulator tank. This air compressor pumps the required air to the air container until the pressure inside the air container satisfies the operation pressure (2 bar).

2-The Air Storage Tank**:** The capacity of the storage tank is (2 m^3) with maximum pressure (4 bar).

3-The Orifice meter : An orifice meter is used to measure the discharge in the pipe. A mercury manometer is connected a cross the orifice to measure the difference in pressure in order to determine the velocity of the air flow through the pipe.

4-The Voltage Regulator: The voltage Regulator is a device being using to balance the voltage across the heater.

5-The Heater: The heater capacity (1000 Watt) which supported into the pipe (D= 1.25 inch).

6-The U- tube mercury manometer: The U-tube mercury is used to measure the pressure difference across the orifice meter.

7-The main Glass pipe: The main pipe has inner diameter (3.175 cm) and length of (125 cm) show the behavior of the flow (gas and solid) and records this behavior.

8-The Thermocouples: The type thermocouple is (k). The thermocouple is fixed on the glass pipe at equal distance (10 cm) from the beginning of the up to the end of the glass pipe. The number of the thermocouple is (8) which are fixed on the glass pipe.

9- Interface: This interface is connected with a personal computer so that the measured temperatures at various eight regions are displayed directly on the computer screen.

Experimental were carried out to show the effect of different operation conditions on temperature profile in fluidized bed .Such conditions are the Fluidized bed velocity, particle size and the amount of heat. The selected experimental values are presented in table (1).

Heat input q(watt)	**Fluidized bed velocity (m/s)**	**Particle size $d_p(\mu\ m)$**
80 W	2 m/s	450 $\mu\ m$
240 W	2.4 m/s	650 $\mu\ m$
350 W	2.8 m/s	850 $\mu\ m$

Table (1) the values of operation conditions used in experimental.

The experimental operation steps are:

1-Aweight quantity of sand (150 g) was put into the column a above the distribution plate.

2- Turn on the air compressor until the pressure inside the air storage tank reaches about (2 bar).

3- Open the valve for feeding the air into the pipe.

4- Record the pressure drop through the orifice meter to determine the fluidized bed velocity.

5- Turn on the electrical circuit to obtain the required amount of heat .The quantity of heat was controlled by voltage regulator and measured indirectly by an ammeter and voltmeter.

6- Record the temperature with time along the vertical pipe by using thermocouples connected to interphase and computer.

The above procedure; it will repeat by changing the fluidized bed velocity, heat input and particle size and we will get different data.

3-Mathematical model:

The mathematical model Presented has been developed for transition state gas-to-solid particles heat transfer in fluidized bed with periodical heating of solid particles. A two phase bed model that defines bed phases, interstitial gas phase, and solid phase, has been used in the development of this model. Each phase has been considered as pseudo homogeneous media characterized by effective transport coefficients ,one dimensional problem has been considered, *i. e.* it is assumed the variation of the analyzed quantities (such as interstitial gas temperature, temperature of solid particles) only in longitudinal direction while its variations in transversal direction have been neglected.

The presented model based on the following assumptions are used [12]:

- Interstitial gas can be considered to be in plug flow *i. e.* there is no backflow mixing,
- Solid particles are uniform in size, shape and density and its thermo-physical properties are independent of temperature variation,
- Gas-to-particles heat transfer occurs only on the particle surface, since the particles are small, the temperature gradient inside the particles can be neglected, and
- Radiation heat transfer is not included into consideration.

Presented mathematical model includes energy, continuity, and momentum equations for each of two phases and equation of state for gas phase [12].

Energy equation

For interstitial gas there is:

$$\rho_g c_g V_{gef} \frac{\partial T_g}{\partial t} = -\rho_g c_g V_{gef} U_g \frac{\partial T_g}{\partial x} + h_{pg} a_p V_g (T_p - T_g) \qquad (1)$$

T_{gu} the gas temperature at bed inlet.

The appropriate initial and boundary conditions are:

$$\begin{aligned} &T_g(x,0) = T_g^0(x) \quad for \quad t=0, \quad 0 \le x \le H_f \\ &T_g(0,t) = T_{gu} \quad for \quad x = 0, t\rangle 0 \end{aligned} \qquad (2)$$

Where $T_g^0(x)$ is the initial temperature profile of gas in emulsion phase.

For solid phase there is:

$$\rho_p c_p V_p \frac{\partial T_p}{\partial t} = -\rho_p c_p V_p U_p \frac{\partial T_p}{\partial x} + h_{pg} a_p V_p (T_g - T_p) + V_p \frac{\partial}{\partial x}\left(\lambda_e \frac{\partial T_p}{\partial x} \right) \qquad (3)$$

The appropriate initial and boundary conditions are:

$$\begin{aligned} &T_p(x,0) = T_p^0(x) \quad for \quad t=0, \quad 0 \le x \le H_f \\ &\frac{\partial T_p}{\partial x} = 0 \quad for \quad x = 0, t = H_f \end{aligned} \qquad (4)$$

Where $T_p^0(x)$ is the initial temperature of solid particles.

Equation of state and thermal properties of gas

In order to complete the mathematical model, the ideal gas equation of state and the relations of thermo-physical properties of gas phase have to be added to the above set of equations.

4-Numerical approach:

The differential equations (1) and (3) expressing the variation of temperature for some phases along the height of fluidized bed can be generalized by the following form of differential equation for general variable Φ:

$$\frac{\partial}{\partial t}(\rho\Phi) + \nabla(\rho U \Phi) = \nabla(\Gamma \nabla \Phi) + S \qquad (5)$$

Equation can be written in Cartesian coordinate system, for one dimensional problem, obtains the form:

$$\frac{\partial}{\partial t}(\rho\Phi) + \frac{\partial}{\partial t}(\rho U \Phi) = \frac{\partial}{\partial x}\left(\Gamma \frac{\partial \Phi}{\partial t} \right) + S \qquad (6)$$

And the continuity equation becomes:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial t}\left(\rho U\right)=0 \qquad (7)$$

In fact, that the foregoing equations expressing the variation of temperature for some phases along the height of fluidized bed can be reduced in the same form eq. (5), enables the simpler numerical solution.

In order to solve the foregoing equations in a numerical way, the discretization method based on control volume procedure has been used. This method is a modification of the finite difference method [12].

In the prediction of the unsteady gas-to-solid particles heat transfer in fluidized bed, the computer code (FLBD) which is written with MATLAB 2008 code is used see figure (2).

5. Results and Discussion:

Figures (3) to **(7)** show that effects of heat flux on unsteady state temperature distribution along the column for different value of particle size and at different fluidized bed velocities with different value of time, namely changing between (0 min) to (4.85 min) at long the vertical fluidized bed pipe (Z).It can be observed that the increase of heat flux cause increase the temperature profile for different particle and fluidized bed velocity.

The temperature increases in figures (3) to (7) when increase the heat flux from (80 W) to (350 W) along the time interval due to increase of amount of the heat which is transferred to the fluidized bed system.

Figure (8) shows the effect the fluidized bed velocity on the temperature distribution along the fluidization column height for different particle sizes and heat flux at time (time=3.25 min).It can be observed that the temperature distribution along the fluidization column increases, this is due to increase of the amount of air with great heat that increases the heat transfer to the solid particle and so increases the temperature.

Figures (9, 11) shows the effects of the heat flux on temperature profile at time (time=3.25 min) for different particle size and at different fluidized bed velocities. It can be observed that the temperature profile along the fluidization column increases with increasing the heat flux and as velocities of fluidized bed increase the temperature profile increases. This is because when velocities of fluidized bed increase, the solid particles will be more action and as a result the temperature distribution increases and when increase the amount of heat flux the temperature distribution increases this is due to increase of amount of the heat which is transferred to the fluidized bed system .

Figures (12) show the effect of particle size on temperature profile for different heat flux and fluidized velocities. It can be observed that the temperature profile increase when decreased the particle size. The temperature profile increases as the mean solid particle diameter decreases this is due to the small particle can cause higher heat transfer coefficient due to the smaller particles can increase the effective heat transfer area covered by particle itself.

Figure (13) show experimental and theoretical results for different heat flux and fluidized bed velocities. It can be observed a good agreement between the experimental and theoretical results.

6. Conclusions:

In this work, the unsteady investigation of experimental and theoretical study for effect of particle size, fluidized bed velocity and heat flux on the thermal behavior for two phase flow (gas-solid) has been studied .MATLAB code has been developed to calculate the theoretical results and have been compared with experimental data and a good agreement has been found .From this study, it can be conclude that the unsteady investigation, decrease the particle size the temperature profile increase for different fluidized bed velocities and value of heat fluxes , the temperature profile increases as fluidized bed velocity increases for different particle size and value of the heat fluxes and the temperature profile increases as the heat flux increases for different particle size and fluidized bed velocities.

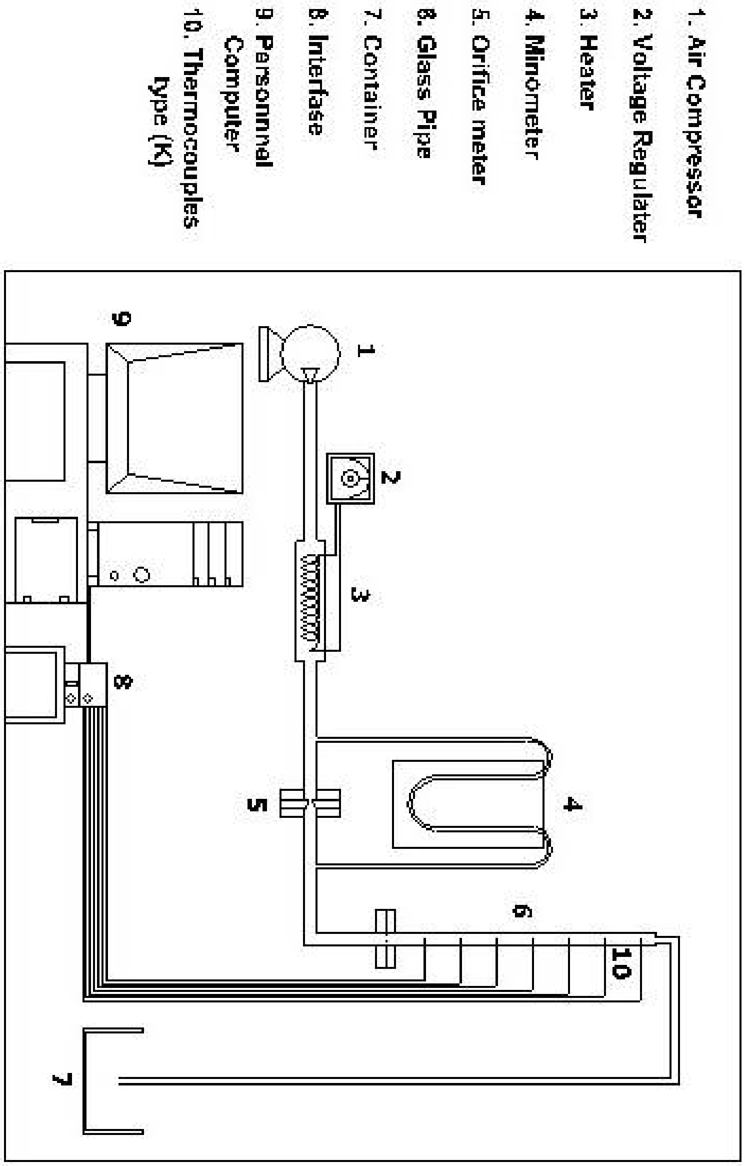


Figure (1) :The Experimental rig reference [11]

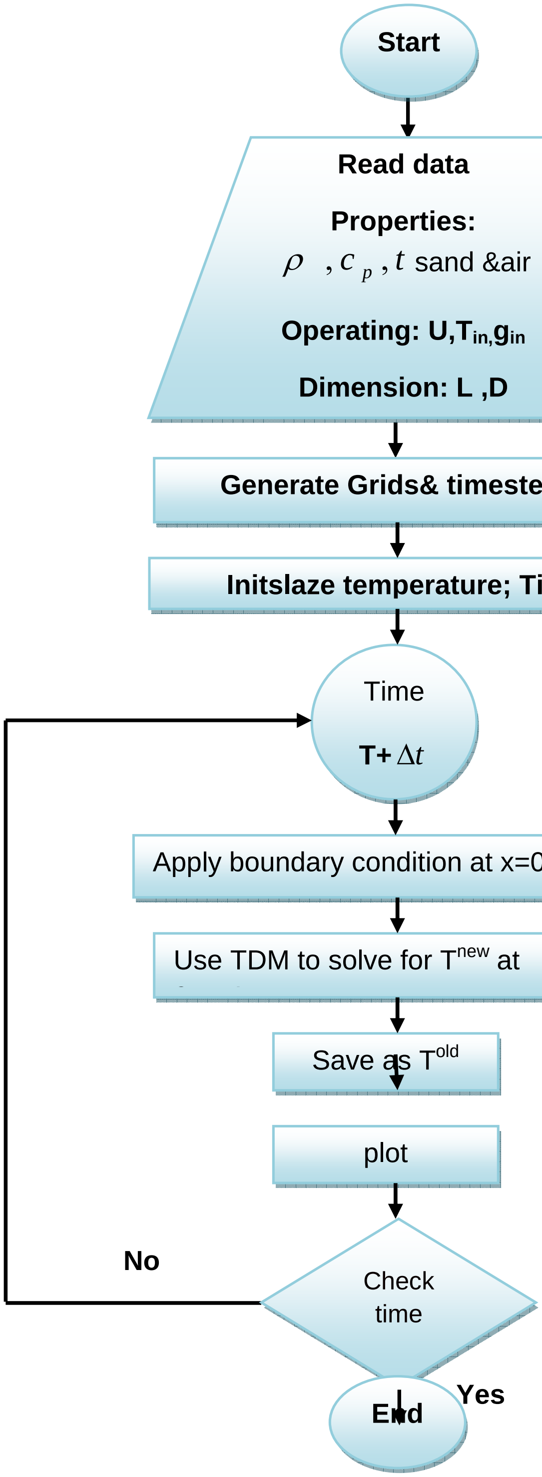


Figure (2) Flow chart of the computer program

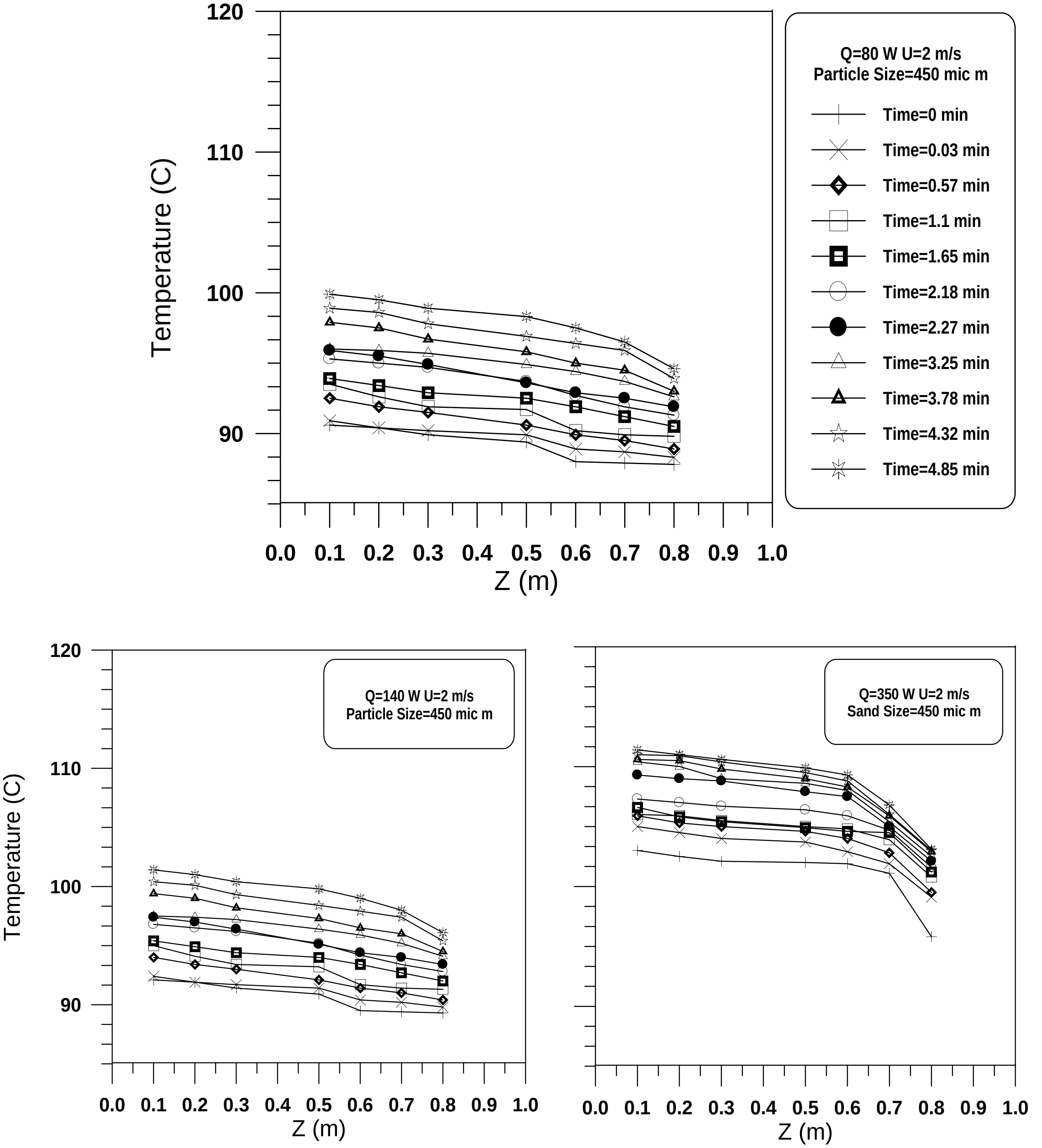


Figure (3): Effect Of Heat Flux On Temperature Profile At Fluidized Velocity (2 m/s) For Particle Sizes (450 μ m)

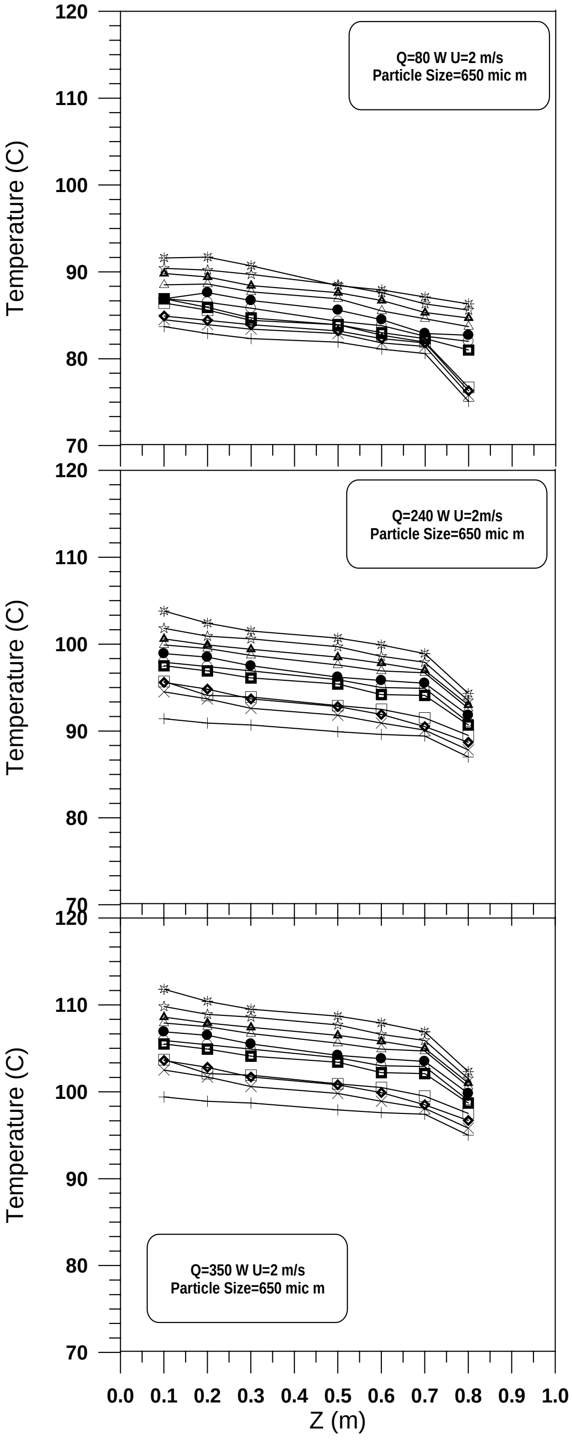


Figure (4): Effect Of Heat Flux On Temperature Profile At Fluidized Velocity (2 m/s) For Particle Sizes (650 μm)

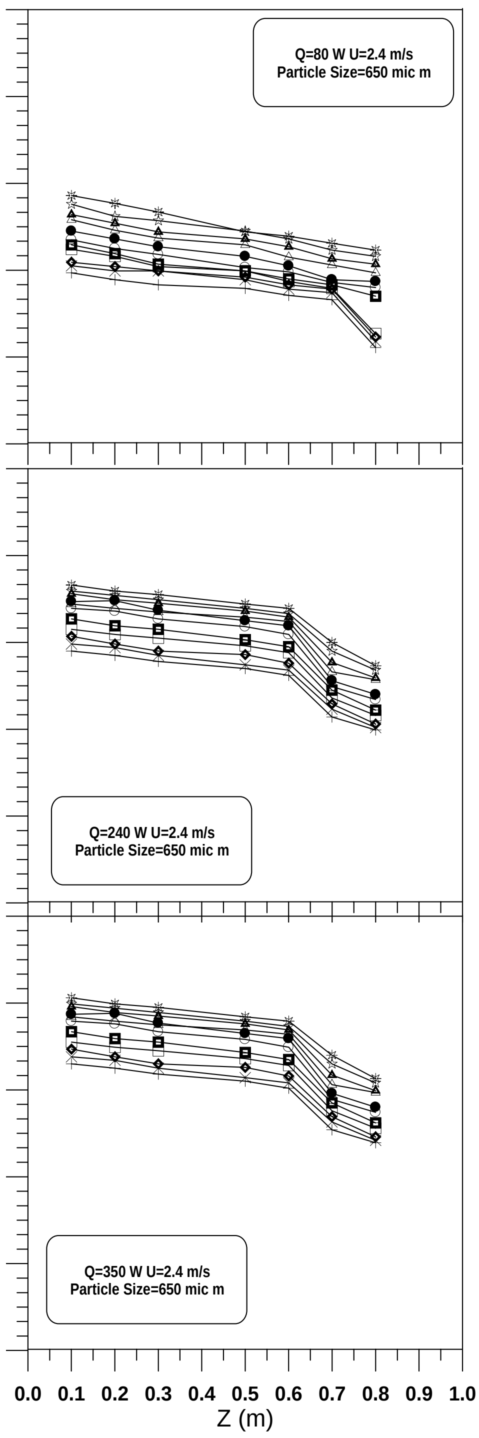
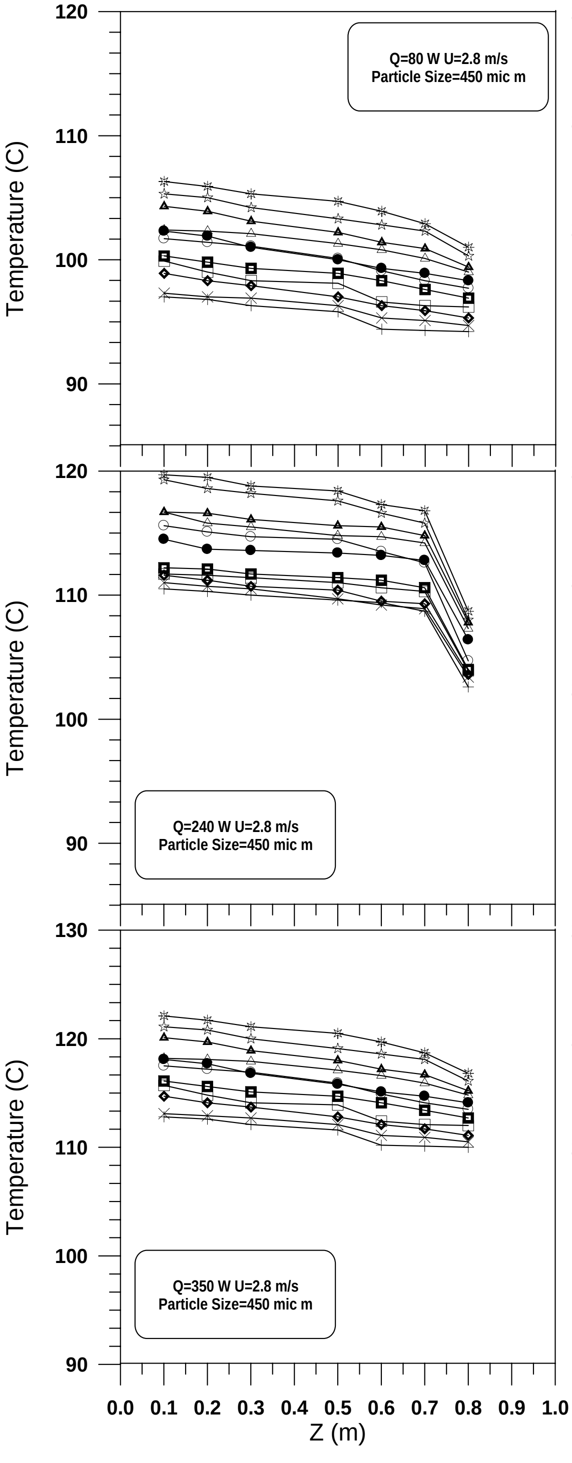


Figure (5): Effect Of Heat Flux On Temperature Profile At Fluidized Velocity (2.4 m/s) For Particle Sizes (650 μm)



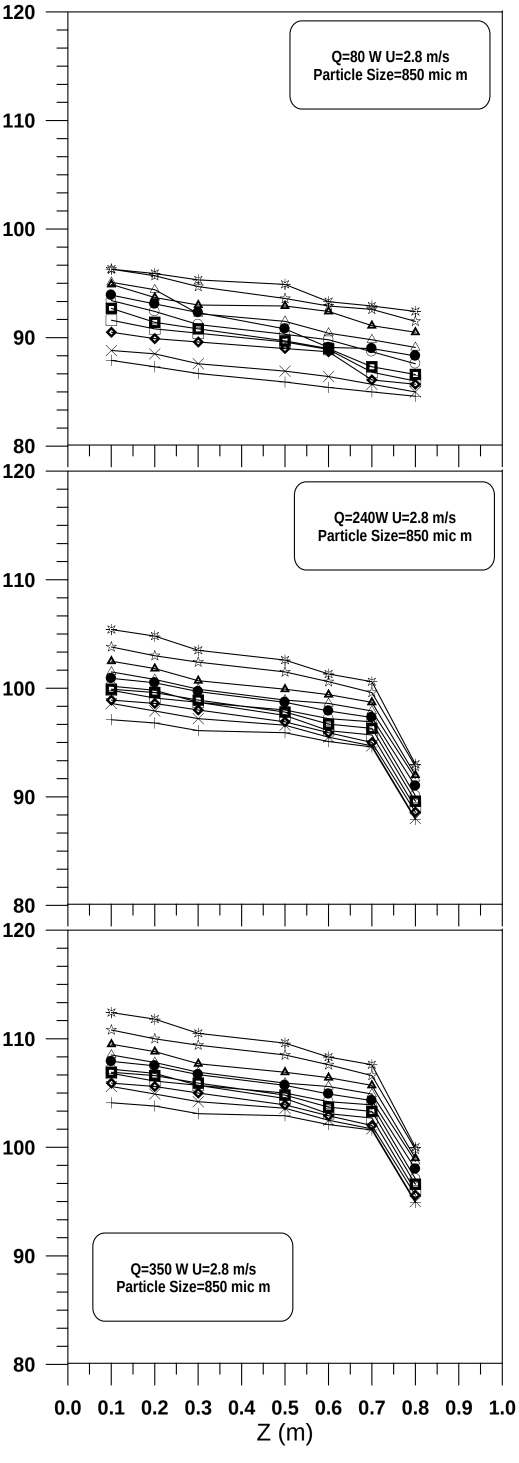


Figure (6): Effect Of Heat Flux On Temperature Profile At Fluidized Velocity (2.8 m/s) For Particle Sizes (450 μ m)

Figure (7): Effect Of Heat Flux On Temperature Profile At Fluidized Velocity (2 m/s) For Particle Sizes (850 μ m)

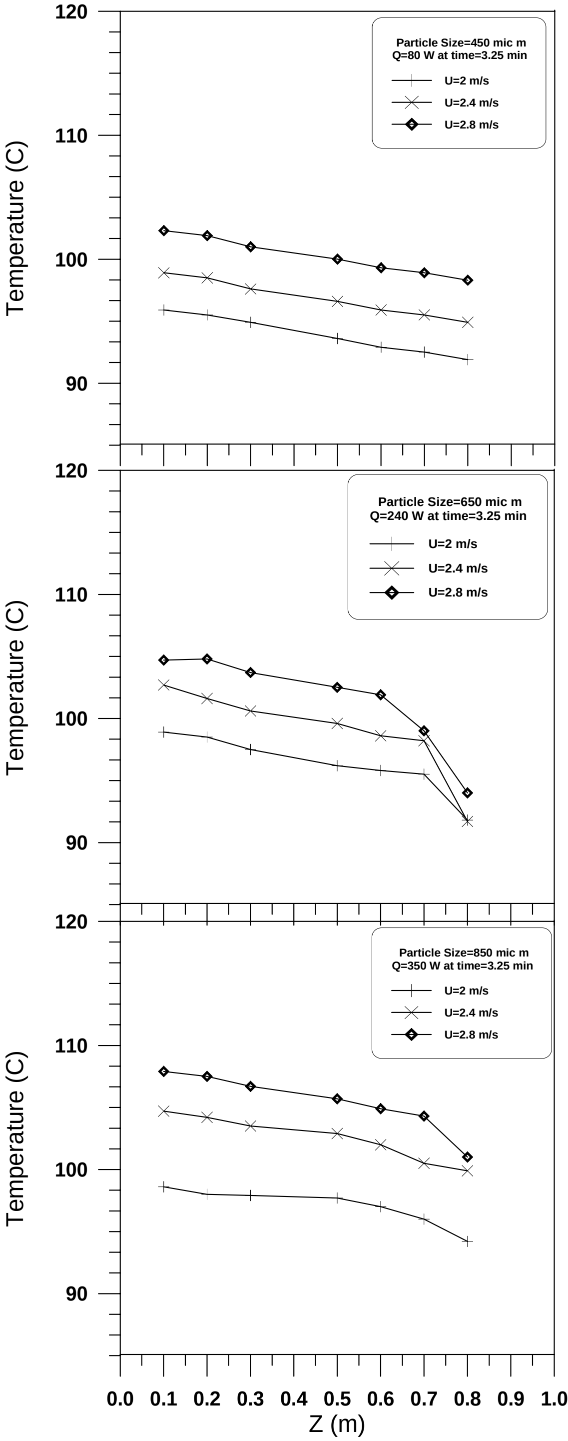


Figure (8): Effect Of Fluidized Velocity On Temperature Profile For Different Heat Flux And Particle Sizes

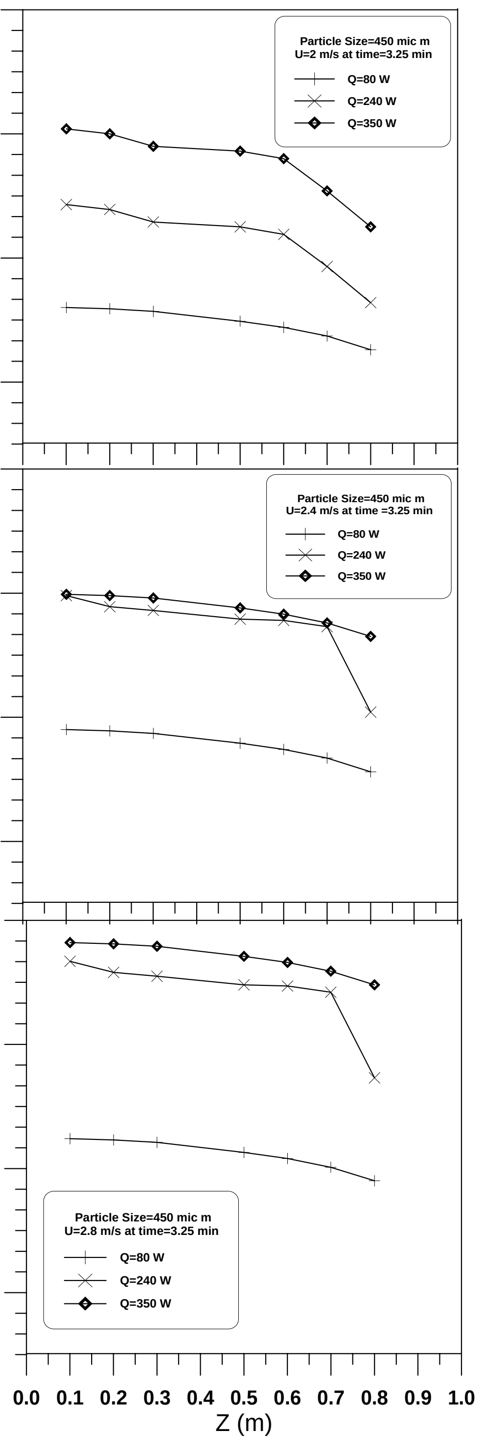


Figure (9): Effect Of Heat Flux On Temperature Profile For Different Fluidized Velocities For Particle Sizes (450 μm)

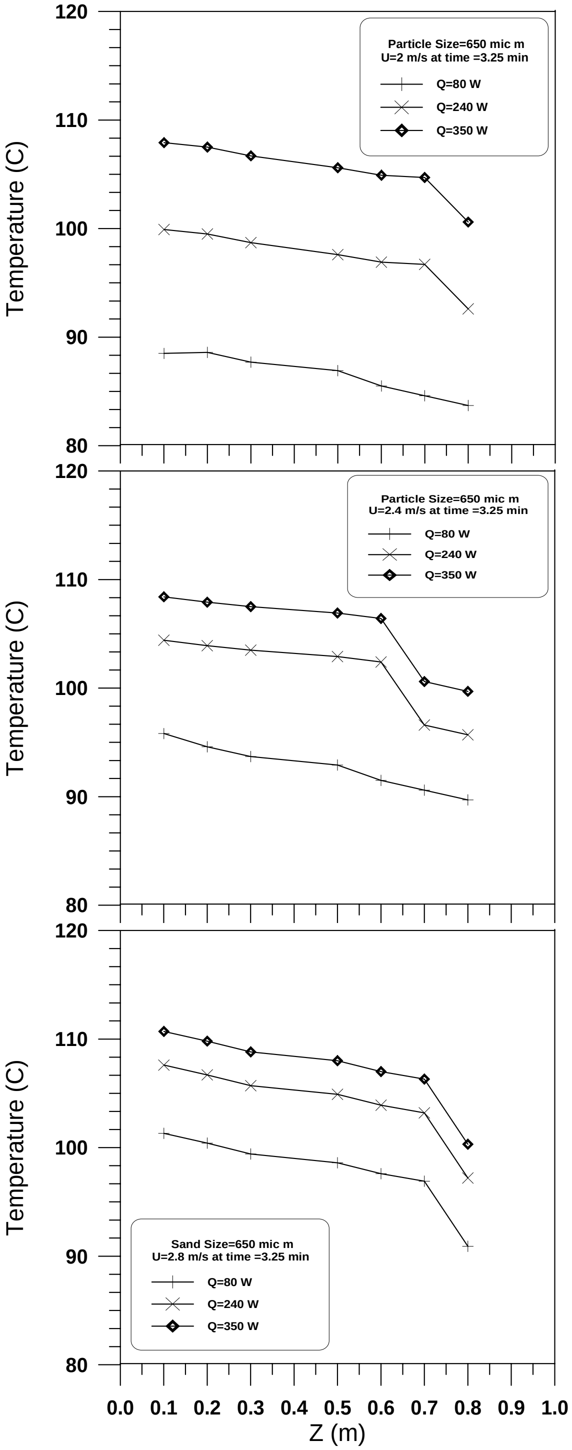


Figure (10): Effect Of Heat Flux On Temperature Profile For Different Fluidized Velocities For Particle Sizes (650 $\mu\ m$)

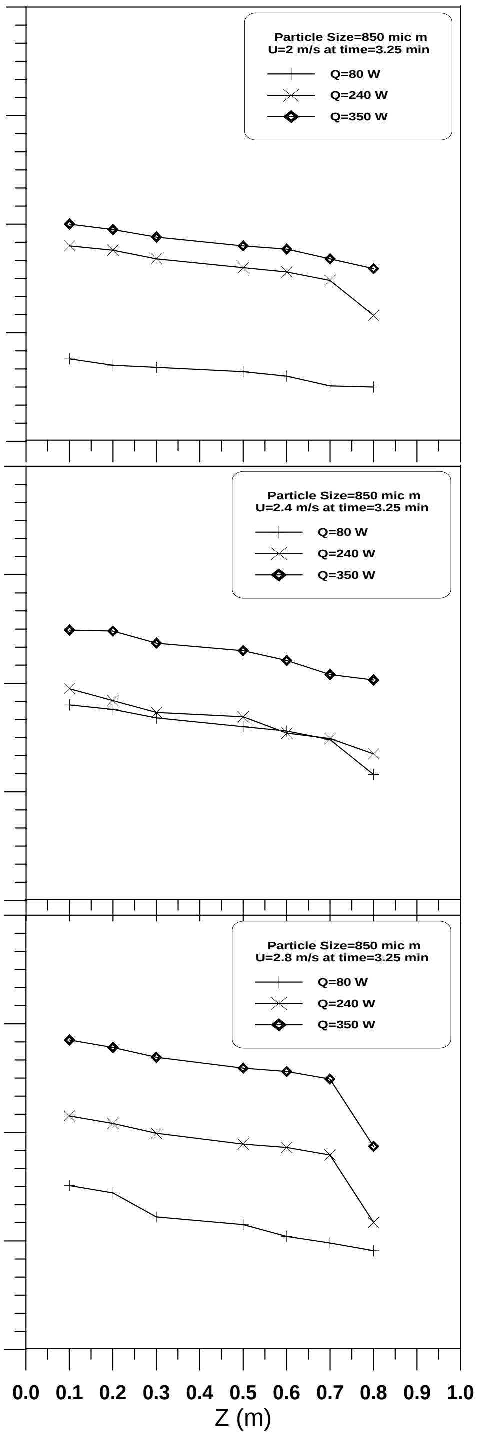
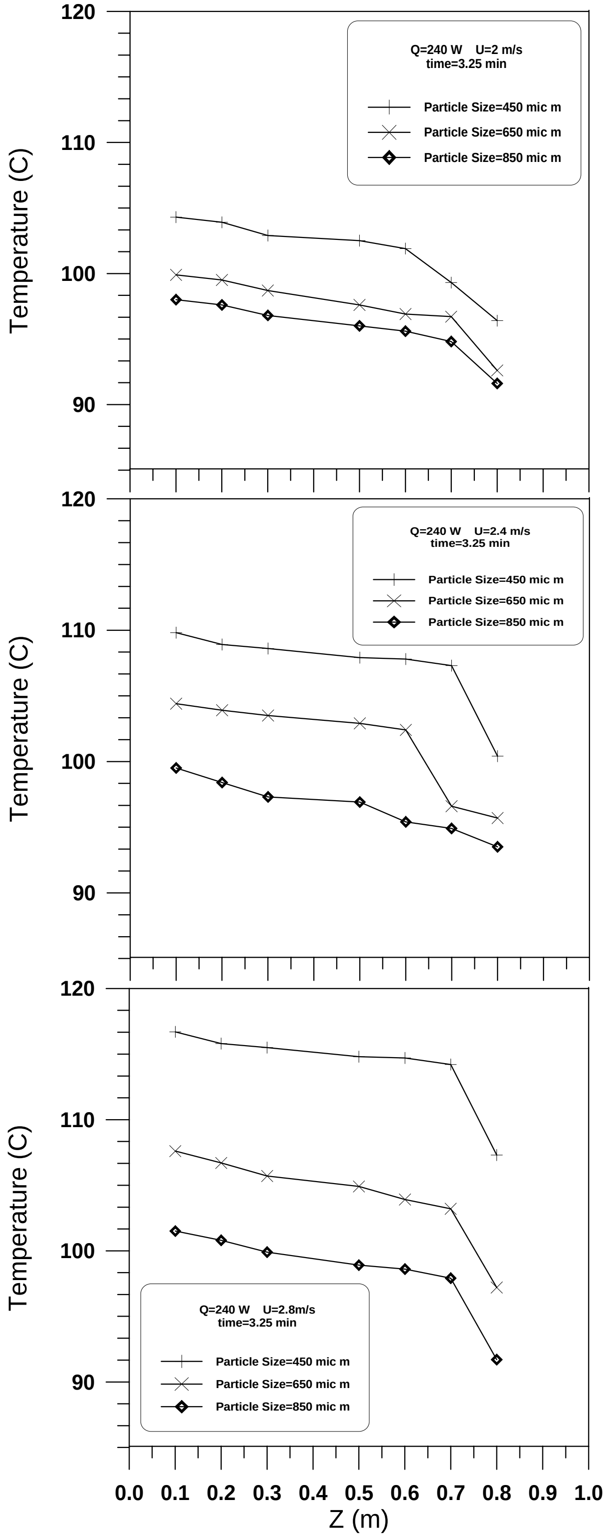


Figure (11): Effect Of Heat Flux On Temperature Profile For Different Fluidized Velocities For Particle Sizes (850 $\mu\ m$)



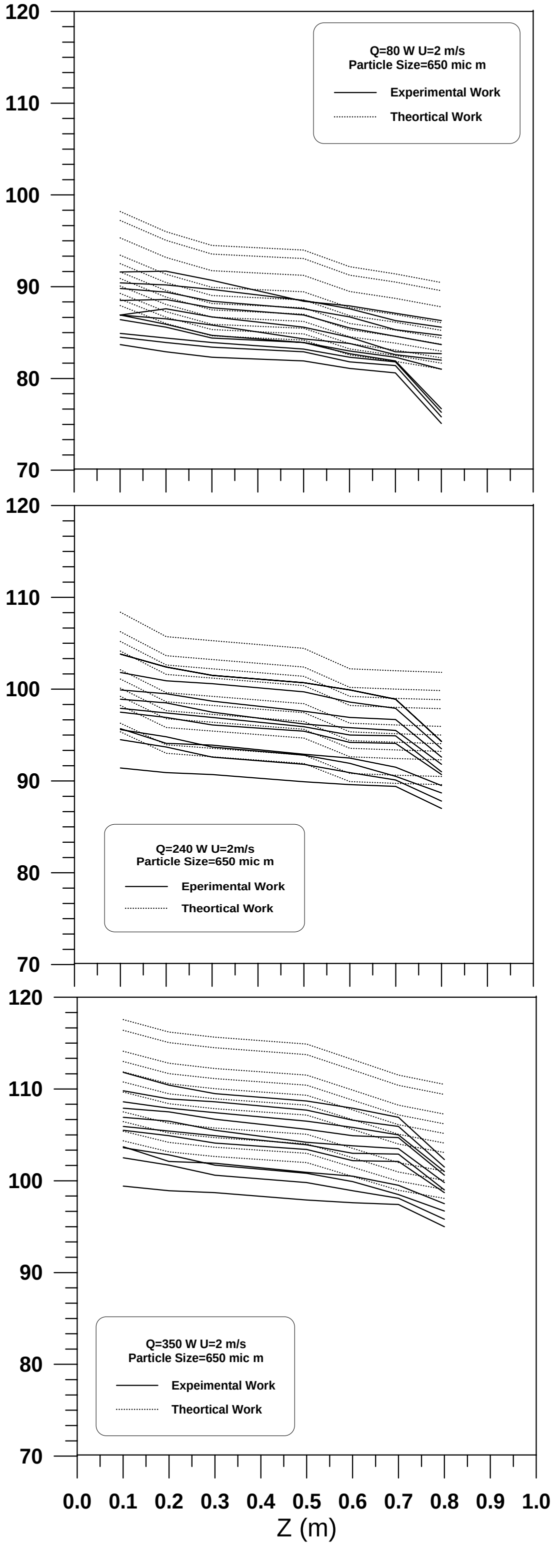


Figure (12): Effect Of Particle Size On Temperature Profile For Heat Flux (240 W) And Different Fluidized Velocities

Figure (13): Compared Experimental and Theoretical Work for Different Heat Flux at Fluidized Velocity (2 m/s)

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a_p	Surface area per unit volume of particles,[=6(1-ε_{mf})(1-δ)/φd_p],[m^2m^{-3}]
c	heat capacity, [$Jkg^{-1}K^{-1}$]
d_p	Mean particle diameter , [m]
g	acceleration of gravity, [ms^{-2}]
H	height of bed, [m]
h	distance from distribution plate, [m]
h_{pg}	Gas to particle heat transfer coefficient,[$Wm^{-2}K^{-1}$]
S	source term
T	temperature[K]
t	Time [s]
U	velocity [ms^{-1}]
V	Volume [m^3]

Greek letters

Γ	diffusion coefficient
δ	Fraction of solid phase volume
ε	Voidage fraction
λ	heat conductivity, [$Wm^{-1}K^{-1}$]
ρ	Density [kgm^{-3}]
ρ_g	Volumetric density [kgm^{-3}]
Φ	General variable
φ	Shape factor,[-]

Subscripts

e	effective
ef	Emulsion phase
f	Fluidized bed
g	gas
o	Packed bed
p	particles