The design of spray nozzle for washing aggregates in mining industry

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Abstract

Silica (dust) that is created during the crushing of aggregates is presently one of the main causes of silicosis to mining employees and to the surrounding community. The silica created normally attached to the crushed aggregates (road-stone) during manufacturing. This dust must be wash off to prevent the spread of silicosis and other illness during mining process. Currently, the major problem faced in washing the crushed aggregates is that the spray nozzle that are currently used by most companies required the aggregates to be washed twice, which in turn costs the company extra money for washing twice. Water again is being wasted due to continuous usage. Currently there is no adequate study on aggregates washing at low cost under high efficiency. More so, most spray nozzle are so complicated to operate and they are usually very expensive. In the current study we have designed a spray nozzle that is cost effective and very easy to operate under high operating efficiency. The tools of fluid dynamic and design theorem were used to model the nozzle diameter for optimal flow of water distribution during operation. The parameters used in modelling are velocity of the spray nozzle, flow rate of the spray nozzle, and the area that the nozzle will cover. The optimal velocity, flow rate and nozzle diameter were obtained for efficient flow of water during operation. The following facts were theoretically revealed by the model and validated. It was shown that there was an optimal nozzle diameter that gave optimal flow of water. It was shown that there is a certain nozzle diameter size that will offer maximum efficiency during operation. It was also shown that to cover a certain washing area a certain angle of the nozzle must be achieved during operation.

Keywords: spray nozzle, flow rate, velocity, nozzle diameter and efficiency

1. Introduction

In mining industry crushing is one of the tasks which takes place every day and different aggregates are crushed into different sizes suitable for the task in hand. One of the aggregates that has to be crushed is the road-stone, which is 19mm in size. During crushing process, the 19mm road-stone will be exposed to the crushing dust and sometimes the other different smaller sizes will be present at the end product of the 19mm road-stone. Which is not a good product because of other different sizes present. This reduces the quality of the road-stone product and also the quality of the road to be constructed. This aggregate is used for the road construction as the top layer. The aggregate that has been crushed need to be clean before it is sent to the client. Aggregate has to be mixed with bitumen, and for it to be mixed with bitumen correctly it has to be properly washed through a vibrating screen, the screen will screen out the other small sizes present. The use of the correct spray nozzles has to be applied as to wash or clean the aggregates properly of dust. The spray nozzle must have high flow rate as to create a pulsating jet of fluids to wash away all the dust and other small aggregate sizes. By cleaning the aggregates this helps the bitumen to be mixed properly with the road-stone and by this the quality of the road-stone will be improved. According to Samuel ((rashid, 2012) having the multiple effect of cleaning out the fines and dust, bringing the entire aggregate to a uniform condition. There are different types of spray nozzles and some of the nozzles has fluid jet that has atomized fluid this due to cavitation.

This is the formation of an empty space in a body (fluid) is defined as Cavitation. And in this case of spray nozzle is the formation of bubbles in the liquid. It has been clarified that great turbulence in the nozzle hole, due to cavitation phenomena, contributes greatly to the disintegration (to loose strength) of the liquid jet. When the cavitation occurs in the nozzle hole, the atomization of the liquid jet is enhanced considerably. The results of the present study indicate that the enhancement of the atomization of the liquid jet is possible by simply installing the wire net over the inlet of the nozzle hole, and making a gap at the nozzle hole. And most spray nozzles that are used do not have a pulsating strength to wash the aggregates. Spray nozzles have different designs to for different tasks, one of the member of the spray nozzle is the spray orifice. Spray orifice is used for the reduction of pressure or for restricting flow of fluid. An opening. Clear description of the orifice is described such that the outer face of the orifice member contains a V-shaped groove having oppositely curved walls and a concavely curved bottom or apex. This groove resembles the groove in the outer face of the both the Carrol and Fischer nozzle orifice member. The inner face however, contains not a curved bottomed groove but rather a slot cut at approximately 90o to the groove in the outer face, which has essentially straight walls and a straight bottom.

The straight bottom of said slot may form an angle with the straight walls, or there may be a radius of curvature where the walls and bottom meet such as would result if the slot was cut with a preformed cutting tool or end mill with a convex cutting surface. As the spray orifice is an opening, there is another member that can be used to act as restriction. Pre-metering, this is the process of inserting a device on the spray nozzle, it acts as a restriction to the flow. It reduces the velocity of the flow and it also reduces the performance of the associated nozzle. During crushing or screening of aggregates the respirable dust is being produced. Silica is one of the substances that are produced during the crushing of aggregates. This silica causes silicosis on the human being. Because employees will not be present as the result of being ill, the production will be reduced and less material will be produced.
The dust produced also affect the surrounding environment, it blocks the leaves of the plants and disturb the photosynthesis circle of plants, which results in plants dying. Few ideas have been invented and a lot of members have been modified to achieve the pulsating effect on the road-stone aggregates. Pre-metering is one of the modification that was done on the spray nozzle but as it reduces the velocity of the flow and also reduces the performance of the nozzle, it will not be able to wash the aggregates clean. The effect of Cavitation is very useful when trying to achieve atomization on the fluid, but it breaks down the strength of the fluid jet, and the fluid it will not wash the aggregates to the standard. In this project the desired spray nozzle with the orifice member that will create a pulsating effect on the aggregates will be designed. The spray nozzle designed will have greater flow rate and also greater velocity. This orifice will have both the properties that will prevent it from wear from the fluid with great speed. The spray drop-lets will be big in size to be able to wash the dust off and leave the road-stone washed. The angle of the spray nozzle will also be in the right position to cover a larger surface area.
The design of a spray nozzle used for washing of crushed aggregates in mining industry.

2.Methodology

Spray nozzle is a device or a tool that converts the pressurized energy of the liquid (water) into kinetic energy. For one to choose the right spray nozzle for the task at hand, there are principles to consider, which are the spray nozzle efficiency, droplet size, velocity of the spray nozzle discharge, the spray angle, the force that the spray waterjet will impinge the surface and also the area that the waterjet will cover. There are different spray nozzles and all of them have different functions. The spray nozzles differ because of their designs, the type of material used, the diameter of the spray nozzle, whether it has orifice or not, the interior design, the length of the nozzle. So a great decision has to be made when it comes to the selection of the spray nozzle for a certain function. The diameter of the spray nozzle and also the orifice inserted they determine the droplet size of the waterjet.

Droplet size affect how the liquid sheet will be, thick or thin. For the washing of aggregates large droplets sizes are required as they clean well the aggregates. According to (Butller, et al., 1997)"larger droplets are less prone to drift". (Quy, 2006)Explained that "droplet size affects the travel of spray between the sprayer and the ground. Under optimal conditions, a spray of small droplet provides very even coverage over a given space area. However, small droplets are more susceptible to spray drift, a condition whereby the droplets land outside of the intended spray area. (Wen, et al., 2016)Said that "The droplet size in the spraying field plays an important role in dust trapping and settling. And when the droplet size is 8–10 times larger than the particle size of dusts, the droplets' dust-trapping capability is optimal. The droplet size can hardly be reduced to below 10μm in practical spraying applications, i.e., the smaller the droplet size, the more easily the dusts can be trapped." (Nuyttens, et al., 2007)Said that "the larger the International Standard Organisation (ISO) nozzle size, the larger is the droplet size spectrum. The nozzle diameter affects the liquid sheet thickness (Shibo , et al., 2018), it also showed that the "liquid sheet thickness can be modified by changing the nozzle input section diameter once the pressure, spray angle and flow rate have been defined. There is a strong correlation between droplet sizes and velocities. In general, bigger droplet sizes correspond with higher droplet velocities. That is why anti-drift flat fan nozzles generally produce faster droplets compared to standard flat fan nozzles for the same pressure and nozzle size.

Spray angle (Tao, et al., 2017)"is the angle formed between two boarder lines, drawn along the spray from nozzle orifice". (Tao, et al., 2017)Explained that "spray angle is affected by the nozzle shape and size (swirl chamber, nozzle orifice length and diameter), spray liquid physical properties (i.e. liquid density and viscosity), and spray environmental factors (i.e. ambient temperature and density). Spray angle of pressure nozzle increases as the working pressure. This research will focus on the design of the spray nozzle that will be used for washing/cleaning of crushed aggregates in the mining industry. The spray nozzle to be designed will have to produce a waterjet that has a pulsating effect on the crushed aggregates. To do so, it will be result of increased waterjet velocity, which is proportional to the increase in the on the water pressure from the source of water. For the spray nozzle to be able to cover a larger surface area on the crushed aggregates, the nozzle design will have a triangle cut extruded inside the nozzle body to the point of the spray nozzle diameter.

3.Equations of waterjet thickness during application

Models have got different associated parameters, and they can be calculated differently. The parameters that the model have will help to find the desired results and from that a valid conclusion can be drawn from the calculations based on model. The first model that will be used is the model by Zhou (Zhou, et al., 1996), which is identified from the literature review. The Zhou (Zhou, et al., 1996) model focused on the relationship between the flow rate (Q) and spray angle (∅) to give the thickness of the liquid sheet or the spray droplets as a whole.

$$T = \frac{180 \times Q}{\pi \times \emptyset \times U} \tag{2.1}$$

The inlet velocity is described as follows

$$V = \frac{Q}{\frac{\pi}{4} \times D^2} \tag{2.2}$$

From Bernoulli's Equation, the average exit velocity is

$$U = Cd \times \sqrt{V^2 + \frac{2\Delta P}{\rho}} \tag{2.3}$$

Where T=thickness of liquid sheet, Q=liquid flow rate (m^3/s), ∅=spray angle (o), V=inlet velocity (m/s), U=average velocity (m/s), D=nozzle diameter, Cd=spray nozzle co-efficient, ρ=water density (kg/m^3), ΔP= difference in pressure (KPa). The second model to be used is the model by Guijun (Guijun, et al., 2018)this model gives the relationship between the spray nozzle flow rate and the spray nozzle diameter.

$$Q = \frac{K \times D \times \sqrt{P} \times 10^{-6}}{60} \tag{2.4}$$

And the same model gives the relationship between the spray nozzle velocity and the water pressure

$$V = \frac{200 \times K}{3 \times \pi} \times \sqrt{P} \tag{2.5}$$

Where Q=FLOW RATE, K=TEST COEFFICIENT, D=SPRAY NOZZLE DIAMETER (mm), P= WATER PRESSURE (MPa), V=VELOCITY (m/s)

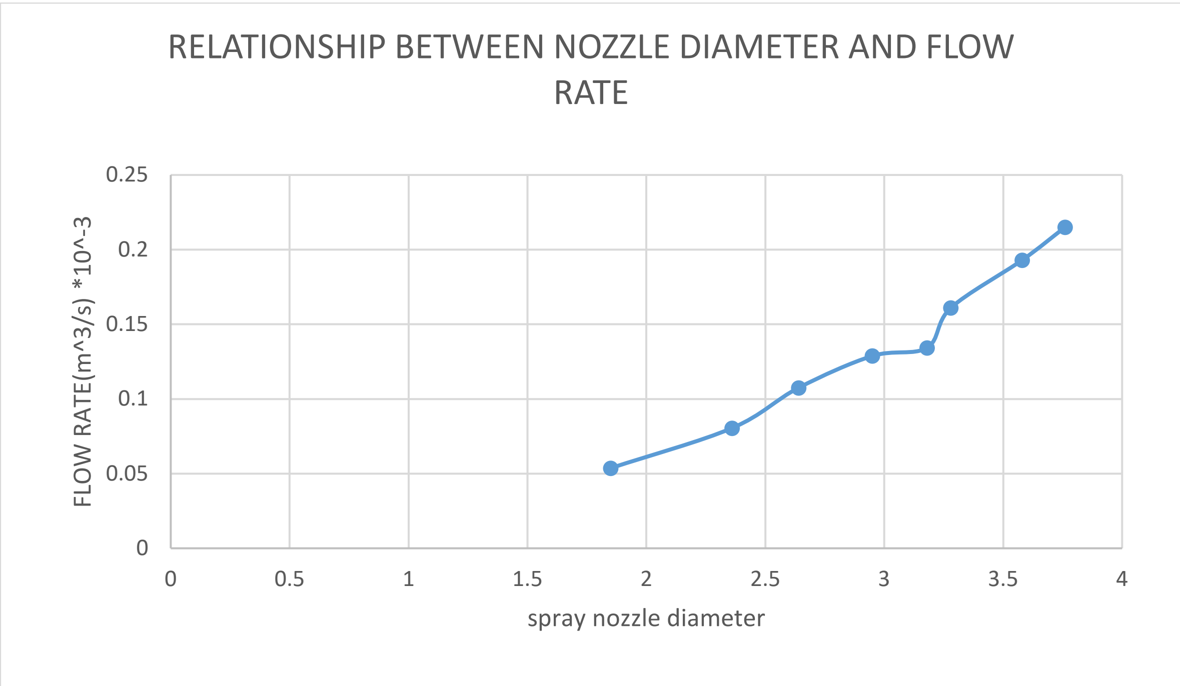
Table 1: the performance of spray nozzle on varying diameter, head loss, discharge, velocity and droplet thickness during operation

DIAMETER(mm)	k-factor	Q(m3/s)×10-3	Velocity(m/s)	Average velocity(m/s)	Droplet thickness(m m)
1.85	2.28	0.05367	19.966	11.162	0.00189
2.36	3.42	0.0805	18.403	16.187	0.001965
2.64	4.56	0.1075	19.639	22.1706	0.001915
2.95	5.47	0.1288	18.844	26.1441	0.001946
3.18	5.70	0.1343	16.9095	26.064	0.002036
3.28	6.84	0.161	19.054	32.842	0.001937
3.58	8.20	0.193	19.173	39.473	0.001932
3.76	9.12	0.215	19.363	44.081	0.001927

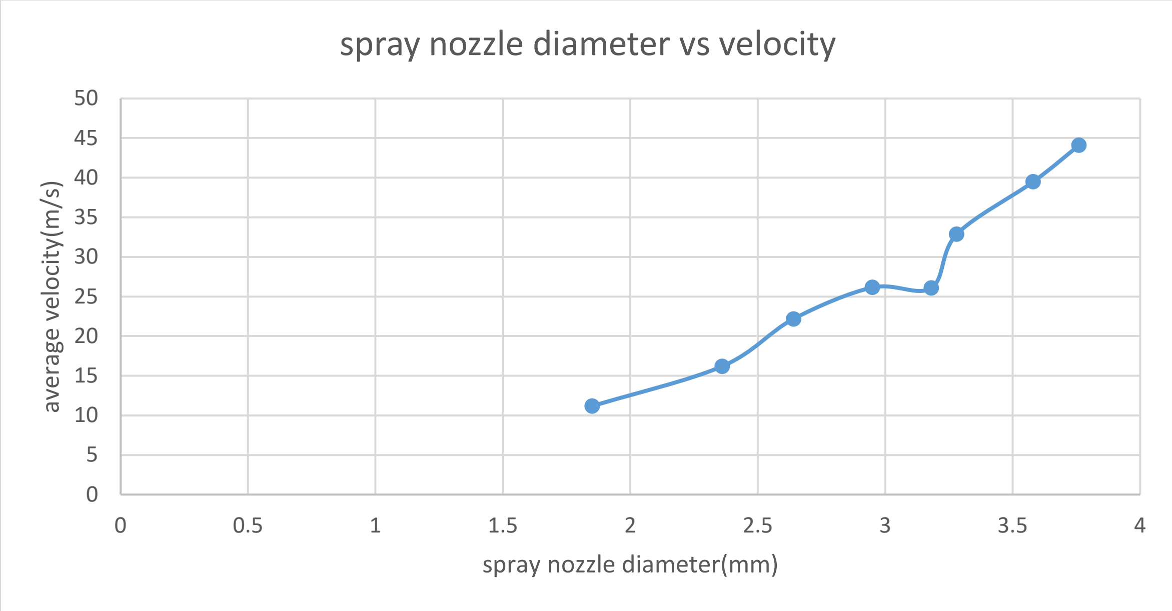
4.Results and discussion

The following table shows the results of the FF DEFLECTION WIDE ANGLE SPRAY NOZZLE

The graph in Fig.1 (a) shows the relationship between nozzle diameter and flow rate and Fig.1 (b) shown the relationship between average velocity, spray nozzle diameter and velocity



(a)



(b)

Figure 1 (a): Relationship between nozzle diameter and flow rate, (b) Relationship average velocity and spray nozzle diameter and velocity

In all of the following calculations the above model of Guijun (Guijun, et al., 2018) was used to calculate the required parameters and different variables such as Water Pressure and K-Coefficient where kept constant and only the spray nozzle diameter was varying to find its effect and to see if its change will give the expected results.

Calculations of the spray nozzle flow rate:
P= 0.27 MPa
K=1.34

$$Q = \frac{K \times D \times \sqrt{P} \times 10^{-6}}{60}$$

$$Q = \frac{1.34 \times 0.0008 \times \sqrt{0.27} \times 10^{-6}}{60}$$

$=9.284\times 10^{-9}\ m^3/s$

Table 2: the performance of spray nozzle on varying diameter and discharge during operation

D(mm)	Q(m3/s)×10^{-9}
0.8	9.78
0.9	11.009
1	12.232
1.5	18.349
2	24.465
2.5	30.581
3	36.697

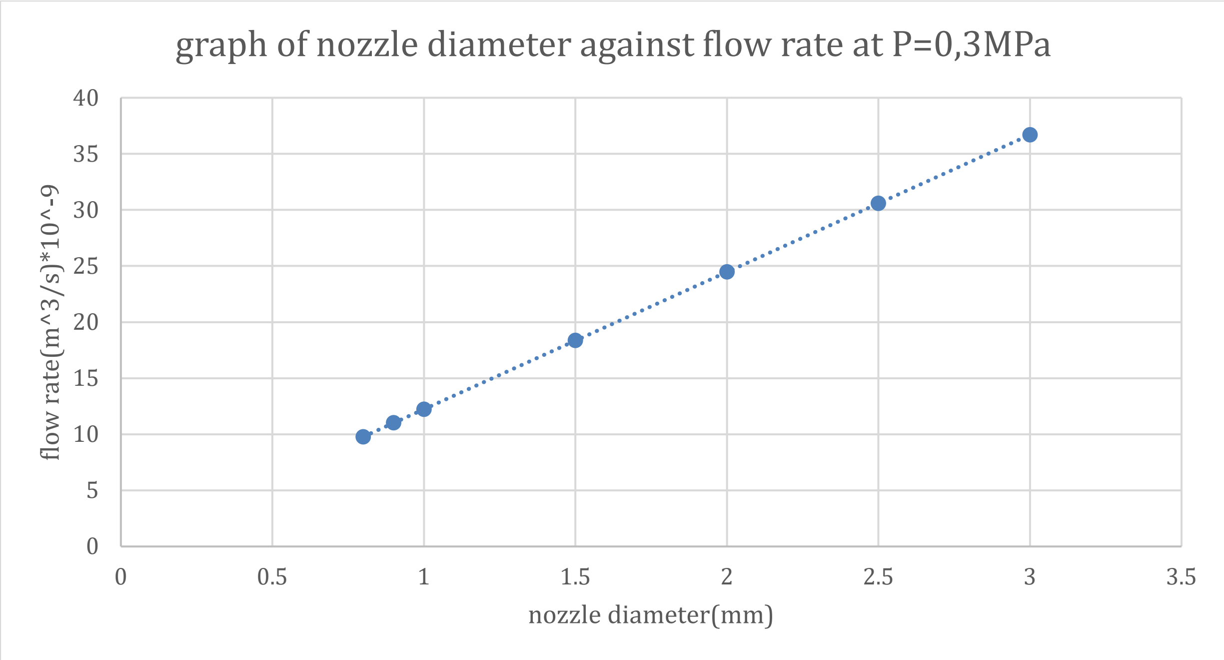


Figure 2: Relationship between flow rate and nozzle diameter

Figure 2 shows the relationship between different spray nozzle diameters against flow rates. All of the graphs are sketched under constant pressure. From the graphs it can be seen that that as the diameter of the spray nozzle increases, also the flow rate it is seen to increase.

To calculate the velocity of the waterjet

$$V = \frac{200 \times K}{3 \times \pi} \times \sqrt{P}$$

$$V = \frac{200 \times K}{3 \times \pi} \times \sqrt{0.27}$$

$$= 14.776 m/s$$

Table 3: the relationship between water pressure and water velocity

Water pressure(MPa)	Water velocity(m/s)
0.27	14.776
0.3	15.575
0.35	16.823
2	40.214
3	49.25
4	56.87
5	63.58
6	69.65

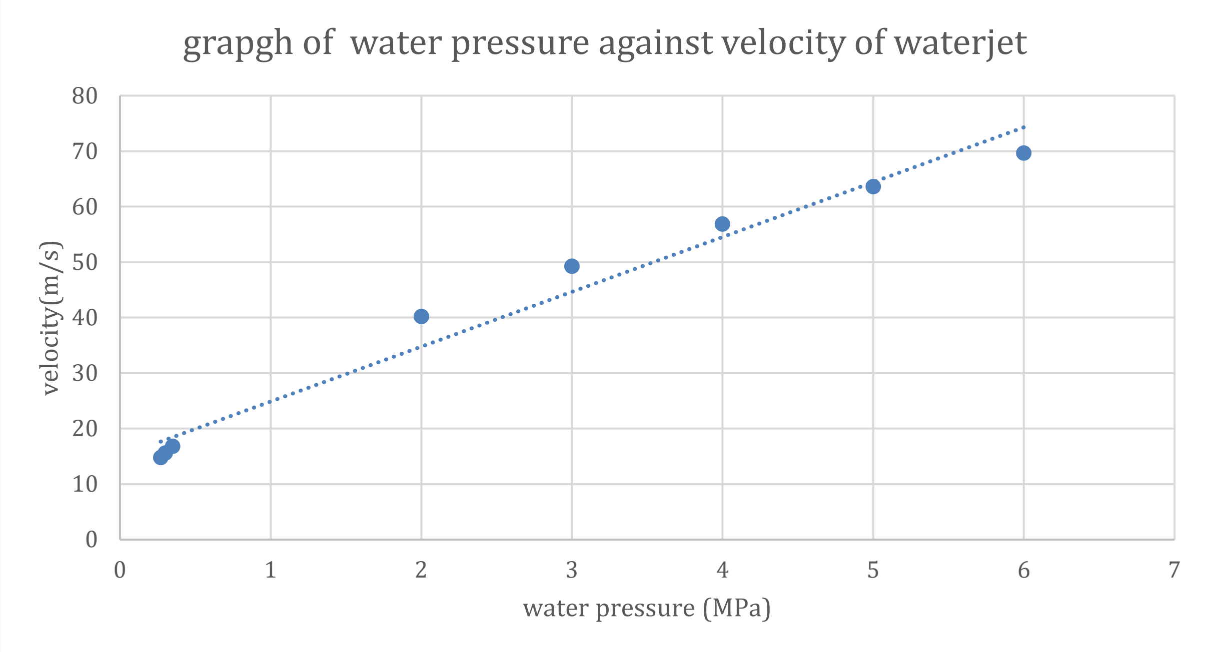


Figure 3: Relationship between velocity and water pressure

Figure 3 shows that as the water pressure is increasing on the system, the velocity of the water droplets increases. It can also be seen that as the pressure is increasing on the 3 mm diameter, the spray nozzle flow rate is seen to increase as well.

Table 4: Solidworks results on the impacts of varying parameters on minimum and maximum iteration during operation.

Name	Minimum	Maximum
Density (Fluid) [kg/m^3]	972.67	997.56
Pressure [Pa]	-2.71e+07	6.56e+08
Temperature [°C]	20.05	78.99
Temperature (Fluid) [°C]	20.05	78.99
Velocity [m/s]	0	455.561
Velocity (X) [m/s]	-40.985	346.423
Velocity (Y) [m/s]	-73.156	134.686
Velocity (Z) [m/s]	-308.915	46.311
Aspect Ratio CV [ ]	1.0135963	19734.0916955
Brick Quality [ ]	0	0
Cell Volume [m^3]	1.554063e-18	4.030691e-08
Curvature Criteria [rad]	0	1.730
Domain Index [ ]	0	1
Domain Index (Fluid) [ ]	0	0
Geometry Index [ ]	0	1
Phi (cylindrical) [rad]	0.026	6.271
Phi (spherical) [rad]	0.026	6.271
Position Vector R (spherical) [m]	2.858e-04	0.160
Radius r (cylindrical) [m]	1.211e-04	0.076
Theta (spherical) [rad]	-1.554	1.499
Tolerance Criteria [m]	0	7.781e-04
Wall Distance [m]	1.060e-04	0.019
X (cartesian) [m]	-0.068	0.068
Y (cartesian) [m]	-0.035	0.014
Z (cartesian) [m]	-0.142	0.033

Z-axis (cylindrical) [m]	-0.142	0.033
Velocity RRF [m/s]	0	455.561
Velocity RRF (X) [m/s]	-40.985	346.423
Velocity RRF (Y) [m/s]	-73.156	134.686
Velocity RRF (Z) [m/s]	-308.915	46.311
Vorticity [1/s]	1.09	358631.49
Relative Pressure [Pa]	-3.31e+07	6.50e+08
Shear Stress [Pa]	0	280106.17
Dynamic Viscosity [Pa*s]	0.0004	0.0010
Fluid Thermal Conductivity [W/(m*K)]	0.6024	0.6693
Prandtl Number [ ]	2.0294043	6.8323895

Specific Heat (Cp) [J/(kg*K)]	3761.6	4260.2
Bottleneck Number [ ]	6.4400553e-09	1.0000000
Heat Transfer Coefficient [W/m^2/K]	0	0
ShortCut Number [ ]	3.0029415e-07	1.0000000
Surface Heat Flux [W/m^2]	-0	-0
Surface Heat Flux (Convective) [W/m^2]	-1.995e+11	8.630e+11
Turbulence Intensity [%]	1.49	1000.00
Turbulence Length [m]	1.087e-05	0.003
Turbulent Dissipation [W/kg]	0.24	2.28e+09
Turbulent Energy [J/kg]	0.002	128938.153
Turbulent Time [s]	5.185e-06	0.040
Turbulent Viscosity [Pa*s]	0.0003	638.4294
Acoustic Power [W/m^3]	1.692e-21	9.875e+08
Acoustic Power Level [dB]	0	209.95
Refinement level [ ]	0	4

Table 5: Solidworks results on the impacts of varying parameters of mass flow and pressure during operation

Name	Current Value	Progress	Criterion	Averaged Value
SG Av Total Pressure 1	5.98829e+08 Pa	Achieved (IT = 97)	148749 Pa	5.98808e+08 Pa
SG CAD Area 1	0.00446237 m^2	Achieved (IT = 88)	4.46237e-11	0.00446237 m^2
SG Force 1	0 N	Achieved (IT = 0)	0 N	0 N
SG Mass Flow Rate 1	-0.521984 kg/s	Achieved (IT = 91)	0.0310924 kg	-0.513955 kg/s
SG Max Static Pressure 1	5.95585e+08 Pa	Achieved (IT = 88)	1.24898e+06	5.95698e+08 Pa
SG Max Total Pressure 1	8.02014e+06 Pa	Achieved (IT = 88)	1.73671e+06	7.85231e+06 Pa
SG Max Turbulence Length 1	0.00176499 m	Achieved (IT = 88)	1.76499e-11	0.00176499 m
SG Max Velocity (Y) 1	18.3139 m/s	Achieved (IT = 89)	1.47407 m/s	18.3082 m/s
SG Max Velocity 1	5 m/s	Achieved (IT = 88)	5e-08 m/s	5 m/s
SG Min Total Pressure 1	273487 Pa	Achieved (IT = 91)	27938.7 Pa	266137 Pa
SG Volume Flow Rate 1	0.000896234 m^3/s	Achieved (IT = 88)	1e-08 m^3/s	0.000896234 m^3/s

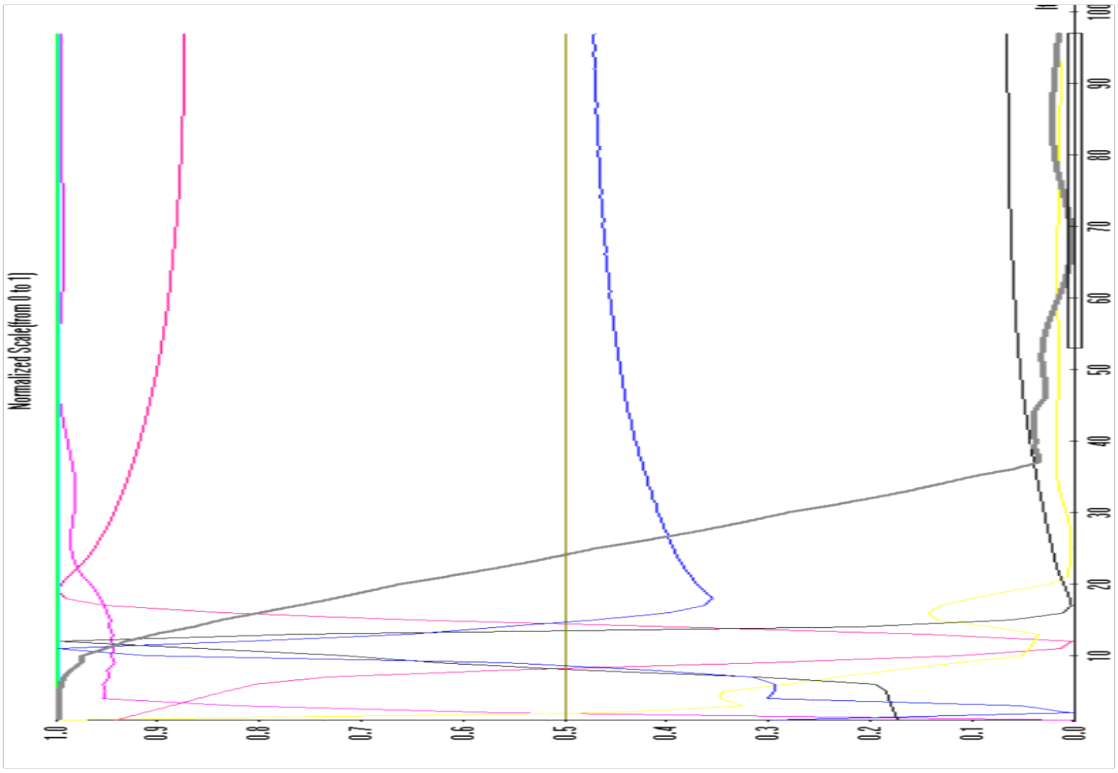


Figure 4: Normalized performance of nozzle shown by Solidworks during varying parameters of mass flow and pressure during operation

The discussion of the result is based on the flow simulation which was done on solidworks flow simulation. The discussion will be focusing on table 4 and table 5 Table 4 it has got all of the minimum results and also maximum results of the designed spray nozzle. Table 6 was also used on the following discussion as it was of assistance when it comes to the convergence or divergence of the simulated results. On the discussion I also included two figures or snipped pictures from Solidworks simulated results. The figures consist of cut cross-section of the designed spray nozzle. One shows the normal cut plane and the simulated regions of different colours which show the area which is being acted on by the water, and the other figure shows the flow trajectories, which shows the fluid that passes through selected surfaces, sort of visualised flow.

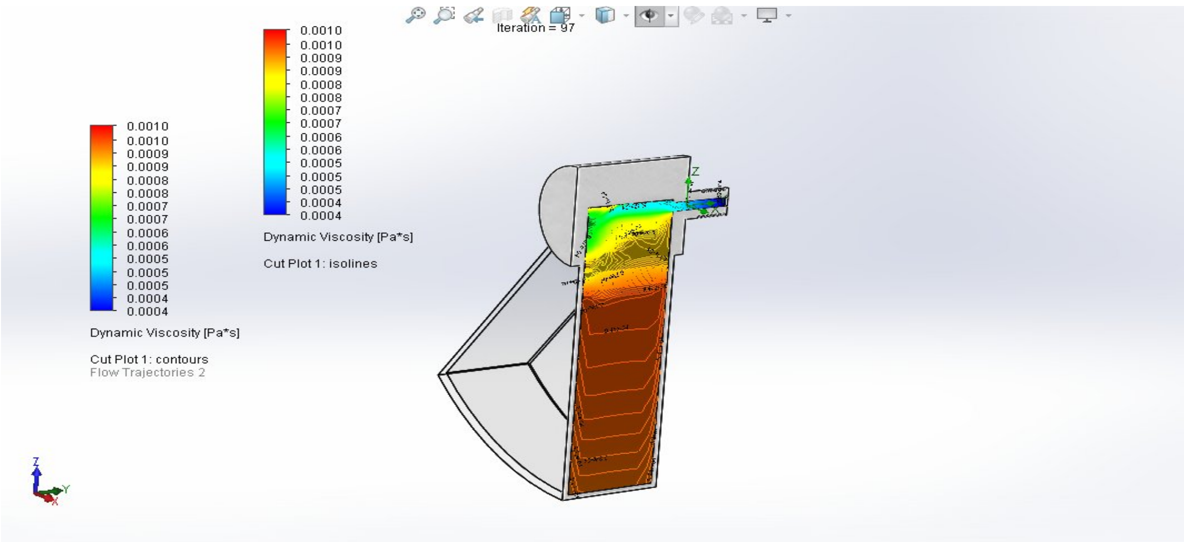


Figure 2: dynamic velocity during operation

This is the quantity to measure the force needed to overcome the internal friction in the fluid. As the turbulent viscosity of the entrance of the spray nozzle is approximately 343.7698Pa*s also the force needed to overcome such a friction is simulated to be 0.0006Pa*s. So this shows that at the entrance of the spray of the spray nozzle, there is sufficient force to overcome such a friction. That is where it can be seen that at entrance the velocity of the fluid is 249.794m/s which is more than what was calculated theoretically.

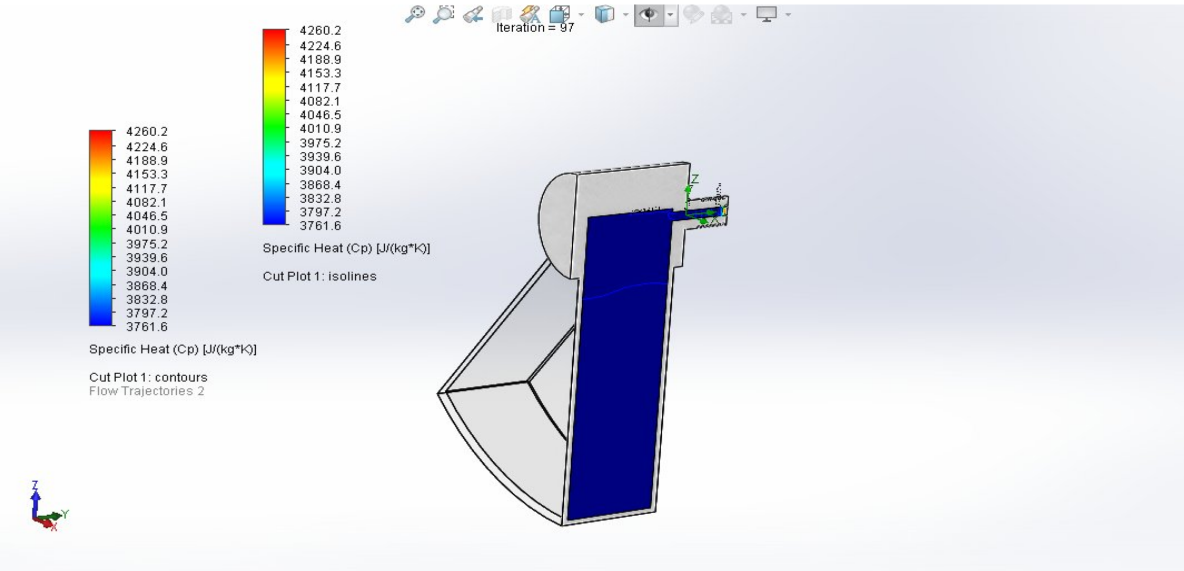


Figure 3: Specific heat of the system during operation

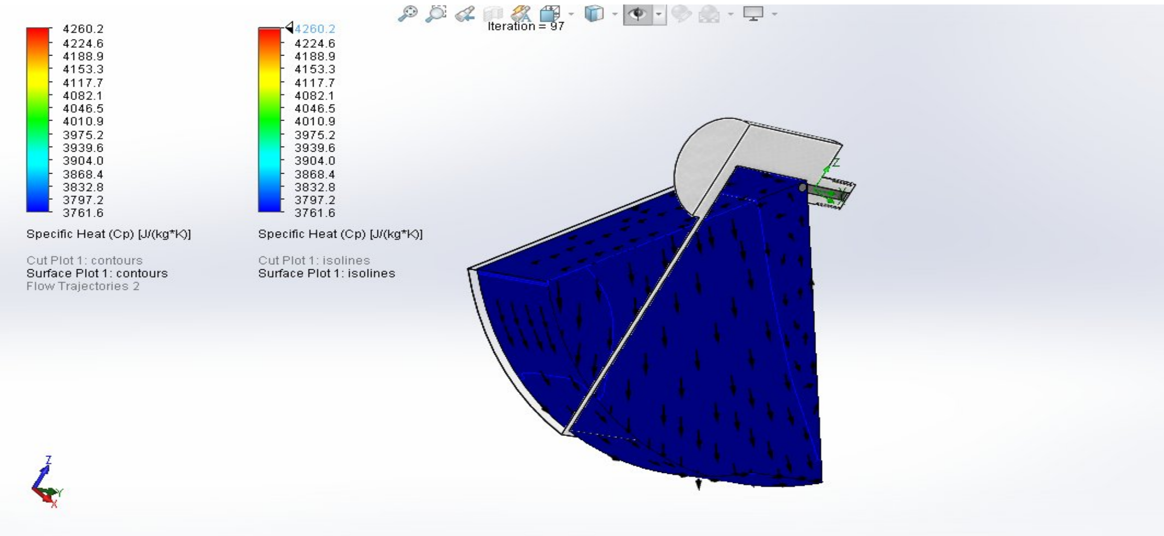


Figure 4: Specific heat of the system during operation

This value is constant throughout the design of the spray nozzle. Which was simulated to be 3761.6J/kg.k which is the normal specific heat for water at room temperature (in this case which is 25OC)

5.Turbulent viscosity

This is the internal fluid friction, in a manner analogous to the action of molecular viscosity in laminar flow. As we are dealing with a flow of fluid in the spray nozzle, there is a friction of fluid flowing at a high speed (velocity). The simulation results show that the turbulent viscosity of the spray nozzle is of between 0.0003Pa*s to 98.2202Pa*s. Because of the internal fluid friction, this effect will lower the speed of the fluid flow.

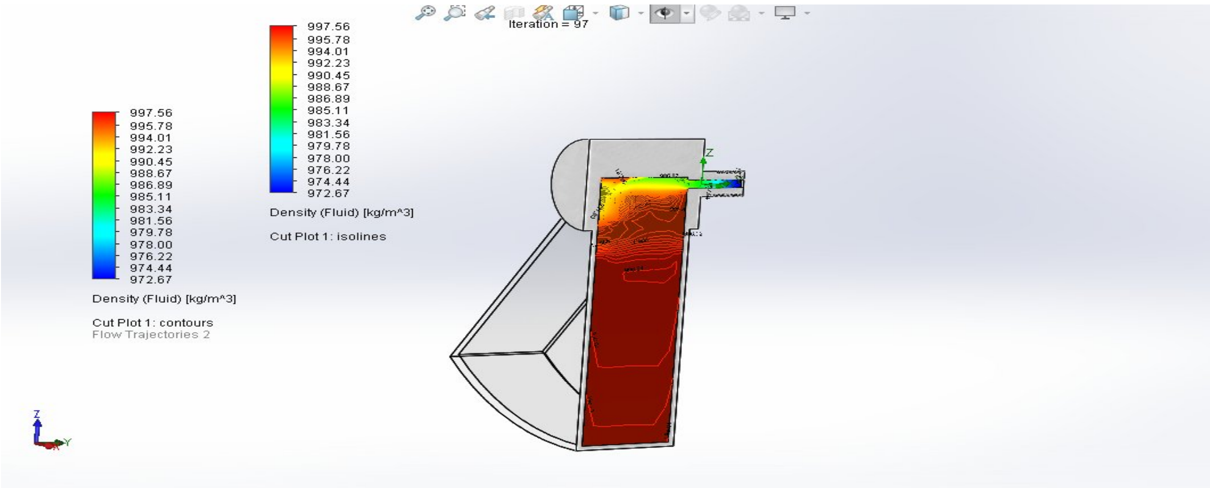


Figure 5: Density of the system during operation

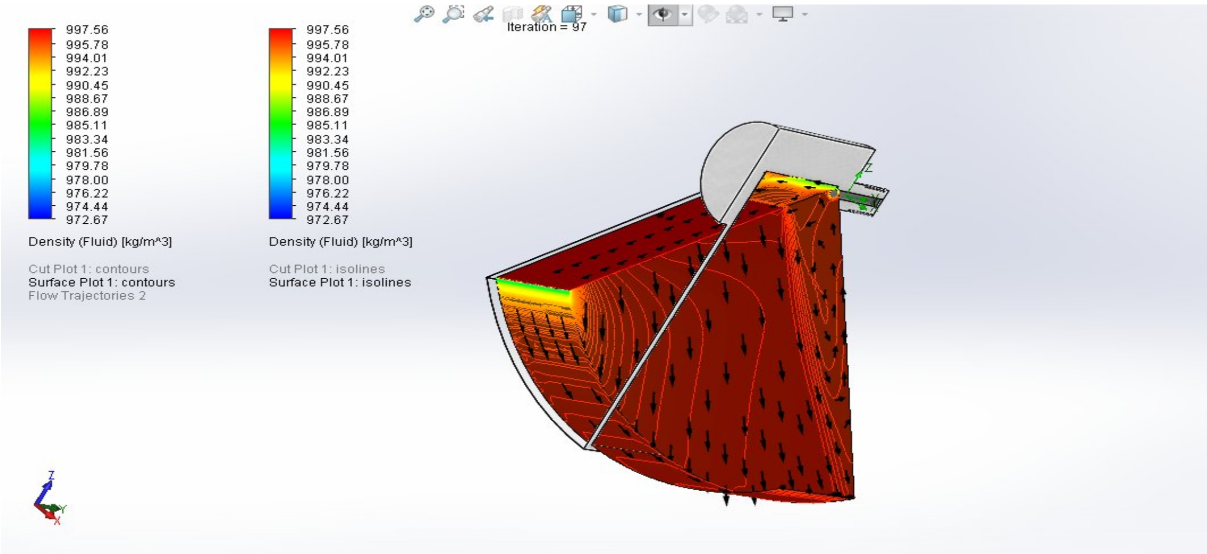


Figure 6: Density of the system during operation

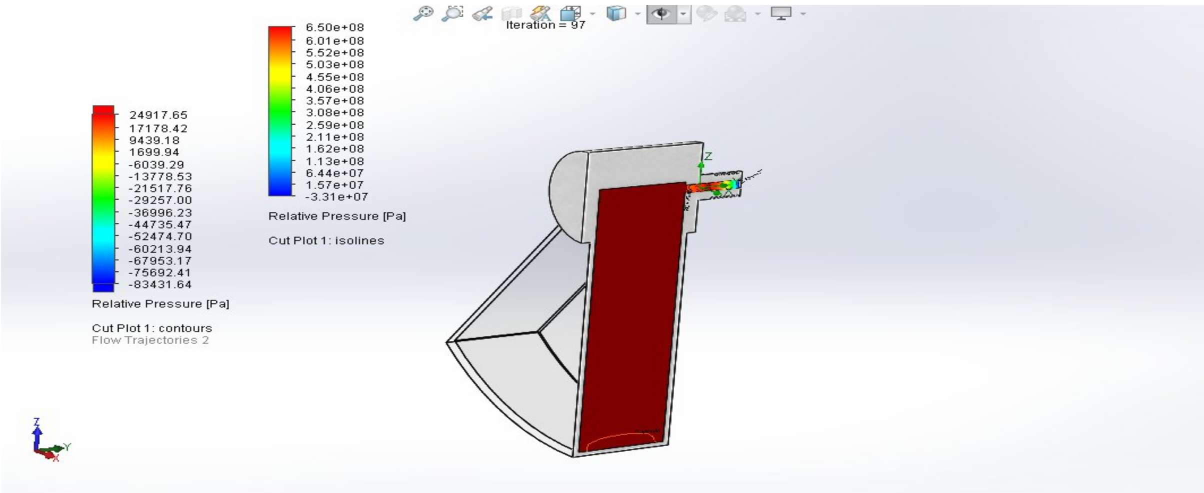


Figure 7: Relative Pressure of the system during operation

Is the atmospheric pressure corrected to sea-level conditions. The design of the spray nozzle can withstand such high pressures of up to 24917.65Pa (0.025MPa)

6.Turbulent energy

This is the type of energy associated with the eddies in turbulent flow. At entrance of the designed spray nozzle, this energy is a lot simulated to be 69428.237j/kg. This is the energy that will be needed to overcome the friction at the entrance of the nozzle because of the small nozzle diameter which is 3mm. At exit or inside the vacant opening of the spray nozzle, less energy will be needed to overcome such internal friction of the fluid flowing as the turbulent viscosity also it is at its minimum which was simulated to be 0.0003Pa*s

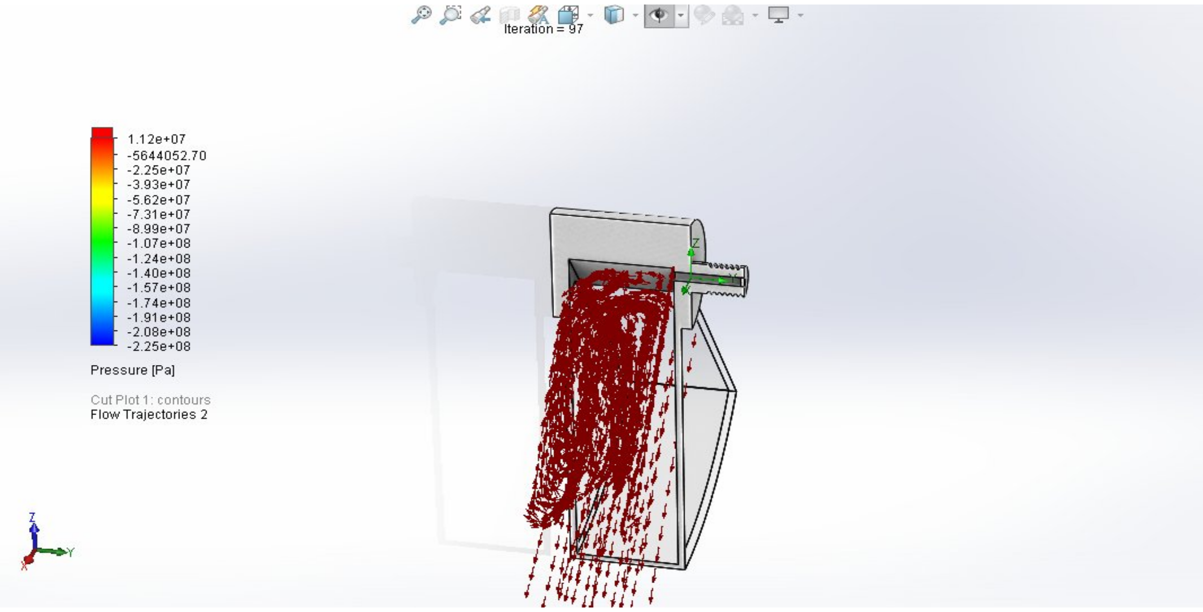


Figure 8: Pressure of the system during operation

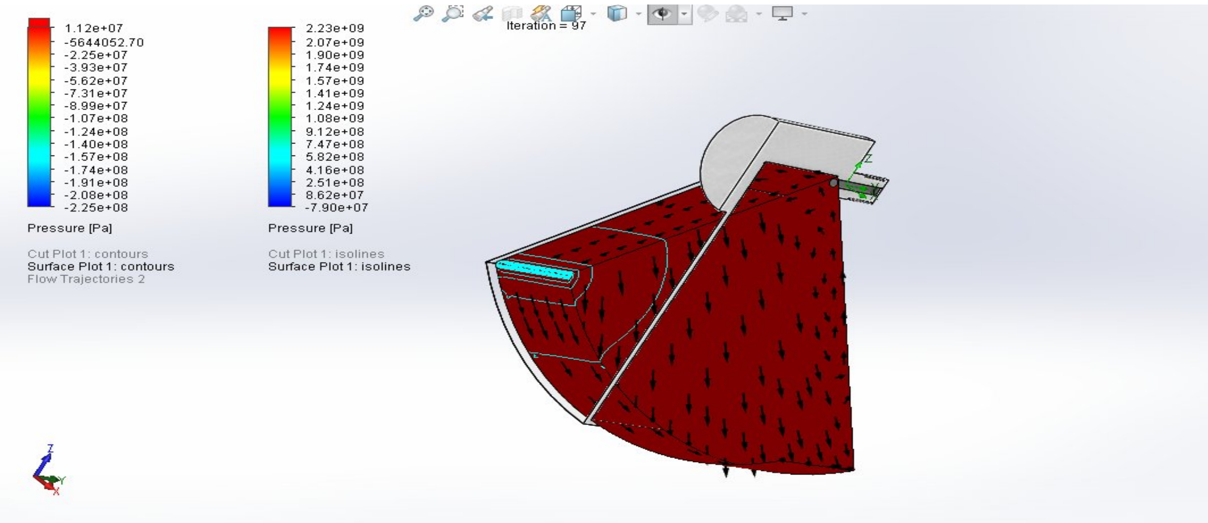


Figure 12: Pressure of the system during operation

The designed spray nozzle can be operated at greater pressures than what was calculated theoretically. During theoretical calculations, the highest calculated pressure that the spray nozzle can reach at diameter of 3mm was 6MPa. The simulated results show that the pressure that the designed spray nozzle can reach is 11.2MPa, which is the maximum pressure that the designed spray nozzle can be operated and also the small pressure that spray nozzle can be operated at is -225MPa, from this it can be seen that the objective of the design has been met and it will have a pulsating effect on the crushed aggregates as high pressures will be used. P=F/A as area (diameter) decreases the pressure increases so they are inversely proportional.

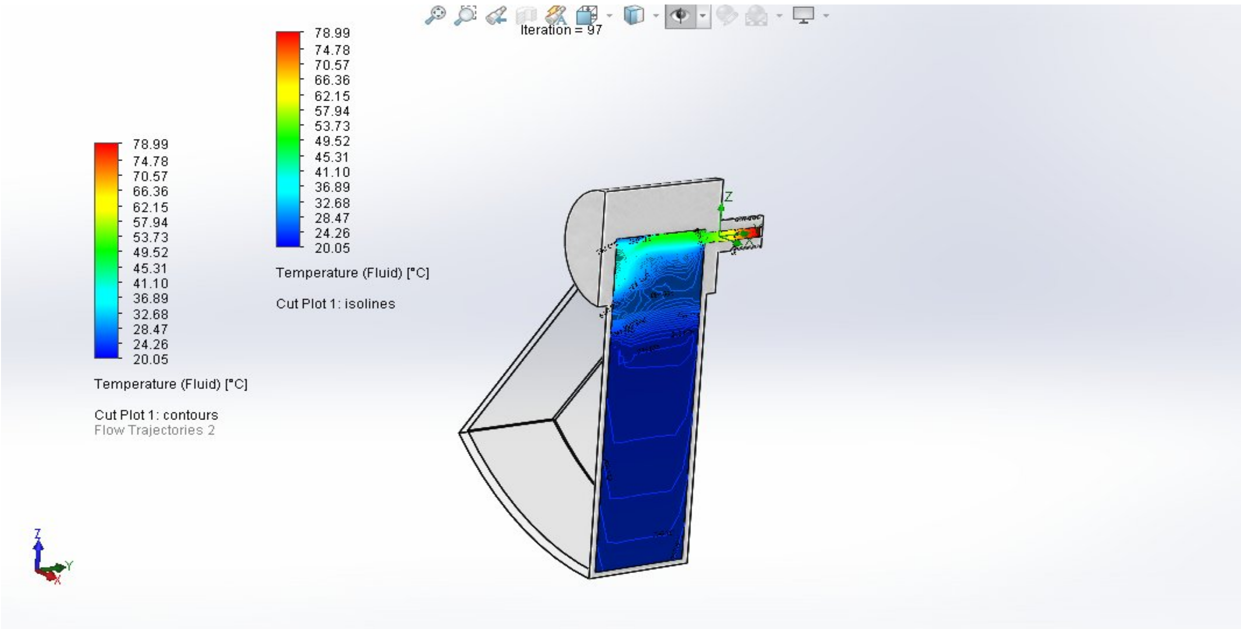


Figure 13: Temperature of the system during operation

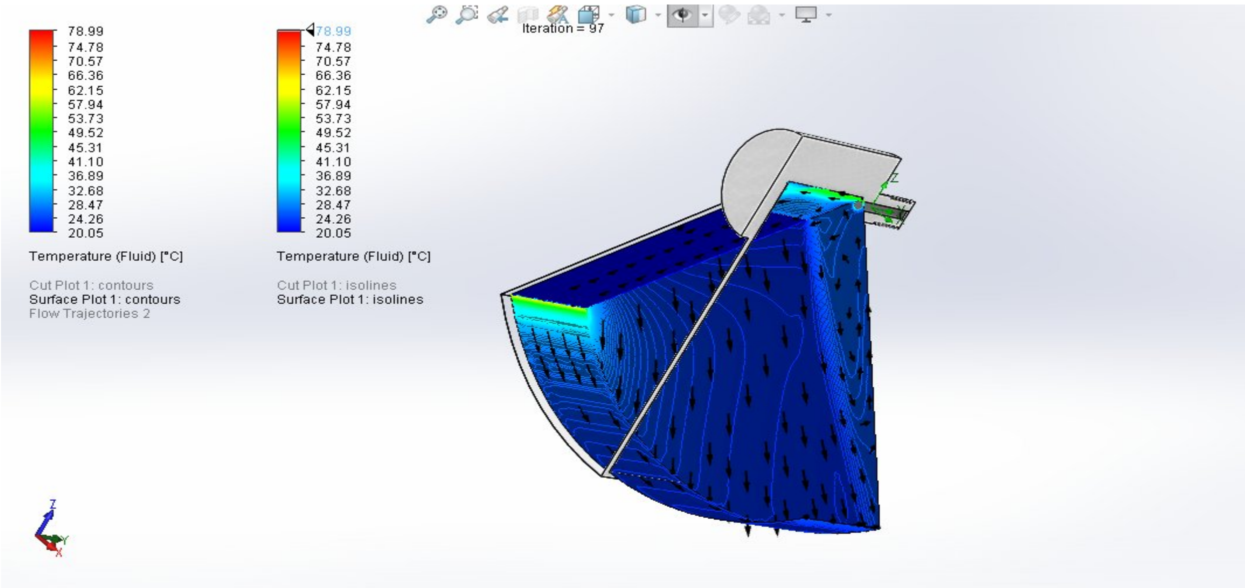


Figure 9: Temperature of the system during operation

From the material that was chosen which is polyethylene plastic to design the spray nozzle, at will be able to operate at high temperatures of fluid with maximum temperature to be 78.99oC and the minimum temperature to be 20.05OC.

7.Velocity in Z-direction

The spray nozzle design can have greater velocities of up to +46.311m/s in the Z-direction that is the speed (velocity) that will be hitting or washing the crushed road aggregates. The velocity in the Z-direction that was simulated is a vector quantity, it can be positive or negative. The negative sign is only indicating the direction of the flow. The fluid velocity that will be washing the aggregates was simulated to be 117.639m/s.

8.Velocity in the X-direction

This is the velocity entering the spray nozzle at the diameter of 3mm. The maximum simulated velocity that can enter was simulated to be 346.423m/s. But the one entering the spray nozzle at the assigned pressure was simulated to be 108.018m/s. As it can be seen, all those velocities are greater than what was calculated theoretically.

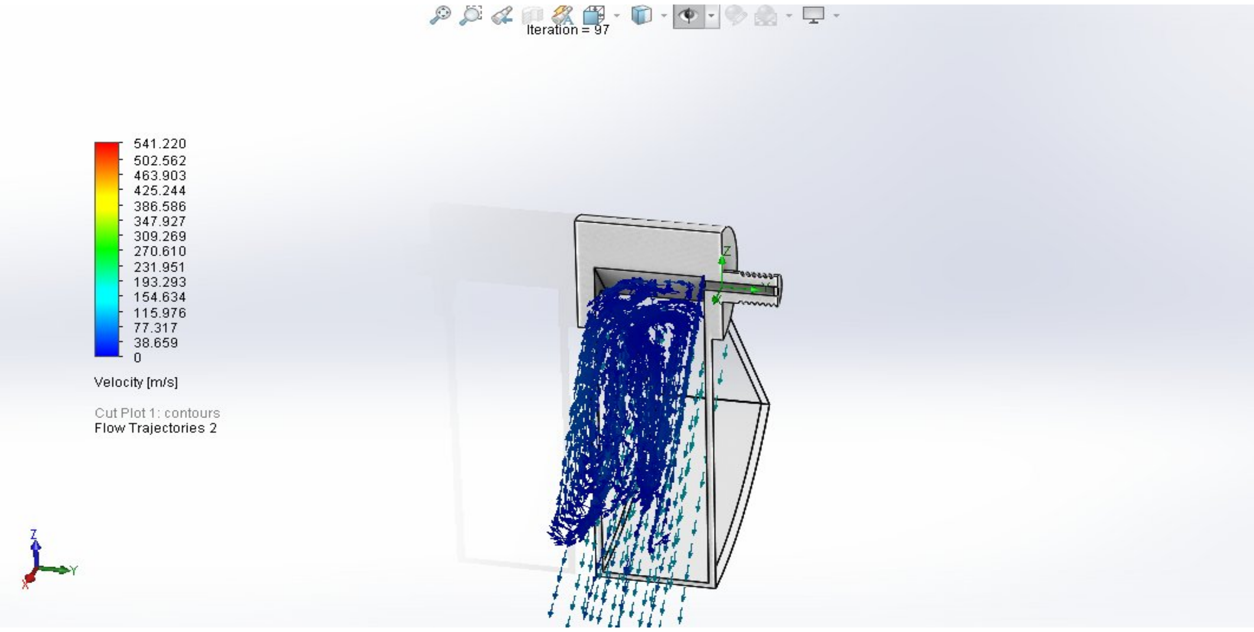


Figure 10: Velocity of the system during operation

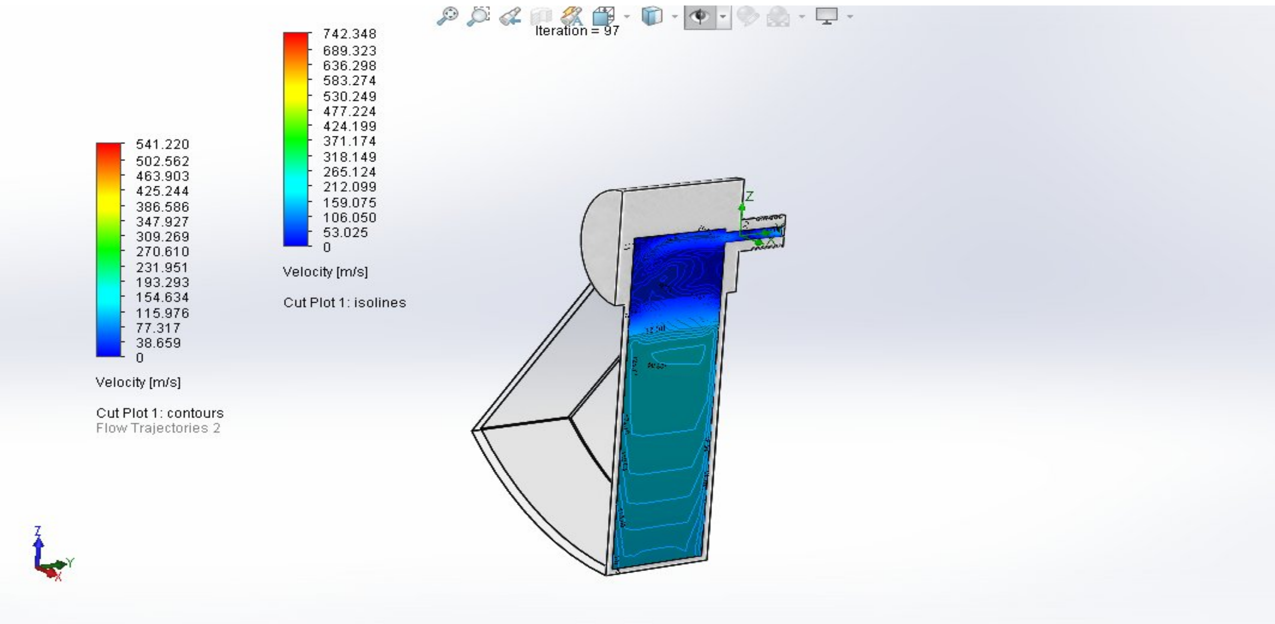


Figure 11: Velocity of the system during operation

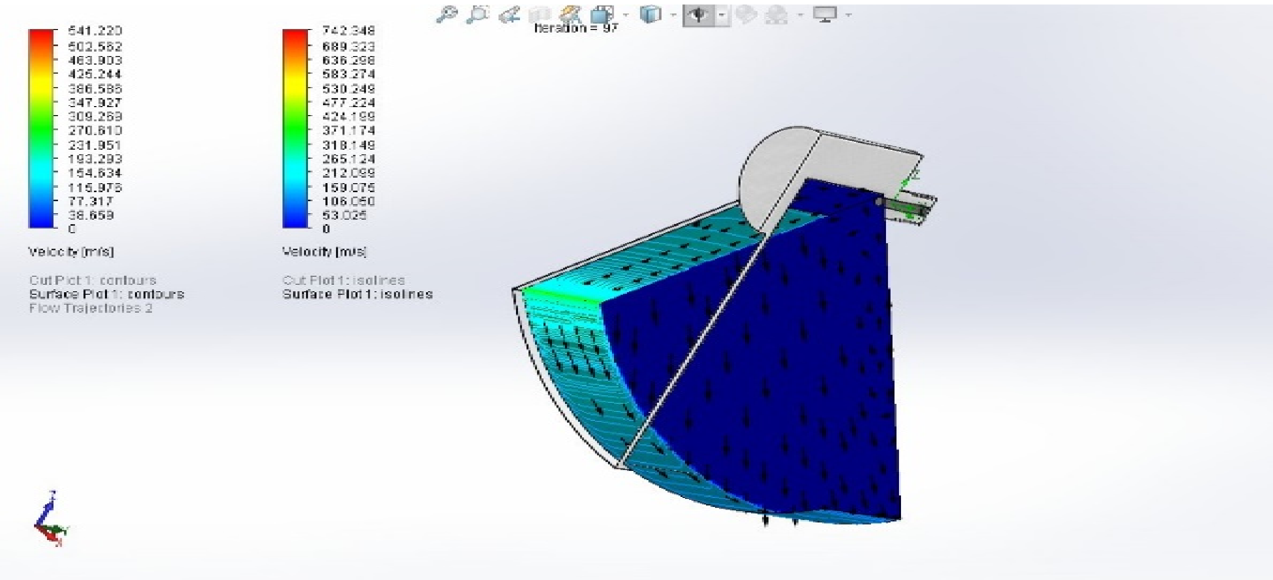


Figure 12: Surface performance of the system during operation

The designed spray nozzle was calculated theoretically to operate at the maximum velocity of 69.65m/s. The designed and the simulated spray nozzle can operate at maximum flow velocity of 541.220m/s. This is greater to what was expected. The solidworks simulation show that the designed spray nozzle can operate at greater velocities and that it can have positive pulsating effect on the crushed aggregates. Such greater velocities are what is expected on the designed spray nozzle. Comparison of calculated results to the simulated results. Two models were used to calculate theoretically at what diameters can the spray nozzle operate to its maximum, at what diameter will the spray nozzle have the greatest velocity flow of water and also at what pressures this can be operated. This results are all from constant diameter of 3mm

	Theoretical results	Simulated results
Velocity (m/s)	69.65	38.659-77.314
Pressure (MPa)	6	0.266-595.698

Table 3

From the comparison of the calculated results and simulated results, the velocity of the water flowing in the spray nozzle shows that simulated nozzle will have range of velocities from 38.659m/s to maximum velocity of 77.314m/s. This is the range that the theoretical calculated results lies between the simulated results, which means that the velocity of the simulated spray nozzle and the theoretical spray nozzle calculations are correlated to each other. The calculated pressure at which the spray nozzle can be operation al was calculated to be 6MPa and the simulated results was simulated to be between 0.226MPa to maximum of 595.698MPa. And from this my calculated pressure lies in between the simulated values. The simulated spray nozzle has the greatest velocity of flow and also the greatest pressures can be used. This mean that my design can be functional and my calculated results can be used with greater pressures to still increase the velocity during operation. This is an advantage to the design.

9.Conclusion and recommendations

The study was aimed at achieving the spray nozzle that will be efficient and cost effective as to saving water and also saving employees life by preventing them to be exposed to dust. A spray nozzle that will have greater velocity, flow rate and operating pressures. This was achieved by using the principles of fluids mechanics, and the two models of Zhou (Zhou, et al., 1996) and also Guijun (Guijun, et al., 2018) and also by simulating the results using solidworks. It was observed that the designed spray nozzle can was a success. The optimal diameter that the spray nozzle can operate at its full potential was found and it was also found that as the diameter of the spray nozzle was being increased, the flow rate also increases. And also as the pressure increases, the velocity of the spray nozzle increases. The simulations also showed that the spray nozzle can operate can operate with great efficiency and at low cost.

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