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MODELING OF DIESEL- COMPRESSED NATURAL GAS BUBBLY FLOW UNDER INFLUENCING OF A MAGNETIC FIELD

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Abstract

Numerical simulation of a single compressed natural gas bubble in diesel flow with effecting magnetic flux is presented in this paper. The three dimensional incompressible Navier-Stokes equations have been used to solve the Diesel and compressed natural gas laminar two phase flow in horizontal pipe. The simulation was carried out using COMSOL Multiphysic software version 4.4, Level-Set method. The interface between the gaseous and liquid phases was described as the zero level set of a smooth function. The results showed that compressed natural gas bubble under magnetic field grow up vertically to have bigger elliptical shape in the Diesel phase, doubling in diameter before it breaks away in two parts of 0.2 and 0.8 tesla. Also, it has been noted that the compressed natural gas bubble velocity is decreasing as the magnetic field is strengthening. The numerical procedure has been validated by comparing the computational results with experimental results reported in the literature where a good agreement was achieved.

Keywords: Two-phase flow, Bubbly flow, Magnetic field, Level-set method.

1. Introduction

Two- phase flows under effect of external fields especially magnetic field have a wide range of engineering applications, such as magneto hydrodynamic problems MHD, gas and oil facilities, fusion nuclear reactors, MHD power plant, etc., Ki H. [1]. Sussman and Smereka [2] discussed that an example of complex flow simulation is the flow of two fluids with high density and viscosity ratios, such as

Nomenclatures

$\vec{B}$	Magnetic field induction, tesla
f	Smooth function
$H(f)$	Smooth unit step function
$\vec{K}$	Sum of volume forces, N
$\vec{K}_{fric}$	Friction force, N
$\vec{K}_{Lor}$	Lorentz force, N
p	Pressure, N/m^2
$\vec{U}$	Velocity, m/s

Greek Symbols

α	Parameter of thickness of the interface
ρ	Density, kg/m^3
μ	Viscosity, N.s/m^2
μ_o	Magnetic constant, (tasla.m/A)
σ_l	Electrical conductivity of liquid, (ps/m)
ϑ_l	Kinematic viscosity, m^2/s

Subscript

l	Represent liquid phase
g	Represent gas phase

Abbreviations

CNG	Compressed Natural Gas
CFD	Computational Fluid Dynamic
MHD	Magneto-Hydro Dynamic
VOF	Volume-of-Fluid Technique

bubbly and droplets flows. They stated that the main concern is the gas bubble behavior and it’s deforming in a viscous liquid. The mechanism of movement of the bubbles and the action of coalescence and bubble break-up is due to high density and viscosity ratios as well as topology changes. Hence, the inspection of the shape of the bubble domain in sporadic flows is very important to enhance the expectancy of the flow structure, flow pattern transition, as well as definition of a wide range of fluid properties. Recently, Taha et al. [3] and Asadolahi et al. [4] adopted computational fluid dynamic (CFD) techniques to simulate the single bubble flow behavior in sporadic flows. Bhaga and Weber [5] was determined the shape and velocities of bubbles in viscous liquids by experiment, while Ryskin and Leal [6] developed a numerical method to compute the steady motion of a bubble rising in the liquid. Most popular numerical methods for interface tracking are Volume-of-Fluid (VOF) technique implemented in ANSYS Fluent or Level-Set (L-S) method in COMSOL Multiphysic. It can be said that the study of the bubbly flow in a flow field under magnetic impose is new approach. So far, Ishimoto et al. [7] have studied experimentally the effect of non-uniform magnetic field on a bubbly flow; and compared his results with the numerical and experimental results reported by Hnat and Buckmaster [8], where excellent agreement have been achieved.

Literature review shows that various researches have studied the effects of non-uniform magnetic field on two-phase flows or uniform magnetic field on electric conductive of vertical two-phase flows. But, the effects of changing the intensity of uniform magnetic field on the bubble shape deformation in horizontal pipe, has not been studied in details. Hence, in this study, the effect of changing the intensity of uniform magnetic field on compressed natural gas (CNG) bubbly flow in diesel, in horizontal pipe was studied. Single bubble behavior of CNG in diesel is to cover a wide range of two phase flow properties (velocities of liquid and gas, bubble shape and size, and liquid-gas properties). For that, single bubble of CNG in diesel flow has been modelled and simulated using COMSOL Multiphysic software version (4.4), Level-Set (L-S). The simulation results are presented at various magnetic field intensity influencing on diesel-CNG flow.

2. Computational Modeling

2.1. Level set method

The level set method for moving interfaces was used in Osher and Sethian [9]. An application of the level set formulation to incompressible two-phase flow was used in Sussman and Smereka [2]. The original ideas of level set method is to define a smooth function $f(x,t)$ that represents the interface at $f(x,t)=0$. The interface can be captured at any time by locating the zero level set, ($f < 0$) in the gas phase and ($f > 0$) in the liquid phase. Since the interface moves with the fluid particles the evolution of f in flow field is given by:

$$f_t + \vec{U} \cdot \nabla f = 0 \tag{1}$$

Where ($\vec{U}$) is the velocity of fluid. The numerical oscillation in the interface may occur due to large density ratio of gas and liquid phase. In order to avoid this numerical instability, the density and viscosity of fluids are replaced by:

$$\rho(f) = H(f) + (\rho_g / \rho_l)(1 - H(f)) \tag{2}$$

$$\mu(f) = H(f) + (\mu_g / \mu_l)(1 - H(f)) \tag{3}$$

The subscript g and l represent in gas and in liquid, respectively and $H(f)$ is the smooth unit step function given by:

$$H(f) = \begin{cases} 0 & if \;\; f < -\phi \\ 0.5\left(1 + \dfrac{f}{\phi} + \dfrac{1}{\pi}\sin\left(\dfrac{\pi f}{\phi}\right)\right) & if \; |f| \le \phi \\ 1 & if \;\; f > \phi \end{cases} \tag{4}$$

The physical concept is that the zero thickness interfaces expands to 2ϕ width. In our numerical model, we take $\phi = \alpha \, \Delta h$, where Δh is the minimum grid size and α is a parameter of thickness of the interface, it usually takes 1.0~3.0 [10]. We use α=1.0 in our model.

2.2 Governing equations

Bubble flow dynamics in electrically conductive liquid in external DC electromagnetic field can be characterized by the following set Eqn 5 and Eqn 6:

$$\nabla^2\vec{B}/(\mu_o\sigma_l)+(\vec{B}.\nabla)\vec{U}-(\vec{U}.\nabla)\vec{B}=0 \tag{5}$$

$$\vec{J}=\sigma_l\left(-\nabla\varphi+\left[\vec{U}\times\vec{B}\right]\right) \tag{6}$$

where $\vec{B}$ is magnetic field induction, μ_o - magnetic constant, σ_l - electrical conductivity of liquid, $\vec{U}$ – velocity, the pair of equations describes electromagnetic nature of the process: Amperes circuital law (5) (where displacement currents are neglected), and Ohm’s law (6).

$$\nabla\cdot\vec{U}=0 \tag{7}$$

$$\frac{\partial\vec{U}}{\partial t}+\left(\vec{U}\cdot\nabla\right)\vec{U}=-\frac{1}{\rho_l}\nabla p+\vartheta_l\nabla^2\vec{U}+\vec{K} \tag{8}$$

where p – pressure, ϑ_l - kinematic viscosity, $\vec{K}$ - sum of volume forces, e.g. friction force $\vec{K}_{fric}=N(\Delta\vec{U}_{l,g})/\rho_l$, Lorentz force $\vec{K}_{Lor}=(\vec{J}\times\vec{B})/\rho_l$ ($\vec{J}$ - current density) and gravitational neglected. This pair of equations denotes on hydrodynamic processes of conductive viscous liquid (diesel) that is considered as incompressible (7). Momentum balance is achieved on account of equation (8).

2.3 Methodology

The analysis adopted for the present work is as follows. Diesel flows through the horizontal pipe (10 mm diameter and 100 mm length) and single CNG bubble (2 mm diameter) hold up in it. An external magnetic field affects the flow perpendicular to the two phase flow line to study the CNG bubble behavior during work conditions. Figure 1 shows the suggested scheme, which includes the following steps:

- Solid modeling of single CNG bubble in Diesel flow.
- Mesh generation.
- Solution of the governing equations with appropriate boundary conditions.
- Comparison of the simulated results with the available results in experimental test.

The study is expected to explore the potential of using COMSOL Multiphysic software tools for analysis of two phase flow characteristics. The package includes user interfaces to input problem parameters and to examine the results. The three-dimensional model of the single CNG bubble in Diesel flow is developed by using the pre-processor COMSOL Multiphysic software. The type of element cell used in this model was normal type (the number of elements for domain was 264,492). Mesh refinement investigation has been carried out to optimize the type of cells used. It has been found that changing the type of cell to finer type has no effect on the results accuracy. Hence, the normal type was selected to be the optimum type of cell that can be used in the simulation. Figures 2 (a) and (b) show the solid modeling and the mesh for case under study respectively.

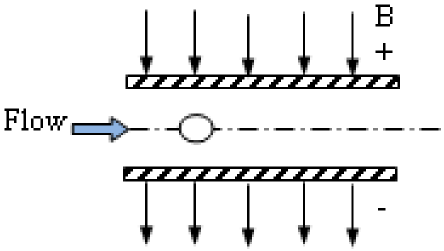


Fig. 1. Show the suggested scheme for single bubble of CNG in diesel flow under influencing a magnetic field.

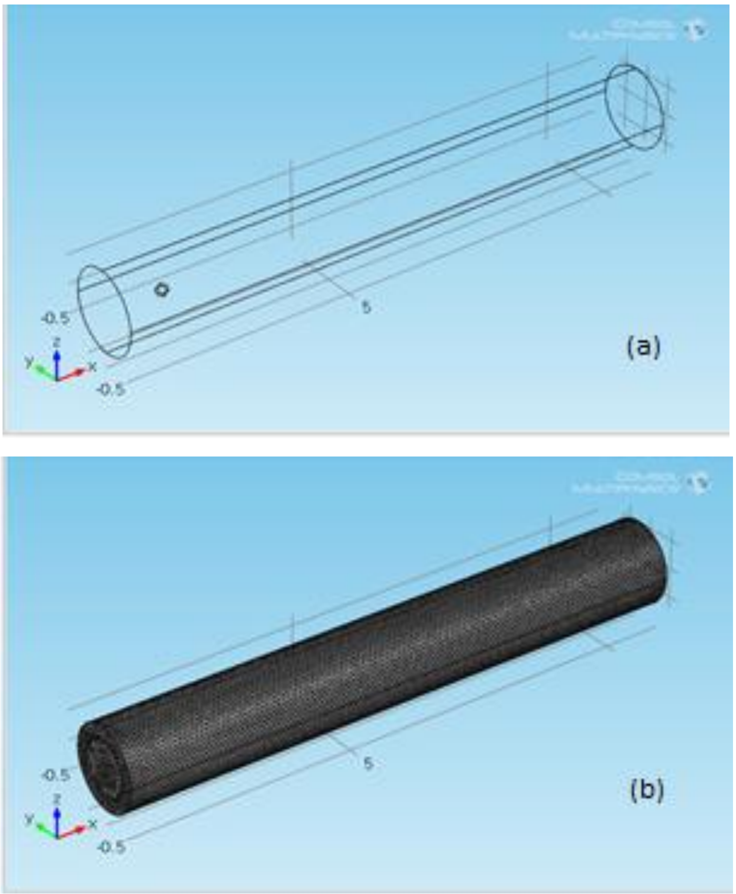


Fig. 2. Shows (a) the solid modeling, and (b) the normal type mesh for case under study.

2.3 Boundary conditions

Consider unsteady, laminar, hydro-magnetic, fully developed, a single CNG bubble in Diesel suspension in a horizontal circular pipe. A uniform transverse magnetic field is applied normal to the flow direction (see Fig. 1). The liquid phase (diesel) is assumed to be electrically conducting depending on the sulfur content of the fuel. No electric field is assumed to exist and the hall effect of MHDs is negligible. The governing equations for this study are based on the conservation laws of mass and momentum of both phases. Attach boundaries are specified on the coincident cell face near the cells around CNG bubble. No slip wall boundary condition in conjunction with logarithmic law of wall is used. Table 1 shows the properties of diesel fuel and CNG [11].

Table 1. Properties of diesel fuel and CNG [11].

Parameter	Diesel Fuel	CNG
Density (kg/m^3) (23 ^{o}C)	840	0.72
Viscosity (N.s/m^2) (23 ^{o}C)	0.0024	7.8×10-6
Carbon (%, w/w)	86.83	73.3
Hydrogen (%, w/w)	12.72	23.9
Oxygen (%, w/w)	1.19	0.4
Sulphur (%, w/w)	0.25	ppm < 5
Electric Conductivity (ps/m)	250	-
Relative permittivity	2.0-2.2	-

The inlet velocity of diesel was 0.06 m/s and assumes spherical bubble of CNG injected to the flow, CNG bubble at 2 mm diameter and the bubble velocity equal zero when (t =0) (in injection time). Magnetic field intensity changed (0, 0.2, and 0.8 tesla).

3. Results and Discussion

3.1. Effect of magnetic field on shape of CNG bubble in Diesel flow

The effect on the growth of a single CNG bubble of a magnetic field oriented normal to the flow is numerically investigated. The results showed to CNG bubble on vertical magnetic field grow bigger in diesel flow, doubling in diameter before it breaks away in (0.2 and 0.8 tesla). Hence, the effect of the magnetic field caused by the Lorentz force was devoted at the break-off mechanism rather than to pumping driven. Figure 3 shows simulated positions and shape variations of a single CNG bubble in Diesel flow and time increment is 0.1 sec, with magnetic flux 0.2 tesla. In this case, the bubble is changing from sphericity at injection time (t = 0) and nearly an oblate sphericity at (t = 0.4 sec) before break away at (t = 0.5 sec). And this behavior is similar when it applied magnetic field intensity 0.8 tesla. It appears that the field influences the break-off mechanism itself, and that this dominates any twist-off effect on a single bubble.

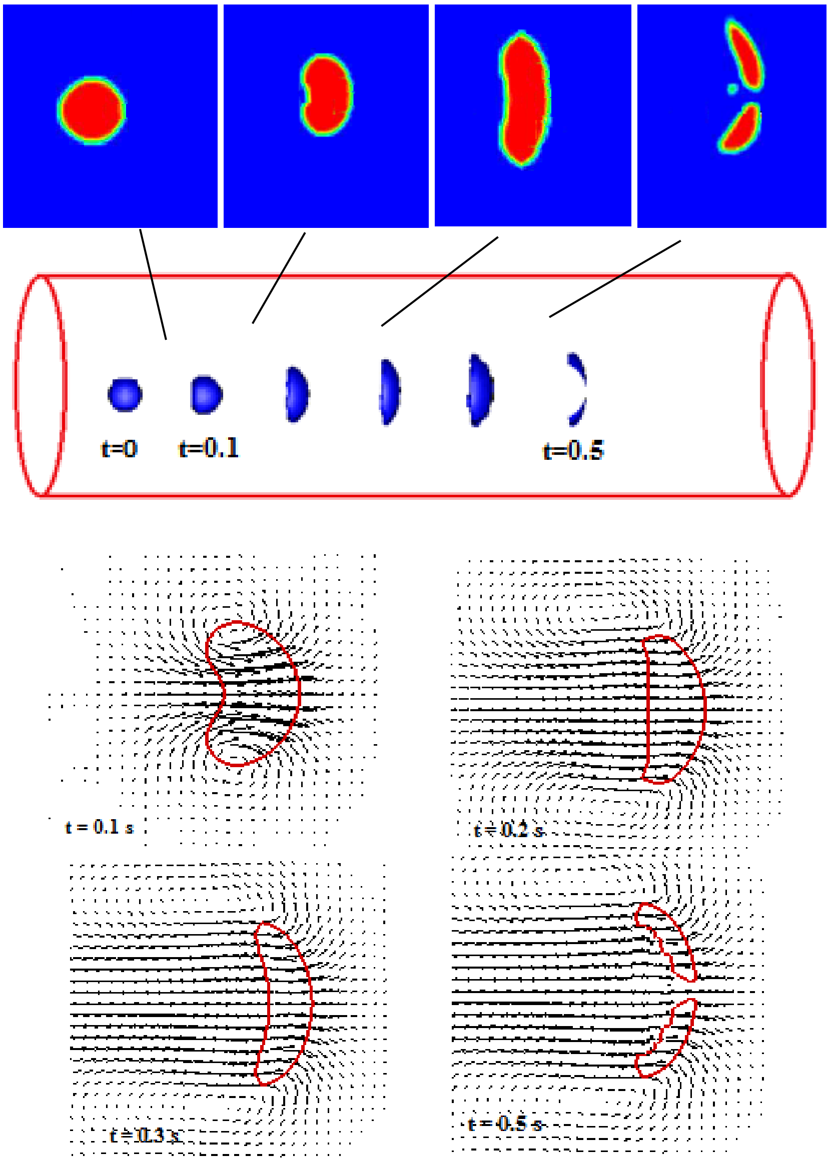


Fig. 3. Simulated positions and shape variations of a single CNG bubble in Diesel flow and time increment is 0.1, with effecting magnetic flux = 0.2 tesla.

3.2. Effect of magnetic field intensity on CNG bubble velocity in diesel flow

The results shown in Fig. 4 generally, the velocity of CNG bubble decreases with growing magnetic field strength. The figure presents the time development of the CNG bubble velocity for changing magnetic field intensity (0, 0.2, and 0.8 tesla). It is seen in Fig. 4 that increasing magnetic field intensity decreases the CNG bubble velocity. The effect of the magnetic field normal to the flow direction gives rise to a drag-like or resistive force and it has the tendency to slow down or suppress the movement of the liquid in the pipe, which, in turn, reduces the motion of the gas bubble. This is translated into reductions in the average velocity of bubble (CNG) phase and, consequently, in their flow rate. In addition, the reduced motion of the CNG bubble in the pipe as a result of increasing the strength of the magnetic field causes lower velocity gradients at the wall. This has the direct effect of increasing the period of transfer of momentum of both of phases.

The results for CNG's bubble were agreement for the experimental results of Fernandez et al. [12] on H_2 bubble. Figure 5 shows comparison of terminal bubble shape observed in experiment on H2 bubble Fernandez et al. [12] and predicted in simulations (present model).

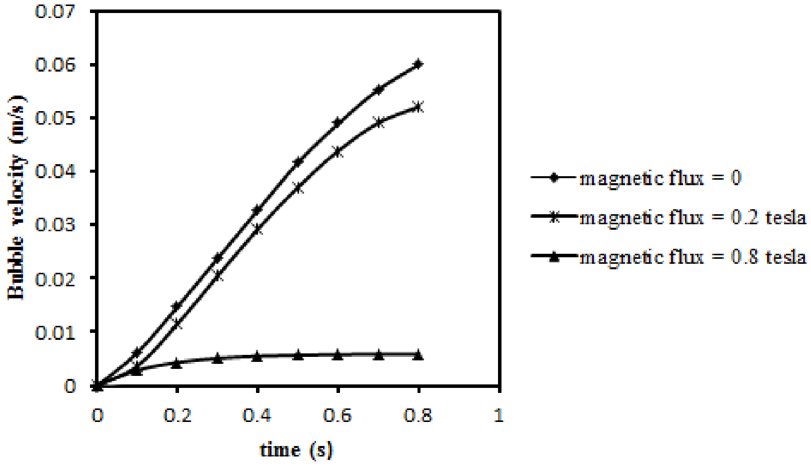
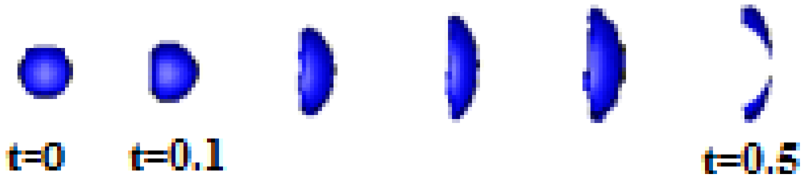


Fig. 4. Simulated results to velocity of CNG bubble in diesel flow with changing magnetic flux (0, 0.2, 0.8 tesla).

Simulation results on CNG bubble (present model)



Experiment results on H_2 bubble [12]

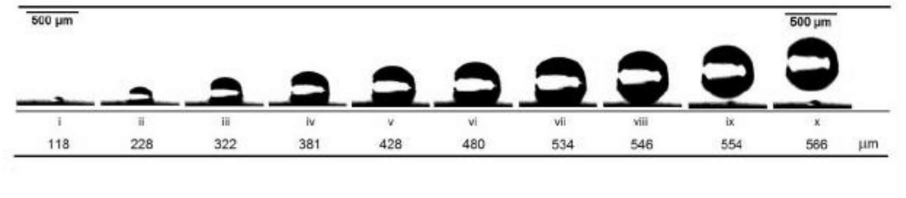


Fig. 5. Comparison of terminal bubble shape observed in experiment on H_2 bubble Fernandez et al. [12] and predicted in simulations (present model).

4. Conclusions

The Level Set Method and three-dimensional incompressible Navier-Stokes equations have been used for simulating the motion of a single CNG bubble in Diesel flow. The results showed that CNG bubble under magnetic field grows to a bigger volume and expands vertically in the diesel flow before it breaks away in 0.2 and 0.8 tesla. The CNG bubble velocity decreases with increasing of the magnetic field strength. The computational results have been compared with experimental data from work in the literature and a good agreement has been shown.

It is recommended to improve the numerical method to simplify the computational procedure, and to simulate multi bubbles flow in the diesel domain to investigate the collision and breaking of the CNG in Diesel flow.

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