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CFD Analysis of Spherical Capsule Flow in Horizontal Pipeline

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Abstract: The connotation of capsule pipelines has become increasingly common over time, the idea of hydraulic capsule pipeline (HCP), but still a new study and there is relatively little research and study in this area. It was therefore, selected as the focus of this research. For the aims of this study, Computational Fluid Dynamics (CFD) was used. CFD is a useful tool for the analysis of pipe flow problems. Optimization and analysis of the capsule may be performed by problems such as FLUENT CFD packages.

The behaviour of a drop in pressure of three, trains-capsule was studied under the effect of various bulk speed and an altered diameter of the capsule. The results obtained from the study concluded that the pressure drop in a tube increases as the concentration increases the size and capsules. Using the results obtained from CFD, a mathematical relationship has been derived from the pressure drop in a capsule transport hydraulic line. The correlation is consistent with experimental data and the theory. In addition, an effective method to optimize the tubes which carry the capsule has developed along the correlation with the pressure drop at constant density spherical capsule train in a hydraulic.

There are several recommendations for further studies and research from both CFD and experimental analysis of flow problems of the capsule.

Keywords*—Capsule Flow, CFD Analysis, Capsule Pipelines, Hydraulic Capsule Pipeline.*

I. INTRODUCTION

Systems relying upon a hydraulic mode of action are a more modern invention. Hydraulic systems are believed to have originally been designed and developed in Canada, during the 1960s, however since then extensive research and projects have been carried out around the globe, including more recent work in the USA and Japan. Although much theoretical work and papers have been investigated, there is a lack of physical work gone into designed successful pipe-line transportation systems**.** Many studies concentrate on investigating and improving techniques for refining the sizing of the systems, and reducing the total cost of the structure, making them more cost-efficient. Albertson et al**.**Hathoot et al**.** Cheremisinoff et al, and Daugherty and Franzini `have all published work on the involvement of these factors in the development of hydraulic pipe transport.

During the mid-20th century, development teams turned their attention to the improvement of capsule design via modification. Aspects of this involved work exploring how the shape of the capsule container affected the flow. The density of the capsule vessel in these experiments was generally larger or equal to that of the designated transport liquid medium.

Because of the nature of these studies involving an individual transport container in each scenario, a minimal raised pressure gradient was noted, so these studies were further pursued in systems relying upon continual streams of capsule delivery. However, this research has been restricted to investigating the effect of forces acting upon the outside of the transport vessel upon its surface-area and the velocity and movement/flow patterns of the fluid. In most of these cases, the transportation medium used in the hydraulic pipeline was water, even where the viscosity of the liquid was altered by the addition of a polymer substance. (Ellis et al. 1974; Round et al. 1965)**.** By increasing the viscosity of the carrier medium through the manipulation of polymer complexes, a reduction in the pressure drops within the system was recognised (Drag Reduction Effect). (Vlasak et al. 1995). Researchers (Eillis et al. 1974) carried out speed measurements using a 'Plexiglas pipe'. This device was set on a flat, horizontal plane and covered 10 metres. They chose a structure with a 0.04m diameter. The transport vessels used was a single capsule of spherical design-shape, and adapted to have a density equal to that of the liquid transport medium (Ellis et al. 1964). The results yielded implied the velocity of the container (V_c) when having a higher speed (e.g. ranging in the the values of 0.06 metres/second to 3.7 metres/second) becomes 1.05 to 1.5 times the speed bulk (V_m)**.**
Govier& Aziz preformed work to identify the correlation of the velocity of the capsule and the flow velocity in the upper spherical capsule by a coefficient (V_C = CoV_m). They have stated that this distribution coefficient might assume a Co-value between 1.0 and 1.2 when the capsule is in a concentric position and has a capsule to pipe diameter ratio of 0.8–0.9 (Govier et al., 1972)**.** The results and conclusions taken from these single-capsule studies cannot be accurately applied to models which use multiple capsules transportation, such as the real-life systems in use today**.** Therefore, throughout the 1970s, additional research was conducted to better understand these concepts upon multi-capsule systems. Previous work had focused on continuous delivery systems where the transportation vessels were suspended within the pipeline**,** and these aimed to investigate the way in which the flow mechanics affected the continual stream of delivery capsules. This research yielded the probability of a positive correlation between the pressure gradient and density of the transport capsules within the system (Ellis et al., 1974)**.**
Before this time, there was little to no work being conducted into the production of formula and theoretical models to investigate the decrease in system pressure in structures using multiple spherical shaped capsules as a form of delivery system, where the density of the containers were in fast lower than that of the propellant fluid being used as the transportation medium. These representations could also be adapted to examine the outcomes of using a vertically positioned pipe as opposed to the horizontal plane used in most studies (Latto et al., 1978; Chow et al. 1979). Obviously, the flow-pattern of the transport liquid in a vertical pipe is considerably different to horizontal one. The progress of carrier-containers through an upright system is affected by the transportation fluid applying force to the units, while in horizontal models there is reduced rolling movement and surface-friction loss. Because of these factors, equations developed to be applied to scenarios involving vertical pipelines cannot be directly transferred and applied to those implementing designs based on a horizontal plane.

Govier& Aziz performed analysis on the theoretical friction factor, flow properties and characteristics of the decreased pressure while observing the movement of transport capsules along the pipeline**.** The preceding research was analysed, adapted, and applied to successfully produce models that covered concentric and non-concentric flow capsules, which could then be applied to 'real-life' systems**.** This was the first work on studies investigating these specific conditions (spherical transport containers in a hydraulic pipeline with density equal or below that of the liquid in the pipeline), and no-one had carried out a theoretical analysis of the observed reduction in pressure, behaviour and movement patterns of capsules with a spherical design, both concentric and non-concentric**.** An analogy was made with the Taylor bubbles in vertical pipes at normal velocities and for 0.8–0.9 values of the diameter ratio, so that it was calculated that Rv ¼ 1.2 for the expression Vc ¼ RvVb**.** Govier and Aziz showed that using the density of the mixture and the mixing rate, can determine the pressure drop, as it is instigated and affected by single-phase liquid flow (Govier et al.1972)

Agarwal and Mishra (1998) spent time researching ways to optimize pipeline transportation systems by adjusting the pumping stations accordingly. They used a model developed for spherical capsules and altered the size and distance of the 'pumping-stations' to make the pipeline system more efficient. The results of their work suggested a negative-correlation between friction co-efficient and the Re (as the first decreases, an increase in the latter can be noted). These results imply that the mixture of a fluid capsule as a homogeneous single-phase current according to the conclusions reached by Govier and Aziz is a pressure drop and drop in the velocity of spherical capsules**.**

Teke and Ulusarslan conducted thorough investigations, taking, and developing earlier research based upon using spherical, multi-capsule delivery systems. From their work, we can draw a range of conclusions, and the results their study yielded have been summarised as a series of mathematical expressions involving the pressure gradient, as demonstrated in Fig 6. They produced an experiment based upon pipeline systems being used (Ulusarslan, 2003)**.** They implemented the use of Plexiglass to form a system covering a distance of six metres, with a internal radius of 0.05 metres. Only a four-metre-long section of the pipeline was used to acquire the results**.** Two pressure taps were associated through piezometric hoses to the ends of a degree of different pressure transmitters used for measuring pressure drops with a space of 4m between them**.** The design of the containers used as transport vessels was important; they used containers with a spherical shape, designed to be inflexible, with an exact gravity of 0.87 and a diameter ratio of 0.8. Pressure drops were measured at 1.2x104 <Re <1.5x105 and transported at low concentrations of 5-30% (Ulusarslan et al. 2006)**.**

Ulusarsalan and Teke are also responsible for conducting further research upon systems relying upon spherical, multi-capsule delivery systems:

-Work examining capsule speed, spacing between units and concentration rate through a series of experiments.

- Evaluation of the effect of a pressure gradient correlation upon the movement and behaviour of a series of delivery containers, along with statistical illustration.

- Correlation between the frictional coefficient and Reynolds value for said capsules moving along a horizontal pipeline.

Upon evaluation of the above studies, we can conclude that the concept of hydraulics as a method of powering a pipeline transportation system has not yet been thoroughly researched, and this can perhaps be attributed to the fact that the hydraulic method is a more recent adaptation of the pneumatic method. Most of the studies conducted to this date focus on the manner in which pressure alterations (e.g. the pressure drops) and capsule design, such as the dimensions, density, separation distance in multi-capsule systems alter the workings of the overall transportation system.

As described previously, Ulusarslan&Teke, Agarwal & Mishra, and Govier& Aziz have all contributed work to this field of study. There is one important aspect to take into consideration when referring to these studies and that is that they were all conducted upon physical, small scale, experimental models or upon theoretical basis. In none of these cases was the use of Computational Fluid Dynamics (or CFD) employed in order to produce results. By taking into account the importance of minimising cost and producing work on an economical basis, the method has developed to determine the most appropriate dynamics of Hydraulic pipeline system (HPS) in order to maximise its effectiveness at delivering its required service. The aspects taken into account for this are the dimensions of the transport vessels, and the concentration of capsules within the system. We are able to use CFD to achieve these goals.

For this research, a similar design to that in the Ulusarslan-Teke experiment was implemented, and although the basic test section remains unchanged, factors such as flow-dynamics and geometrics were altered accordingly. In the Ulusarslan-Teke study, they used a capsule with a set diameter of 0.08m, and this remained unchanged throughout the test in order to produce valid results. The bulk speed varied within the boundaries of 0.2 – 1.2 meters/sec and they manipulated the concentration variable using intervals of 5, from 5 to 30%. Computational Fluid Dynamics allows for more variability of an experiment, so a wider range of aspects could be altered to produce results including; the transport vessel's diameter, flow features and geometric conditions. The outcome of the CFD analysis could then be applied to such experiments and theories for additional reliability, and then therefore developed into a statistical means, thus allowing for the calculation on the pressure decrease along a horizontal HPS.

From Hydraulic Capsule Pipelines has developed the idea of [Coal] Log Pipelines. Heavily based upon the idea, these systems have been mildly adapted to accommodate a 'capsule' consisting of a 'log' of the coal, having been compressed and processed into shape to form a solid chunk to act as the transport vessel. In such pipelines, the hydraulic fluid used as a propellant is generally water, which has little impact on the goods themselves (e.g. no corrosive or damaging properties), as the goods are not protected by being sealed within a separate transport container as with most systems. Once the coal has reached the end-point of the pipeline it can be processed as necessary by the industry.

Newer equipment can implement ice (relying upon its latent heat) to produce effective cooling systems, although this is still being researched and improved. The cooling capacity increases with the mass flow rate, as in refrigeration systems using conventional methods. On the other hand, the cost of the cooling system can be reduced by using pipelines with a narrower radius and decreased mass flow, as the ice 'capsules' will retain their solid state for longer in these circumstances, leading to more effective cooling process on the system. By implementing coatings or coverings around the ice, it will also prolong the time-frame the ice is in its solid state, for example plastic membrane.

The rate of ice concentration velocity of ice capsules is significantly higher than the concentration ratio and the mixing rate obtained by the flow of ice water suspension. Therefore, the cooling capacity of the system will increase distinctly (Ellis et al.1974). Using solid ice capsules designed in spherical shape as a method of cooling has not been fully researched, and is still a new, developing technology. Due to ice having such a high latent heat capacity, an equal quantity produces a greater cooling effect, resulting in a more cost-effective system, as less exhaust mass and small diameter tubes are required. Using spherical capsules ice cooling systems, the ice occupies 80-90% of the diameter of the tube, and is an innovation in refrigeration technology bringing numerous advantages.

II. EXPERIMENTAL DETAILS

A hydro-dynamically smooth (i.e. ε / D = 0) test section like Ulusarslan and Teke (2003) has been modelled numerically for L = 1m and D= 0.1m (fig. 1). An additional pipe length of 10*D has been introduced before and after the test section (Munson and Young 2002).

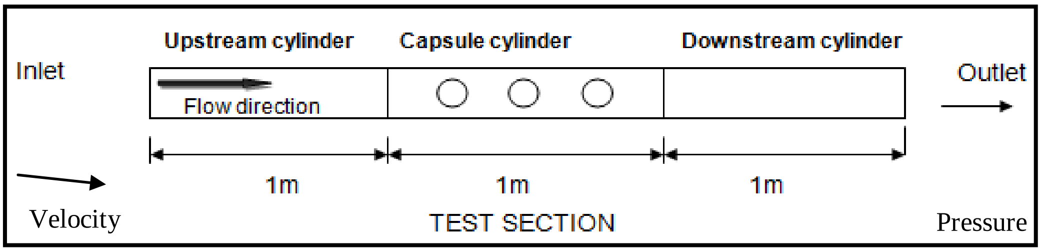

Fig. 1. Geometrical capsule setup in the pipeline

Pipe Geometry

The pipe was constructed using a cylinder with a diameter of 0.1m and 3m length, as shown in figure 2.

3.3 Mesh A mesh of around 2 million elements has shown to give accurate results for pressure drop and hence has been chosen for analysis.

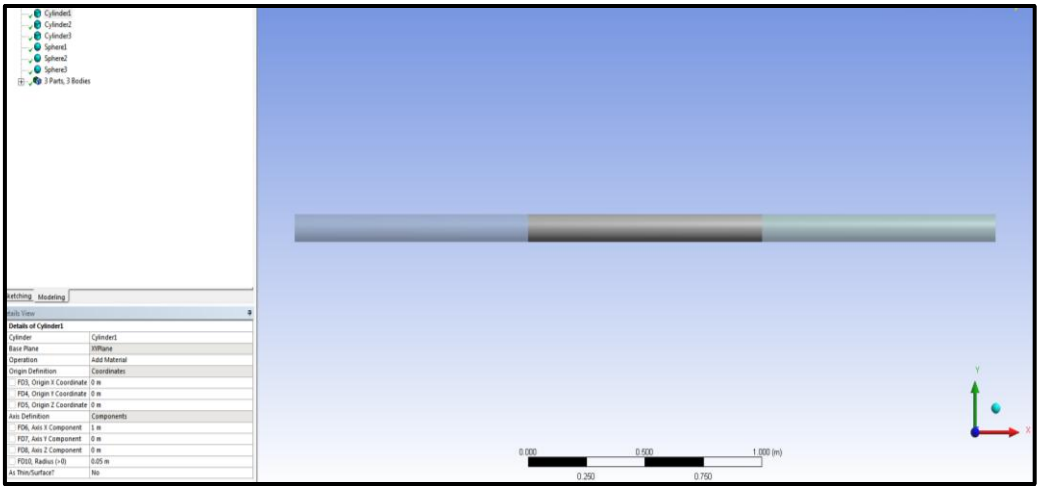

Fig. 2. Geometry of pipe with 3m length and 0.1 m diameter

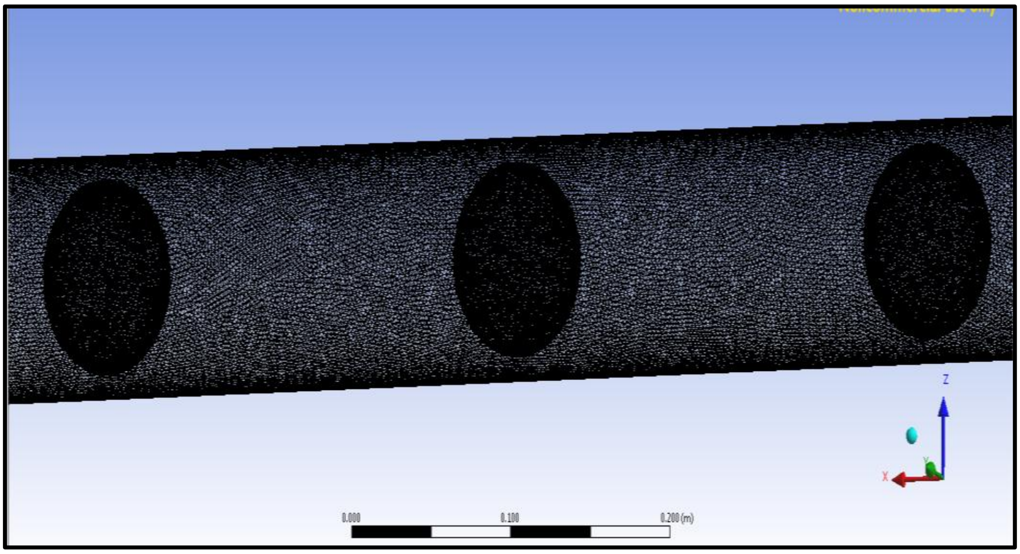

Fig. 3. Mesh inside the pipe with capsules

Computational Fluid Dynamics (CFD)

Computational fluid dynamics (hence referred to as CFD) relies upon software run by a computer system in order to produce an in-depth, detailed and accurate evaluation or analysis of systems employing the use of fluid flow (e.g. the transport medium in hydraulic pipelines), temperature differentiation and the exchange of heat and chemical reactions. CFD is a highly useful and robust tool, with a variety of applications in real life situations (both in industry and non-industrial).CFD is being integrated into so many designs and manufacturing industries, it is now playing an essential role in product development. Whereas physical experiments can be highly cost-ineffective and time consuming (from hiring structures, workers, space constraints etc), CFD is capable of producing vast amounts of high-quality data for virtually no fee, making it a much more economical choice for companies in today's world. By investing in CFD, companies have a realistic way of improving their products, devices and apparatus to function to maximum efficiency within their budget (Radomir, 2010).
Pressure based solver has been chosen as the flow is incompressible. Velocity formulation is absolute and time is steady. Steady state analysis has been carried out because it was assumed that the flow is steady.

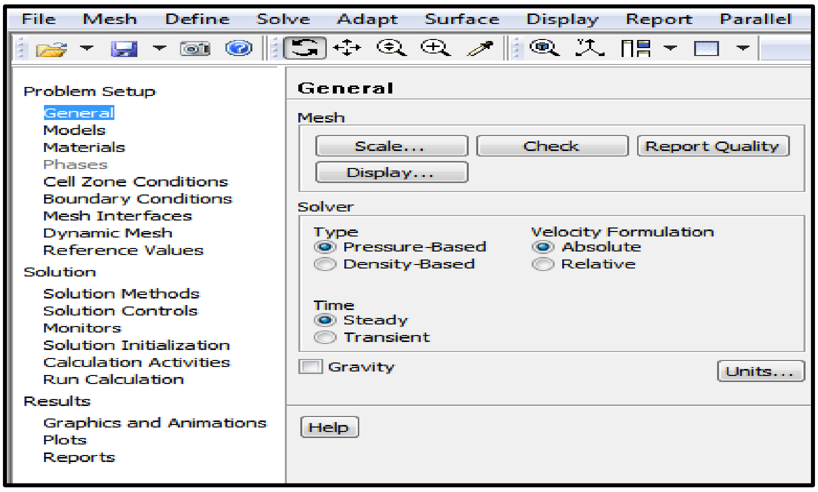

Fig. 4. Solver pressure, velocity, and time settings

The SST k-omega is a two-equation turbulence model which gives more accurate results for pressure drop in a pipe. As the flow in the pipe is of water, hence, water has been chosen as the fluid inside the pipe.

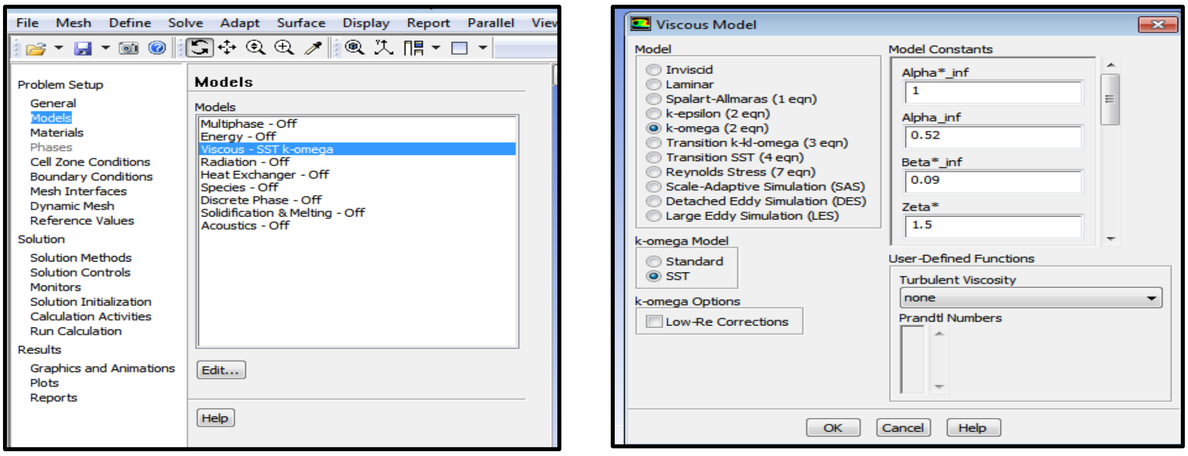

Fig. 5. Turbulence model

After bringing the water-liquid material inside Fluent, it needs to be specified to the domain.

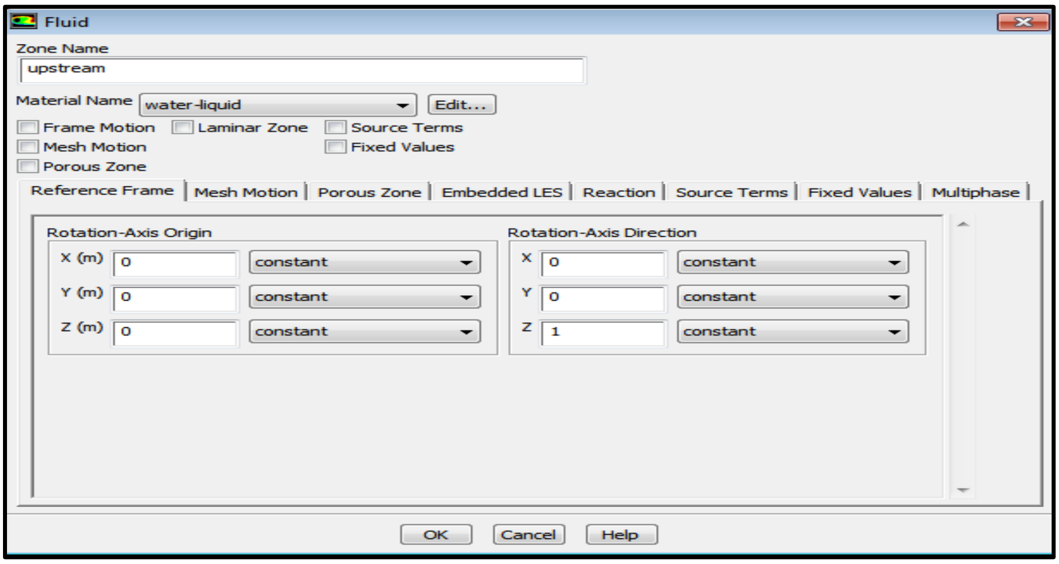

Fig. 6. Cell zone condition

Capsule cylinder, downstream cylinder and upstream cylinder have been given wall boundary conditions. The other conditions are:

- Inlet velocity – velocity changes from 0.2 to 1.4 (m/s) - Hydraulic diameter = 0.1 m - Hydro dynamically smooth pipe with Roughness constant =0
- Outlet pressure 0 pa (gauge) – Hydraulic diameter =0.1m
- Upstream cylinder – Roughness constant =0
- Downstream cylinder – Roughness constant =0
- Capsule cylinder – Roughness constant =0
- The capsules translational moving with velocity =0.2,0.4,0.6,0.8,1,1.2,1.4 (m/s)
- Change all connections to interface.

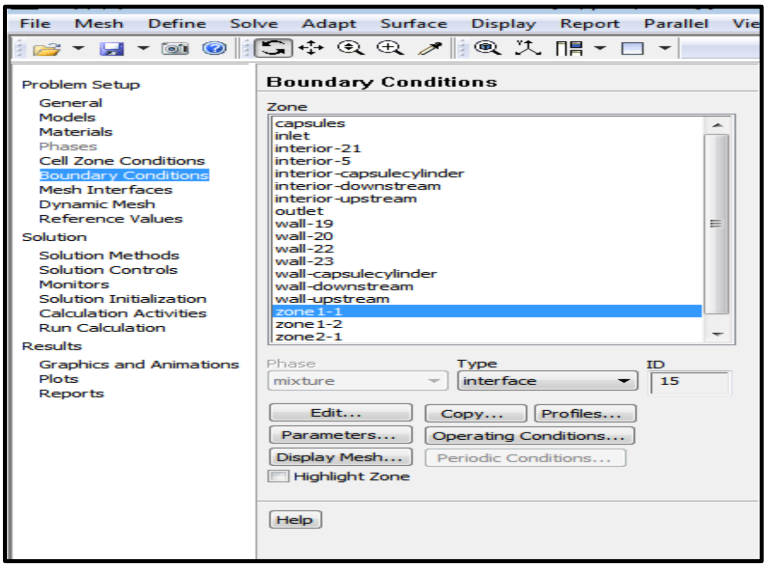

Fig. 7. Boundary conditions

Mesh Interfaces create a Name for Mesh interface to choose two connections.

Gradient – Green – Gauss Node Based. Using second order upwind for pressure, momentum, turbulent kinetic energy, and specific dissipation rate because more accurate.

- Second order selected for Pressure.
- Second order selected for Momentum.
- Second order upwind selected for Turbulent kinetic Energy.
- Second order upwind selected for Specific Dissipation Rate.

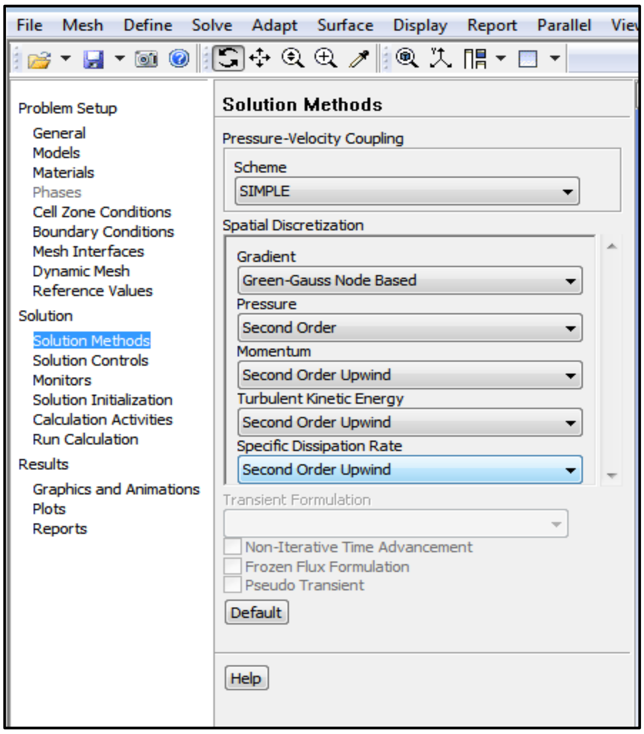

Fig. 8. Solution methods

III Results and Discussion

The velocity of the fluid through a hydraulic line depends on both the flow rate of the carrier fluid and the cross-sectional area of the pipe. The friction that occurs between the fluid flowing through a tube and its losses inner wall of the causes is measured as the pressure drop. For the purposes of this research, the pressure drop in the carrier fluid of the hydraulic line has been calculated for several different conditions. Geometric and flow parameters were altered as follows:

- The number of capsules: the pressure drop was calculated for one, two and three capsules.

- The inlet velocity: the pressure drop was calculated for inlet velocities of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4 Velocities were measured in m/s.

- The velocity of the capsule: This was the same input velocity.

In this project has been conducting experiments using one, two capsules, and three capsules with different pipe lengths and with changes in the mesh to one million, two million, three million and four million mesh .And that testing has been completed to measure the pressure drop and the relationship between the pressure drop and the different velocities on the two million that were more accurate.And will be exposed to the effect of velocity on the pressure drop as follows:

Effects of Velocity on the Pressure Drop

Pressure drop observed in one capsule, two capsules, and three capsules is a noticeable change. The study shows the effects of pressure drop due to velocity change. It is observed in the case of one capsule, two capsules and three capsules that greater the velocity, the bigger the pressure drop

One Capsule

In the case of one capsule, velocity 0.2 m/s, pressure drop was 31.2 (pa). After increasing the velocity to 1.4(m/s), pressure drop increased to 669.6 (pa/m), Graph below shows one capsule velocity effect on pressure drop Higher velocity increases pressure drop.

TABLE1 Relationship between velocity of one capsule and corresponding pressure drop

Velocity inlet=velocity capsules (m/s)	Interface one pressure P_1 (Pa)	Interface two pressure P_2 (Pa)	Pressure drop between interfaces $\Delta p = p_1 - p_2$
0.2	35.7	4.5	31.22
0.4	106.2	16.7	89.5
0.6	204.5	35.1	169.5
0.8	328.4	59.6	268.9
1	475.4	89.5	385.9
1.2	636.7	124.9	511.8
1.4	833.3	163.6	669.7

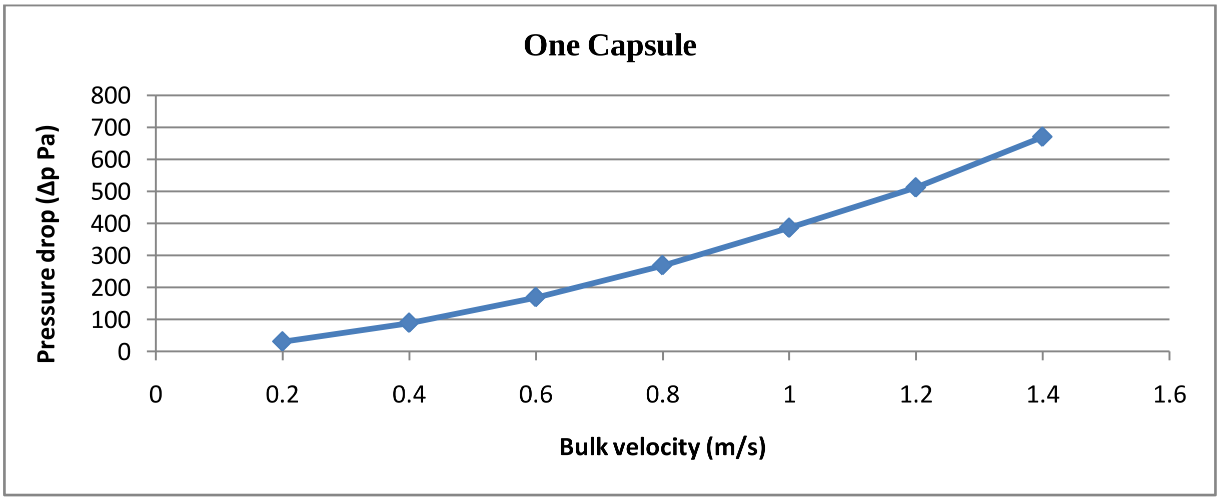

Fig. 9. Pressure Drop of one capsul

Two Capsules

Case two capsules the pressure drop is 55.908 (pa/m) at velocity 0.2(m/s) where the pressure drop reached to 1273.4(pa/m) at velocity 1.4(m/s).

TABLE2 Relationship between velocity of two capsules and corresponding pressure drop

Inlet velocity = Capsule velocity (m/s)	Interface one pressure p_1 (Pa)	Interface two pressure p_2 (Pa)	Pressure drop between interfaces $\Delta p = p_1 - p_2$
0.2	60.3	4.4	55.9
0.4	178.5	13.8	164.7
0.6	343.3	27.8	315.5
0.8	548.1	47.3	500.8
1	781.8	77.6	704.2
1.2	1094.7	108.8	985.7
1.4	1416.5	143.1	1273.4

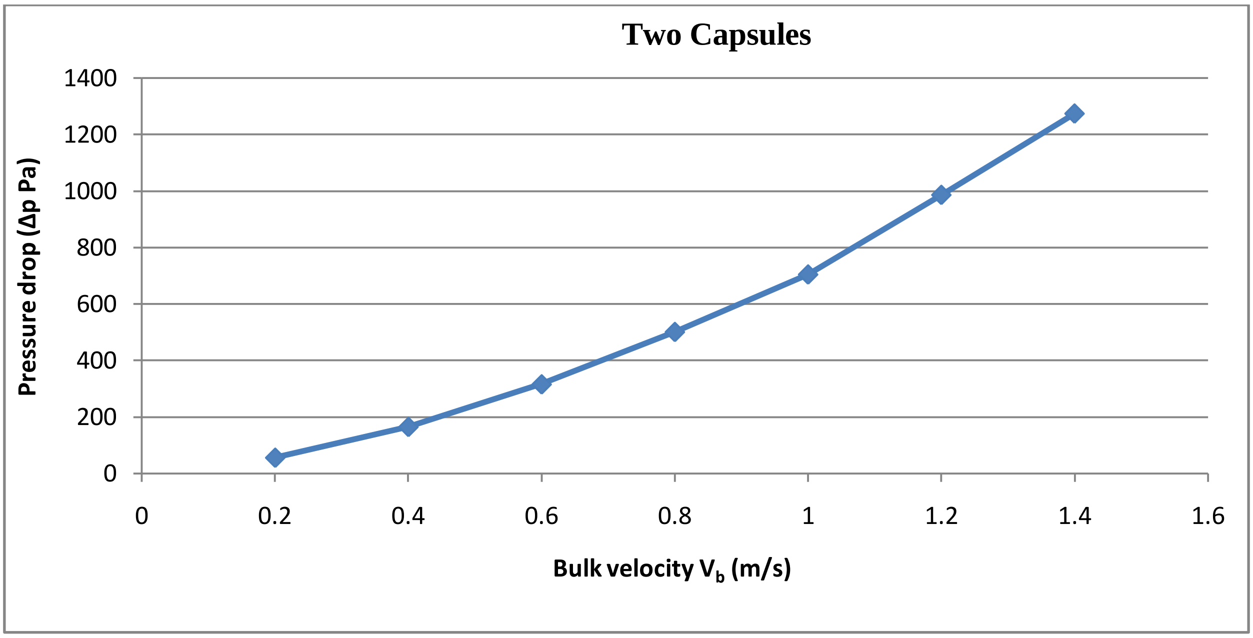

Fig. 10. Pressure Drop of two capsules

Three Capsules

In last case three capsule capsules the pressure drop is 83.1 (pa) at velocity 0.2(m/s) where the pressure drop reached to 1884.7(pa) at velocity 1.4(m/s). The graph below shows three capsules velocity effect on pressure drop Higher velocity increases pressure drop.

TABLE3 Relationship between velocity of three capsules and corresponding pressure drop

Velocity inlet=velocity capsules (m/s)	**Interface one pressure (p_1) (Pa)**	**Interface two pressure (p_2) (Pa)**	**Pressure drop between interfaces** $\Delta p = p_1 - p_2$
0.2	86.4	3.2	83.1
0.4	249.5	11.7	237.8
0.6	481.2	23.3	457.8
0.8	760.6	39.4	721.2
1	1114.7	55.4	1059.3
1.2	1513.5	83.6	1429.8
1.4	2000.7	116.0	1884.7

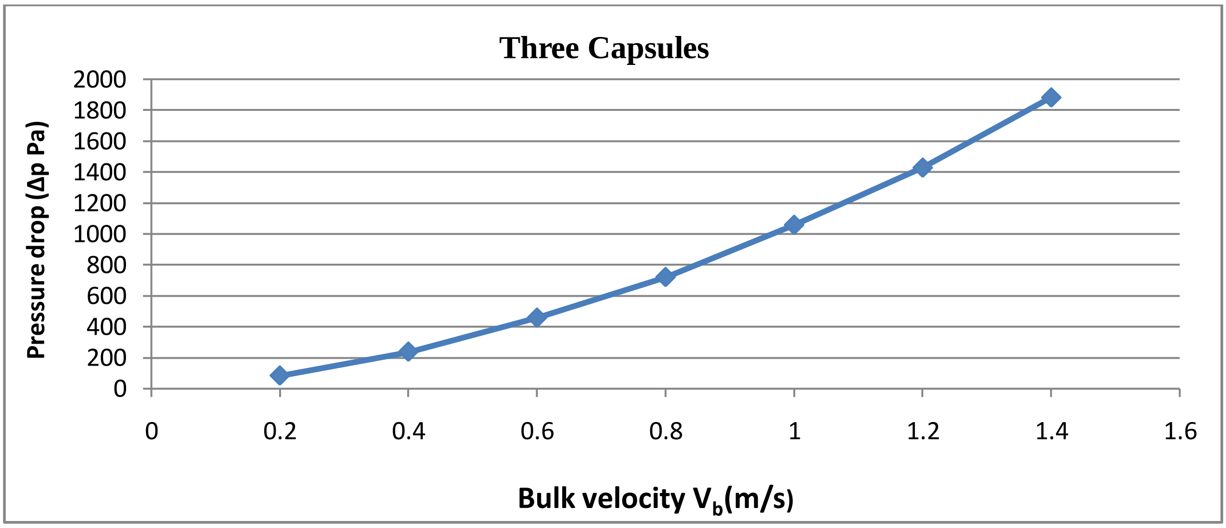

Fig. 11. Pressure Drop of three capsules

Comparison between one, two and three capsules pressure drop

Looking at the results in the graphs below, the more the number of capsules, the more the pressure drops, therefore a pipe containing a smaller number of capsules will have less pressure drop.

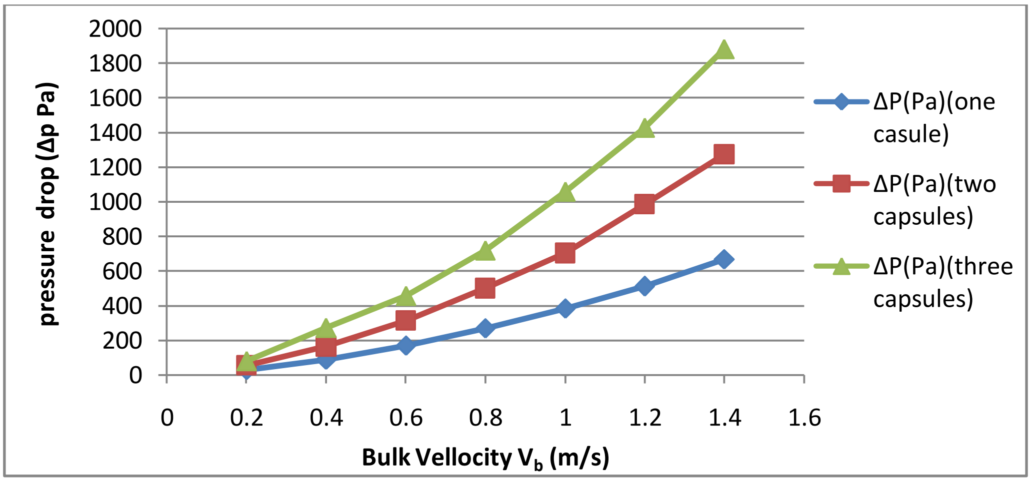

Fig. 12. Comparison between results of one, two and three capsules

Contours of pressures and velocities in the pipe

In the contours of pressures and velocities, where the velocities and pressures were measured to show changes that happened during the flow coming inside the pipe, So, we took different points for the velocities and pressures of one, two and three capsules for instance, velocities which have been chosen 0.2, 0.8 and 1.4 m/s.

Contour of pressure of one capsule with 0.2 (m/s) velocity

It can be seen from the contour of pressure that pressure (40.10pa) was far more at the beginning just before the flow touched the capsule. As the velocity of the flow increased due to the narrow pathway of the flow, the pressure decreased (-30.99pa). Once the flow has bypassed the capsule, the pressure started increasing again

(10.07pa) and the velocity starts decreasing as there is an inverse relationship between pressure and velocity (Fig. 13) Therefore, the pressure difference noticed was:

Initial pressure (41.0pa) – Final pressure (10.07pa) = (30.3pa)

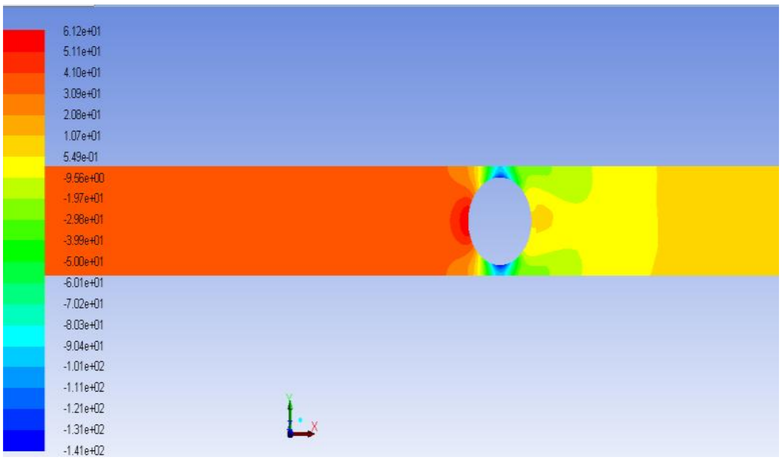

Fig. 13. Contours of pressure at 0.2 (m/s) flow velocity

Contour of velocity of one capsule with 0.2 (m/s) velocity

Velocity contour clearly shows that the flow velocity (0.21m/s) was moderate before it touched the capsule, as soon as the flow had to compress through the narrow gaps around the capsule, the flow velocity reached its maximum value (0.6m/s). This only took place all around the capsule. It can be easily noticed that the flow separates and goes around the obstructing object which was a capsule in this case, hence almost zero velocity (0m/s) of fluid flow can be seen at the front of the capsule, facing flow and behind the capsule where the flow is unable to stay attached to the capsule and separates (Fig. 14).

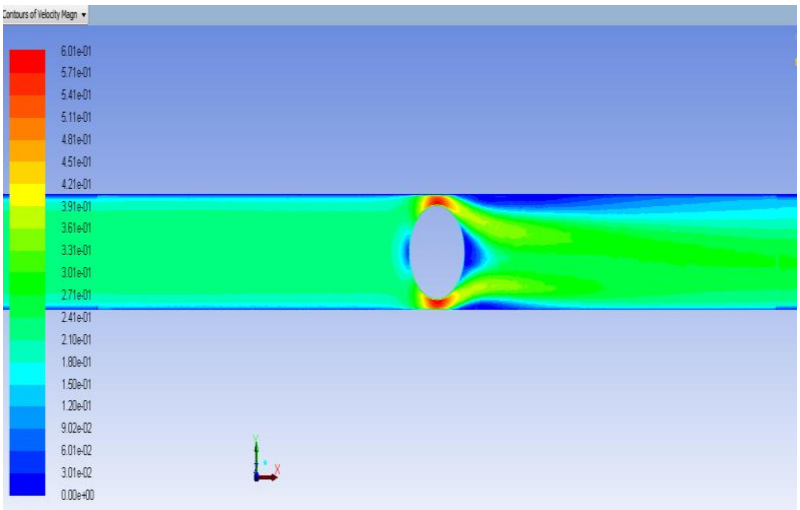

Fig. 14. One capsule: 0.2 m/s flow velocity (contours of velocity)

Contour of pressure of one capsule with 0.8(m/s) velocity

With the increment of flow velocity, pressure drop is directly affected. It can be noticed from the results that with increased flow velocity, pressure drop (initial pressure is (398Pa) and final pressure (is87Pa)) is less however, if the flow velocity is decreased, pressure drop will be more (pressure drop when flow velocity is 0.2 m/s) (Fig. 15). Therefore, pressure different with one capsule and flow velocity of 0.8 m/s was:

Initial pressure (398pa) – Final pressure (87pa) = (311pa)

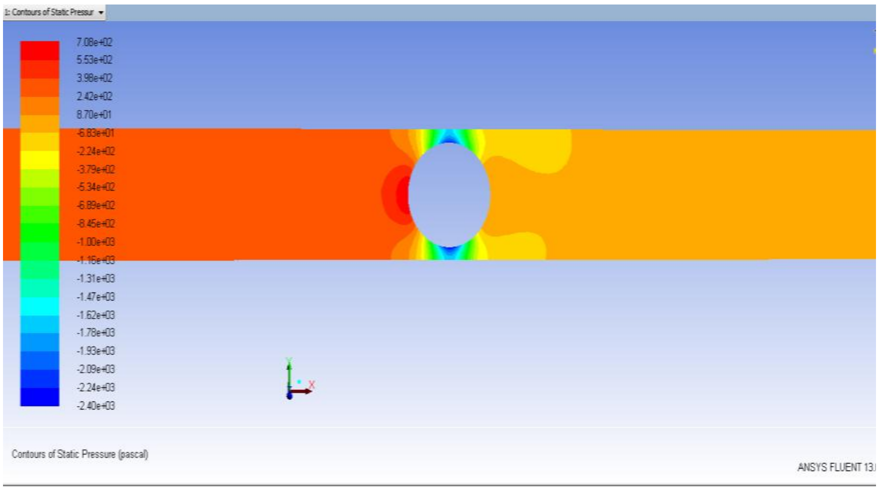

Fig. 15. One capsule: 0.8 m/s flow velocity (contours of pressure)

Contour of velocity of one capsule with 0.8 (m/s) velocity

Contour of velocity for flow velocity of 0.8 m/s is rather similar to that of flow velocity 0.2 m/s. the only minor but noticeable changes that can be seen in the contour is that the highest flow velocity does not travel further than the surface of the capsule also the wake region behind the capsule is elongated (Fig. 16).

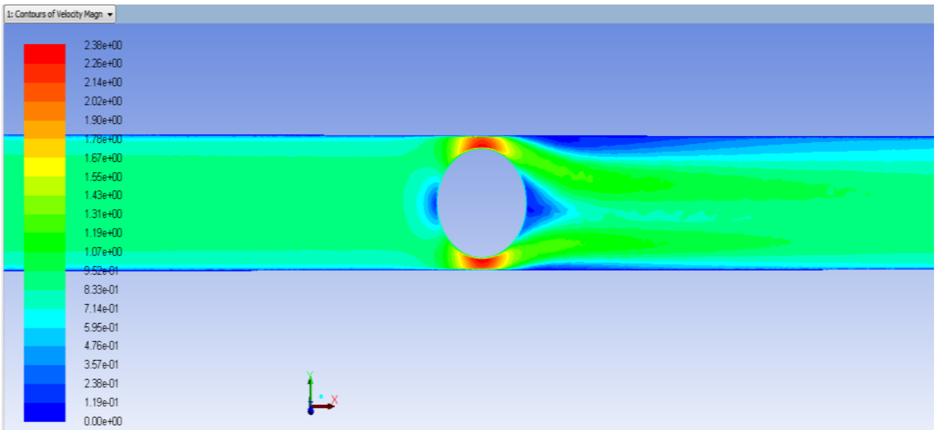

Fig. 16. One capsule: 0.8 m/s flow velocity (contours of velocity)

Contour of pressure of one capsule with 1.4(m/s) velocity

Highest flow velocity (1.4 m/s) follows the obvious trend and it can be seen that the highest pressure region is the area of capsule directly exposed to the inlet pressure as the flow moves around the capsule it reaches the minimum pressure which is almost zero and then it starts to increase again. Higher pressure can be notice exactly behind the capsule as the flow rebounds from the walls of the pipe. Pressure continues to increase as the flow moves towards the outlet (Fig. 17).

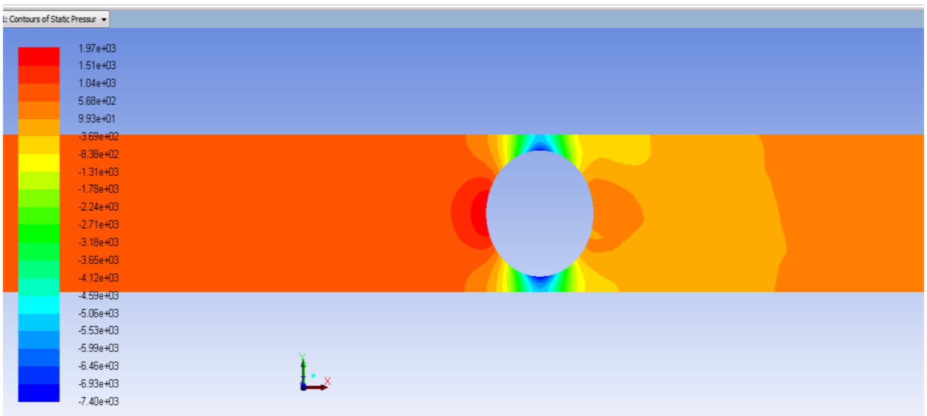

Fig. 17. One capsule: 1.4 m/s flow velocity (contours of pressure)

Contour of velocity of one capsule with 1.4 (m/s) velocity

As the velocity of flow is highest (1.4 m/s) coming from the inlet it reaches zero value where the flow starts to move towards the walls of pipe. Since it is a narrow gap for the fluid to pass through, it is forced through and reaches its highest velocity (fig. 18). As soon as the flow passes over the capsule and has much wider opening, its velocity drops which is gained as it moves towards the outlet. It is visible from the velocity contours that higher the velocity, longer is the wake region behind the capsule.

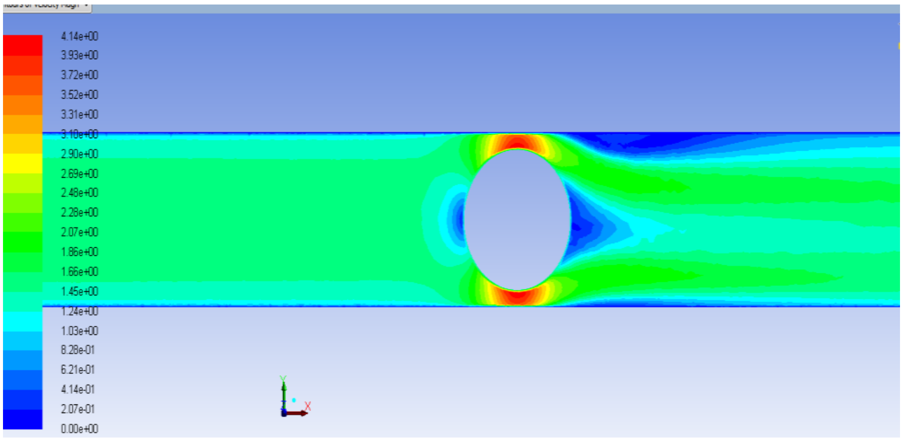

Fig. 18. One capsule: 1.4 m/s flow velocity (contours of velocity)

Contour of pressure of two capsules with 0.2 (m/s) velocity

We can see that from the contour of pressure that pressure (63.5 pa) was far more at the beginning just before the flow touched the capsule. As the velocity of the flow increased due to the narrow pathway of the flow, the pressure decreased. Once the flow has bypassed the first capsule, the pressure started increasing again, and the velocity starts decreasing as there is an inverse relationship between pressure and velocity after that when the flow touched the second capsule the pressure started decreasing again until reaching (5.7pa) (Fig. 19).

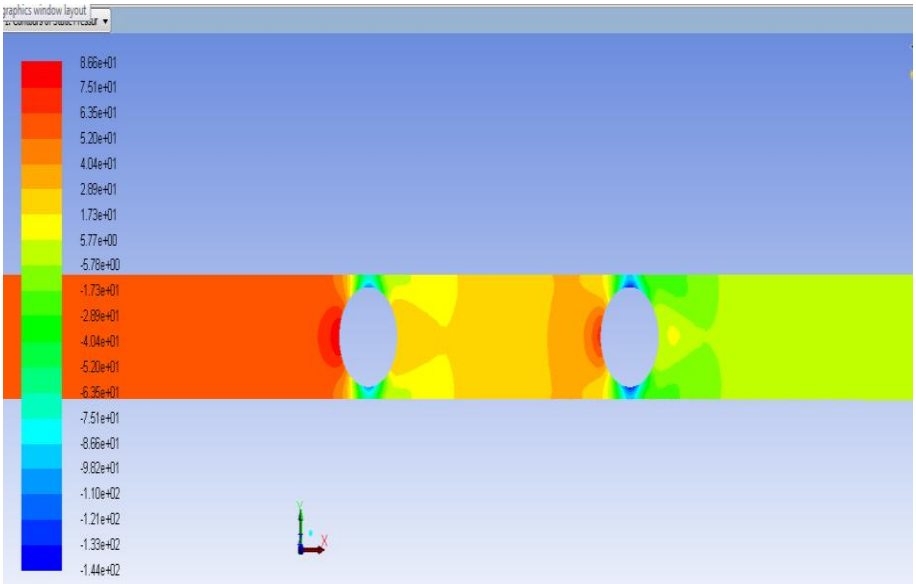

Fig. 19. Two capsules: 0.2 m/s flow velocity (contours of pressure)

Contour of velocity of two capsule with 0.2 (m/s) velocity

Velocity contour clearly shows that the flow velocity (0.21m/s) was moderate before it touched the first capsule, as soon as the flow had to compress through the narrow gaps around the capsules, the flow velocity reached its maximum value (0.6m/s). This only took place all around the capsules (fig. 20). It can be easily noticed that the flow separates and goes around the obstructing object which were a capsules in this case, hence almost zero velocity (0m/s) of fluid flow can be seen at the front of the capsules, facing flow and behind the capsules where the flow is unable to stay attached to the capsules and separates.

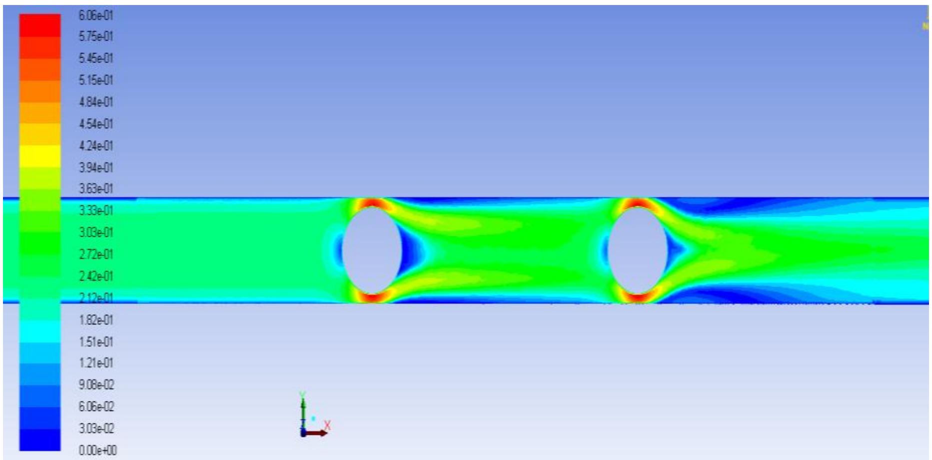

Fig. 20. Two capsules: 0.2 m/s flow velocity (contours of velocity)

Contour of pressure of two capsules with 0.8 (m/s) velocity

We can see that from the contour of pressure that pressure (599pa) was far more at the beginning just before the flow touched the capsule. As the velocity of the flow increased due to the narrow pathway of the flow, the pressure decreased .Once the flow has bypassed the first capsule, the pressure started increasing again, and the velocity starts decreasing as there is an inverse relationship between pressure and velocity after that when the flow touched the second capsule the pressure started decreasing again until reaching (91.5pa) (Fig. 21).

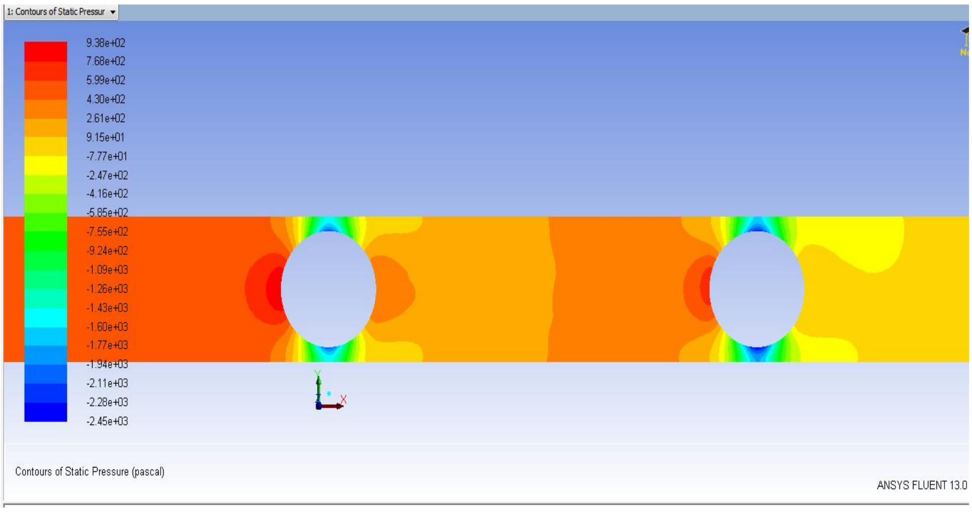

Fig. 21. Two Capsules: 0.8 m/s flow velocity (contours of pressure**)**

Contour of velocity of two capsule with 0.8 (m/s) velocity

From figure 25 Velocity contour that the flow velocity (0.84m/s) was moderate before it touched the first capsule, as soon as the flow had to compress through the narrow gaps around both capsules, the flow velocity reached its maximum value (2.42m/s) . This only took place all around both capsules. It can be easily noticed that the flow separates and goes around the obstructing object which were two capsules in this case, hence almost zero velocity (0m/s) of fluid flow can be seen at the front of the capsules, facing flow and behind the capsules where the flow is unable to stay attached to the capsules and separates (Fig. 22).

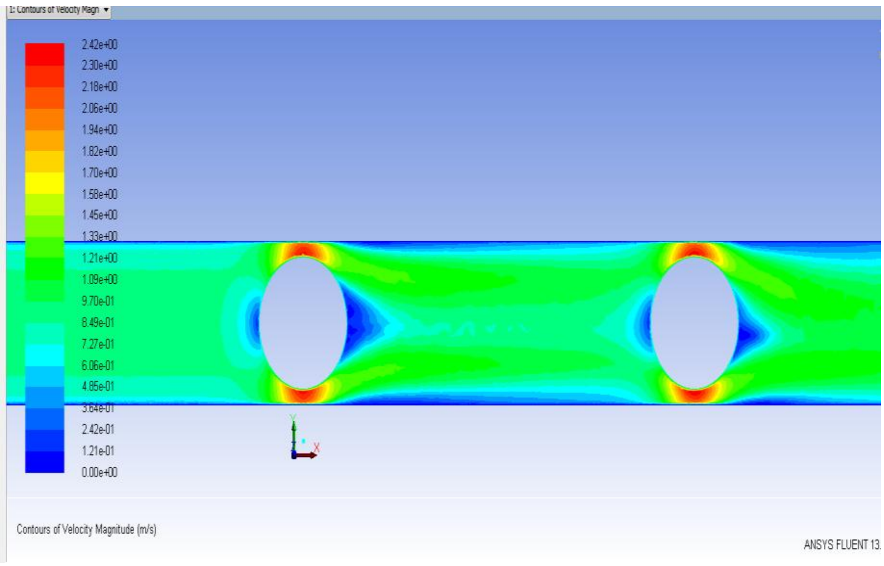

Fig. 22. Two capsules: 0.8m/s flow velocity (contours of velocity)

Contour of pressure of two capsules with 1.4 (m/s) velocity

From figure above the contour of pressure that pressure (1580pa) was far more at the beginning just before the flow touched the first capsule. As the velocity of the flow increased due to the narrow pathway of the flow, the pressure decreased .Once the flow has bypassed the first capsule, the pressure started increasing again, and the velocity starts decreasing as there is an inverse relationship between pressure and velocity after that when the flow touched the second capsule the pressure started decreasing again until it reached (573pa) (Fig. 23).

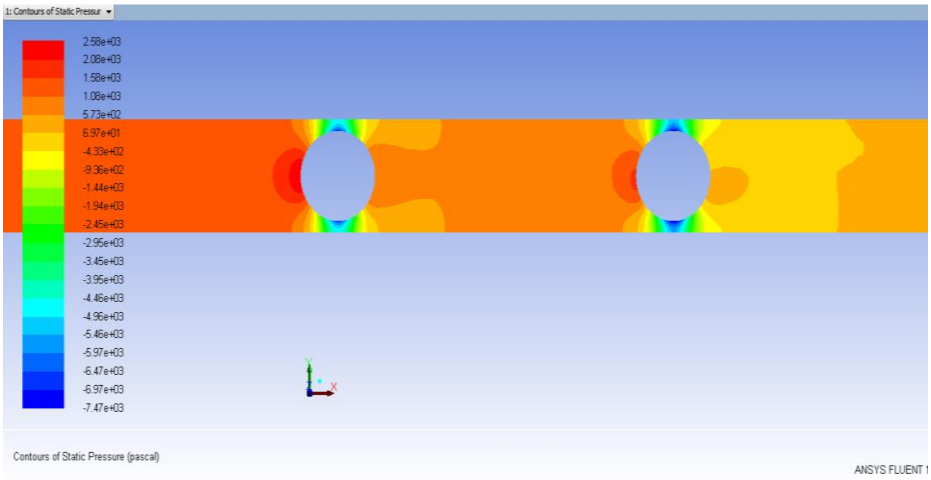

Fig. 23. Two capsules: 1.4 m/s flow velocity (contours of pressure)

Contour of velocity of two capsule with 1.4 (m/s) velocity

Velocity contour clearly shows that the flow velocity (1.46 m/s) was moderate before it touched the first capsule, as soon as the flow had to compress through the narrow gaps around the capsules, the flow velocity reached its maximum value (4.21m/s). This only took place all around the capsules. It can be easily noticed that the flow separates and goes around the obstructing object which were a capsules in this case, hence almost zero velocity (0m/s) of fluid flow can be seen at the front of the capsules, facing flow and behind the capsules where the flow is unable to stay attached to the capsules and separates (Fig. 24).

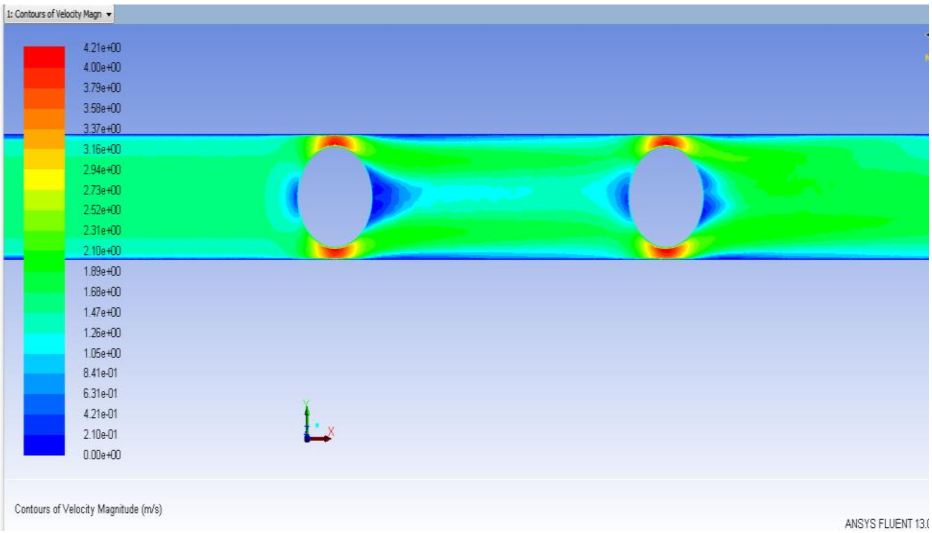

Fig. 24. Two capsules: 1.4m/s flow velocity (contours of velocity)

Contour of pressure of three capsule with 0.2 (m/s) velocity

As shown from Fig. 25 that from the contour of pressure that pressure (98.9 pa) was far more at the beginning just before the flow touched the first capsule. As the velocity of the flow increased due to the narrow pathway of the flow, the pressure decreased to (46pa) between the well and first capsule .Once the flow has bypassed the first capsule, the pressure started increasing again, after that when the flow touched the second capsule the pressure started decreasing again after the second until reached to (70.8 pa). So, with the third capsule until the pressure reached to (14.5pa).

Initial pressure (98.9pa) – Final pressure (14.5pa) = (84.4pa)

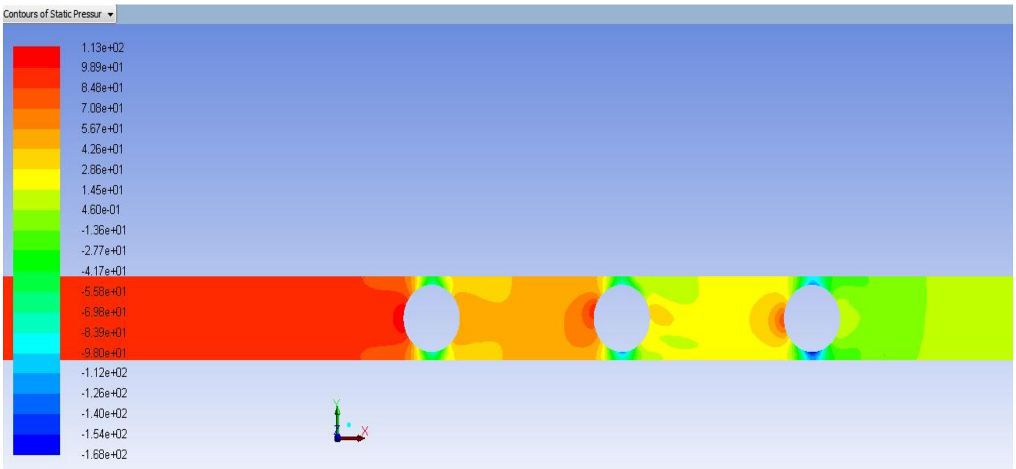

Fig. 25. Three capsules: 0.2 m/s flow velocity (contours of pressure)

Contour of velocity of three capsule with 0.2 (m/s) velocity

Velocity contour clearly shows that the flow velocity (0.2 m/s) was moderate before it touched the first capsule, as soon as the flow had to compress through the narrow gaps around the capsules, the flow velocity reached its maximum value (0.66m/s). This only took place all around the capsules. It can be easily noticed that the flow separates and goes around the obstructing object which were a capsules in this case, hence almost zero velocity (0m/s) of fluid flow can be seen at the front of the capsules, facing flow and behind the capsules where the flow is unable to stay attached to the capsules and separates (Fig. 26).

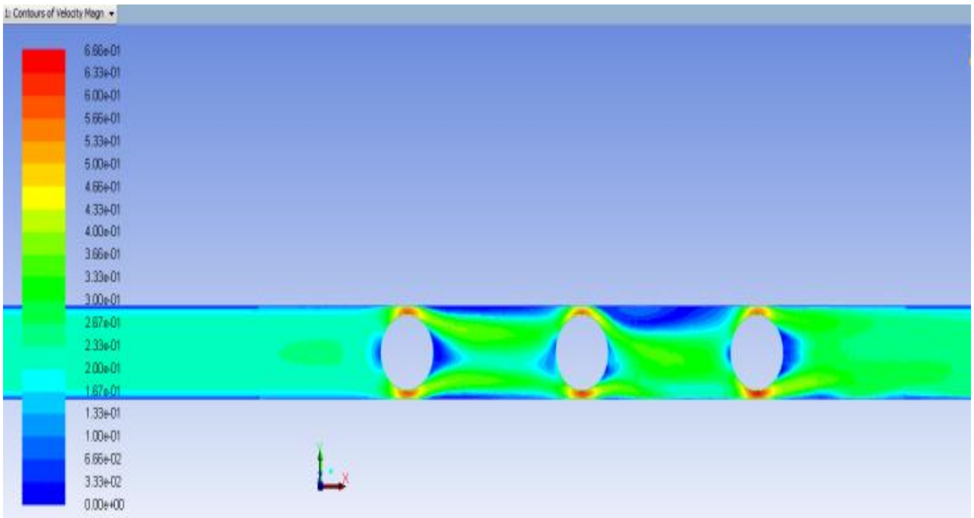

Fig. 26. Three capsules: 0.2m/s flow velocity (contours of velocity)

IV Conclusion

With the help of modern computational power, Computational Fluid Dynamics (CFD) has become an essential need for the industry to analyse the pipe flow problems. Not only the pipe flow problems can be effectively analysed but optimisation can also be done. In addition, analysis involving capsule train problems can also be effectively carried out using specialists CFD packages such as FLUENT. Major conclusions taken from this project after the in-depth analysis of results achieved are:

- Pressure drop is higher at higher flow velocity.

- Pressure drop is lower at lower flow velocity.

- Pressure drop is directly proportional to the number of capsules in the pipeline; therefore, more the number of capsules, at the same flow velocity, more will be the pressure drop.

- Capsule flow optimisation can be carried out by analysing the capsule spacing in a capsule train.

- Higher inlet to outlet velocity difference for higher flow velocity.

- Higher velocity leaves elongated wake region behind the capsules.

Results obtained with the help CFD analysis show the trends of data. These trends are essential to predict the changes in capsule flow at various flow velocity values.

Strong method of capsule flow optimisation can be developed from the data achieved from the CFD analysis.

Correlation between the density of capsules train and pressure drop has also been achieved which is essential information to calculate head losses, costing, and maintenance for any required number of capsules as well as their diameter.

There are wide ranges of recommendations that can be anticipated in relation to computational fluid dynamics analysis of capsules.

These recommendations can be summed up as following:

- For this project, fluent solver was selected to be in steady-state settings. This analysis could also be carried out by using the multi-phase settings.

- This project is limited to the study of straight horizontal pipe, other considerations such as bends, contraction, expansion, valves, and fittings etc. can be considered to understand the various factors for pressure drop.

- The pipeline used for this study was smooth; however, more realistic approach could have been used with the study of realistic moment of a capsule.

- Density of the capsule was chosen to be equal to that of transporting water, to analyse the effect of position of the capsule within pipeline, capsule density could be varied.

- Only one kind of capsule motion (transitional) was used for the analysis, more forms of motion could have been considered such as rotational.

Recommendations made above are regarding the potential alterations within the computation fluid dynamic analysis for capsule flow problems. Furthermore, for future research, the recommendations are:

- Experimental results can be obtained to analyse the effects of size, capsule spacing and concentration of capsules in a pipeline.

- CFD analysis of capsule flow was limited; therefore, additional studies can be carried out to advance the discovered knowledge.

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