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Experimental and Numerical Investigated of Heat Transfer Coefficient for Three-Phase Flow (Water-Gasoil-Air) over Triangle Ribs in Upward Rectangular Channel

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Abstract: In this paper, the local heat transfer coefficient for three -phase flow(water-gasoil-air) over triangular ribs in rectangular channel has been studied experimentally and numerically. Four values of water superficial velocity (Uw = 0.16446, 0.3289, 0.4934, 0.6578 m/s), three values of gasoil superficial velocity (U_g = 0.1315, 0.3963, 0.6577 m/s) and three values of air superficial velocity (U_a= 1.3368, 2.6735, 4.0103 m/s) with three values of heat flux (11278.195, 13157.894, 15037.593 w/m^2) have been investigated. Theoretical study has been done using ANSYS FLUENT15.0, where the conservation equation of continuity, momentum and energy was solved for the same variables that used experimentally. The local heat transfer coefficient results and behavior flow that was found experimentally and compared with the computational results and they were in good agreem ***Keywords: heat transfer; triangle ribs; three-phase flow; vertical rectangular channel.***

I. INTRODUCTION

Increase with interest for saving energy and material caused by the world resource lack and environmental concerns has motivated to develop more effective heat transfer equipment for that the technique of heat transfer boost by ribs are often used to enhance forced convective heat transfer. There are many researches in the field ribs with single phase flow, two-phase flow and a few of it or limited with three-phase flow. Ansari and Arzandi 2012, experimentally studied the effect of height ribs on the flow pattern by taken three different values for heights rectangular ribs with three different positions, two phase flow air side at top wall, water side at the bottom wall and both of them. Results show the transition boundary line between the stratified and the plug flow patterns occurred at higher liquid velocities and the transition line between the slug and the plug flow pattern occurred at lower gas velocities. Tuqa Abdulrazzaq et al. 2013, numerically studied the enhancement of heat transfer and turbulent water flow in rectangular channel with triangular ribs placed at different angles (45˚ , 60°, 90°). The numerical simulation was completed by the Ansys14 ICEM for meshing process and Ansys 14 Fluent for solving the equations with k-ω Model for shear stress transport (SST). The channel is heated at constant surface temperature (313 K) at bottom and top of the wall for the channel with the range of Reynolds number varied from 20000 to 60000.They compared heat transfer performance with smooth channel. The results show that the Nusselt number increases with the increase of Reynolds number for all the rib angles and observed at the Reynolds number of 60000 for the ribs angle 60° was greatest improvement of heat transfer is of rib compared to other types of angles. A. M. I. Mohamed et al. 2011, experimentally and numerically investigated for heat transfer and fluid flow characteristics by study the effect of the corrugation rib angle of attack on the inside the corrugated ribbed passage where the different corrugated rib angles of attack are 90˚, 105˚, 120˚, 135˚, and 150˚. Governing equations continuity, momentum and energy equations solved by use the commercial computational fluid dynamics code PHOENICS 2006 where the turbulent model was k-ε model. Results show the maximum heat transfer enhancement in the corrugated ribbed passage is achieved at a corrugation rib angle of attack of 150˚. The optimum thermohydraulic performance for rib angle of attack that gives was between135˚ and 150˚. Asano et al. 2004, experimentally studied the adiabatic two-phase flow (water-air) and R141b boiling two-phase flow in heat exchangers with a single channel located vertically. They divided flow patterns into two groups, depended on the gas flow rate, firstly when the gas flow rate was little air flowed in water intermittently. Secondly, when the gas flow rate was a higher, air and water phases flowed continuously. AL-Turaihi 2016, studied experimentally the effect of the discharge of gas and liquid, the particle amount on pressure distribution for liquid-gas-solid three- phase flow in horizontal pipe. Results show increase pressure magnitude at increasing loading ratio, water discharge and air discharge. Ahmed M. Bagabir et al. 2013, numerically investigated the heat transfer and turbulent flow characteristics in a square cross-section channel with three shapes of rib 90˚ transverse, 45˚ inclined and 45˚ V-shaped are mounted in in line and staggered arrangements on the lower and upper walls of the channel. A constant heat flux applied at the two opposite channel walls with the ribs. They use Fluent 6.3 CFD code for simulate by taken different grids for all cases with RNG k - ε turbulence model. The results show 45˚ V-shaped rib improve the heat transfer rate better than 45˚ inclined rib and 90˚ transverse rib. Also, they found at in line manner for 45˚ inclined rib and 45˚ V-shaped rib reveal heat transfer improvement of about 17% - 50% higher than that for the 90˚ rib. As well as they found at staggered manner for 45˚ inclined rib produce similar thermal profile as inline manner and for staggered manner is lower the thermal performance and the staggered manner of 90˚ transverse is similar case for 45˚ inclined rib and 45˚ V-shaped rib.Lawrence and Panagiota 2014, studied liquid–liquid flows (oil-water) for stratified flow. Using conductance probes, average interface heights were obtained at the pipe center and close to the pipe wall, which revealed a concave interface shape in all cases studied. A correlation between the two heights was developed that was used in the two-fluid model. In addition, from the time series of the probe signal at the pipe center, the average wave amplitude was calculated to be 0.0005 m and was used as an equivalent roughness in the interfacial shear stress model. Weisman et al. 1994, experimentally investigated the patterns and pressure drop of two-phase flow in a horizontal circular pipe with helical wire ribs. the ribs of a circular cross-section were used with different values of heights and different helical twist ratios. Results showed, if the fluid velocity at the entrance of the pipe exceeded the minimum value that depended on experience, so the flow in the pipe be a swirling annular flow at all qualities, and this would improve the heat transfer rate. Yuyuan et al. 1994, experimentally investigated the influences of nominal gap scales for boiling two-phase flow on the critical heat flux (CHF) and heat transfer coefficients through a lunate channel. Results show when the scale of nominal gap was less than (2 mm), the heat transfer coefficient increased significantly. Depending on the results, the heat transfer coefficient being improved by nine times of that for bare pipes when the scale of nominal gap about (1 mm). When, the circular flow pattern predominated the fluid flow in lunate channel, the temperature difference along it dropped unexpectedly during the increase heat flux. Yasuo Hatate et al. 1987, experimentally investigated for heat transfer characteristics between the inner tube wall and fluid of air-water-fine glass spheres three-phase vertical up flow by using three kinds of glass spheres and two tubes from copper different diameter. Results show the heat transfer coefficients of gas-liquid-fine solid particles three-phase flow was giving larger values than those of gas-liquid two-phase with (0-40wt%) solid particles concentrations. In this work triangle ribs have been designed. In order to investigate the convective heat transfer performance of triangle ribs, an experimental set-up was established. The effects of triangle ribs on the heat transfer characteristic was examined.

A. Experimental Apparatus and Procedure

1) Experimental Apparatus: Experimental rig structured to study enhancement heat transfer for working fluid inside rectangular channel by triangle ribs with three-phase flow as shown in figure (1). Test channel is a rectangular cross section area, made from Perspex sheet (1 cm) thickness with dimensions (3 cm * 8 cm) from inside channel and (70 cm) length. It consists of four holes at different locations, it is mounted Sensors (thermocouples) to measure the temperature of the three-phase flow inside the channel. Also, ribs are installed at hole (10cm*8cm) on one side of the channel. Ribs is made from aluminum metal as shown in figure (2) where two fingers heaters from stainless steel fixed on the back side of it to give a constant heat flux with use a (10cm) thickness glass wool to prevent thermal losses. The experimental equipment's include the following:

a) Three tanks to store the water, gasoil and air, three centrifugal pumps and three flow meters to measure the flow rate of water, gasoil and air.
b) Air compressor to compressed air to the air tank and then supply the rig.
c) Thermometer to record the temperature reading at different positions of the test channel with five thermocouples (T type) one on the surface rib and others distributed on the test channel.
d) Valves to control flow discharge and check valves to prevent back flow.
e) Power supply and digital power analyzer.

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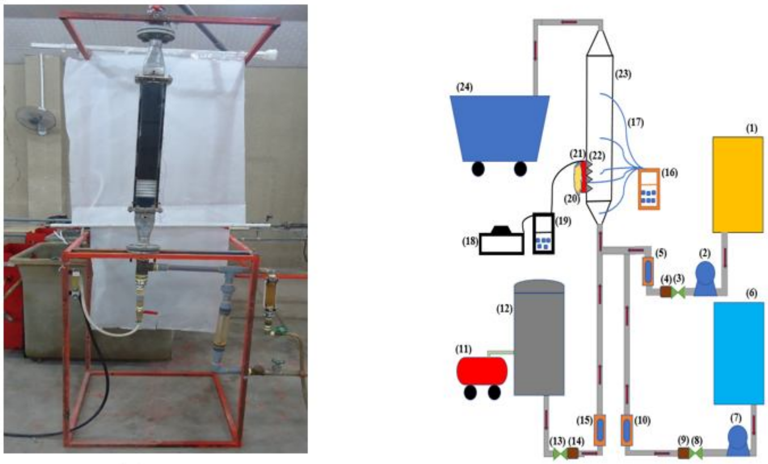


(a) (b)

1	Gasoil tank	9	Gate check valve	17	Thermocouples
2	Gasoil centrifugal	10	Water flow meter	18	Power supply
3	Gate valve	11	Air compressor	19	Power analyzer
4	Spring check valve	12	Air Reservoir	20	Glass wool
5	Gasoil flow meter	13	Ball valve	21	Heaters
6	Water tank	14	Spring check valve	22	Triangular ribs
7	Water centrifugal	15	Air flow meter	23	Test channel
8	Gate valve	16	Thermometer	24	Separator tank

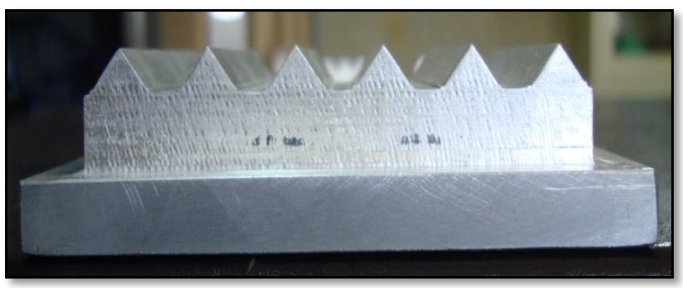


Figure (2) Triangle ribs

B. Experimental Procedure

In experimental work one hundred and eight test carried out by taken different values of water, gasoil and air superficial velocities and different values of heat flux as shown in table (1), for the first test is:

1) Turn on the water centrifugal pump at the initial value of (5 l/min).
2) Supply the electrical power to the heaters at the first value (120 watt) which is constant for all thirty-six tests.
3) Wait few minutes (5-10 min) until the rib reach to the desired temperature (46 ºc) by observing the temperature variations in different locations along the test channel.
4) Turn on the gasoil centrifugal pump at the initial value of (1 l/min) and then turn on air compressor at the initial value of (8.333 l/min).
5) Recording the temperature by sensors which are located at five points four of them along the test channel and one for the rib surface as well as, with recording video to observe the flow behavior
6) Change the second value of air volume flow rate with still water and gasoil values constant and repeat the above steps until to finish all the air volume flow rate values.

7) Change the second value of gasoil volume flow rate with still water value is constant, repeat the above steps until to finish all the gasoil volume flow rate values
8) Repeat all above steps with a new water volume flow rate value until to finish all the water volume flow rate.

Heat flux (w/m^2)	Water discharge (l/min)	Gasoil discharge (l/min)	Air discharge (l/ min)
11278.195	5	1	8.333
13157.894	10	3	16.666
15037.37	15	5	25
-	20	-	-

Table (1): Values of work conditions used in experiments

II. DATA REDUCTION

A. Superficial Velocity

Superficial velocities were found for water, gasoil and air from Eq. (1) where the fluid flow rate was measured directly from the flow meter (Asano et al. 2004; Ansari and Arzandi. 2012),

$$U = \frac{Q}{A} \qquad \text{........... (1)}$$

Also, to calculate the Reynolds Number need to make assumptions to calculate the working fluid properties. Where the working fluids in a present study are water, gasoil and air which have different properties. For example, the water and gasoil density are relatively a thousand times greater than air density so water-gasoil-air three-phase flow can be simplified into gas-liquid two-phase flow but still complex. Fluid properties Such as density and viscosity depend on continuous phase and fraction dispersed phase as shown below (Hanafizadeh P. et al. 2017). In this study water is continuous phase and dispersed phase is gasoil and air.

$$Re = \frac{\rho_m U_m D_h}{\mu_m} \qquad \text{........... (2)}$$

$$\rho_m = \rho_c (1+\alpha) \qquad \text{...... (3)}$$

$$U_m = U_w + U_g + U_a \qquad \text{....... (4)}$$

$$D_h = 4A/W \qquad \text{....... (5)}$$

$$\mu_m = \mu_c (1+\alpha) \qquad \text{..........(6)}$$

B. Heat Transfer Coefficient

The local heat transfer coefficient calculates from Newton’s law of cooling as shown below, rectangle channel is isolated by a glass wool that is mean no thermal losses to environmental.

$$h_y = \frac{q''}{(T_s - T_b)} \qquad \text{........ (7)}$$

$$q'' = \frac{(Q_{el} - Q_{loss})}{A} \qquad \text{......... (8)}$$

The local bulk temperature (T_b) at position Y along stream wise direction. It was calculated assuming a linear working fluid temperature rise along the flow rectangular channel and is defined as:

$$T_b = T_{in} + (T_{out} - T_{in})\frac{Y}{L} \qquad \text{.......... (9)}$$

$$q = m^{\bullet} cp \, \Delta T \qquad \text{......... (10)}$$

$$m^{\bullet} = \rho \upsilon A \qquad \text{......... (11)}$$

Where the rib surface temperature (T_s), internus temperature (T_{in}) and outlet temperature (T_{out}) were read from thermocouple output. L is the heated surface length.

III. NUMERICAL WORK

Numerical work is done by using computational fluid dynamics model through ANSYS FLUENT 15.0. Euler Lagrange multiphase-mixture model has used along with the k-ε turbulent model.

A. Geometry Model and Boundary Conditions

As shown in figure (3), Solid Work 2013 software used to modeling as a two-dimension structure for the three-phase flow system as a rectangle with lines represented as a ribs on the x-y plan with (3 cm) horizontal dimension and (70 cm) vertical dimension. After that, a surface was generated from the sketch. Entry region was divided to the thirteen sections, six sections for inlet water superficial velocity, six sections for inlet gasoil superficial velocity and one section for inlet air superficial velocity which is bigger from the other sections. Boundary conditions, From the bottom of the of the geometry, continuous phase (water) and dispersed phase (gasoil, air) superficial velocities enter with inlet phases temperature and volume fraction where these are taken from experimental data. Ribs region set as constant heat flux which is same the experimental value. The outlet of the geometry, was set to be outlet pressure and the right and left sides set as wall. The remaining portion of the left side and right side was set to be adiabatic wall.

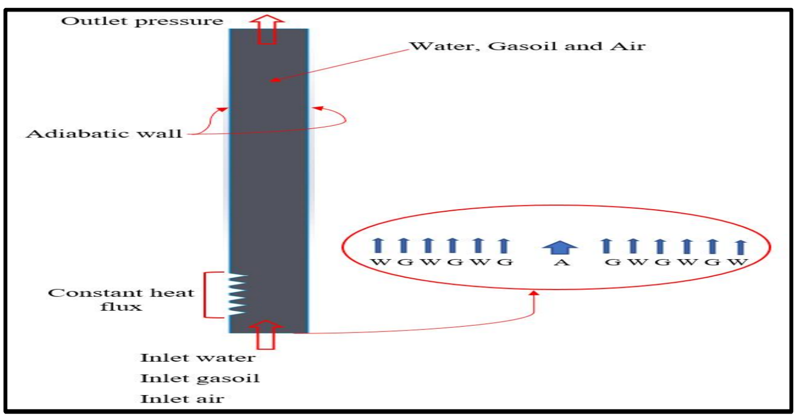


Figure (3) Geometry Model

B. The mesh

In this work, the geometry of the rectangular channel with ribs was divided into small square element (Quadrilateral structured grid) using the Meshing combined with Ansys Workbench 15.0 with maximum and minimum size equal to (0.001 m) through fine span angle center and medium smoothing mesh. Figure (4) depict mesh for three-phase system.

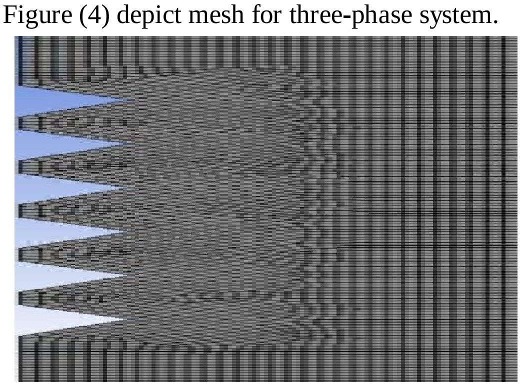


Figure (4) Geometry Mesh

C. *Problem Assumptions*

In order to simulate the three-phase flow with heat transfer model, the following assumptions were made.

1) Steady state two-dimensional fluid flow and heat transfer.
2) The flow is turbulent and incompressible.
3) Constant fluid properties.
4) Negligible radiation heat transfer, body forces and viscous dissipation.
5) Uniform heat flux.
6) No-slip boundary is applied at all walls of the flow channel.
7) The gravity in y direction is (-9.81 m/s^2).

D. *Governing Equations*

The fundamental governing equations of fluid dynamics in the numerical work are continuity, momentum and energy equations in two dimensional. Mixture model solves the governing equations for each phase, a mixture model was used where the phases moved at different velocities. The general form of governing equations can be written from (Fluent User's Guide, 2006)

1) *Continuity Equation:* The continuity equation was used to calculate the phase's volume fraction. Because the volume fractions for all phases equals to one for that volume fraction of the primary phase was calculated through the summation of the volume fraction of the secondary phases:

$$\frac{\partial}{\partial t}\left(\rho_m\right)+\nabla.\left(\rho_m \vec{\upsilon}_m\right)=0 \qquad \text{……….. (12)}$$

Where $\vec{\upsilon}_m$ is mass-averaged velocity is represented as:

$$\overrightarrow{\upsilon_m}=\frac{\sum_{k=1}^{n}\alpha_k\,\rho_k\,\overrightarrow{\upsilon_k}}{\rho_m} \qquad \text{……….. (13)}$$

and ρ_m is the density of mixture:

$$\rho_m=\sum_{k=1}^{n}\alpha_k\,\rho_k \qquad \text{……….. (14)}$$

α_k is the volume fraction of phase *k*.

2) *Momentum Equation :* The momentum equation for the mixture can be obtained by summing the individual momentum equations for all phases. It can be expressed as:

$$\frac{\partial}{\partial t}\left(\rho_m\vec{\upsilon}_m\right)+\nabla.\left(\rho_m\vec{\upsilon}_m\vec{\upsilon}_m\right)=-\nabla P+\nabla.\left[\mu_m\left(\nabla\vec{\upsilon}_m+\nabla\vec{\upsilon}_m{}^{T}\right)\right]+$$
$$\rho_m\vec{g}+\vec{F}+\nabla.\left(\sum_{k=1}^{n}\alpha_k\,\rho_k\,\vec{\upsilon}_{dr,k}\,\vec{\upsilon}_{dr,k}\right) \qquad \text{…(15)}$$

Where *n* is the numer of phases , $\vec{F}$ is a body force, and μ_m is the viscosity of the mixture, which is given by:

$$\mu_m=\sum_{k=1}^{n}\alpha_k\,\mu_k \qquad \text{……….. (16)}$$

Where $\vec{\upsilon}_{dr,k}$ is the drift velocity for secondary phase k:

$$\vec{\upsilon}_{dr,k}=\vec{\upsilon}_k-\vec{\upsilon}_m \qquad \text{……….. (17)}$$

3) *Energy Equation:* The general form of this equation is given by:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}\left(\alpha_k \rho_k \mathrm{E}_k\right)+\nabla\cdot\sum_{k=1}^{n}\left(\alpha_k \vec{\upsilon}_k\left(\rho_k \mathrm{E}_k+\mathrm{P}\right)\right)= \nabla\cdot\left(\mathrm{k}_{eff}\nabla\mathrm{T}\right)+S_{\mathrm{E}} \qquad \text{.......... (18)}$$

Where is the effective conductivity $\left(\sum\alpha_k\left(\mathrm{k}_k+\mathrm{k}_t\right)\right)$, where k_t is the turbulent thermal conductivity. The first term on the right-hand side of Eq. (18) represents energy transfer due to conduction. S_{E} includes any other volumetric heat sources. Also, in equation (18)

$$E_k = h_k - \frac{p}{\rho_k} + \frac{\upsilon_k^2}{2} \qquad \text{.......... (19)}$$

For an incompressible phase $E_k = h_k$, where h_k is the sensible enthalpy for phase k.

E. Turbulent Model

Ansys Fluent 15.0 exhibit three approaches for the k-epsilon turbulence model in the multiphase flow

1) Turbulence mixture model
2) Turbulence dispersed model
3) Turbulence model for each phase

Depending on the deviation between experimental and numerical results, being choosing the turbulence K-ε standard mixture model was set for the three phases model which can be defined through these equations (Fluent User's Guide, 2006).

$$\frac{\partial}{\partial t}\left(\rho_m k\right)+\nabla.\left(\rho_m \vec{\upsilon}_m k\right)=\nabla.\left(\frac{\mu_{t,m}}{\sigma_k}\nabla k\right)+G_{k,m}-\rho_m\varepsilon \qquad \text{.......... (20)}$$

$$\frac{\partial}{\partial t}\left(\rho_m \varepsilon\right)+\nabla.\left(\rho_m \vec{\upsilon}_m \varepsilon\right)=\nabla.\left(\frac{\mu_{t,m}}{\sigma_\varepsilon}\nabla\varepsilon\right)+\frac{\varepsilon}{k}\left(C_{1\varepsilon}G_{k,m}-C_{2\varepsilon}\rho_m\varepsilon\right) \qquad \text{.......... (21)}$$

Where ε is the turbulent dissipation rate, G_k is the generation of turbulence kinetic energy, and σ is the turbulent Prandtl number for k and ε.

The density and the velocity of the mixture, ρ_m and $\vec{\upsilon}_m$, are computed as following:

$$\rho_m = \sum_{i=1}^{n}\alpha_i \rho_i \qquad \text{.......... (22)}$$

$$\vec{\upsilon}_m = \frac{\sum_{i=1}^{n}\alpha_i \rho_i \vec{\upsilon}_i}{\sum_{i=1}^{n}\alpha_i \rho_i} \qquad \text{.......... (23)}$$

The turbulent viscosity, $\mu_{t,m}$, and the production of turbulence kinetic energy, $G_{\kappa,m}$, are computed as following:

$$\mu_{t,m} = \rho_m C_\mu \frac{k^2}{\varepsilon} \qquad \text{.......... (24)}$$

$$G_{\kappa,m} = \mu_{t,m}\left(\nabla\vec{\upsilon}_m + \left(\nabla\vec{\upsilon}_m\right)^{T}\right):\nabla\vec{\upsilon}_m \qquad \text{……….. (25)}$$

The model constants can be seen in table (4.5).

The constant	Value
C_{mu}	0.09
C_1-Epsilon	1.44
C_2-Epsilon	1.92
Dispersion Prandtl number	0.75

Table (4.5): Model Constants

These default values have been determined based on experiments for fundamental turbulent three-phase flow.

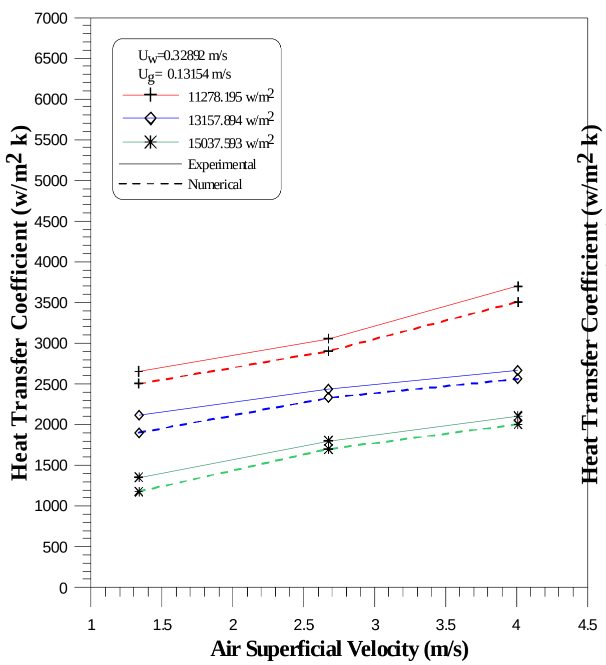
IV. RESULTS AND DISCUSSION

A. Heat Transfer Coefficient Results

1) *Effect Water Superficial Velocity:* Figure (5a, b, c) show the effect of increasing water superficial velocity on the local heat transfer coefficient for three different values of water superficial velocity with various values of air superficial velocity and various values of heat flux with constant gasoil superficial velocity. It can be seen that the heat transfer coefficient profile increased with increasing water superficial velocity for all heat flux values. When the amount of water increases inside the channel, water superficial velocity increase for that the turbulence inside the test channel is increased and the mixing between phases (water, gasoil and air) being high, leading to increase in the heat transfer coefficient inside the test channel. The numerical results seemed to have the same influence as the experimental results with a deviation of about (2.092 % - 14.657 %) found between them.
2) *Effect Gasoil Superficial Velocity:* Figure (6 a, b, c) show the local heat transfer coefficient increased with gasoil superficial velocity increase with respect to the different values of water superficial velocity and constant air superficial velocity value for different values of heat flux. Also show a comparison between the experimental and numerical results at the same as the previous point in water effect case which created with the same coordinate where the temperature sensors situated experimentally. The numerical results seemed to have the same influence as the experimental results with a deviation of about (2.58% - 17.545%) found between them. When gasoil phase adds to the working fluid, velocity of working fluid is increase that's lead to the heat transfer coefficient increase. The reason back to more increase for turbulence which create a vortex aid to high heat transfer from the rib surface to the working fluid.
3) *Effect Air Superficial Velocity:* The effect air phase showed in figure (7 a, b, c) which is illustrates the effect of increasing air superficial velocity on the local heat transfer coefficient results for various values of gasoil superficial velocity and heat flux with constant water superficial velocity. It is also, show a comparison between the experimental and the numerical results found at a same mentioned pervious point at case water and gasoil effect. The numerical results seemed to have the same influence as the experimental results with a deviation of about (1.588 % -16.594 %) found between them. Adding air phase to the working fluid also aid to increase the working fluid superficial velocity by increase the turbulence generated by create bubbles which creates vortices around top surface of the triangular rib for that high heat transfer from the rib surface to the working fluid. For all figures (5,6,7) the temperature difference between the rib surface and mixture core is decreases at phase superficial velocity increase. Because the relation between temperature difference and phase superficial velocity is inversely proportional according to equation (7). The highest values of heat transfer coefficient were at effect water superficial velocity on heat transfer. because heat transfer coefficient is a function of the properties of the system such as geometry of the system and fluid regime and one of the factors which depends on it is physical property of the working fluid (three-phase flow) such as density (ρ) where the water density is bigger from the other fluids (gasoil and air).

B. Effect Rib on Heat Transfer Coefficient

Rib shape is a significant influence on the temperature field during recirculation possesses, for that triangle shape give better fluids (water, gasoil and air) mixing between the surface ribs and the core region of the rectangular channel, because it had a sharp edge and smallest tip. The thick boundary layer causes the velocity to decrease. This decreases the local heat transfer coefficient. For that triangular rib across the rectangular channel break the laminar sub layer and buffer layer and create local wall turbulence due to flow separation, reversal and reattachment between the ribs, which helps to exchange heat. So, working fluid absorb more heat. The rib not only disrupts the boundary layer and buffer layer, but also forms a significant secondary longitudinal vortex structures as shown in figure (8 a). This vortex carries cooler working fluid from the core of the channel towards the side wall (surface rib) which enhances the heat transfer. In figure (8) shows numerical result for stream lines for the turbulent intensity for the triangular rib, it has been observed eddies formation are more predominant between the ribs as shown in figure (8 b, c). For that more fluctuations in the flow and hence intensity of turbulent increase with insertion of these ribs. Hence heat transfer enhances inside the channel. Lead to increase local heat transfer coefficient. As the superficial velocity of phases (water, gasoil and air) increased, the volume fraction for these phases is increase, increasing turbulence of flow in the channel then heat transfer increased as shown in figures (9) to (11). These figures show the experimental flow behavior through the photographs that were taken for test channel and visually compared it with the contour of water, gasoil and air volume fraction respectively found by numerical simulation. The rectangular channel fitted with triangular rib. The presence of this rib helps separate flow, for that a turbulence flow is higher, since separation causes local flow reversal, enhanced mixing, and thus more heat transfer. A close similarity for the behavior of flow between the experimental photos and the images of water, gasoil and air volume fraction found with ANSYS FLUENT 15.0.The computational fluid dynamics simulation results depended on the superficial velocity of water, gasoil and air and heat flux input into the channel, the channel outlet mixture gage pressure, geometry and type of the ribs, and the volume fraction which gave a simulation results varied up and down the experimental results with a deviation as pervious mentioned. This is because, it was a changed phenomenon and controlled by different parameters that being assumed throughout these simulations, so those values can be changed by making different asumptions.



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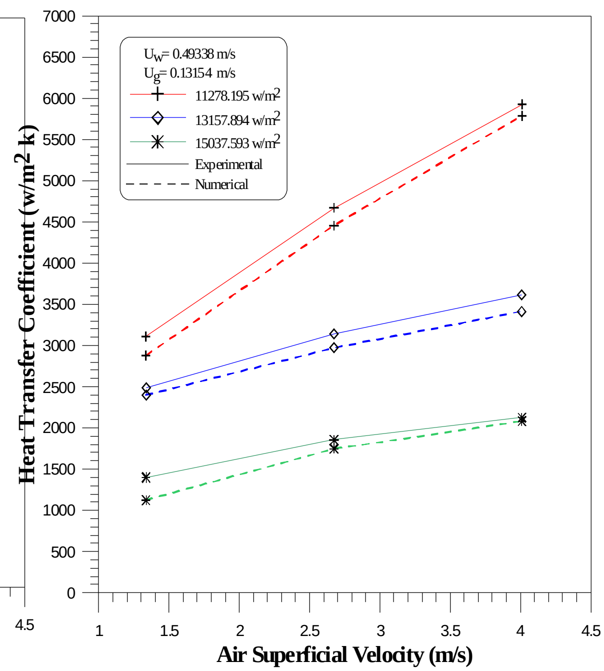

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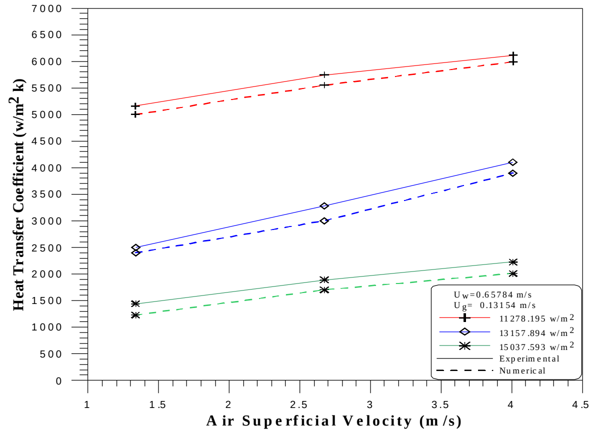
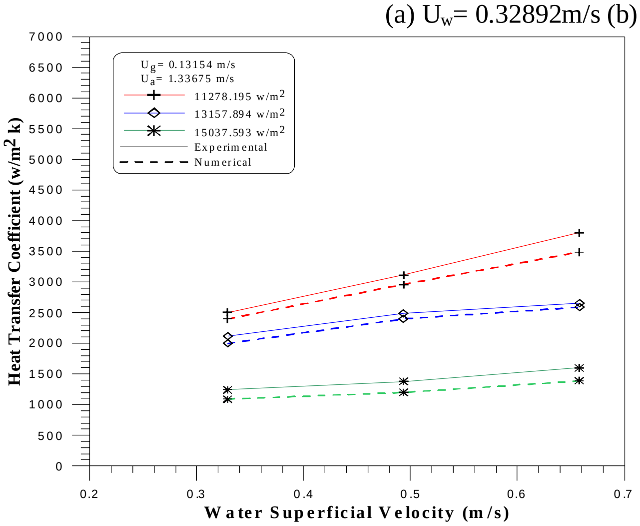
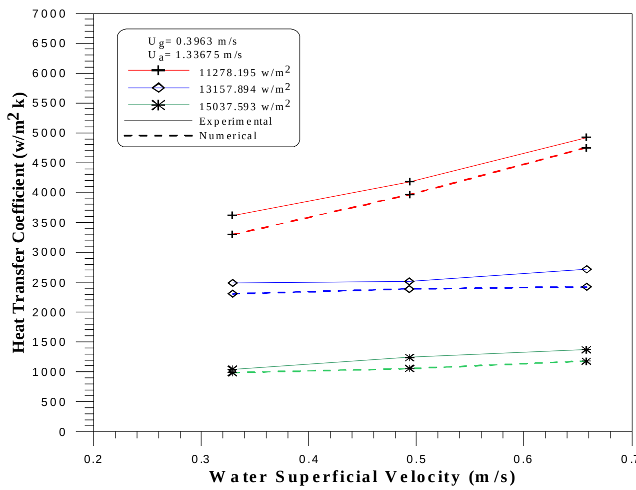


(c)

Figure (5): Effect Water Superficial Velocity on Heat Transfer Coefficient
(a) U_w= 0.32892m/s (b) U_w= 0.49338 m/s (c) U_w= 0.65784 m/s



(a)



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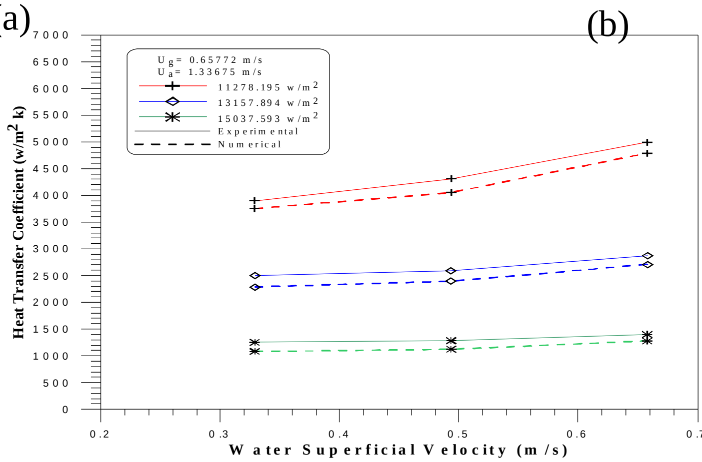
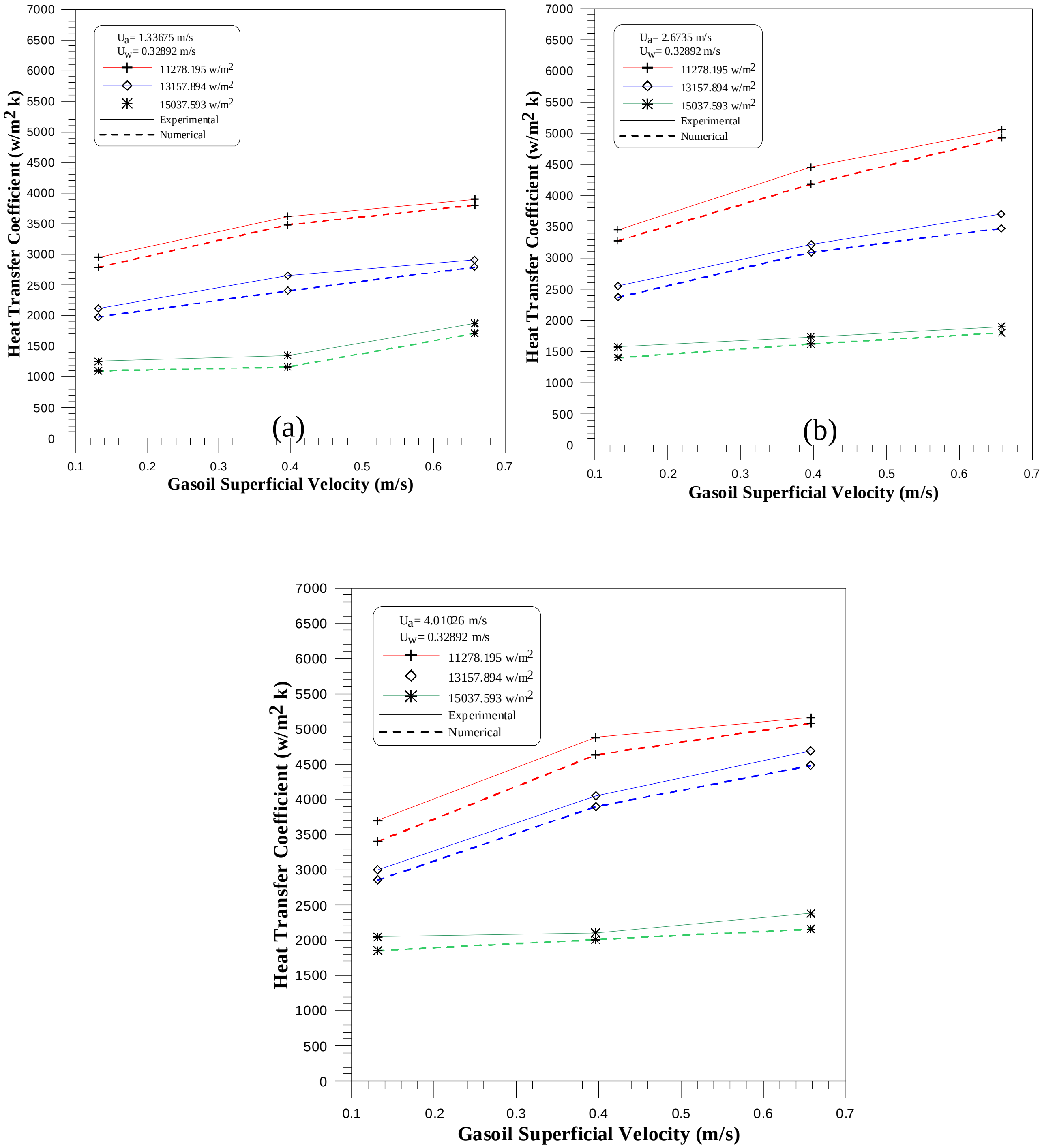


(c)

Figure (6): Effect Gasoil Superficial Velocity on Heat Transfer Coefficient
U_g= 0.13154 m/s (b) U_g= 0.3963 m/s (c) U_g= 0.65772 m/s



(c)

Figure (7): Effect Air Superficial Velocity on Heat Transfer Coefficient

(a) U_a= 1.33675 m/s (b) U_a= 2.6735 m/s (c) U_a = 4.01026 m/s

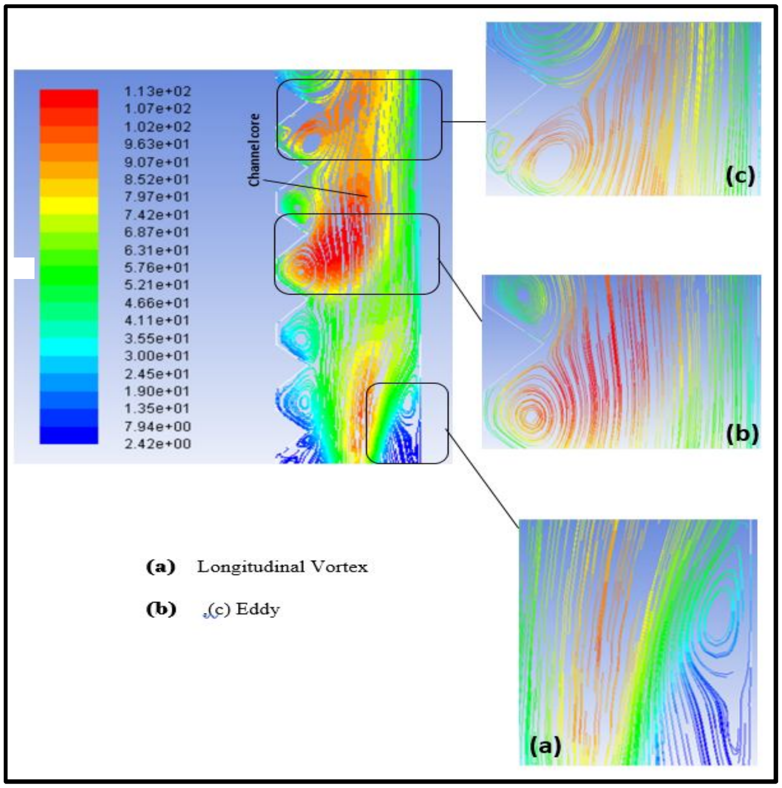


Figure (8) stream lines for the turbulent intensity inside the channel

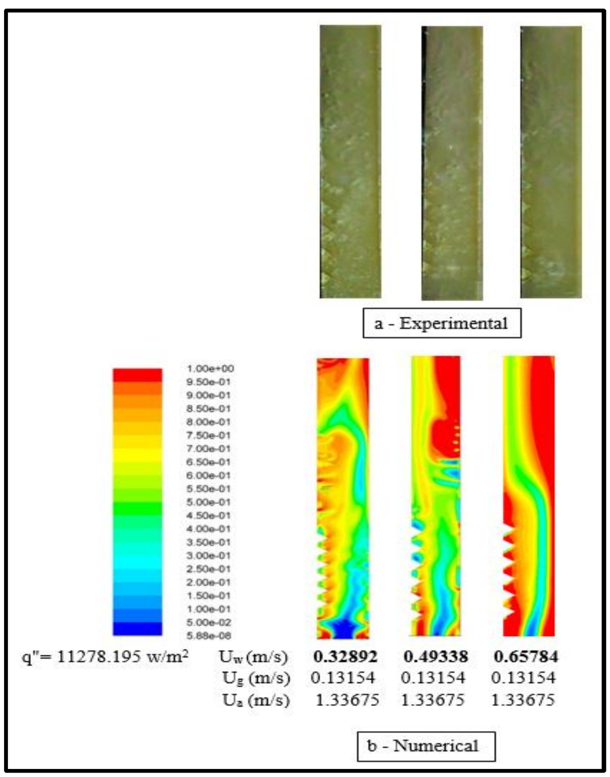


Figure (9) Contours of Water Volume Fraction

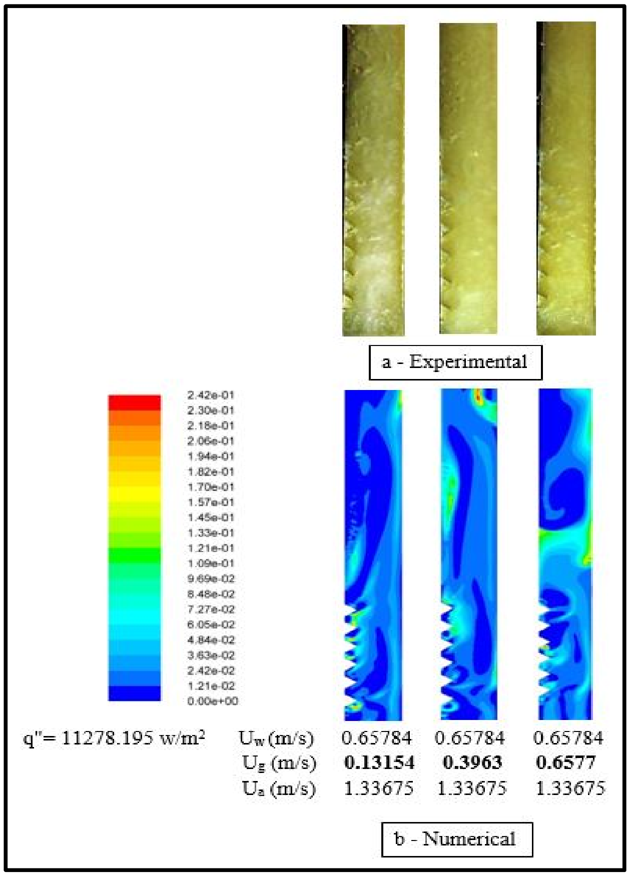


Figure (10) Contours of Gasoil Volume Fraction

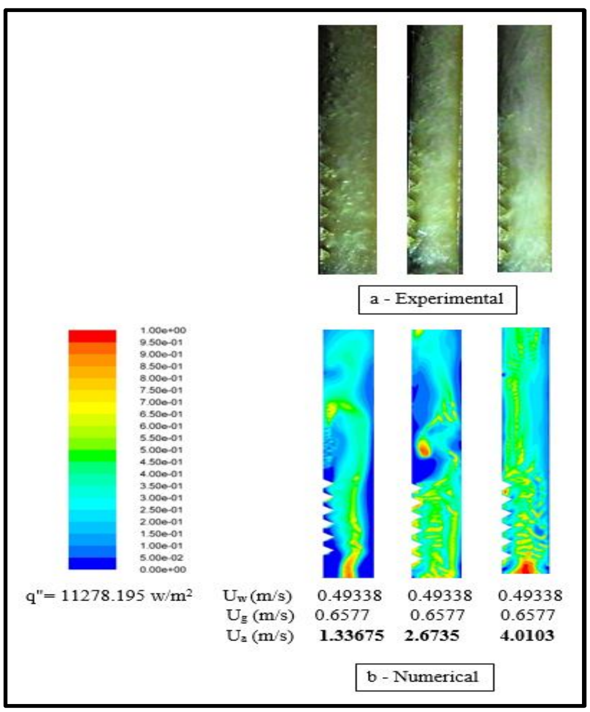


Figure (11) Contours of Air Volume Fraction

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C. Temperature Distribution

1) Effect Water Superficial Velocity: Figure (12 a, b) shows the effect of water superficial velocity on the contours of temperature distribution inside the channel with triangular rib at constant values of gasoil and air superficial velocities and various values of heat flux, 0.1315 m/s, 1.3368 m/s and 11278.195 $w/m^{2,}$ 15037.593 w/m^2 respectively. As the superficial velocity of water increased from 0.3289 m/s to 0.6578 m/s the temperature distribution decreased inside the channel. The reason for this effect was a result of increasing the superficial velocity of water and decrease the time residence of mixture inside the channel which caused an increase in the water flow rate and reduced the temperature difference along the channel according to Eq. (7).

2) Effect Gasoil Superficial Velocity: Figure (13 a, b) shows the effect of gasoil superficial velocity on the contours of temperature distribution inside the channel with triangular rib at constant values of water and air superficial velocities and various values of heat flux 0.6578 m/s, 1.3368 m/s and 11278.195 $w/m^{2,}$ 15037.593 w/m^2 respectively. As the superficial velocity of gasoil increased from 0.1315 m/s to 0.6577 m/s the temperature distribution decreased as a temperature difference from 5.170 k˚ to 2.185 k˚ inside the channel. The reason for this effect was a result of increasing the superficial velocity of gasoil which aids to increase the mixture velocity and create a high turbulence but with percentage low from the water effect resulting different density and decrease the time residence of mixture inside the channel which caused an increase in the gasoil flow rate and reduced the temperature difference along the channel according to Eq. (7).

3) Effect Air Superficial Velocity: Figure (14 a, b) show the effect of air superficial velocity on the contours of temperature distribution inside the channel with triangular rib at constant values of water and gasoil superficial velocities and various values of heat flux, 0.3289 m/s, 0.1315 m/s and 11278.195 $w/m^{2,}$ 15037.593 w/m^2 respectively. As the superficial velocity of air increased from 1.3368 m/s to 4.0103 m/s the temperature distribution decreased as a temperature difference from 5.332 k˚ to 2.891 k˚ inside the channel. At adding air to the mixture as a three phase, bubbles create and filled the channel which works to increase the turbulence, then improvement heat transfer but with percentage low from the water effect also resulting different density and decrease the time residence of mixture inside the channel which caused an increase in the air flow rate and reduced the temperature difference along the channel according to Eq. (7).

V. CONCLUSIONS

In this work heat transfer coefficient for three-phase flow (water– gasoil – air) over triangle rib in a rectangular channel are studied experimentally and numerically. Four values of water superficial velocity are used (0.16446,0.2389,0.4934,0.6578m/s), three values of gasoil superficial velocity (0.1315,0.3963,0.6577 m/s) and three values of air superficial velocity(1.3368,2.6735,4.0103m/s). The effect of water, gasoil and air superficial velocities on heat transfer coefficient and temperature distribution is studied. The following conclusions are drawn from these tests.

o Heat transfer coefficient is increased as the water superficial velocity increased.

o Heat transfer coefficient is increased as the gasoil superficial velocity increased.

o Heat transfer coefficient is increased as the air superficial velocity increased.

o Temperature distribution has an inverse proportional with water, gasoil and air superficial velocities along the channel for the turbulent three-phase flow, increasing these variables leads to decrease the temperature difference along the channel.

A. Nomenclature	*Subscripts*
Re: Reynolds number.	m: mixtrue
U: velocity. m/s	w: water
$D_{h:}$ hydrodynamic diameter, m	g: gasoil
A: cross-sectional area, m^2	a: air
W: wetted perimeter of the channel, m	c: continuous phase
h: heat transfer coefficient, w/m^2 k	y: y- direction
T: temperature, k^o	s: rib surface
$q^{"}$: heat flux, w/m^2	b: bulk temperature
$\dot{Q}_{el}$ electric power	Y: position along stremwise
$\dot{Q}_{loss}$ thermal losses	in: entrance
$\dot{m}$: mass flow rate, kg/s	out: outlet
ΔT: temperature different	

cp: specific heat at constant pressure, J/kg k
υ: mass averaged velocity, m/s
U: Liquid superficial velocity m/s.
Q: Volume flow rate m^3/s.

B. Greek Symbols

μ: viscosity, kg/m. s
α: fraction of dispersed phase in liquid mixture
ρ: density, kg/m^3

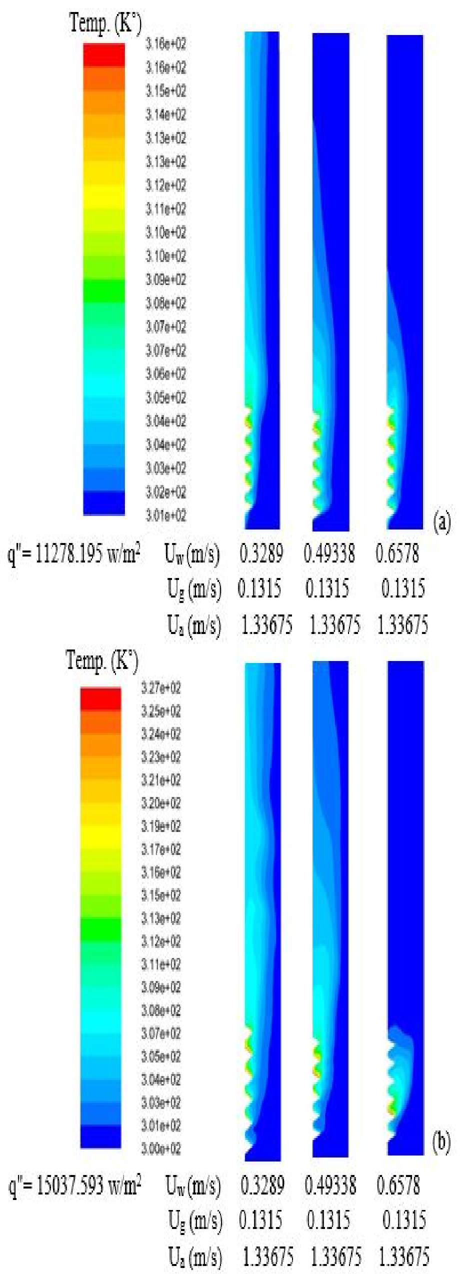

Figure (12) Effect Water Superficial Velocity on Temperature Distribution

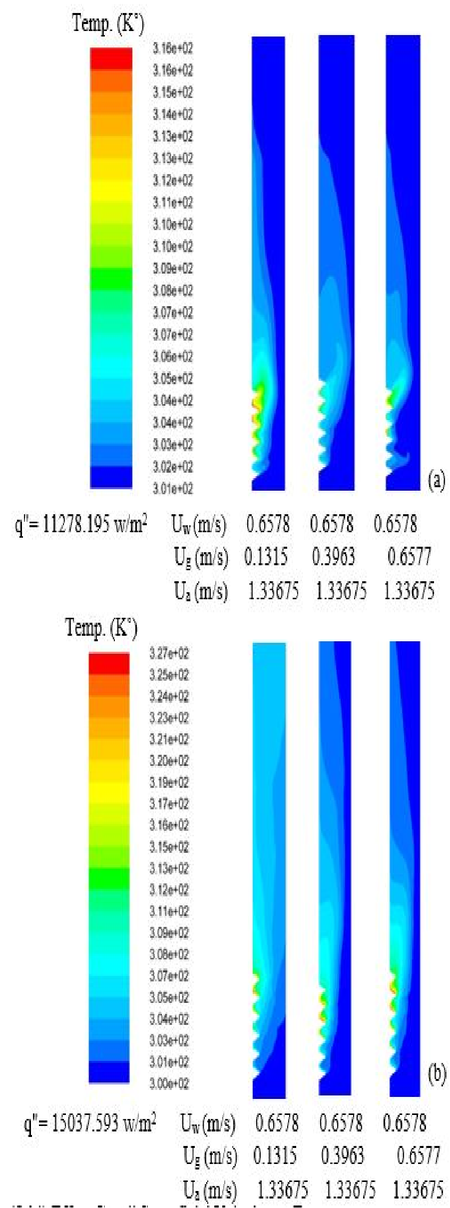

Figure (13) Effect Gasoil Superficial Velocity on Temperature Distribution

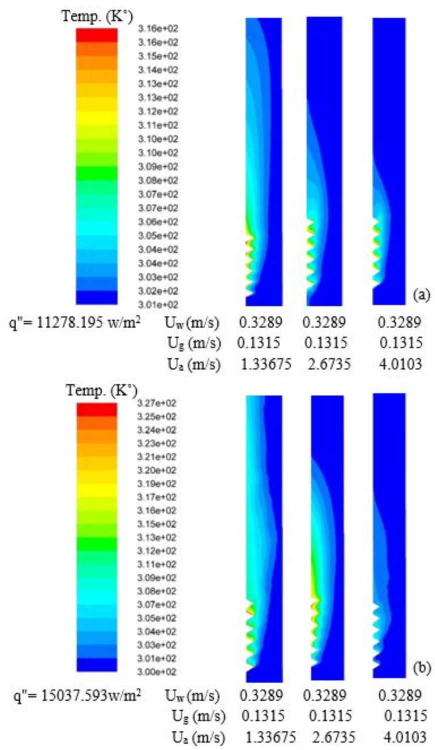

Figure (14) Effect Air Superficial Velocity on Temperature Distribution

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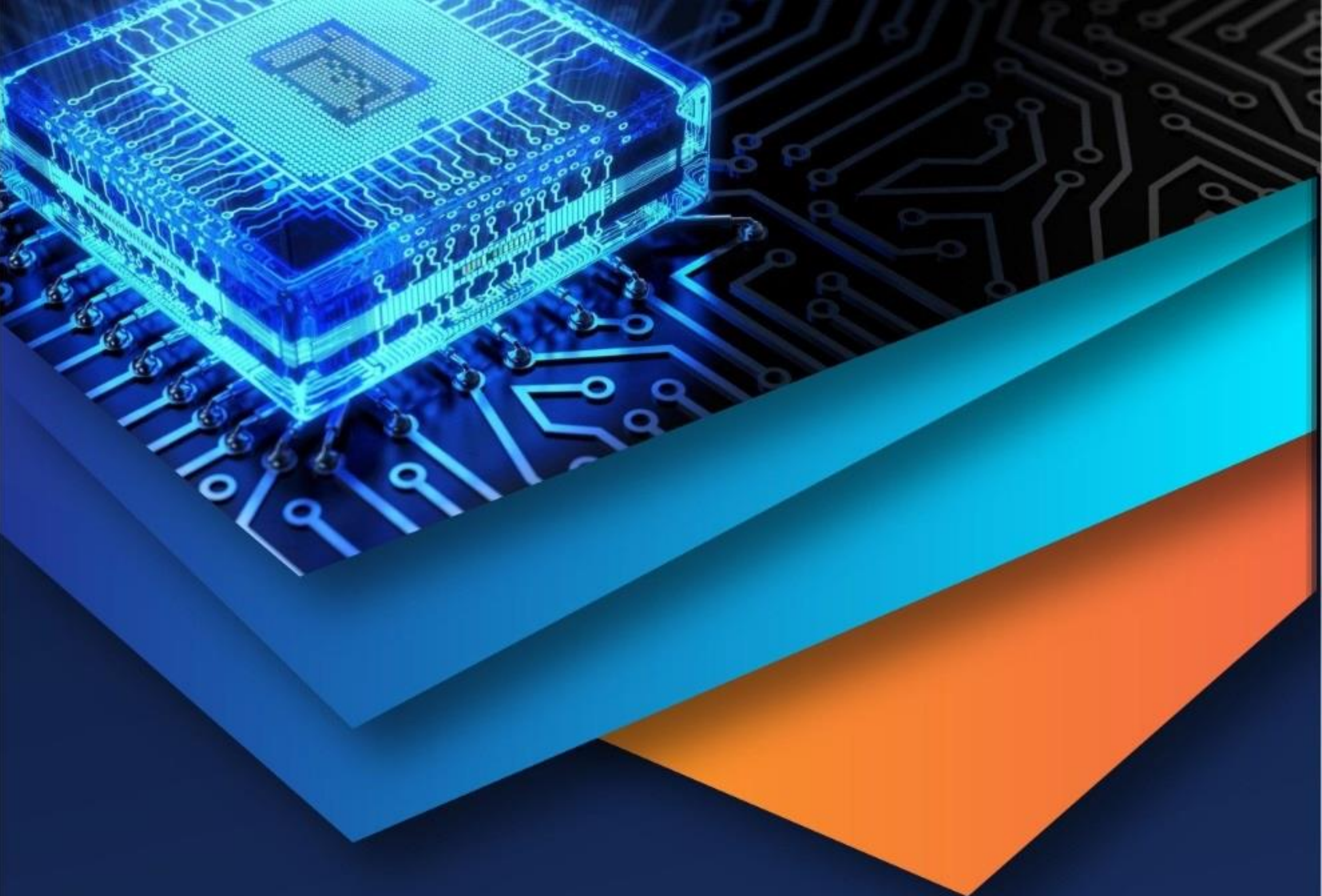

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