# Effect of Changing Particle Diameters in Porous Media on Heat Transfer Coefficient for Three-Phase Flow in Vertical Pipe.

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## Abstract

The paper is dedicated to of study heat transfer coefficient of three-phase mixture through porous media 20 cm length, the packaging material made of chrome-steel used are 2, 6 and 10mm and its carried out in Perspex vertical pipe 3.175 cm diameter and overall length of 2 m .The gasoil, water and air used as working fluids. The heat transfer coefficient values for 2mm case is higher than 6, 10 mm cases because of higher thermal conductivity for small particle diameter. It observed the inversely relationship between the heat transfer coefficient and particle diameters. In addition, it observed that porous media region has a minimum value because damping in velocity through it. Also, it found the heat transfer coefficient values increase with increase temperature of water phase Simulation results by using computational fluid dynamics CFD building a modeler using VOF model .The volume of fluid VOF approach is used to simulate the flow in porous media with three-sizes of particles respectively. The deviation between results with other researchers was acceptable is about 17.04 %.

**Keywords**: Three–phase flow, Gasoil-water-air; Heat transfer Coefficient; Vertical pipe; Simulation by CFD.

| *NOMENCLATURE* | | $\Delta P$ | Pressure drop for inlet and out let segment | Pa |
|---|---|---|---|---|
| Symbol | Description | q | Power of heaters | watt |
| $A_T$ | Total area .m$^2$ | $T_{in}$ | Temperature of sensor 1 | K |
| $A_{porous}$ | Surface area of porous media wall. .m$^2$ | $T_{out}$ | Temperature of sensor 10 | K |
| $A_{particles}$ | Surface area of particles .m$^2$ | $\Delta T$ | Temperature difference. | K |
| $A_{pipe}$ | Cross-section area of pipe m$^2$ | **Greek Symbols** | | |
| *C* | Constant | μ | Viscosity | N.s/m2 |
| **D** | Pipe diameter m | μT | Turbulent Viscosity | N.s/m2 |
| $\mathbf{d_{particle}}$ | Particle diameter mm | ρ | Density | kg/m3 |
| **g** | Acceleration of gravity; Standard values =- 9.81m$^2$/s | g | Acceleration of gravity; Standard values = 9.81 | m/s2 |
| ***h*** | Heat transfer coefficient | ε | porosity | dimensionless |
| $\mathbf{K_{eff}}$ | Thermal conductively | | | |
| **Q** | Flow rate | | | |

| **Subscripts** | |
|---|---|
| water | Water phase |
| Oil | Oil phase |
| air | Air phase |
| **Abbreviations** | |
| **CFD** | Computational Fluid Dynamics |
| **VOF** | Volume of Fluid model |
| **RANS** | Reynolds Averaging Navier-Stokes model |
| **K-ϵ** | Model of Turbulent |
| **CPU** | Central Processing Unit |
| **CFD** | Computational Fluid Dynamics |

## 1-Introduction

Several studies extensively for over 150 years in convection heat transfer in porous media [1].(Petroleum engineering is important technological applications containing multiphase flow and multicomponent displacement in porous media ,where multiple flowing phases naturally exist in oil reservoirs) .In thermal devices such as heat exchangers in all types , reactors ,chemical processes and power stations [2] [3].To illustration all this processing ,it is necessary to limit the design parameters such as pressure drop and heat and mass transfer coefficients in order to determine the suitable operating conditions and the system for specific purposes .Some of researchers studied theoretically and experimentally to understand the phenomena of flow the single-phase and heat transfer in porous media such as [4] [5].

Theoretical and experimental studies focused on forced convection in porous media Some of researchers studied experimentally and viewed the effects of fluid properties ,particle diameter ,type of porous media (sintered or non-sintered),and velocity on the convection heat transfer [6].The porous media material have a highly effective and using (bi-dispersed porous media and mono-dispersed porous media) ,it found bi- dispersed has a lower value of resistance of flow than mono-dispersed [7].There are several material such as fibrous medium [8],another used metal-wool filled a tubes [9]. Theoretical studies carried out as two-dimensional ,or three-dimensional and steady or unsteady state or transient such as [10] [11] and [12].To understand the numerical solution in porous media and take into account the boundary condition ,it should use a suitable model .(Brinkman–Forchheimer)extended to Darcy model [13].Also ,some researchers studied the relationship between experimentally pressure drop and porosity in packed beds of mono-sized spheres .All experiments for conditions at $3< Re_p< 379$ and $3\leq D/d_p \leq 17$ found that the average bed porosity increases as $D/d_p$ decreases. Also the effect of Reynolds number, ratio $D/d_p$ increased values with increasing pressure gradient ***[14]*** .The relationship between friction factor and Reynolds number and studied the effect of fluid type ,flow rate and packing porosity on friction factor and pressure drop for flow through packed beds of (7.62 cm internal diameter , 57cm long ) packed with spherical glass particles with diameters (0.42 ,0.50 ,0.61 ,0.79 and 1.01) cm [15].

The aim of present work is to investigate the three-phase flow and convection heat transfer occurs due to temperature gradients between fluid and porous media under varying flow conditions including gas and liquid flow rates temperature of continuous phase

## 2-Experimental Formation

The Procedure of experiments of mixture for three–phases oil-water-air through porous media in vertical flow system has been built within the fluid laboratories of Engineering College of Mechanical Department in Babylon University. The schematic diagram of the experimental setup in Fig.(1). Atmospheric air is compressed by compressor and stored in a reservoir. The gas flow rate is arranged by a flow meter, gate valve and check valve ,and flowed through a mixing pipe .The water was pumped by a Centrifugal pump ,from the water tank have two heaters to heated the water (35,40 and 45C$^o$), the water flow rate was controlled by a flow gate valve, check valve and measured by water flow meter and flowed through mixing pipe.

Phase of oil was pumped from the oil tank to the Perspex pipe by a gasoil pump and the oil flow rate was controlled by a flow gate valve and check valve and flowed through mixing pipe. At the same time the air,water, oil phases flow entered the mixing pipe and then passed in Perspex pipe of (0.03175)m internal diameter and 2 m long and involved a porous media made of Perspex pipe (3.175)cm inside diameter and 20 cm height closed in two end by wire mish and packed by chrome –steel balls of (2 ,6 and10) mm in separately cases. High speed camera provided a clear view for process .Five pressure transducers measured pressure in specific points (0.33-0.66-0.99-1.32-1.65)m along Perspex pipe ,and connected in interface device to personal computer .In the end of Perspex pipe found a downward pipe opened in a accumulation tank.Ten channels of thermocouple measured the temperature in specific points, and the data showed in the data logger .In addition there are one in the water tank .The porous media contained a one thermocouple from ten channels and two transducers after and before from the five transducers. The number of experiments was about (165) and the total time of the one test was 30 second. All devices in the system is calibration such as pressure transducers, temperature measurement and flow meters. The properties of (air, oil) flow measured at laboratory temperature about 25 C$^{o}$ .The boundary conditions used in this work is

## 3. Simulation of Three –Phase Flow.

The problem of three–phases flow is considered as transient.This geometry detail is accomplished by using ANSYS FLUNT 16.1 .To solve experiments problem by simulation usually presents the components of Fluent .In this work the finite volume technique has been used.

### 3.1Geometry and Mesh

The meshing kind for this flow field ,and geometry is as a small square element (Quadrilateral structured grid) using the Meshing combined with ANSYS Workbench 16.1 with (0.11994)maximum and(5.9971*10$^{-4}$) minimum size equal to(0.002 m) through medium relevance centered medium smoothing which produced (1569) elements, (1958) nodes as shown in Fig(2) .It is makes process of mesh independence to get a good accuracy in solution .

### 3.2Turbulence Model

To simulate this problem using VOF model of flow with several parameters based on the experiment variables and depending on the experimental results to compare and validate the CFD results... The viscous model is K-ε standard and turbulence multiphase model is mixture .The assumption is such as the flow is fully turbulent and negligible effects of molecular viscosity.

The two-equation for RANS model, first equation for kinetic energy, **k** eq.(1), and second for dissipation, **ϵ** eq.(2), which is the rate of dissipation of k**.**

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial y}{\partial x_i}(\rho\epsilon u_i)\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial\epsilon}{\partial x_j}\right]+G_k+G_b-\rho\epsilon-Y_M+S_k \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial y}{\partial x_i}(\rho\epsilon u_i)\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+G_k\frac{\epsilon}{k}(C_K+G_{3\epsilon}G_b)-\rho\epsilon-C_{2\epsilon}\rho\frac{\epsilon^2}{K}+S_\epsilon \quad (2)$$

Its value calculated by this equations, $K$: energy of turbulence kinetic,$\epsilon$: rate of dissipation, $G_k$: energy kinetic of turbulence by the mean velocity gradients, $G_b$ is the kinetic energy of turbulence by buoyancy ,$Y_M$: in turbulence contribution in fluctuation of expansion incompressible to total rate of dissipation with constant $C1\epsilon$, $C2\epsilon$, and $C3\epsilon$. $\sigma K$,$\sigma_\epsilon$: Prandtl numbers of turbulent for k and $\epsilon$, respectively. $S_k$, $S\epsilon$: using-considered as a source terms .Equations Solved by FLUENT.

The governing differential equations of this work are continuity and momentum equations.

1. Continuity Equation.

**To simulate:**

$$\frac{1}{\rho_q}\left(\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla.(\alpha_q \rho_q v_q^{\leftarrow}) = S_{\alpha_q} + \sum_{p=1}^{n}(m_{pq} - m_{qp})\right) \quad (3)$$

This equation is solved by implicint time .

2. Momentum Equation

**To simulate using**

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = -\nabla\rho + +\nabla.[\mu(\nabla\vec{v} + \nabla\vec{v})] + \rho\vec{g} + \vec{F} \quad (4)$$

3. Energy equation

$$\frac{\partial}{\partial t}(\rho E) + \nabla.(\vec{v}(\rho E + p)) = \nabla(K_{eff}\nabla \mathrm{T}) + S_h \quad (5)$$

The VOF model treats energy (E) and temperature (T) as mass averaged variables:

$$E = \sum_{q=1}^{n} \frac{\alpha_q \rho_q E_q}{\alpha_q \rho_q} \quad (6)$$

### 3.3 Boundary Conditions.

VOF for a multiphase model was used with dense discrete phase model parameter and boundary condition, relaxation factors to simulate the three phases in a pipe through porous media .The water was set to be the primary phase and the secondary phase was the air –oil. The drag function between the phases was select "Schiller-Neumann" to use the fluid-fluid drag function described in first case (Fluent User’s Guide 2006).Some boundary condition and relaxation factor in **Table (1)** and **Table (2).**

**Table (1): Boundary conditions**

| Zone | Boundary type |
|---|---|
| | Flow in pipe (with porous media ) |
| Pipe inlet water (35°C,40°C) | Water superficial velocity |
| Pipe inlet air | Air superficial velocity |
| Pipe inlet oil | Oil superficial velocity |
| Pipe content | Water-oil-air |

**Table (2): Relaxation Factors**

| Relaxation Factor | |
|---|---|
| Variable | value |
| Pressure | 0.3 |
| Momentum | 0.7 |
| Volume fraction | 0.5 |
| Other factor | 1 |

### 3-4 Set up and Solution

In order to simulate the flow in pipe in two cases model, the following assumptions were made as steady state flow, Turbulent flow ,Planer two-dimensional space, Pressure based solver ,incompressible flow and the gravity in Y direction is (-9.81 m/s$^2$).The properties of the material used in the model are shown in **Table (3).**

**Table (3): Material properties [16]**

| **Property** | **water** | | | **Air** | **Gasoil** |
|---|---|---|---|---|---|
| | 35C$^o$ | 40C$^o$ | 45C$^o$ | 25 C$^o$ | 25 C$^o$ |
| **ρ** | 994.08 | 992.25 | 990.2 | 1.225 | 830 |
| **µ** | 0.000720 | 0.000653 | 0.000596 | 0.000017894 | 0.00332 |

### 4- Procedure of calculation

There are several assumptions such as heat losses (some heat of water is transferred to air–oil) another some is transferred to wall as equation (7).

$$\mathbf{Q_{Liquid}=Q_{exchange}.} \quad (7)$$

The density and viscosity of mixture are constant through porous media at same temperature. Also, area of heat transfer equal surface area of particles and surface area of wall, L=200mm and d=31.75mm, as equation (8).

D=3.175 cm.

$$A_T=A_{porous}+A_{particles} \quad (8)$$

$$\mathbf{A_{porous}=\pi\times D_{pipe}\times L,} \quad (9)$$

$$\mathbf{A_{particles}=\pi d^2_{particles} \times no._{particles}} \quad (10)$$

The instantaneous local temperature difference at each step along the test pipe is calculated from the follow relation.

$$\mathbf{\Delta T=T_{in}-T_{out}} \quad (11)$$

**Where:-**

**$T_{in}$**:-is the temperature of sensor no. 1, while the **$T_{out}$**: is temperature of the mixture at sensor (10).

The following procedure was followed to calculate heat transfer coefficient by using Newton's cooling law detailed.

$$\mathrm{Q = h\,A\,\Delta T = hA_s(T_{in} - T_{out})} \qquad (12)$$

**ΔT**:represent the difference between inlet temperature and out let from the segment .

$$\Delta \mathbf{T} = T_{in} - T_{out} \qquad (14)$$

## 5- Results

So as to increase the convective heat transfer and make it more effectively, it should be increased the dissipation (contact) area and because of higher thermal conductivity for small particle diameter, also the various motion of the mixture around particles and mixes. The heat transfer coefficient **(h)** of air-water–oil flow along packed bed. Two electric heaters were used to heat the water for different temperature **(35,40**and **45) °C** in tank .The results show that the relationship of heat transfer coefficient of mixture flow over a porous media for three diameters**.**

Figure **(2)** shows particles diameter region and the point (2and 3)represent porous region ,the heat transfer coefficient decrease sharply with increasing surface area value at water temperature **35°C** .The red line represent value of case (1) have lower value because the case(1) has higher surface area .The blue line represent value of case (2) have lower value because the case(2) has lower surface area from previous case. The purple line represent value of case (3) have lower value because the case(3) has lowest surface area from previous case .Figure **(3)** show **h** behavior with changing particles diameter at water temperature 40°C and maintain of behavior . It observed the **h** values increased with increasing temperature.

Figure **(4)** shows **h** behavior with water temperature 45°C and maintain of behavior. It observed the **h** values increased with increasing temperature .These results agree with [13].

Fig (5) represents the validation, it can be seen that the present results are in a good acceptable about the behavior between coefficients of heat transfer against the change in gas with constant liquid superficial velocity. The difference gained for the current work from M. Jamialahmadi *et.al.*[17] towards increase of gas superficial velocity is**(17.04 %)**.These deviation considered relatively high .The reasons for deviation the difference in diameter of particles (1mm) ,the temperature of continuous phase is **30 C°**, and the working fluid is two materials .In addition the condition of experiments is different.

## 6- Conclusion

1. The heat transfer coefficient for three-phase flow through porous media in concurrent flow with different temperature 35°C,40°C,and 45°C.It was found that calculated heat transfer coefficient is strongly depended on the diameters of particles .
2. The relatively small particles diameter region have higher heat transfer coefficient and its decrease sharply with increasing $d_p$ value.
3. It found values increase with increase temperature of water phase.
4. The values of heat transfer coefficient inside region have lower values because the velocity is very low due to damp in porous media.

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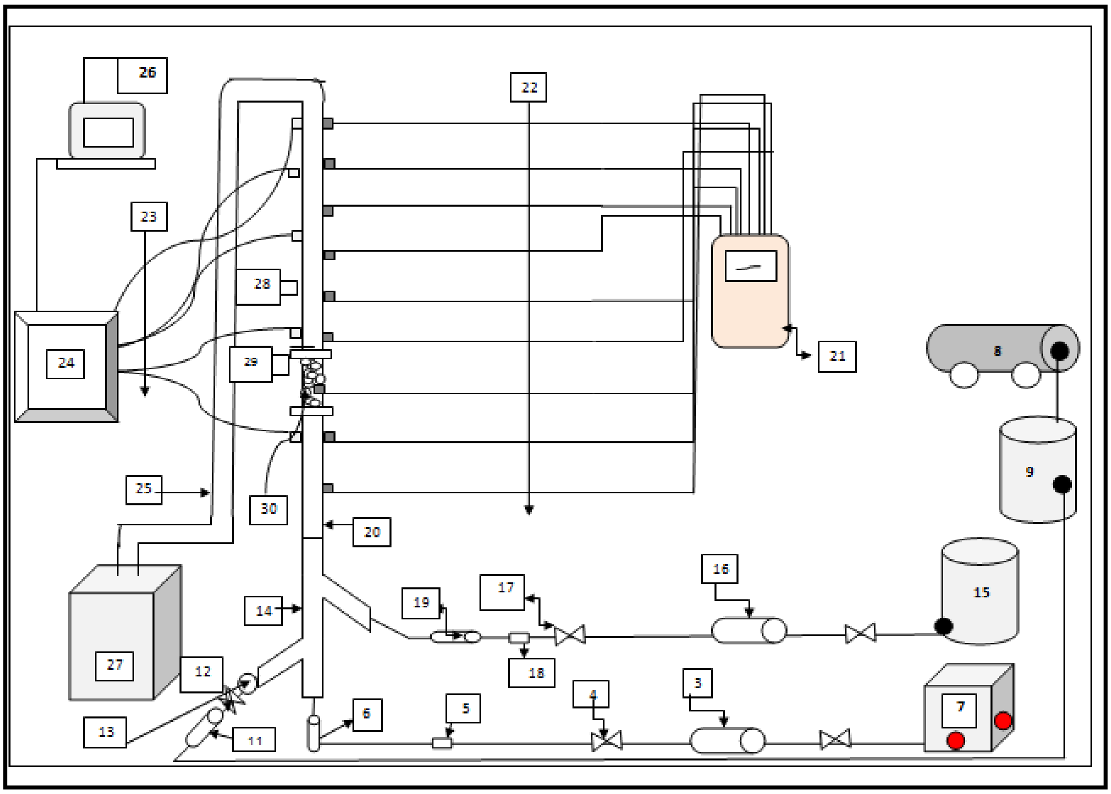

**Fig (1): Schematic diagram of present work.**

| | |
|---|---|
| 1-water's tank. | 16-Gasoil pump. |
| 2-Thermometer. | 17-Gate valve |
| 3-Centrifugal pump. | 18-Check valve |
| 4-water gate valve | 19-Gasoil flow meter |
| 5-water check valve | 20-Perspex pipe (ID=1.25in,L=2m) |
| 6-water flow meter | 21-Temperature recorder device. |
| 7-Heaters | 22-**(10)** Channels Temperature recorder device (thermocouple). |
| 8-Compressor. | 23-**(5)** Pressure Transducers. |
| 9-Reservior | 24-Interface device. |
| 10-Pressure regular | 25-Circulation Pipe. |
| 11-Air flow meter | 26-Personal Computer. |
| 12-Gate valve | 27-Accumulation tank. |
| 13-Check valve. | 28-Ordinary Video Camera |
| 14-Mixing pipe | 29-High Speed Camera. |
| 15-Oil tank | 30-Porous media |

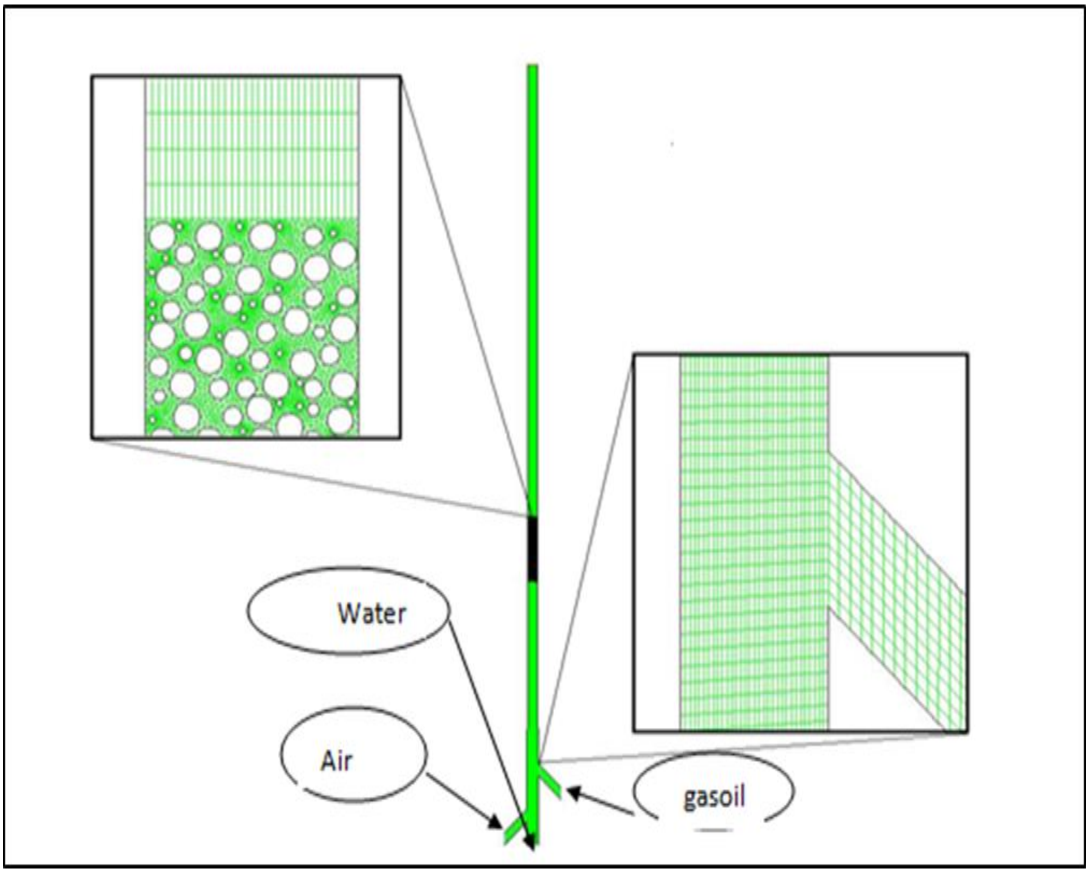


**Figure (2): Geometry and Mesh of modeler.**

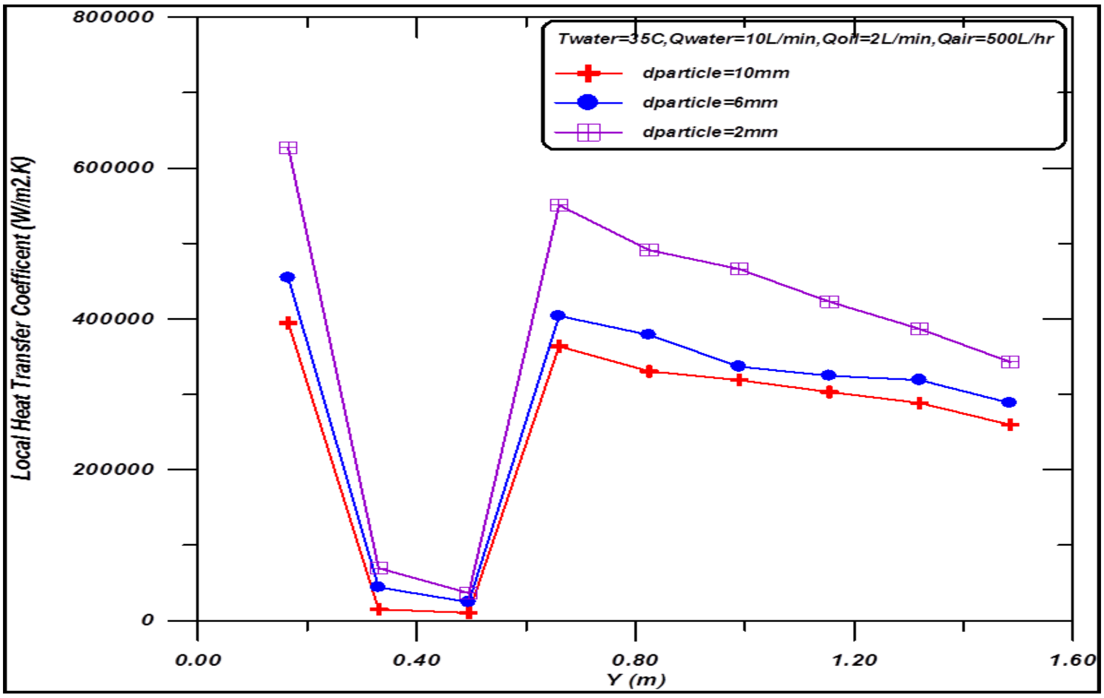


**Figure (2): Heat transfer coefficient along pipe**

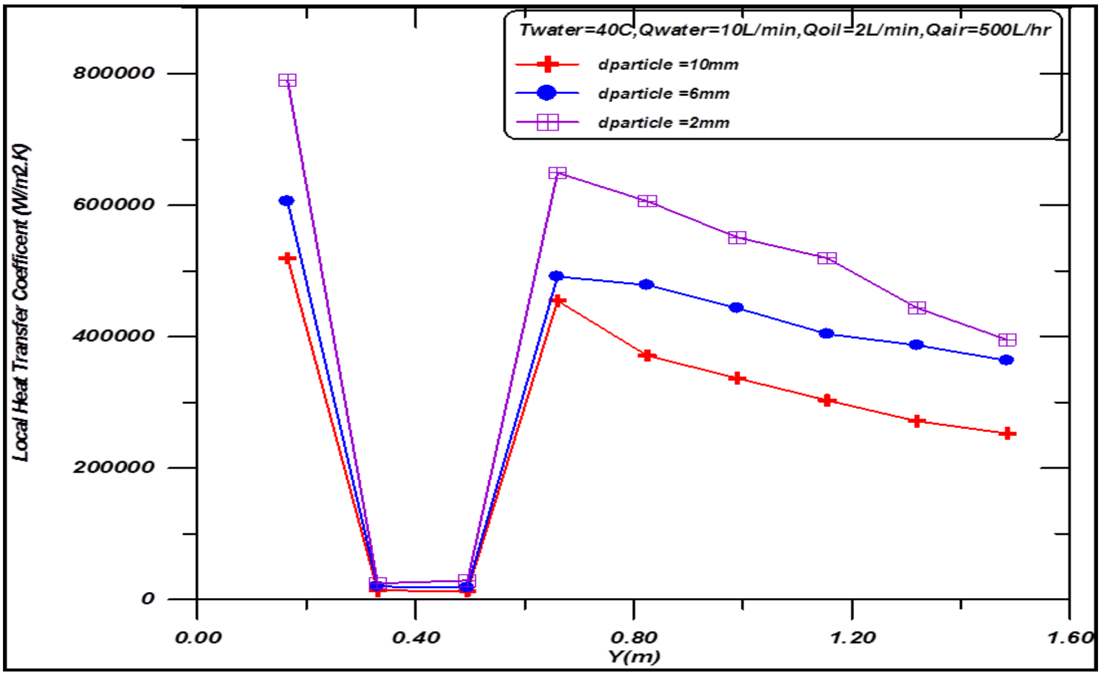


**Figure (3): Heat transfer Coefficient along pipe.**

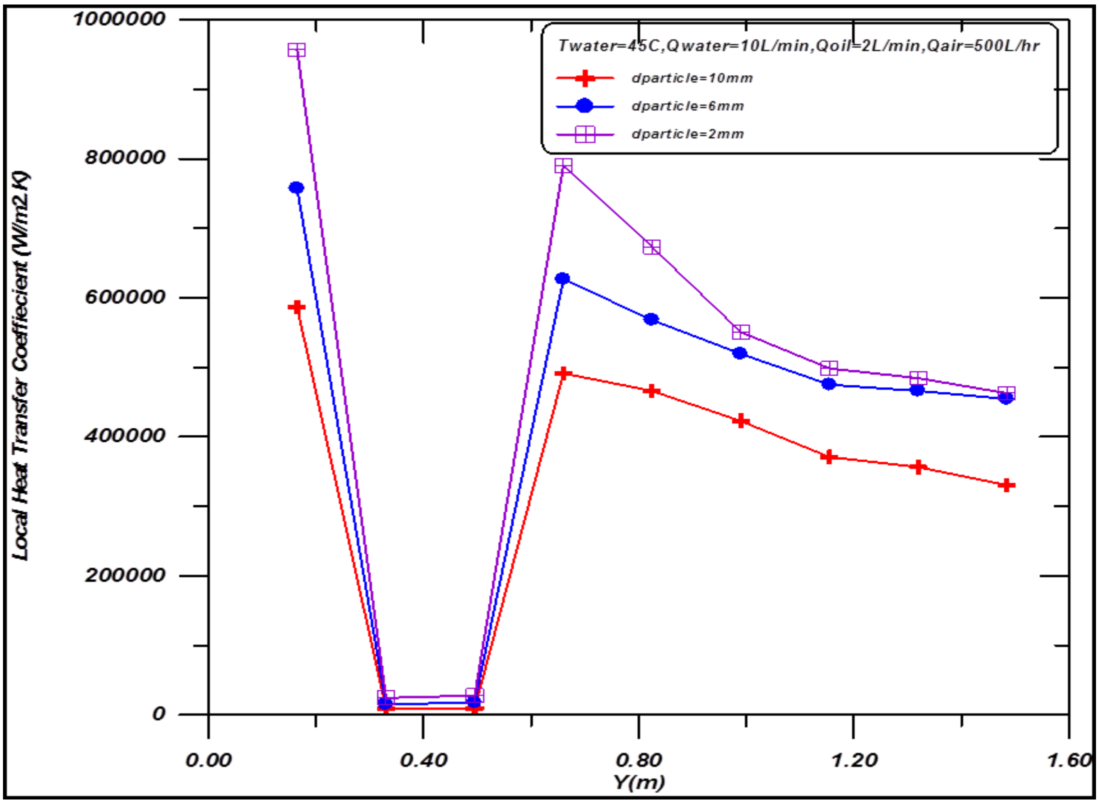


**Figure (4): Coefficient heat transfer along pipe.**

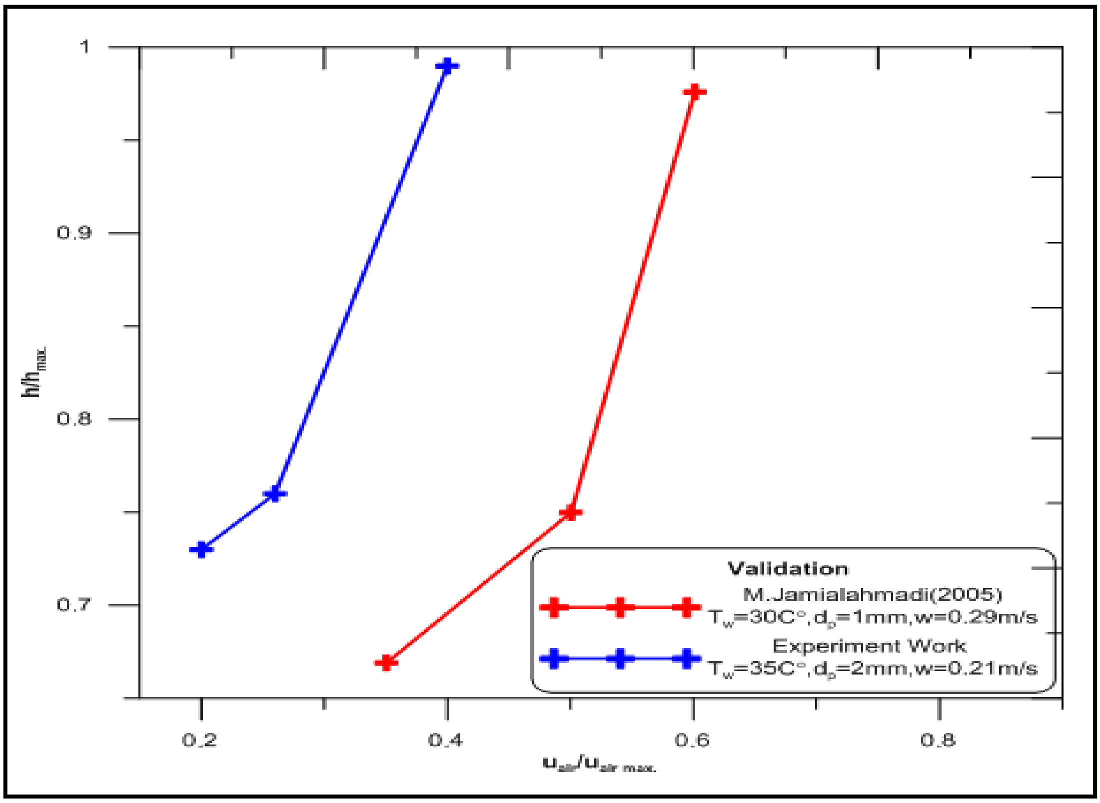


**Figure (5): Comparison heat transfer coefficient with [15] versus uair (m/s).**

# تأثير تغيير اقطار الجسيمات وسط مسامي على معامل انتقال الحرارة

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خصص هذا البحث لدراسة معامل انتقال الحرارة لجريان خليط ذو ثلاثة اطوار خلال وسط مسامي طوله 20 سم، وكانت المادة المستعملة كحشوة (chrome-steel) وبثلاثة اقطار (2، 6، 10) ملم خلال انبوب شفاف عمودي ذو قطر 175و3 سم وطوله الكلي 2 م تم استخدام زيت والماء والهواء كموائع تشغيل. تم استنتاج ان قيمة معامل انتقال الحرارة لحالة 2 ملم هي اعلى قيمة مقارنة مع 6,10 ملم بسبب قيمة معامل التوصيل العالية لقطر 2 ملم. كما ايضا تم ملاحظة العلاقة العكسية بين معامل انتقال الحرارة واقطار الكريات. وايضا تم ملاحظة تأثير وجود الوسط المسامي على معامل انتقال وتناقصه في هذه المنطقة بسبب الاخماد الكبير لسرعة في هذه المنطقة. الحل العددي تم باستخدام برنامج الانسزز فلونت وموديل VOF لثلاث اقطار. واخير تم اجراء مقارنه ما توصل اليه مع باحثين اخرين وكانت نسبة (04و17 %).

**الكلمات المفتاحية:** جريان ثلاثي الطور، زيت – ماء – هواء، معامل انتقال الحرارة، انبوب عمودي والمحاكاة العددية CFD.