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SIMULATION OF WATER DROPLET IMPINGEMENT ON A HEATED SURFACE- SINGLE AND DOUBLE DROPLETS

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Abstract: The present numerical work is concerned with the single drop and double drops impingement on a heated surface. Fluid flow and heat transfer coefficients were modeled using a volume of fluid (VOF) code. The stainless –steel thin plate surface is uniformly heated to reach a constant temperature at (50C°), this was done by using relatively thicker plate underneath the heated plate. The thick plate is made of high conductivity aluminum alloy 2mm thickness. Relatively a lower temperature water drop is used for cooling to ensure that drop temperature remains below the boiling point of water. The drop –plate initial impingement distances were varied in the range (10-60) cm which represent an impact velocity in the range (1.4-3.4) m/s. The single drop fluid flow simulation results are compared with that in the literature ,while the heat transfer fluid flow results are represented as instantuous heat transfer coefficient variation as alternative to values of heat flux on the surface. Double drops impingement results are then presented and its features are compared to the single drop. Results show that the flow characteristics for the double drops are similar to the single drop at small distances with smaller coverage areas during impingement with lower heat removal rates. As distances increase rebound and splash occurs leading to bigger coverage areas during impingement with relatively smaller heat coefficients compared to the single drop one. The present results shows the same behavior for drop deformation when compared with M.pasandideh-Fard et al. [1] numerical results with an agreement of 90 % and 95 % in calculations the spread factor and impact velocities respectively. The calculated average heat coefficients show acceptable values with that given in litreture

Keywords: *Droplet impact, Spray cooling, impingement.*

1.Introduction

The spray cooling of hot surfaces in industrial applications are widely used. Examples are cooling of turbine blades, fire suppression by sprinkler system, quenching of metal casting and the cooling of electrical components. Though most spray cooling has been principally concerned with drops that boil after landing on a hot surface, single phase heat transfer is often the most important mode of heat transfer. This is usually the case when the objective of spray on object is to keep it cool and prevent over heating in order that the drop temperature is ensured to remain below the boiling temperature. A lot of work were carried out concerning the flow field conjugated with single drop impingement on a surface. A numerical result was compared to that done experimentally by M.pasandideh-Fard et al. [1]. They done experiments and a numerical model by using (VOF) investigation to study the collision of water drop on a hot stainless steel surface.Results is to declared later. Siddhartha F. Lunkad et al. [2] Carried out numerical study for the effect of the spreading and dynamics of a

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drop collision on inclined and horizontal surfaces by using the volume fluid (VOF) method. For the horizontal surfaces, the spreading and the dynamics of collision of glycerin drops on glass and wax surfaces was scrupulous for which the empirical measure were obtainable. Ilia V. Roisman at al. [3] Carried out experimentally and theoretically the ordinary effect of a liquid drop on a dry solid surface. The time evolution of drop diameter as well as the effect of speed and the initial drop diameter are specified. S. Manservisi and R. Scardovelli. [4]Conducted numerical simulation of the spreading of a one drop affect through horizontal dry surfaces. To study numerically the contact angularity dynamics they used a finite element type locate on a variation expression of the Navier –stokes equation conjugate to an interface front –tracking method. The outcome of this study at minimum Reynolds number where inertial ,viscous and capillary forces act with each other to define drop movement. The drop collision has been numerically studied over non wettable , wettable and portion wettable surface. Mohammad Taghilou and Mohammad Hassan Rahimia.[5] Studied thermal behavior of a drop on the solid surface by the use of a thermal Lattice Boltzmann model which uses the Cahn-Hilliard spread interface theory that is used to take the drop interface and simulate the contact angle between gas and liquid phase and solid. These mentioned research works find out three main flow modes after drop impingement on the surface. First is the case when the drop undergoes rapid deformation as it spreads into a thin film. The spreading starts initially just when the drop touches the solid plate, widening in the horizontal direction due to horizontal velocity components. The drop reaches its maximum diameter due to the horizontal spreading, then starts to reaccumulate due to liquid –solid friction at the contact boundaries and due to the surface tension within liquid layers. Fig .1 shows example of such behavior as presented by M.Pasandideh-Fard et al. [1]

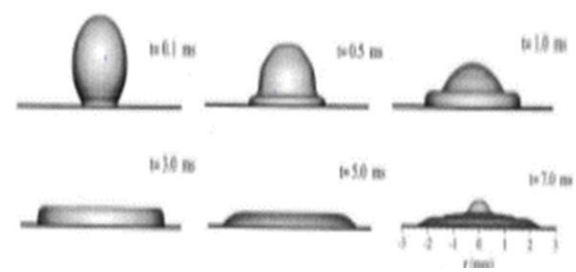


Figure1. Computer generated images and photographs of a 2mm diameter water drop impacting with a velocity 1.3m/s on a stainless steel surface Initally at a temperature of 120 C°. M.pasandideh-Fard et al. [1]

Y. Renardy et al. [6] Discussed the pyramidal and toroidal water drops after impact on a solid surface. The study discussed the super-hydrophobic surface that allows the drop to ball up upon recoil and rebound and for a normal surface, recoil leaves a residue with droplets possibly emitted by a central mass. The work also debated the complexity that emerge at great speed: the appearance of the thin film in the center of the toroidal drop and swirling motions observed in the cross-section of the toroidal drop. Their numerical outcomes predict the dry-out of this film in the middle of the toroidal drop.

The third flow structure that can occur during drop impact on a solid surface is that presented in. Gangtao Liang at al.[7] which represent the flow and heat transfer during a single drop collision on a liquid film. The work discussed typical outcomes after impact presented by T. Okawa, T. Shiraishi et al.[8] : deposition, tiara formation , splashing and without splashing. For drop splashing, G.E. Cossali et al. [9] featured two kinds of splashing : delayed splashing and prompt splashing. The delayed splashing happen near or after tiara maximum extension and is related with tiara wall break up, while the promote splashing is related with ejected drops from the tiara edge when it still advance. Fig .2 shows the gas-liquid interface after drop impact on a liquid film crown shape and drop splashing is noticed.

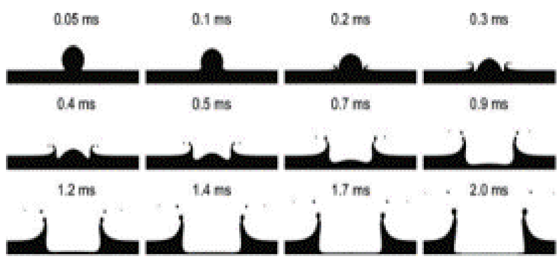


Figure 2. Gas–liquid interface evolution after a drop impact on a liquid film. (Notice the time ellapsed after impact). Gangtao Liang at al.[7]

, R. Vander Wal et al. [10] , A. L. Yarin et al. [11], A. B. Wang and C. C. Chen. [12] Related splashing with production of satellite droplets separating from the tiara rim after collision. The review of different papers concerned with drop impact on a surface declares that the main attention is given to flow structure that occurs after impact, while that concerned to the heat transfer characteristic during drop impingement are rare and can be classified to that for a single drop on a dry heated surface or that for drop impact on a surface with liquid film known as wet surface drop impingement. The researches concerned with heat transfer during drop impingement on a surface studied the heat flux removal rate from a heated surface during the flow of a single drop during the spreading of the drop after its' impact and the effectiveness of a cooling process during the deformation of a drop after impact. The work by M.pasandideh-Fard et al. [1] outcomes developed a simple model for transferring heat to the drop by one-dimensional conduction through a thermal boundary layer that gives an estimate of the effectiveness of the drop cooling that agree well with outcomes from the numerical sample. The analytical model forecast that for fixed Reynolds number (Re) founded on droplet diameter and collision speed, cooling effectiveness rises with Weber number (We). Numerical simulation for a fluid mechanics and heat transfer during drop impact were modeled using a volume of fluid (Vof) code. Their heat transfer results showed that the flux rate of heat is a function of spreading radius of a drop and decreases monomitcally during a short time period after impingement .Gangtao liang et al. [7] established a two-dimensional incompressible model to analyze flow and heat transfer during a single liquid drop affecting onto a liquid film, with an underneath surface of comparatively depressed temperature. The heat transfer process is tested numerically with three different elements including film thickness, drop diameter, and impact velocity. Their results showed that the flow characteristics of the drop during wet surface impingement differs than that with dry one and that the liquid into the film can be classified as three regions according to different heat fluxes , the effective zone , the transition zone and static zone. The results also declared that average surface heat flux can be increased by rising effect speed, while effects of drop diameter and film thickness are minor. G.Castanet at al [13] . Gave the experimental results of water drop impact on a heated plate made of nickel, to observe the impact regime (bounce, spraying and deposition of a liquid film) for a large set of effect cases (wall temperature , velocity and size and drop incidence angularity).Two-color laser induced fluorescence thermometry is used to measure the drop temperature during an collision, when it exceeds the Leidenfrost temperature , it was found that the change in temperature of the drops during the collision depends on the normal speed but not on wall temperature.

The present work deals with the cooling of heated surface using single and double water drops impinges on the surface without phase change. The flow and heat transfer for the single drop had been a dopted and analyzed experimentally and numerically in previous researches as mentioned earlier. Flow characteristics when a second drop of the same size impinges directly with a certain rate is to be tested using the volume of – fluid code . The code was used successfully in previous works concerned with the drop impingement as proved when numerical results gained by other researches were compared to the experimental one.

The present study will give a focus on the actual phenomenon that occurs when more than one drop impinges simultaneously on the surface during certain time steps. The study deals with the flow field and heat rates during the drop impingement and the period that ellapse during its deformation.

2. Mathematical model

To establish the motion of water drop. The governing equations of momentum, energy and mass continuity as follows [14, 15, 16]

2.1. Continuity equation

To get volume fraction equations of conservation, and based on the physical principles of VOF model, the continuity equation is represented as follows

$$\nabla.(\rho V) = -\frac{\partial \rho}{\partial t} \qquad (1)$$

The solution of equation (1) for volume fraction of the one phase (gas) is used, to track the boundary edges between the phases. Thus, the equation of continuity for the other phase (liquid) can be expressed as:

$$\nabla.(\propto \iota \rho\iota V) = -\frac{\partial}{\partial t}(\propto \iota \rho\iota) \qquad (2)$$

The continuity equation declared above could be the equation of volume fraction and it will not be resolve for the (gas) first stage, because first stage volume fraction is studied using the next term

$$\sum_{g=1}^{n} \propto_g = 1 \qquad (3)$$

When the cell is not wholly full with primary phase (g) or with the secondary phase (I) occur a mixture of the phase's g and l. So that studied the mixture density as averaged density volume fraction as follow:

$$\rho = \propto_\iota \rho_\iota + (1 - \propto_\iota)\rho_g \qquad (4)$$

2.2. Momentum equation

For VOF type the acting forces in the fluid was believed to be gravitational, pressure, friction and surface tension. The continuum surface force (CSF) parameter has been added to the 3D momentum equation, to locate the surface tension influence along the two stage interface

$$F_{CSF} = 2\sigma \frac{\propto_\iota \rho_\iota c_g \nabla \alpha_g + \propto_g \rho_g c_\iota \nabla \alpha_\iota}{\rho_\iota + \rho_g} \qquad (5)$$

By considering the F_{CSF} forces into VOF model, the momentum equation will be as follows:

$$\frac{\partial}{\partial t}(\rho V) + \nabla.(\rho V V^T) = \rho g - \nabla p +$$

$$\nabla.\left[\mu(\nabla V + (\nabla V)^T) - \frac{2}{3}\mu(\nabla.V)^I\right] + F_{CSF} \qquad (6)$$

The equation of momentum be dependent on the (α) volume fraction of the stages in the account of the physical properties like density and viscosity. The dynamic viscosity μ calculated as

$$\mu = \propto_\iota \ \mu_\iota + (1 - \propto_\iota)\mu_g \quad (7)$$

2.3. Energy equation

For the VOF model, energy equation has the following form:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.(\rho E V) = \nabla.(K \nabla T) + \nabla.(pV) \quad (8)$$

The VOF model consider the mass averaged calculation for energy E and temperature variable, while determine the equivalent thermal conductivity k as

$$k = \propto_\iota k_\iota + (1 - \propto_\iota)k_g \quad (9)$$

$$E = \frac{\propto_\iota \rho_\iota E_\iota + \propto_g \rho_g E_g}{\propto_\iota \rho_\iota + \propto_g \rho_g} \quad (10)$$

Where E_g and E_ι are determined on the specific heat C_g and the mass averaged temperature of each phase, as given by equation of state:

$$E_\iota = C_\iota T \quad (11)$$

$$E_g = C_g T \quad (12)$$

3. Model geometry and computational mesh

A two-dimensional model was created. The geometrical path is air whose dimensions consist of a length that varies according to the heights, the nozzle from which

The water drops flow which will impact on the surface of the plate. The plate is made of (stainless steel), with a diameter 160 mm and a thickness of 0.55 mm. The numerical model dimensions are based on the proposed experimental apparatus which will be carried out for the verification of the numerical model. The present numerical results for a single drop is to be verified with experimental results of M. pasandideh-Fard at al. [1] as will be discussed later. The (0.55mm) thickness of the plate is chosen so as to predict the values of heat transfer coefficients on the plate taken into account the conduction within the thin heated plate. To get a solution with a minimum error and reach reality in results by using two dimensional CFD model for the mesh. In CFD software, the flowing area is divided into so small elements and subsequently governing neutralization are solved for little elements. The better and more accuracy results will be generated, when using the smaller element size in Ansys Fluent software. Though, if the small element size is applied the iterative calculation will take a longer time. Mesh properties and methods were set as recommended of ANSYS software documents for two- phase heat transfer and flow conditions to get simulation solution. The simulation mesh includes total element size (0.5mm), with using inflation which is close to the front edge of the plate, thus the concentration of cells is very high in order to get a capture for drop and the temperature change of the drop and also to capture the convection heat transfer coefficient. The present work is carried out at Mech.Eng Department University of al.mustansiriya during January 2020.

4. CFD solution setup and Boundary Condition

A volume of fluid (VOF) code was used to study the fluid flow and heat transfer during drop collision. By solving and tracking the volume fraction of each of the fluids throughout the domain and a single set of momentum equations. The VOF model can model two or more immiscible fluids. In ansys fluent the volume formulation is used to compute a time-dependent solution. The VOF model application include free surface- flows, filling, stratified flows, the motion of liquid after a dam break , sloshing the prediction of jet breakup (surface tension) , the steady or transient tracking of any liquid -gas interface and the motion of large bubbles in a liquid. This model is used by others and has been proven to be correct and compared with them. Two phase flow is used during transient. This condition is covered in ansys theory. Pressure-based is the appropriate solver for two phase simulation [17]. In y-direction is activated with the gravity with its values (-9.81) m^2/sec .To include the thermal effects in the simulation an energy model was activated. Implicit body force was also activating [16]. The interface modeling with sharp/dispersed option is allowed with value of 1 [16, 17].

The materials is included from the fluid (water-liquid, air) and solid (stainless-steel). Air was used as a primary phase, while it was used water-liquid as a secondary phase. The fluid flow conditions was taken as laminar and incompressible. Heat flux applied in the bottom edge for the stainless steel plate is regulated so as to generate surface temperature of 50 C° at the plate surface. At the single drop condition the flow rate is first adjusted to obtain two drops per second in case of double drops conditions. The initial temperature for the drop is 25C°, and the plate surface was initially at 50C° subjected to transient conditions.

The value of the surface tension between the phases is (0.072 N/m). Time step of $1*10^{-4}$ is set to insure a Courant number at phases interface to be less than unity, a coupled scheme method used for pressure based solver to calculate volume fractions at each time step. The numerical setup is shown in Fig. 3

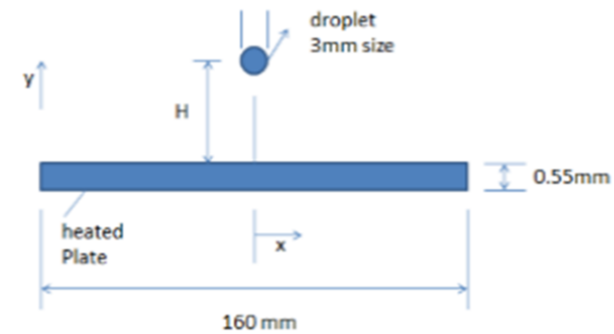


Figure 3. Numerical setup

5. The cases studied:

Table 1. Shows the studied case

Table.1

Drop diameter	No. of drops	Plate Temp.	Water Temp.	Drop to plate heights
3mm	Single and double	50C°	25 C°	10-60cm

6. Results and Discussions

The effect of single drop of relatively cold water at 25 C° impact on a hot plate at 50 C° is analyzed numerically using the VOF code. A similtenuous double drops with same thermal conditions is then tested to show the difference which will appear between the two cases .The numerical solution for single cold drop impact on a hot plate at 50 C° with distances in the range of 10, 30 and 60 cm of drop to plate heights clear out that the flow of water drop remains in the spreading mode, as discussed earlier and as presented by M.pasandideh-Fard et al. [1] whose numerical results agrees well with the experimental results. The present flow and thermal numerical results is shown in fig (4) in which the VOF, velocity contour and temperature variations of the thin stainless plate are shown at time steps of (0.1ms, 5ms and 60.7ms) and at mentioned drop to plate heights range.

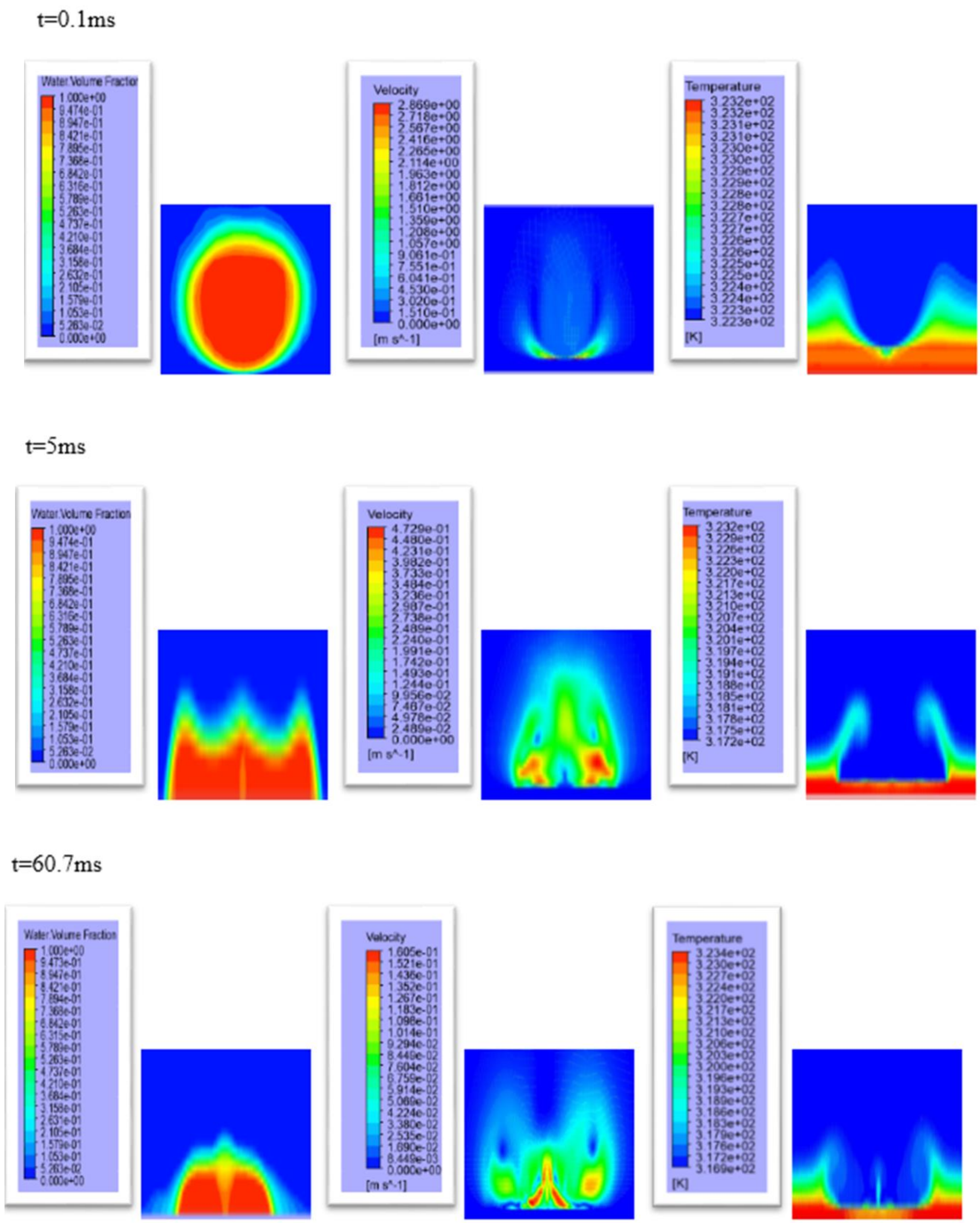


Figure (4-A): Numerical results of single drop for VOF, velocity, temperature of plate at elapsed times of (0.1ms, 5ms, 60.7ms) after impact. H=10cm

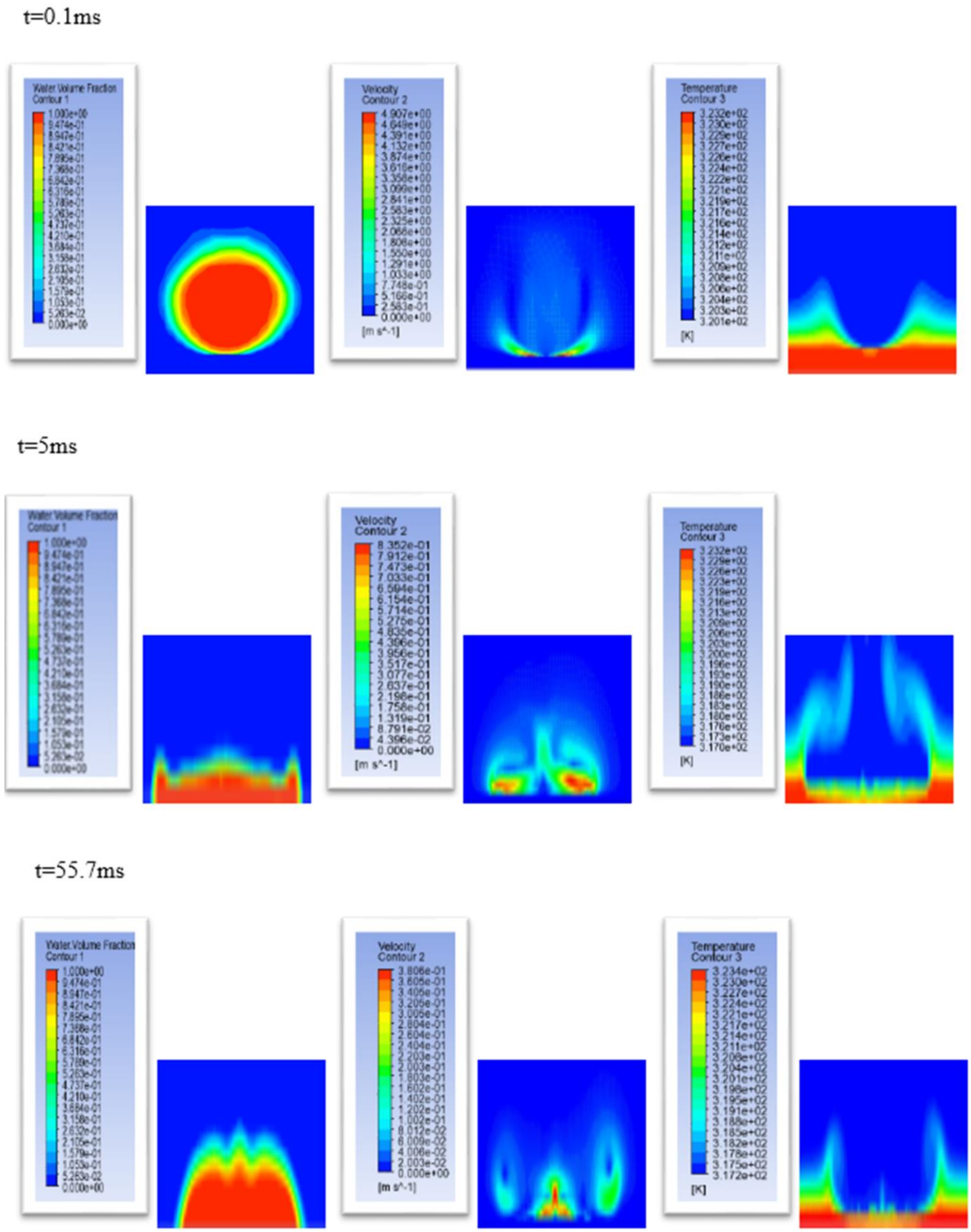


Figure (4-B): Numerical results of single drop for VOF, velocity, temperature of plate at elapsed times of (0.1ms, 5ms, 55.7ms) after impact. H=30cm

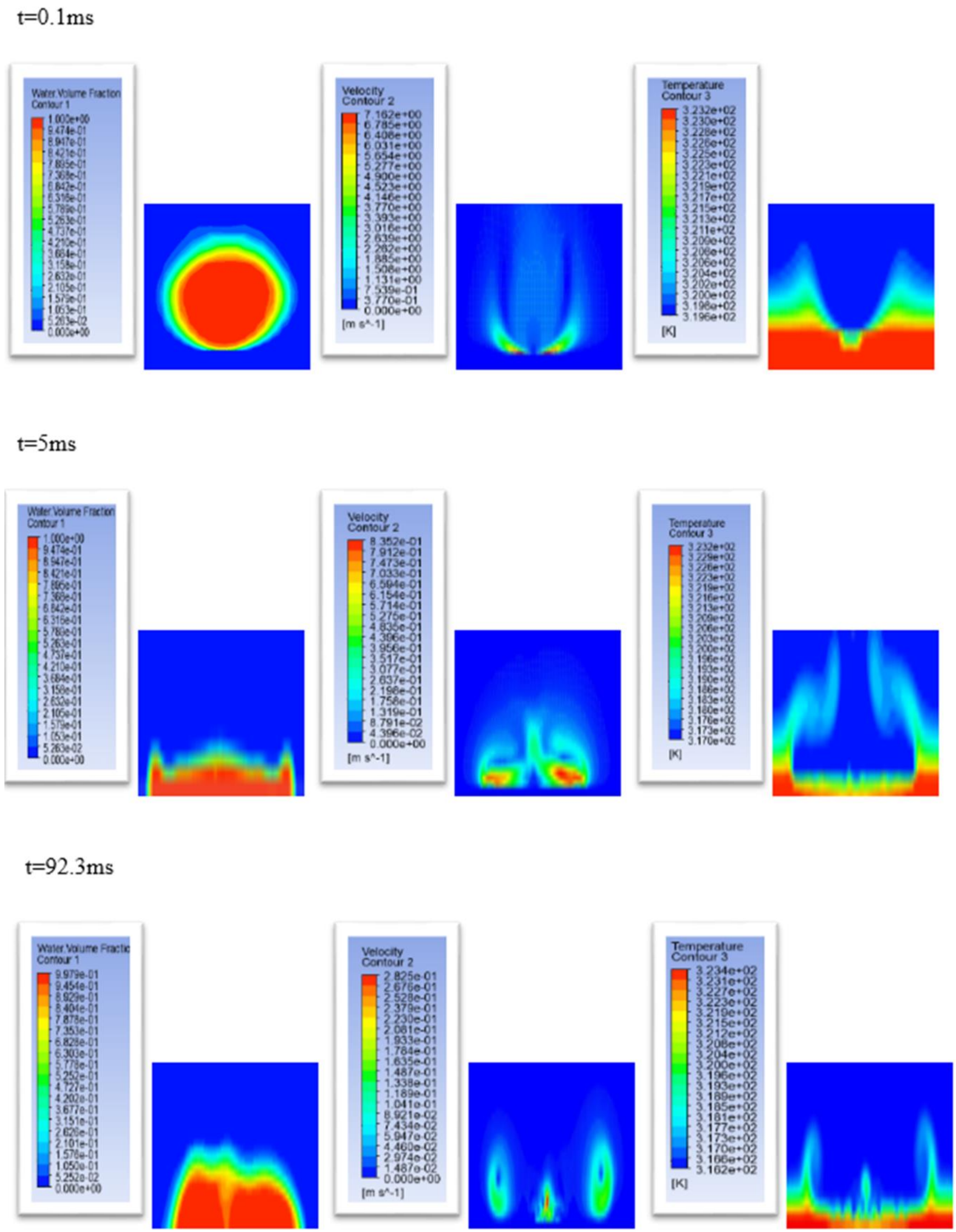


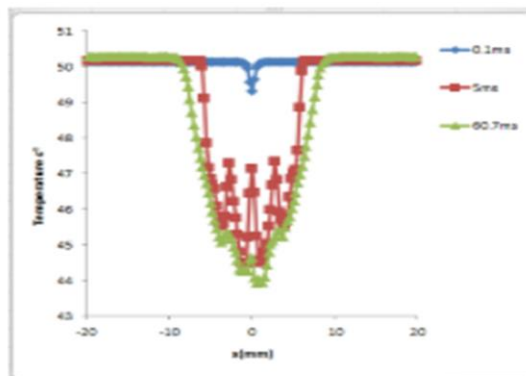
Figure (4-C): Numerical results of single drop for VOF, velocity, temperature of plate at elapsed times of (0.1ms, 5ms, 92.3ms) after impact. H=60cm

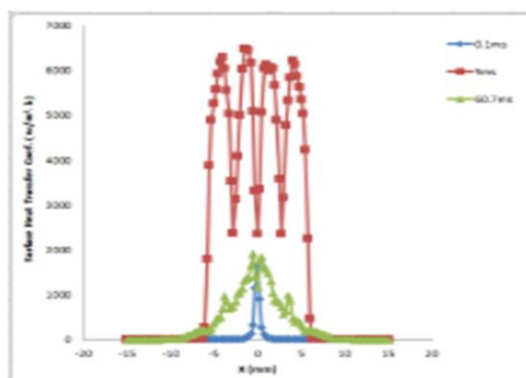
The 0.1ms represent the case when the drop just impact the plate and 5ms represent the time when the drop spread out to the largest diameter after impact and the 60.7ms time is the time elapsed till the accumulation process of the drop is completed. This last time (60.7ms) is found to be variable with drop height as noticed in the figure. Physically the spreading and accumulation process is dependent on the surface tension, viscosity of the water and the inertia of a drop after impact. Velocity contours at different heights (H) of 10, 30 and 60cm and time steps of 0.1ms, 5ms and 60.7ms show the complex flow behavior after impact. At the instance of drop impact the surface (at 0.1ms) the highest velocities occurs at the drop - plate contact point and it's nearly equal to that calculated by gravity motion law. As the time elapsed after impact the fluid pattern and velocity changes in a complex manner indicating the variation in the forces affecting the fluid (water). Ref (1) discussed these forces and the pressure contours within the drop after impact. Velocity contours also clearout the symmetrical behavior which collapse as the time elapsed after impact and the tendency for maximum velocities to occur within the drop mass and not just at the interface boundaries.

Temperature contours for the drop and plate boundaries represent the variation in the plate temperature after impact. Such variation is noticed to be within 5C° range. This temperature difference value agrees with Ref. (1) results for a plate temperature of 50 C° when different drop to plate temperature differences are tested.

The temperature contours also show a fluctuation in the thin plate temperature which is discussed on the basis of small mass of the plate due to the thin plate thickness (0.55mm) and the relatively high heat transfer coefficients encountered in such impact process as will be shown later. A deep look on the temperature contour clearout a thin thermal boundary layer at which relatively almost a big temperature variation exist. Ref (1) examine this layer and discuss its effect in transferring a certain heat flux level in the impact process and estimate its thickness by about 0.06 mm. Fig (5): A, B, C represent the local temperature and local heat transfer coefficients variations due to single drop impact at Tw= 25C° on the plate heated uniformly to a temperature at Ts = 50C° and elapsed time steps of 0.1ms, 5ms and 60.7ms for H=10, 30 and 60 cm respectively

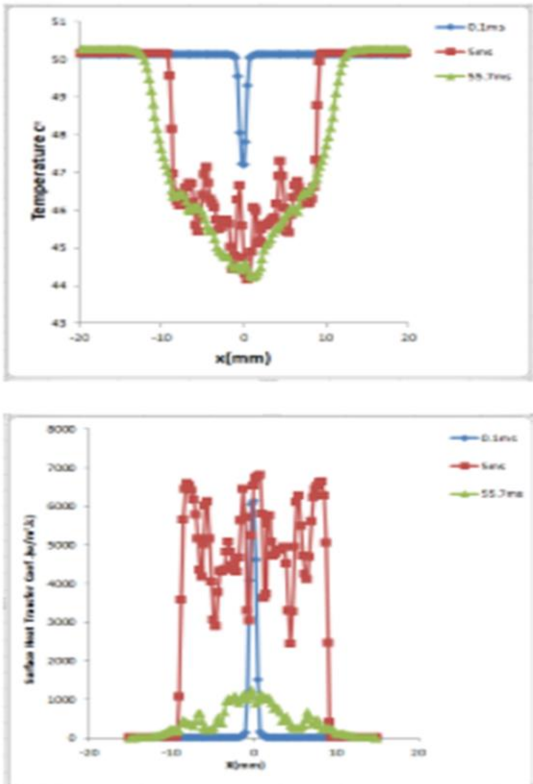
H=10 cm





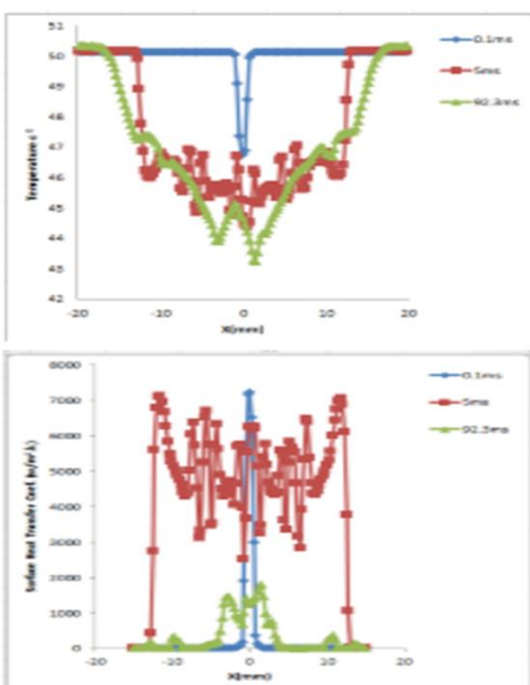
(A)

H=30 cm



(B)

H=60cm



(C)

Figure (5-A, B, C): variation of surface temperature and conjugated heat transfer coefficient of single drop. H=10cm, 30cm and 60cm,

The figure reveals the temperature and heat transfer coefficients variations in the radial direction and also show its variation with time elapsed after impact. The (0.1ms) results declares small values of temperature differences and heat coefficients in a smooth manner, while the variations become with higher values and in fluctuated manner reflecting the complex flow behavior in the drop after its impact on the plate. The variations are symmetrical in behavior in general about the impact point. The figure show smaller affected zone at the start of impact , then widening affected areas as the drop spread away with the tendency for high fluctuation in surface temperature and heat transfer coefficient specially at time interval of 5ms.

Figure (6) A, B, C: declares the VOF, velocity and temperature contours at drop- plate heights of H= 10, 30 and 60 cm respectively. For the condition of a double drops.

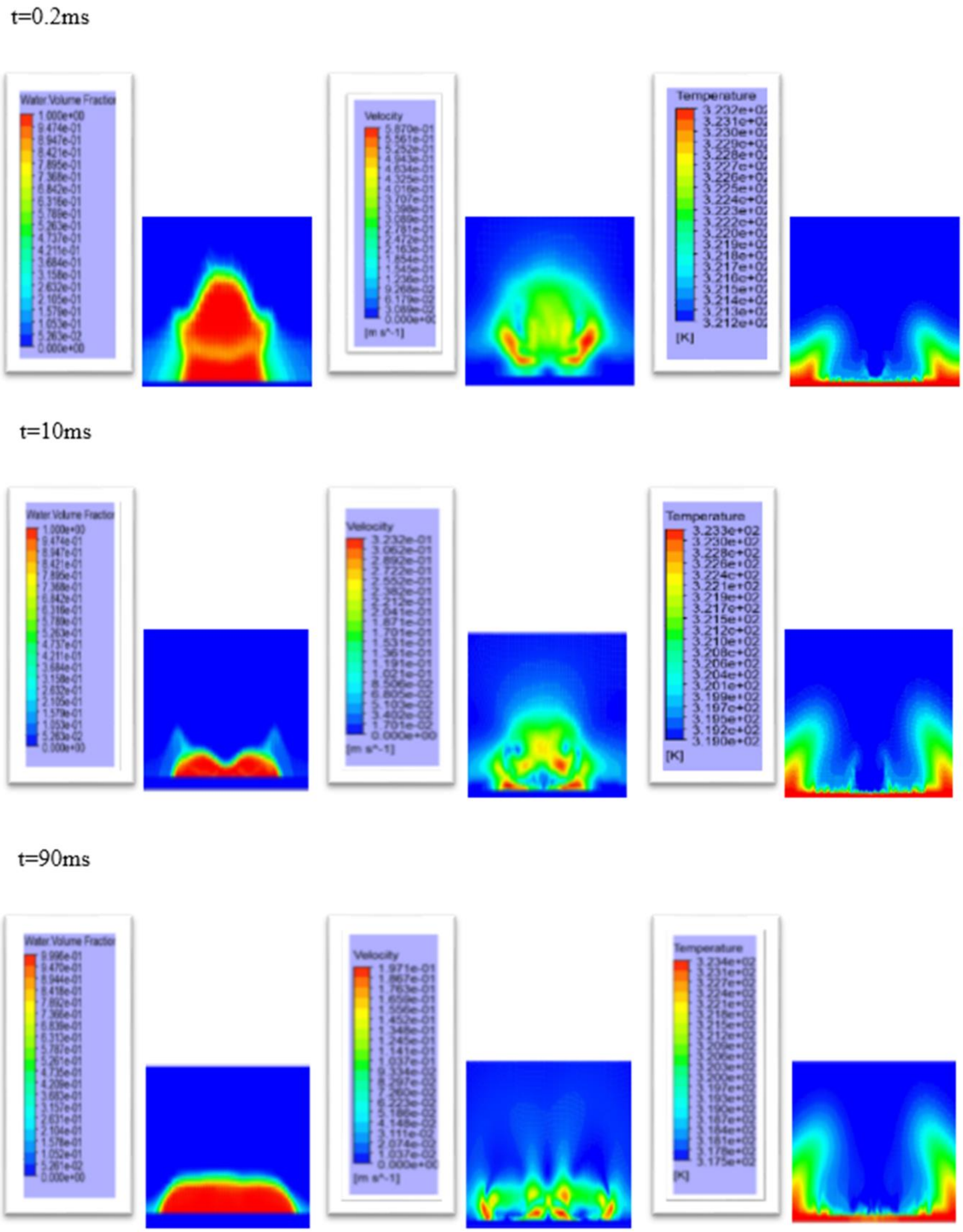


Figure (6-A): Numerical results for double drops, VOF, velocity, temperature of plate at elapsed times of (0.2ms, 10ms, and 90ms) after impact. H=10cm

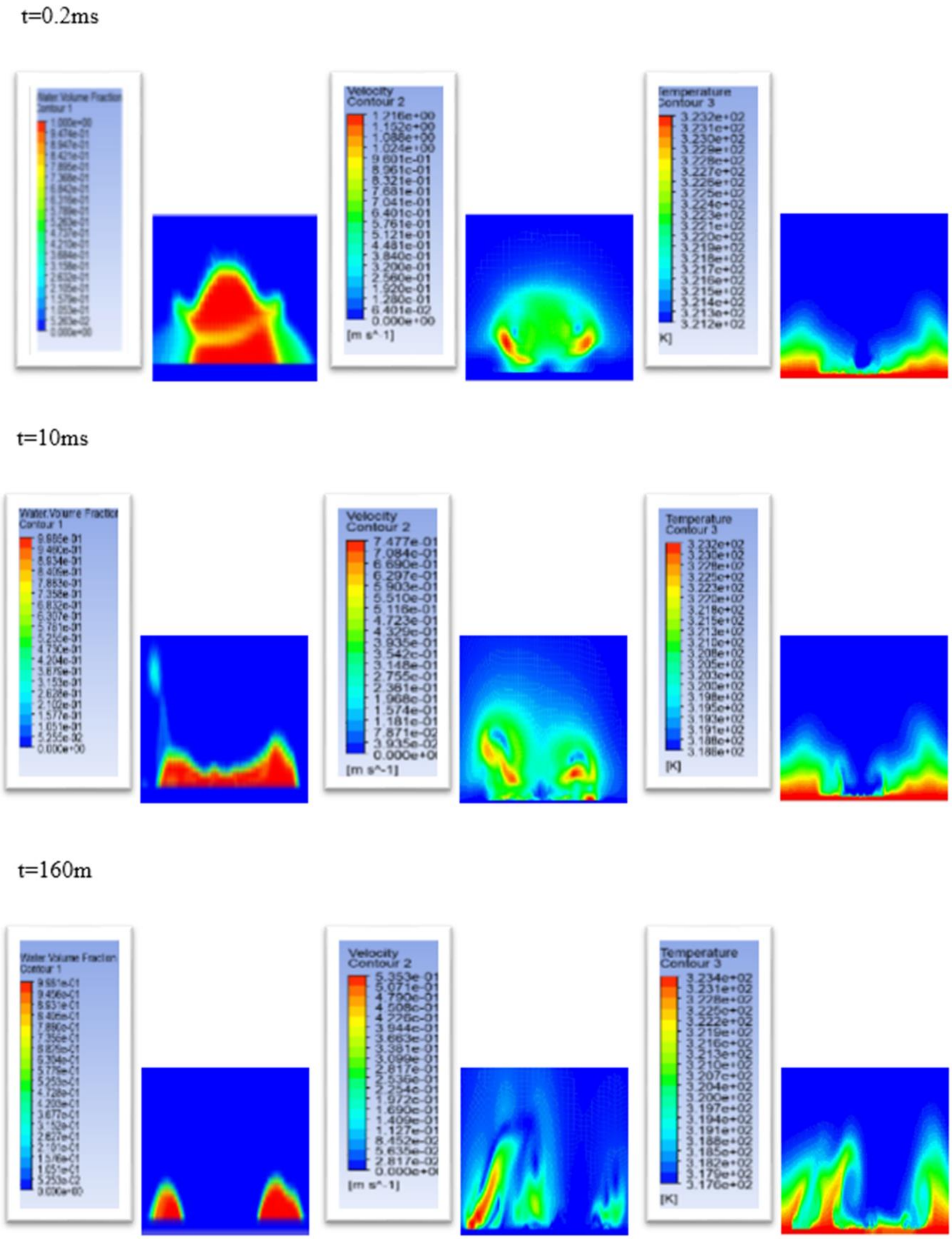


Figure (6-B): Numerical results for double drops, VOF, velocity, temperature of plate at elapsed times of (0.2ms, 10ms, and 160ms) after impact. H=30cm

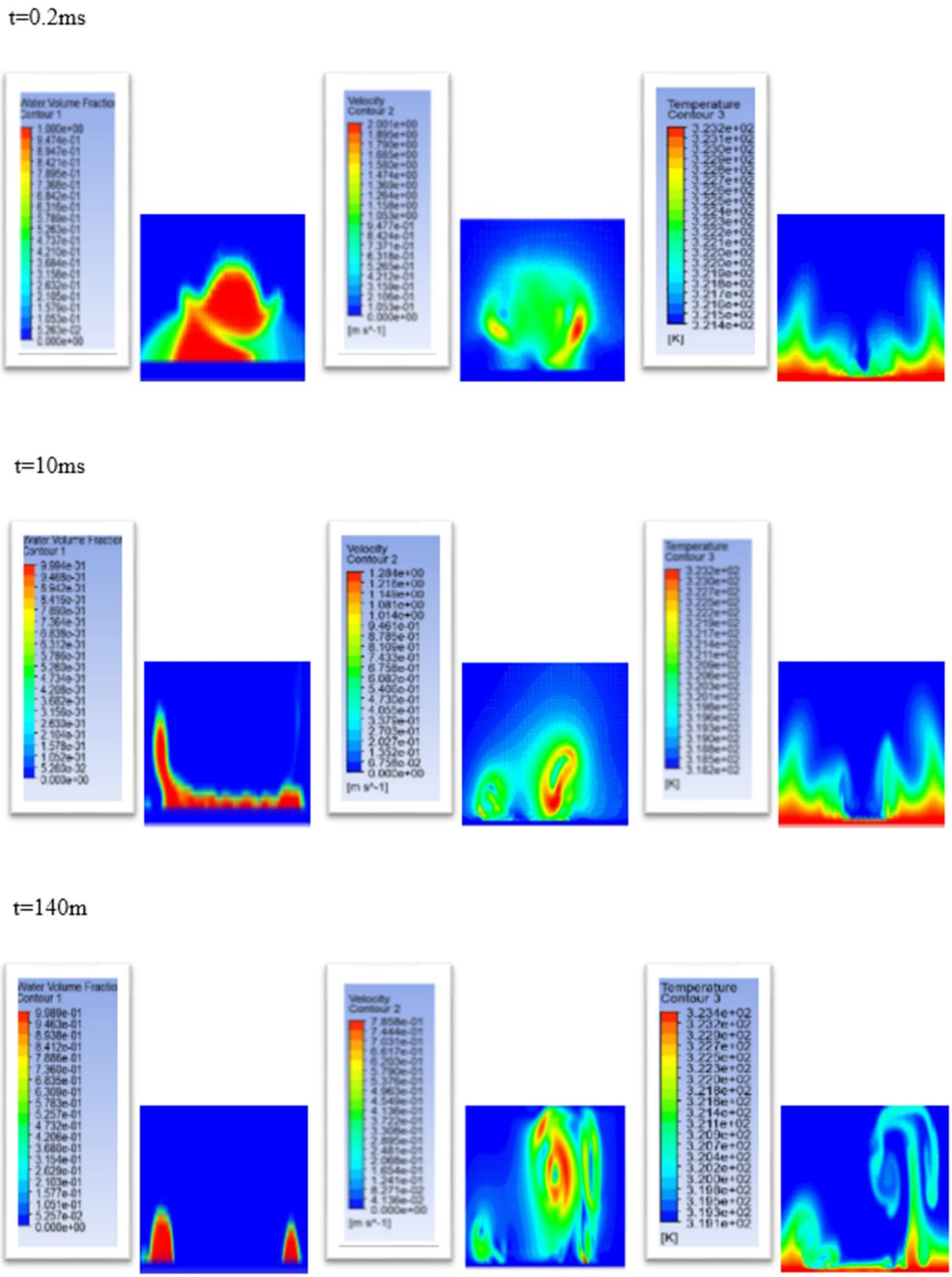


Figure (6-C): Numerical results for double drops, VOF, velocity, temperature of plate at elapsed times of (0.2ms, 10ms, and 140ms) after impact. H=60cm

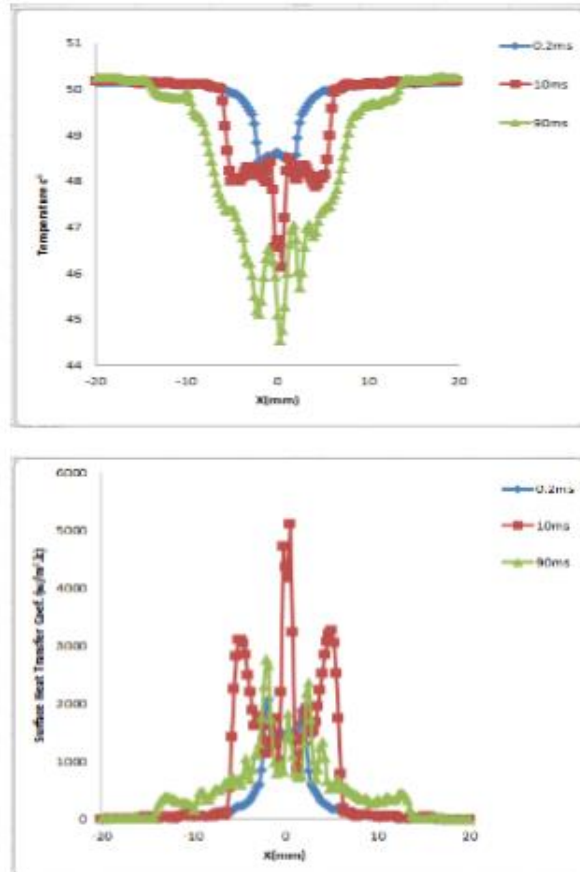
For the condition of double drops, the time elapsed after start of impact is chosen as 0.2, 10 and third time is taken as variable to describe the tendency of reaccumulation process after the second drop impact on the first one.

The time steps is doubled to compare the flow behavior at relatively the same time elapsed of the single drop case. The figure reveals relatively same VOF flow behavior of single drop at H=10cm, while a different behavior is noticed for H=30 cm and H=60 cm conditions with a tendency for separation of the resultant drop shape after impact indicating a high deformation rate due to the inertia of the second drop impact. This tendency for separation will keep a central zone without fluid coverage and burnout condition may occur in case of high heat flux or high temperature of the heated plate.

The velocity contours show that the velocity within the resultant mass drop is variable in a severe manner and maximum velocities occur at random zones within the drop after impact. The temperature contours within the drop and on the plate declares the unsymmetrical shape and indicates the separation effects. As noticed in the figure, sometimes the thermal and velocity boundaries of the drop and the plate cannot be distinguished from each other specially at bigger H values in contrast to the results of single drop and small heights (H=10cm) of the double drops condition.

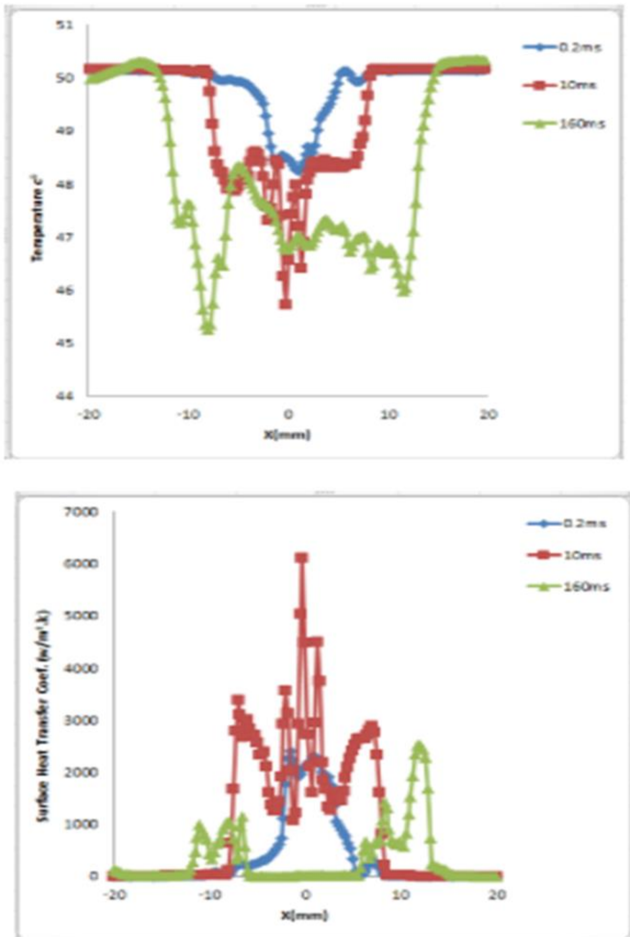
Fig (7): A, B.C shows the temperature distribution and heat transfer variations on the plate after certain steps of time when impact of the first single drop starts. The figure are for H=10, 30 and 60 cm respectively.

H=10cm



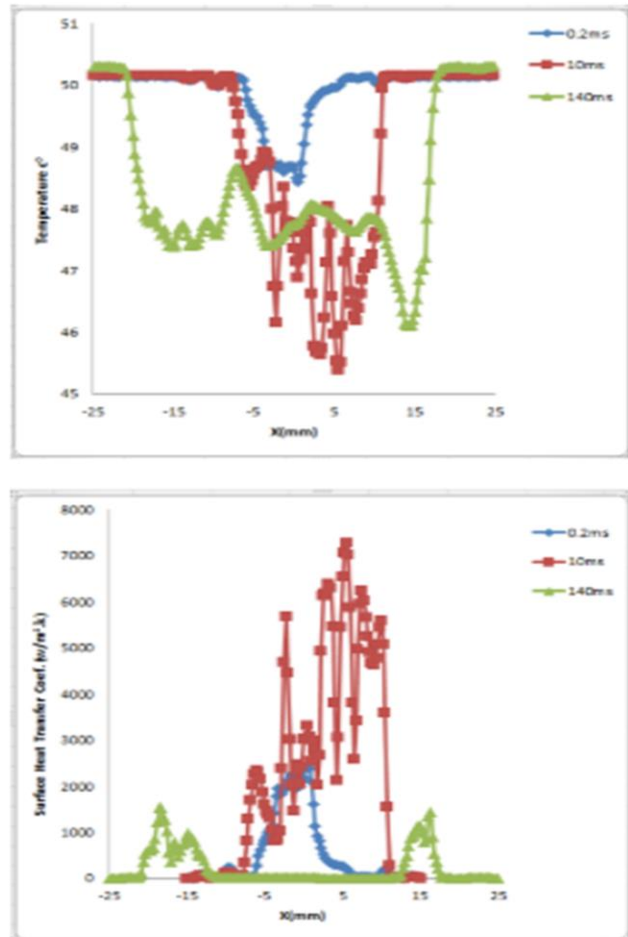
(A)

H=30cm



(B)

H=60cm

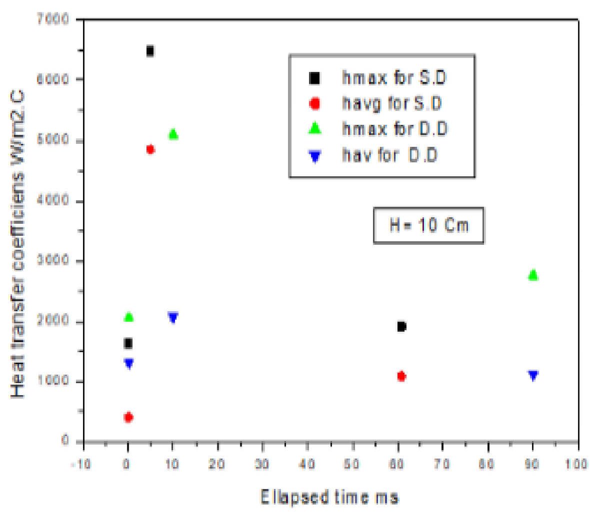


(C)

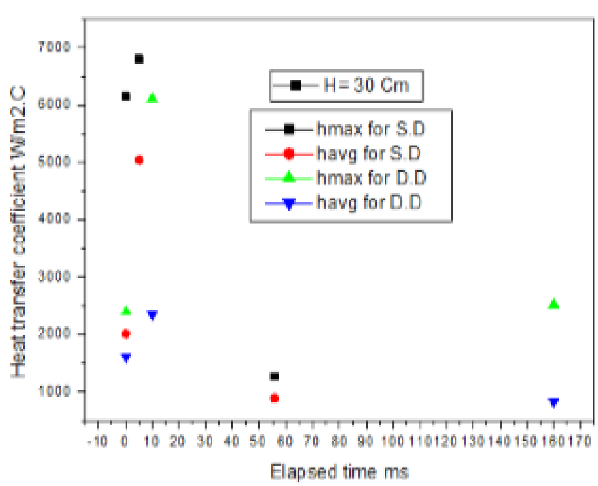
Figure (7-A, B, C): variations of surface temperatures and conjugated heat transfer coefficients during impact for double drops conditions. For H=10, 30 and 60cm.

As the case with the single drop, variations in the plate temperature and heat transfer coefficients in the impact zone can be related to the flow behavior which can be discussed on the basis of two main physical factors affecting it, the inertia forces which increase the pressure of water at certain zones within the drop that enforce the drop molecules to either spread or separate depending on the level of pressure energy within the impinged drop.

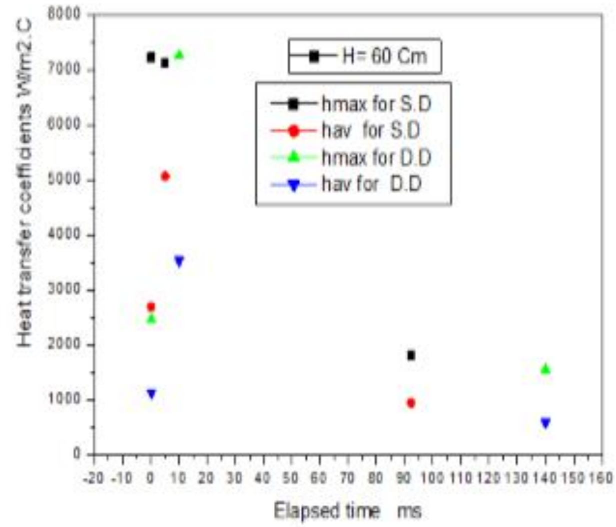
The other force which tends to reaccumlate the drop is the surface tension forces which tends to restrict the molecules separation and keep it to attach each other. The frictional effect is limited at the contact zone between the drop and the plate and may be neglected due to relatively small velocities and smooth plate surface. The unsymmetrical behavior and fluctuated values of temperature and heat coefficients are noticed specially at the longer time steps elapsed after impact of the second drop.



(A)



(B)



(C)

Figure (8) A, B, C: declares the hmax and hav variation during impact of single drop and double drops on the heated plate for H=10, 30 and 60 cm respectively.

At small drop to plate distance of 10 cm the maximum heat coefficients is with relatively small values and the differences than average values is moderate reflecting uniform flow behavior within the drop and relatively small velocities. This behavior is noticed for both single drop and double drops conditions. On the contrary for single drop at H=30cm and H=60cm, the hmax values start with big values at start of impact with big difference to the average values indicating localized effect at small zone of the plate. The double drop behavior is different it, starts with relatively small hmax and hav values reflecting the effect of water drop accumulation in reducing heat rate values. As the time elapsed increases both hmax and hav also increase at the second time step of 5ms and 10ms for single drop and double drops respectively. When reaching the reacumlation mode, the hmax and hav become with relatively small values due to small kinetic energy within the drop and the tendency to the drop to be in static condition. The higher maximum and average heat transfer coefficient values are expected to increase as the H values increase and this behavior will occur at a time period just after the drop impact condition. This expected for the single and double drops cases. Fig (9) represent minimum temperature measured on the heated plate. The figure declares that single drop impact is relatively more effective in reducing the plate temperature relative to the double drops. This is attributed to higher heat transfer coefficient in the case of single drop and the tendency for separation when the double drops process is used. This conclusion may look unimportant due to small temperature difference in this low difference case but it is expected to be important and effective at high temperature difference case if single phase continues

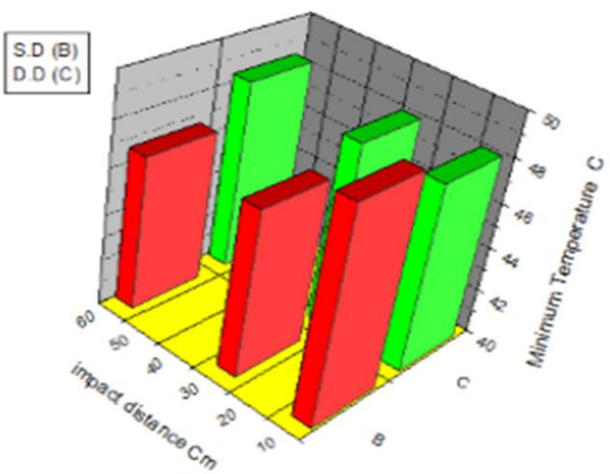


Figure 9. Minimum temperature reached during single drop and double drop impingement process.

7. Conclusions

The present results show the following

1- The same flow behavior of fluid flow spreading and separation tendency given by ref (1) when using the VOF model. This results are for single drop condition.

2- The small drop to plate starting distance show the tendency for spreading while the big distances give the tendency for separation or rebounding condition.

3- The double drops case show a higher tendency for separation and a difficulty for reacumulation process, especially as the H heights values are increased.

4- Heat transfer coefficients distribution is symmetrical during single drop condition with a smooth uniform distribution.

5- For double drops impingement process, low values of heat transfer coefficients are noticed with same behavior when compared with single drop case. As the H values increased the heat transfer rate became with relatively lower values and non-uniform in distribution giving a chance for dry out at the central zones of the impingement area.

6- The tendency to fluctuated values of local heat transfer coefficient are noticed at spreading and reacummulation periods. For both single drop and double drops cases.

7- The unsymmetrical distribution of temperature and heat transfer coefficient are noticed at the bigger drop to plate distances with the tendency for single drop condition to give lower minimum temperatures during the impact process.

Conflict of interest

The publication of this article cause no conflict of interest.

Abbreviations

V=velocity vector
ρ=density
t=time
C = coefficient of surface curvature

σ = surface tension
g=gravitational acceleration
I=unit tensor
P= pressure
S.D =Single drop
D.D = Double drop
hmax = maximum heat transfer coefficient
hav = average heat transfer coefficient
VOF = fractional volume of fluid
Temp = Temperature

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