التنبؤ بالقطرات الناتجة من تذرير نافوري باستخدام رشاشات المياه المحورية لتحسين الظروف المناخية

د. أشرف بن علوي بلابل

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الملخص الإنجليزى:

Abstract:

The integrated simulation of the atomization of round liquid jets by coaxial gas flow is considered as one of the most important multiphase phenomenon commonly encountered in nature, engineering applications and as a synthetic process to improve the climate conditions during Hajj. However, the dynamics of the phase interface is highly complex, poorly understood, and remains an unresolved problem in the area of atomization simulation. The use of coaxial jets is widespread in the context of air blast atomization, that is to say high-speed gas assisted spray formation. The coaxial jets geometry, operating with a large outer (annular) to inner (central) momentum ratio is used for its ability to destabilize fragment and mix the central stream in the outer, rapid stream. These advantages of coaxial liquid jet atomization over those of a single jet have motivated the present research paper.

The purpose of this paper is to investigate the topological changes of the liquid jet, as it becomes destabilized by a coaxial gas stream. By assuming a turbulent environment, the effect of the relative velocity between the two streams on the deformation and breakup of the liquid jet is investigated. The interfacial stresses between the two streams are modelled on the basis of RANS equations and the level set method, which simultaneously; predict the topological changes of the central liquid jet. Consequently, the spatial characteristics of the instabilities that develop at the interface between the two streams can be predicted and the mechanism of the breakup process is recognized .

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تشهد المملكة العربية السعودية في مواسم الحج والعمرة ظروفا مناخية خاصة من حيث شدة درجة الحرارة وإرتفاع نسبة الرطوبة والأتربة الصدرية وقوة الإشعاع الشمسي من أشعة تحت الحمراء أو فوق البنفسجية مما يؤثر علي الحالة الصحية لرواد المشاعر المقدسة والمسجد الحرام ويؤدي ذلك إلي إنتشار أمراض الجهاز التنفسي والأوبئة بين حجاج بيت الله الحرام مما يؤدي إلي خطورة تطور تلك الأمراض إلي أمراض معدية متحورة أو أوبئة غير قابلة للعلاج الطبي.

وطبقا لتوصيات الدراسات السابقة الخاصة بذلك فقد تم وضع بعض الحلول والمقترحات التي تساعد على تحسين البيئة الهوائية بالمسعى والساحات المفتوحة بأماكن المشاعر المقدسة والتي كان من أهمها ضرورة تكييف المسعى مركزيا وعمل نظام تنقية هواء به للتقليل من انتشار الأتربة الصدرية ومستويات الضوضاء ولتوفير جوا أكثر ملائمة للحجاج. كما أكدت الدراسات السابقة على أهمية استخدام رشاشات الماء الرذاذية في الساحات المفتوحة وأماكن المشاعر

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هذا وقد شارك الباحث الرئيسي للبحث المقدم في مشروع بحثي سابق بالتعاون مع فريق العمل بجامعة الملك عبد العزيز وذلك لدراسة استخدام رشاشات مياه أحادية محورية لتحسين الظروف المناخية خلال موسم الحج للعام ١٤٢١هـ. وقد إنتهت الدراسة إلي إستنتاج نموذج عددي وتحليلي يستطيع التنبأ بأقطار قطرات الماء الناتجة من عملية التذرير للماء من خلال رشاشات ذات أقطار مختلفة.

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هذا وتتناول ورقة العمل المقدمة المحاكاة العددية لتذرير نافوري متحد المحور ذو سريان إضطرابي من خلال حل معادلات الحركة المعروفة بإسم معادلات رينولدز وطريقة مجموعة المستويات العددية التي تستطيع التنبأ بعملية التذرير للنافوري المحوري وتكوين القطرات ذات الأقطار المختلفة وكذلك توصيف التغيرات الطوبولوجية لسطح المائع المتحرك.

مقدمة البحث:

Introduction:

The atomization of a liquid jet is one of the challenging problems in computational physics as it involves complex interface topology of large coherent liquid structures where the dynamics of the phase interface is highly complex, poorly understood, and remains an unresolved problem in the area of atomization simulation [1].

The atomization process can be divided into two subsequent processes: i.e., primary atomization followed by secondary atomization. The primary atomization is the initial breakup of the liquid jet into large and small liquid structures. It involves complex interface topology of large coherent liquid structures. The secondary atomization is the subsequent breakup into smaller drops forming sprays. Consequently, different modelling strategies are needed to capture the distinct physical processes involved in each regime [2].

Although many researches have been devoted to numerical simulation of atomization process, a few methods are able to treat accurately atomization, especially primary break-up. Usually most models applied for droplets tracking, in the secondary atomization regime, are based on a Lagrangian approach. But this kind of model is not well adapted to describe the shear-coaxial primary atomization. Indeed, most of them assume that all liquid fragments are spherical. Moreover, the spray is very dense in the primary break-up region, involving a lot of strong exchanges between the two phases, which cannot be taken into account simply in a Lagrangian manner

Although the coaxial liquid jet has the ability to destabilize fragment and mix the central stream in the outer rapid stream, most of the previous researches were focused on the numerical simulation of the primary breakup of a single jet, while the coaxial liquid jet was received relatively less attention [3].

Figure 1-a, -b shows the configuration of three different configuration of simple jet, coflowing jet and coaxial jet, as shown in [4].

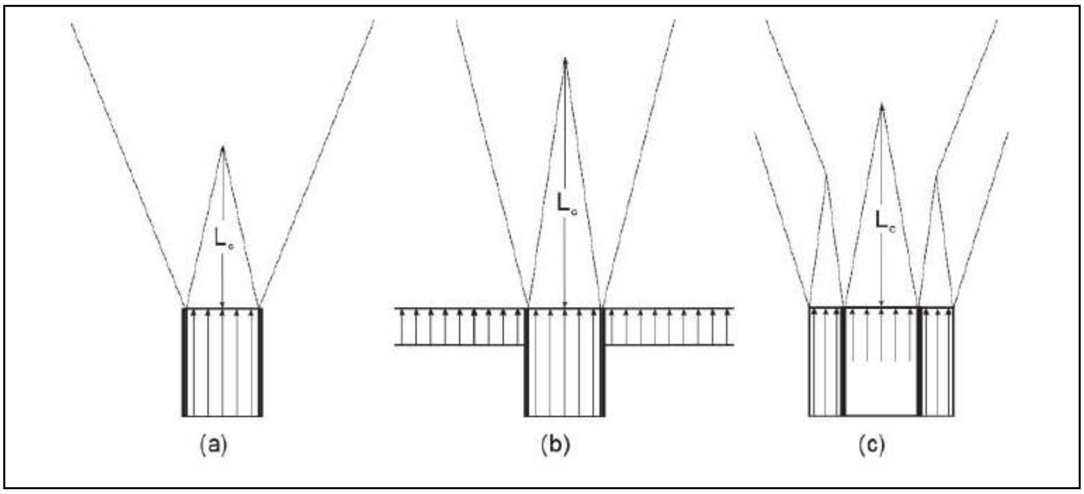


Figure 1 Different configuration and shear layer development for (a) Single jet, (b) coflowing jet, (c) coaxial jet.

As it can be seen from Figure 1, the complex near field mixing structure of coaxial jet plays a significant role in the atomization of the liquid core jet and the final droplet size produced.

The breakup and atomization of a liquid jet injected into a high-speed gas stream is fundamentally different from that which occurs for the same jet discharging into a stagnant gaseous environment. When the gas stream momentum flux is of the same order, or in excess of that of the liquid jet, the atomization is achieved through a kinetic energy transfer from the gas to the liquid. This type of atomization is known as air-assist atomization.

The instability arises at the interface of parallel gas flow and central liquid stream has been previously studied by many investigators (e.g. [5-9]). Raynal [9] has shown that the wavelength of the instability, developed at the gas-liquid interface in coaxial jets, is strongly dependent on the gas vorticity thickness and the density ratio of the two streams. Amplification of this primary wave structure leads to the formation of axisymmetric or helical wave sheets which eventually breakup into droplets. The mechanisms of formation and breakup of these wave sheets or liquid tongues are still poorly understood. These mechanisms are expected to depend strongly on the aerodynamic Weber number, as known from studies of drop breakup in high-speed gas streams [10-12].

Recently, there is a great attention has turned to the detailed researches in order to improve climate conditions during Ramadan and also Hajj [13-15]. These previous researches have recommended that a multi-jet water sprays should be used in order to soften the climate conditions during Ramadan Season and Hajj.

The present author of the current research has contributed in a previous research project [15] dealing with the prediction of droplets size and numbers resulting from the breakup of a single water jet issuing from wide range nozzle diameters into a stagnant air.

The focus of the present research is geared towards the development of a computational method for the prediction of the topological changes and the formation of the ligaments and droplets in the breakup process of a coaxial water jet issuing in a parallel gas stream with a specified relative velocity. The breakup and the following characteristics of small droplets formed in the jet surface are also predicted. The numerical method is based on solving the Reynolds-Averaging Navier-Stokes equations coupled with the level set method.

منهجية البحث:

The main objectives of this research project are to:

- Develop an effective numerical method to deal with the breakup of coaxial liquid jets.
- Validate the numerical method against the previous well established test cases.
- Discuss the effect of relative velocity of the coaxial streams on the deformation and breakup of the coaxial liquid jets.
- Gain an insight into the highly complex mechanism of the atomization of the coaxial liquid jets.

The Governing Equations

The sketch of the coaxial jet with two immiscible fluids (water-air) is shown in Figure 2, as presented in [16].

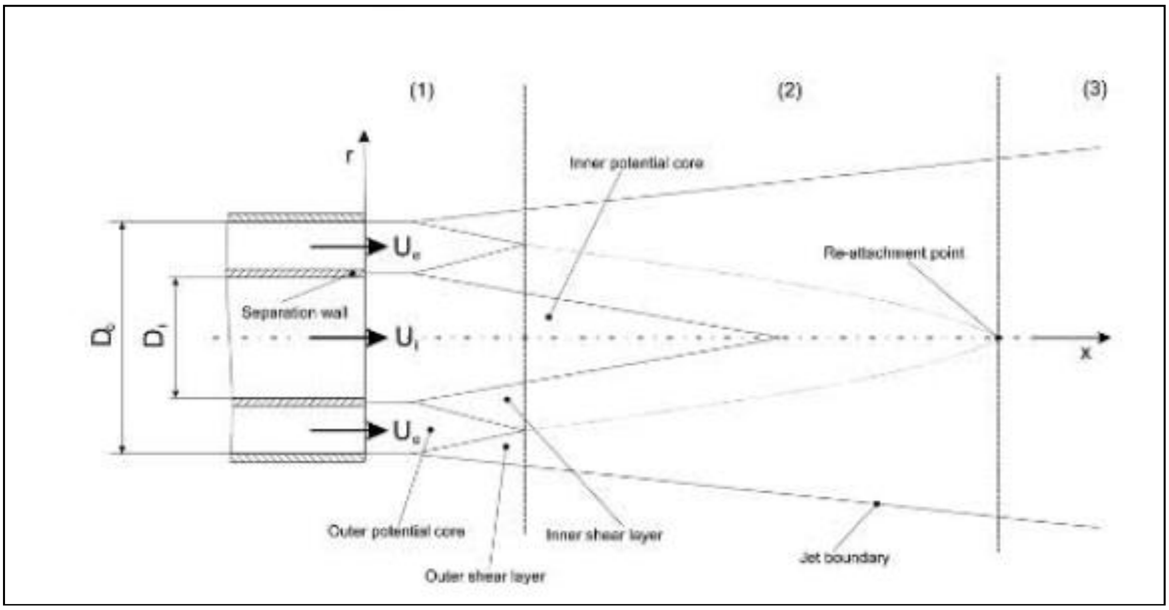


Figure 2. The sketch of coaxial jet

The governing equations to the existing model of coaxial jet with two immiscible fluids are considered in the following. Each fluid has its own material properties ρ_α and μ_α (α=1, 2), where the subscript α = g or l indicates the gas and the liquid phase presented at a given point in space. Following the Reynolds averaging procedure, the unsteady Reynolds-averaged Navier-Stokes (RANS) equations, applied separately in each fluid domain and coupled with the standard k-ε model for predicting the turbulent characteristics can be written as follows:

$$\nabla\cdot(\rho\bar{u}) = 0$$

(3)

$$\frac{\partial(\rho\bar{u})}{\partial t} + \nabla\cdot(\rho\overline{uu}) + \nabla p = \nabla\cdot(2\mu\hat{S} + \hat{\Re}_t)$$

(4)

$$\frac{\partial(\rho k)}{\partial t} + \nabla\cdot(\rho k\bar{u}) = \nabla\cdot(\mu + \mu_t/\Pr_k)\nabla k + 2\mu_t\hat{S}\hat{S} - \rho\varepsilon + G_k$$

(6)

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \nabla\cdot(\rho\varepsilon\bar{u}) = \nabla\cdot(\mu + \mu_t/\Pr_\varepsilon)\nabla\varepsilon + (C_{1\varepsilon}(2\mu_t\hat{S}\hat{S}) - C_{2\varepsilon}\rho\varepsilon)\varepsilon/k$$

(7)

In the above system of equations, ρ is the density, $\bar{u}$ is the velocity vector, p is the static pressure, μ is the molecular viscosity, μ_t is the turbulent viscosity, k is the turbulent kinetic energy, ε is the turbulent dissipation, the turbulent stress tensor $\hat{\Re}_t$ is given by:

$$\Re_{ij} = -\rho\overline{u_i'u_j'} = -\frac{2}{3}\rho k\delta_{ij} + 2\mu_t S_{ij}$$

(8) where δ_{ij} is the kronecker delta, $\overline{u_i'u_j'}$ is the average of the velocity fluctuations, the strain rate tensor and the turbulent viscosity can be described as:

$$S_{ij} = 0.5\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

$$\mu_t = \rho C_\mu k^2/\varepsilon$$

(10)

The coefficients for the standard k-ε turbulence model are given following: $C_\mu = 0.09, \Pr_k = 1, \Pr_\varepsilon = 1.3, C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92$.

Level set method

In the formulation of the level set method, the computational domain is divided into grid points containing the level set function ϕ, which is taken positive inside the liquid phase, negative in the gas phase and zero at the interface Γ. The update of the level set function with time can be determined by solving the following transport equation:

$$\frac{\partial \phi}{\partial t} + \bar{\mathbf{u}} \cdot \nabla \phi = 0$$

(14)

Since the interface is captured implicitly, the level set algorithm is capable of capturing the intrinsic geometrical properties of highly complicated interfaces in a quite natural way. Consequently, the normal vector and the curvature of the interface can be defined as:

$$\bar{\mathbf{n}} = \frac{\nabla \phi}{|\nabla \phi|}, \qquad \kappa = \nabla \cdot \bar{\mathbf{n}}$$

(15)

The time-stepping procedure for the level set equation is based on the second-order Runge-Kutta method. An important step in the solution algorithm of the level set function is to maintain the level set function as a distance function within the two fluids at all times, especially near the interface region, i.e. the Eikonal equation, $|\nabla \phi| = 1$; should be satisfied in the computational domain. This can be achieved each time step by applying the re-initialization algorithm described in for a specified small number of iterations.

Detailed discussion and improvement of such re-initialization algorithm can be found in our previous work [17], where a large number of the standard level set test cases have been performed and the mass conservative property is thoroughly discussed and evaluated.

Analytical method

The limiting case of interest for jet atomization is corresponding to the case where the droplet sizes are much smaller than the jet diameter. Following the asymptotic analysis of the system of the governing equation, described previously, on can obtain the analytical equation of the jet growth rate as a function of the water-air system properties.

$$(\omega + 2\nu_l k^2)^2 + f\,\frac{\sigma}{\rho_l} k^3 - 4\nu_l{}^2 k^3 \sqrt{k^2 + \frac{\omega}{\nu_l}} + \zeta \frac{\rho_g}{\rho_l} (\omega + iU_{rel} k)^2 = 0$$

The above equation is solved analytically to find out the effect of relative velocity (U_{rel}) on the growth rate of the liquid jet. It can be observed from Figure 3, that the increase in the relative velocity leads to an increase of the jet growth rate plotted against the wave length λ. That describes one of the important advantages of the coaxial jet over the simple jet configuration where the relative velocity has a significant effect on the breakup and the atomization processes.

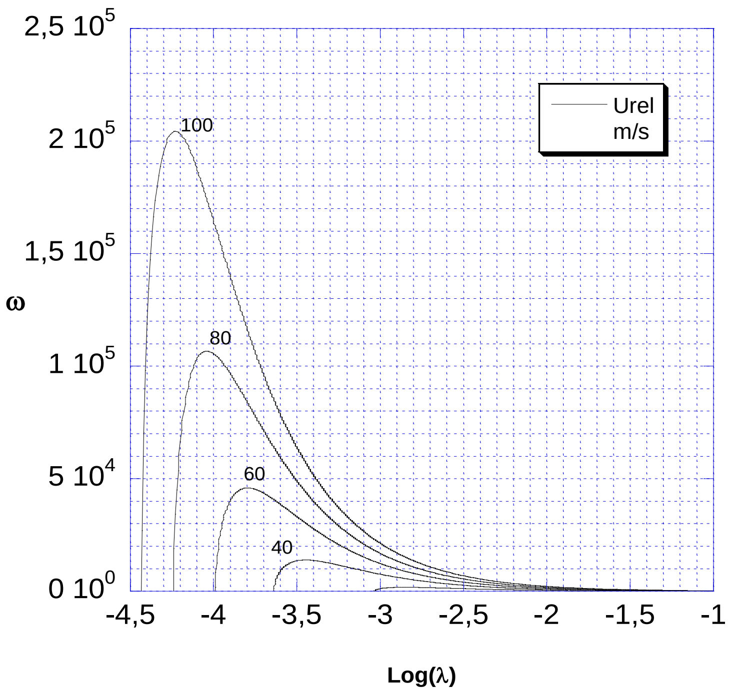


Figure 3. The effect of relative velocity on the jet growth rate

النتائج:

Results

The figures below (Figure 4-a, -b) show the configurations of the simple and coaxial water jet operating at the same conditions except that, in case of simple jet, the surrounding air velocity is assumed to be zero. In case of coaxial jet, the surrounding air velocity is assumed to be equal, but in the opposite direction, of the water jet velocity.

(a) $U_{rel}=50m/s$ (b) $U_{rel}=100m/s$

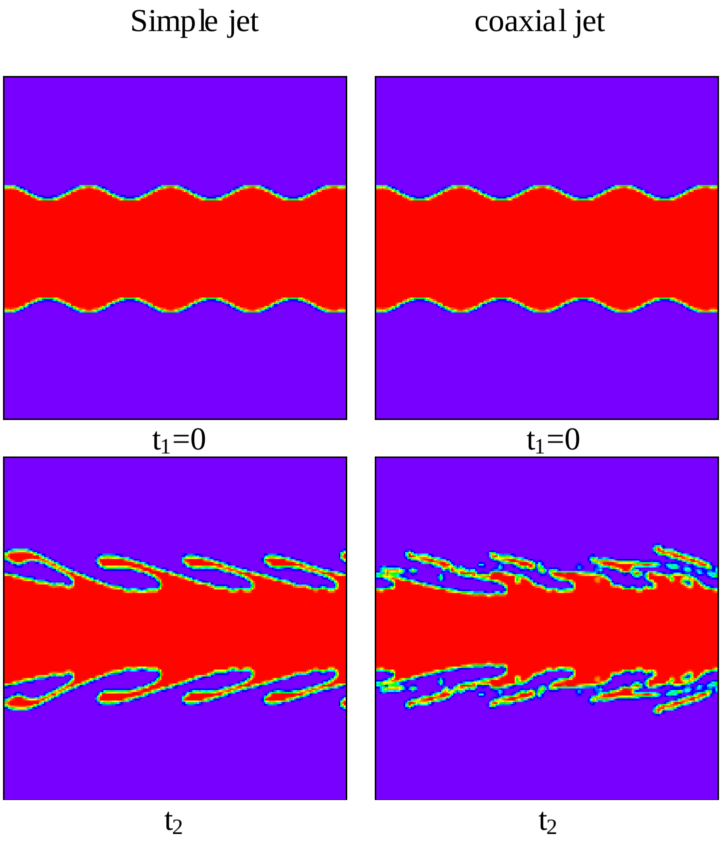
Figure 4. The configurations of (a) simple jet and (b) coaxial jet

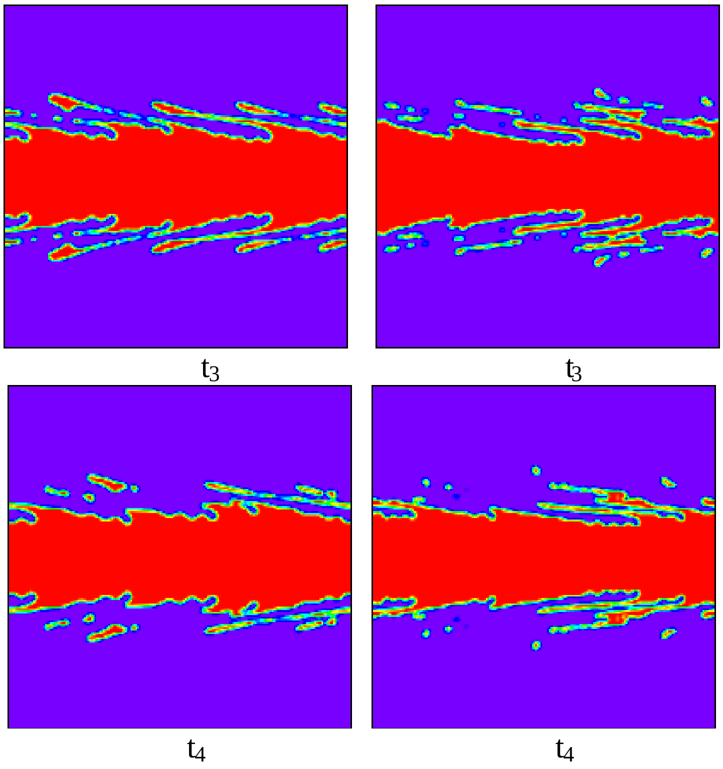
Table1. describes the different properties of the two fluids used in the numerical simulation performed. The Computer program used for the calculation is built by the present author using the FORTRAN language.

Property	Air flow	Liquid Jet
Density	1.0 kg/m^3	2 kg/m^3
Viscosity	1.5e-5 Pa. s	1.5e-5 Pa.s
Surface tension	0.0	0.02 N.m
Initial pressure	1 bar	1 bar
Radius	0.05m	0.025m

The figures below (Figure 5-a, -b) show the important results obtained from the numerical simulation performed for the simple and coaxial water jet operating at the same conditions except that, in case of simple jet, the surrounding air velocity is assumed to be zero. In case of coaxial jet, the surrounding air velocity is assumed to be equal, but in the opposite direction, of the water jet velocity.

The results showed that, the breakup of the liquid jet in case of coaxial jet is faster and the droplet size is smaller in comparison with the atomization process obtained from the normal simple jet.




t3 t3

t4 t4

(a) (b)

Figure 5. Comparison of the atomization process of liquid jet for coaxial liquid jet at different times
(a) Relative velocity=50m/s, (b) Relative velocity=100 m/s

الخلاصة:

Conclusions

The conclusions of the present work are summarized as follows:

1. The currently used fans in the free areas for improving the climate conditions are using the coflowing jet and that should be modified to coaxial jet in order to increase the atomization performance.
2. The required power of the motors, which driving the fans, should be estimated according to the required air velocity for optimum conditions of the atomization.
3. The nozzle design and the number of nozzles distributed over the circumferential of the fan should also be estimated to achieve the best conditions for atomization process.
4. In future work, the effects of the liquid issuing pressure, air temperature and air humidity ratio should be included in our simulation.

التوصيات:

Recommendation:

According to the numerical results obtained, the author recommends the application of the coaxial jet instead of the currently used coflowing jet in the atomization of water during Hajj and Omra after detailed investigations and the providing of design data.

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Introduction:

The atomization of a liquid jet is one of the challenging problems in computational physics as it involves complex interface topology of large coherent liquid structures where the dynamics of the phase interface is highly complex, poorly understood, and remains an unresolved problem in the area of atomization simulation [1].

The atomization process can be divided into two subsequent processes: i.e., primary atomization followed by secondary atomization. The primary atomization is the initial breakup of the liquid jet into large and small liquid structures. It involves complex interface topology of large coherent liquid structures. The secondary atomization is the subsequent breakup into smaller drops forming sprays. Consequently, different modelling strategies are needed to capture the distinct physical processes involved in each regime [2].

Although many researches have been devoted to numerical simulation of atomization process, a few methods are able to treat accurately atomization, especially primary break-up. Usually most models applied for droplets tracking, in the secondary atomization regime, are based on a Lagrangian approach. But this kind of model is not well adapted to describe the shear-coaxial primary atomization. Indeed, most of them assume that all liquid fragments are spherical. Moreover, the spray is very dense in the primary break-up region, involving a lot of strong exchanges between the two phases, which cannot be taken into account simply in a Lagrangian manner

Although the coaxial liquid jet has the ability to destabilize fragment and mix the central stream in the outer rapid stream, most of the previous researches were focused on the numerical simulation of the primary breakup of a single jet, while the coaxial liquid jet was received relatively less attention [3].

Figure 1-a, -b shows the configuration of three different configuration of simple jet, coflowing jet and coaxial jet, as shown in [4].

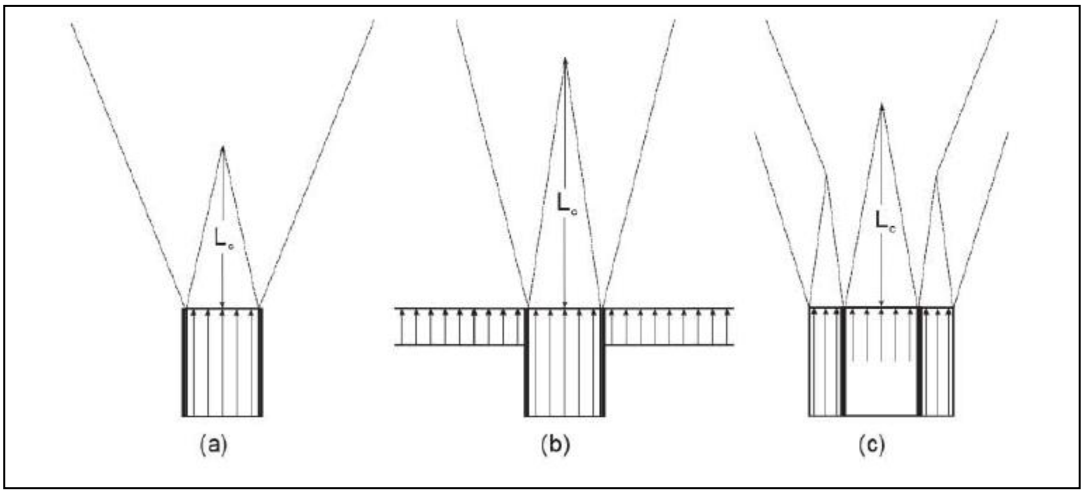


Figure 1 Different configuration and shear layer development for (a) Single jet, (b) coflowing jet, (c) coaxial jet.

As it can be seen from Figure 1, the complex near field mixing structure of coaxial jet plays a significant role in the atomization of the liquid core jet and the final droplet size produced.

The breakup and atomization of a liquid jet injected into a high-speed gas stream is fundamentally different from that which occurs for the same jet discharging into a stagnant gaseous environment. When the gas stream momentum flux is of the same order, or in excess of that of the liquid jet, the atomization is achieved through a kinetic energy transfer from the gas to the liquid. This type of atomization is known as air-assist atomization.

The instability arises at the interface of parallel gas flow and central liquid stream has been previously studied by many investigators (e.g. [5-9]). Raynal [9] has shown that the wavelength of the instability, developed at the gas-liquid interface in coaxial jets, is strongly dependent on the gas vorticity thickness and the density ratio of the two streams. Amplification of this primary wave structure leads to the formation of axisymmetric or helical wave sheets which eventually breakup into droplets. The mechanisms of formation and breakup of these wave sheets or liquid tongues are still poorly understood. These mechanisms are expected to depend strongly on the aerodynamic Weber number, as known from studies of drop breakup in high-speed gas streams [10-12].

Recently, there is a great attention has turned to the detailed researches in order to improve climate conditions during Ramadan and also Hajj [13-15]. These previous researches have recommended that a multi-jet water sprays should be used in order to soften the climate conditions during Ramadan Season and Hajj.

The present author of the current research has contributed in a previous research project [15] dealing with the prediction of droplets size and numbers resulting from the breakup of a single water jet issuing from wide range nozzle diameters into a stagnant air.

The focus of the present research is geared towards the development of a computational method for the prediction of the topological changes and the formation of the ligaments and droplets in the breakup process of a coaxial water jet issuing in a parallel gas stream with a specified relative velocity. The breakup and the following characteristics of small droplets formed in the jet surface are also predicted. The numerical method is based on solving the Reynolds-Averaging Navier-Stokes equations coupled with the level set method.

منهجية البحث:

The main objectives of this research project are to:

- Develop an effective numerical method to deal with the breakup of coaxial liquid jets.
- Validate the numerical method against the previous well established test cases.
- Discuss the effect of relative velocity of the coaxial streams on the deformation and breakup of the coaxial liquid jets.
- Gain an insight into the highly complex mechanism of the atomization of the coaxial liquid jets.

The Governing Equations

The sketch of the coaxial jet with two immiscible fluids (water-air) is shown in Figure 2, as presented in [16].

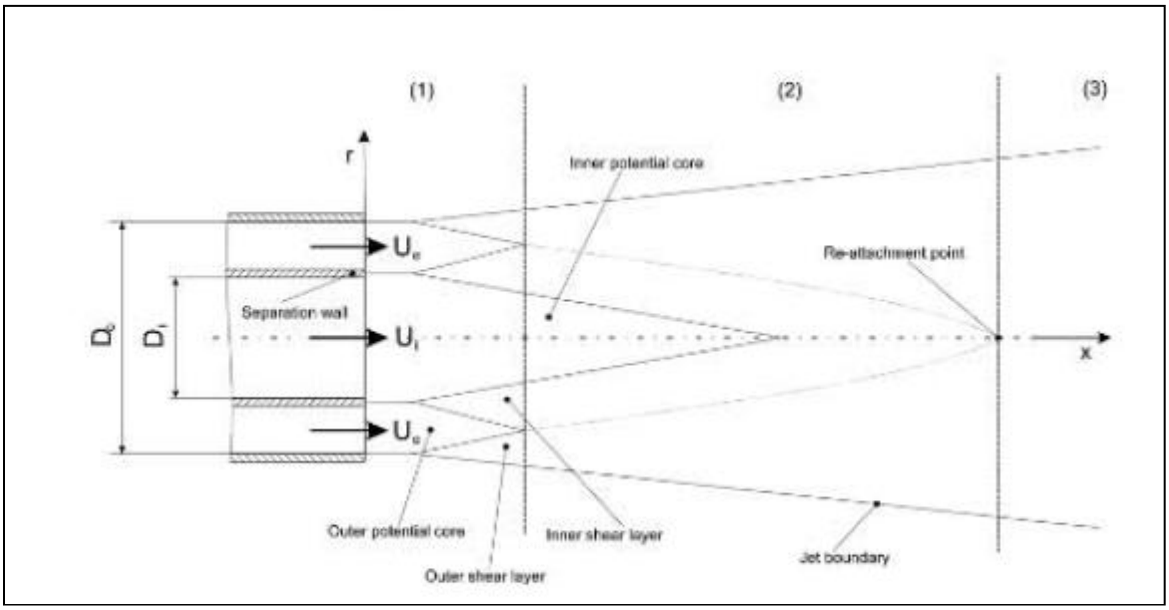


Figure 2. The sketch of coaxial jet

The governing equations to the existing model of coaxial jet with two immiscible fluids are considered in the following. Each fluid has its own material properties ρ_α and μ_α (α=1, 2), where the subscript α = g or l indicates the gas and the liquid phase presented at a given point in space. Following the Reynolds averaging procedure, the unsteady Reynolds-averaged Navier-Stokes (RANS) equations, applied separately in each fluid domain and coupled with the standard k-ε model for predicting the turbulent characteristics can be written as follows:

$$\nabla\cdot(\rho\bar{u}) = 0$$

(3)

$$\frac{\partial(\rho\bar{u})}{\partial t} + \nabla\cdot(\rho\overline{uu}) + \nabla p = \nabla\cdot(2\mu\hat{S} + \hat{\Re}_t)$$

(4)

$$\frac{\partial(\rho k)}{\partial t} + \nabla\cdot(\rho k\bar{u}) = \nabla\cdot(\mu + \mu_t / \mathrm{Pr}_k)\nabla k + 2\mu_t\hat{S}\hat{S} - \rho\varepsilon + G_k$$

(6)

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \nabla\cdot(\rho\varepsilon\bar{u}) = \nabla\cdot(\mu + \mu_t / \mathrm{Pr}_\varepsilon)\nabla\varepsilon + (C_{1\varepsilon}(2\mu_t\hat{S}\hat{S}) - C_{2\varepsilon}\rho\varepsilon)\varepsilon / k$$

(7)

In the above system of equations, ρ is the density, $\bar{u}$ is the velocity vector, p is the static pressure, μ is the molecular viscosity, μ_t is the turbulent viscosity, k is the turbulent kinetic energy, ε is the turbulent dissipation, the turbulent stress tensor $\hat{\Re}_t$ is given by:

$$\Re_{ij} = -\rho\overline{u_i'u_j'} = -\frac{2}{3}\rho k\delta_{ij} + 2\mu_t S_{ij}$$

(8) where δ_{ij} is the kronecker delta, $\overline{u_i'u_j'}$ is the average of the velocity fluctuations, the strain rate tensor and the turbulent viscosity can be described as:

$$S_{ij} = 0.5\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

$$\mu_t = \rho C_\mu k^2 / \varepsilon$$

(10)

The coefficients for the standard k-ε turbulence model are given following: $C_\mu = 0.09, \mathrm{Pr}_k = 1, \mathrm{Pr}_\varepsilon = 1.3, C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92$.

Level set method

In the formulation of the level set method, the computational domain is divided into grid points containing the level set function ϕ, which is taken positive inside the liquid phase, negative in the gas phase and zero at the interface Γ. The update of the level set function with time can be determined by solving the following transport equation:

$$\frac{\partial\phi}{\partial t}+\bar{\mathbf{u}}\cdot\nabla\phi=0$$
(14)

Since the interface is captured implicitly, the level set algorithm is capable of capturing the intrinsic geometrical properties of highly complicated interfaces in a quite natural way. Consequently, the normal vector and the curvature of the interface can be defined as:

$$\bar{\mathbf{n}}=\frac{\nabla\phi}{\left|\nabla\phi\right|}, \qquad \kappa=\nabla\cdot\bar{\mathbf{n}}$$
(15)

The time-stepping procedure for the level set equation is based on the second-order Runge-Kutta method. An important step in the solution algorithm of the level set function is to maintain the level set function as a distance function within the two fluids at all times, especially near the interface region, i.e. the Eikonal equation, $\left|\nabla\phi\right|=1$; should be satisfied in the computational domain. This can be achieved each time step by applying the re-initialization algorithm described in for a specified small number of iterations.

Detailed discussion and improvement of such re-initialization algorithm can be found in our previous work [17], where a large number of the standard level set test cases have been performed and the mass conservative property is thoroughly discussed and evaluated.

Analytical method

The limiting case of interest for jet atomization is corresponding to the case where the droplet sizes are much smaller than the jet diameter. Following the asymptotic analysis of the system of the governing equation, described previously, on can obtain the analytical equation of the jet growth rate as a function of the water-air system properties.

$$(\omega+2\nu_l k^2)^2+f\frac{\sigma}{\rho_l}k^3-4\nu_l^{\,2}k^3\sqrt{k^2+\frac{\omega}{\nu_l}}+\zeta\frac{\rho_g}{\rho_l}(\omega+iU_{rel}k)^2=0$$

The above equation is solved analytically to find out the effect of relative velocity (U_{rel}) on the growth rate of the liquid jet. It can be observed from Figure 3, that the increase in the relative velocity leads to an increase of the jet growth rate plotted against the wave length λ. That describes one of the important advantages of the coaxial jet over the simple jet configuration where the relative velocity has a significant effect on the breakup and the atomization processes.

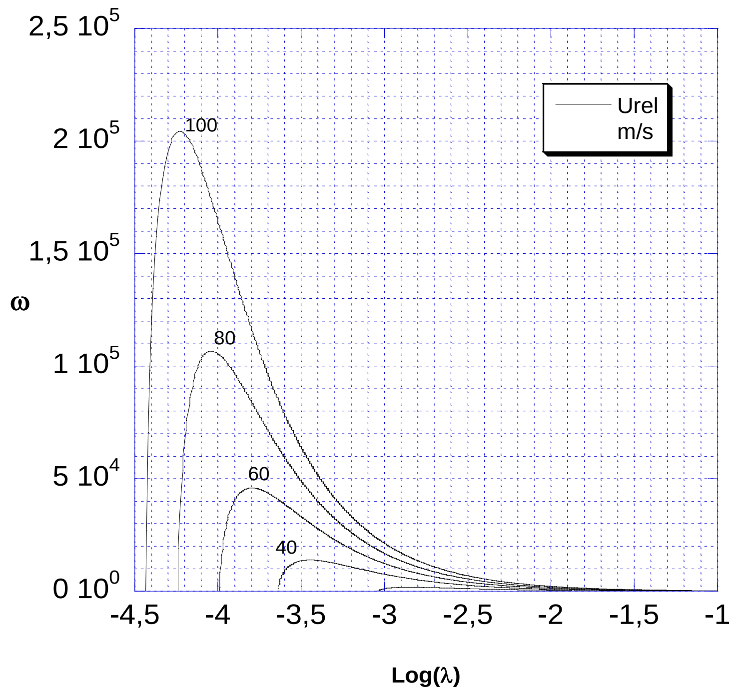
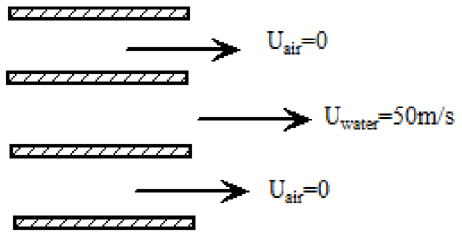


Figure 3. The effect of relative velocity on the jet growth rate

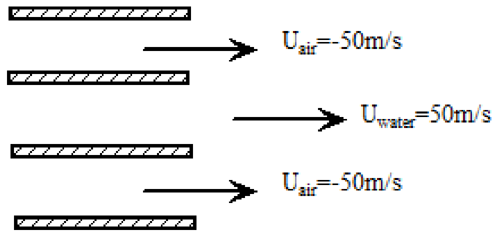
النتائج:

Results

The figures below (Figure 4-a, -b) show the configurations of the simple and coaxial water jet operating at the same conditions except that, in case of simple jet, the surrounding air velocity is assumed to be zero. In case of coaxial jet, the surrounding air velocity is assumed to be equal, but in the opposite direction, of the water jet velocity.



(a) U_{rel}=50m/s



(b) U_{rel}=100m/s

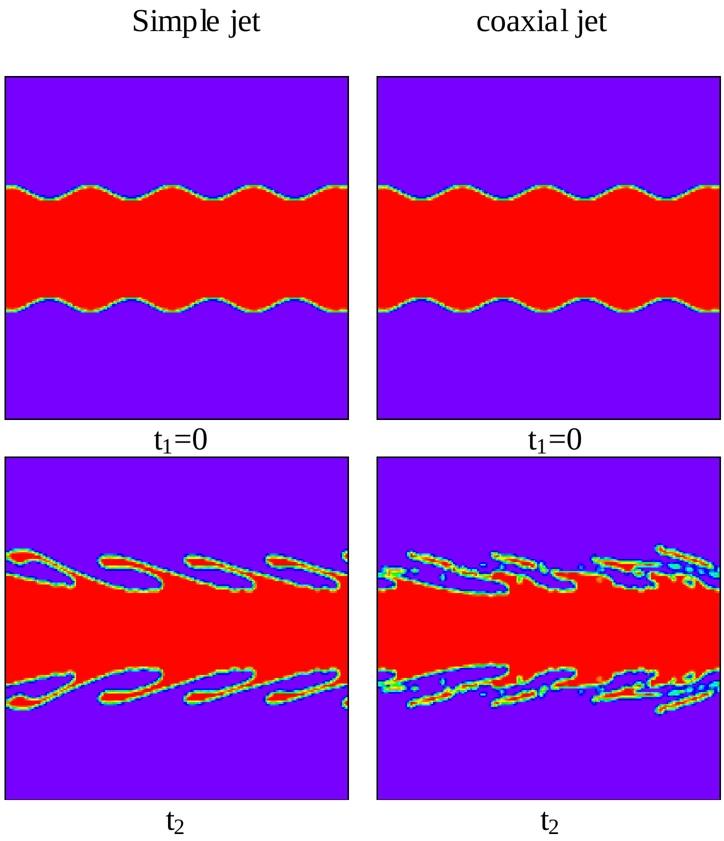
Figure 4. The configurations of (a) simple jet and (b) coaxial jet

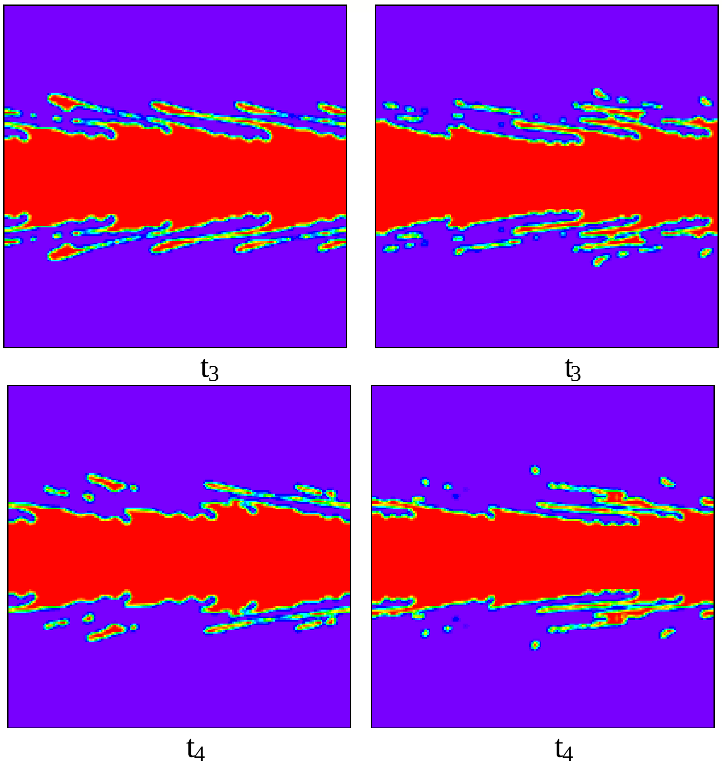
Table1. describes the different properties of the two fluids used in the numerical simulation performed. The Computer program used for the calculation is built by the present author using the FORTRAN language.

Property	Air flow	Liquid Jet
Density	1.0 kg/m^3	2 kg/m^3
Viscosity	1.5e-5 Pa. s	1.5e-5 Pa.s
Surface tension	0.0	0.02 N.m
Initial pressure	1 bar	1 bar
Radius	0.05m	0.025m

The figures below (Figure 5-a, -b) show the important results obtained from the numerical simulation performed for the simple and coaxial water jet operating at the same conditions except that, in case of simple jet, the surrounding air velocity is assumed to be zero. In case of coaxial jet, the surrounding air velocity is assumed to be equal, but in the opposite direction, of the water jet velocity.

The results showed that, the breakup of the liquid jet in case of coaxial jet is faster and the droplet size is smaller in comparison with the atomization process obtained from the normal simple jet.





(a) (b)

Figure 5. Comparison of the atomization process of liquid jet for coaxial liquid jet at different times
(a) Relative velocity=50m/s, (b) Relative velocity=100 m/s

الخلاصة:

Conclusions

The conclusions of the present work are summarized as follows:

5. The currently used fans in the free areas for improving the climate conditions are using the coflowing jet and that should be modified to coaxial jet in order to increase the atomization performance.
6. The required power of the motors, which driving the fans, should be estimated according to the required air velocity for optimum conditions of the atomization.
7. The nozzle design and the number of nozzles distributed over the circumferential of the fan should also be estimated to achieve the best conditions for atomization process.
8. In future work, the effects of the liquid issuing pressure, air temperature and air humidity ratio should be included in our simulation.

التوصيات:

Recommendation:

According to the numerical results obtained, the author recommends the application of the coaxial jet instead of the currently used coflowing jet in the atomization of water during Hajj and Omra after detailed investigations and the providing of design data.

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