Optimizing the velocity and discharge produced by a spray nozzle for efficient washing of aggregates in a mining industry

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Abstract

In this paper the discharge and velocity of flow produced by a spray nozzle during the washing of aggregates is optimized for efficient operation of the nozzle during the washing of aggregates. This needed for efficient washing of crushed aggregates that produced silica that are harmful to human life and the environment. The increased in discharge and velocity of flow increases the jet pressure, and droplets that are needed for efficient and more economical washing of aggregates. In this study, the tools of fluid dynamic and solid works are used in optimizing the proposed design. The major parameters used in modelling optimal performance of the jet nozzle are flow velocity of spray nozzle and discharge of spray nozzle. The following results are theoretically revealed after modelling and simulation with solid works.

It was revealed that the optimal flow velocity gave high discharge with proper scattering of droplets during the washing of aggregates. An optimal discharge at an optimal nozzle diameter were revealed for efficient discharge during the washing of aggregates. It was also shown that there was an optimal nozzle diameter that gave optimal flow of water during the washing of aggregates. It was also revealed that the optimal nozzle diameter and droplet thickness gave an optimal discharge and velocity of the spray nozzle during operation. Varying direction of velocities in the system during operation given was revealed by solid works to have different impacts on flow velocity and discharge. The correlation between theoretical obtained results and simulated results from solid works revealed that the velocity of the water flowing in the spray nozzle have a range of velocities from 38.659m/s to maximum velocity of 77.314m/s as shown in the simulated result. The obtained results revealed close correlation in both modeling and simulation. It could be concluded that the design will function efficiently at optimal velocity and flow rate during operation.

Keywords: optimizing, discharge, velocity, efficient spray nozzle, flow rate, velocity, nozzle diameter and efficiency.

1. Introduction

Most mining industries that are crushing aggregates are faced with several challenges during crushing process [1-8]. The most common problem reported is poor discharge, flow velocity and operating pressure during the washing of aggregates [1-11]. This has leads to several environmental, issues, heath issues and operating cost [1-15]. This often leads to reduction in the quality of road-stone produce and the quality of the road to be constructed [12-17]. The use of the correct spray nozzles must be use during the washing of the aggregates for efficient and more economical washing of aggregates [1-14]. The spray nozzle must have the require flow rate as to create a pulsating jet of fluids to wash the dust and other small aggregate sizes [1-10]. This can be achieved by designing a spray jet with the require jet pressure, velocity, and discharge for efficient washing of aggregates [1-17]. It is no doubt that efficient and optimal operation of the jet spray nozzle is need for proper washing of aggregates [1-16]. For over the years now, most researchers have tried to design a spray nozzle with the require washing of aggregates characteristics. This has faced several setbacks in terms of operating parameters and behaviour during real life operation. One of such parameters facing setback are velocity and discharge produced by the nozzle during aggregates washing process.

Most Information which relate the spray velocity of droplets and discharge produced by the spray nozzles with the relevant data relating to the droplet particles size and the flux distributions during operation in the spray are vital factors to be taken into consideration if the behaviour of sprays pattern in complex air flows system must be understood. The velocities of spray droplet close to the spray nozzle and the nozzle diameter are vital input parameters to the physical models being derived to predicting droplet trajectories and discharge and any possible risk of drift during washing of aggregates from the spray application [1-12]. It is difficult to design a spray with optimal spray velocity and discharge during for washing of aggregates. This is due to lower droplets that usually decelerate from a release velocity line. Researcher like Miller et al., [27] used spray velocity measurements and develop a model which describe entrained air velocities at varying positions within a flat spray fan. The derived model by Miller et al [27] shown that the Phase Doppler instrument system gave more enhanced droplet density which produced a higher discharge during operation. Few comparative analyses in nozzle spray [28] revealed reasonably agreement between size/velocity profiles measured during operation. This is mostly applied in the development of agricultural spray nozzles, but it has not been applicable in the mining industries during the washing of aggregates. The main problem of optimizing the spray velocity and discharge is creating a serious issue of drift control problem.

Most design air spray induction nozzles produced large spray droplets with an air inclusion during operation and there is evidence that the presence of air inclusions in the system influences the Phase Doppler behaviour during operation. This has given rise to other problem such as the challenges in analysing sprays droplet and emulsions produced during operation as reported in the agricultural and chemical industries. Oxford Lasers "VisiSizer" developed a new spray analyser and the velocity and sizes during operation can be computed for a spray. This paper reports the results of optimal velocity and discharge produced by a spray nozzle for efficient washing of aggregates in the mining industry.

2. Methodology

To model the optimal velocity and discharge produced by the spray nozzle, it is important to study the waterjet thickness produced by the spray nozzle during operation which is given by Zhou (Zhou, et al., 1996). The Zhou (Zhou, et al., 1996) model focused on the relationship between the flow rate (Q) and spray angle (∅) which gives the thickness of the liquid produced by the spray as droplets during operation given as

$$T = \frac{180 \times Q}{\pi \times \emptyset \times U} \qquad [1]$$

where T=thickness of liquid sheet, Q=liquid flow rate (m^3/s), ∅=spray angle (o), U=average velocity (m/s). From Bernoulli's theory the spray nozzle average exit velocity is can be computed.

$$U = Cd \times \sqrt{V^2 + \frac{2\Delta P}{\rho}} \qquad [2]$$

where V=inlet velocity (m/s), Cd=spray nozzle co-efficient, ρ=water density (kg/m^3)

ΔP= difference in pressure (KPa). To establish the flow of fluid energy from the inlet and exit of the pressure nozzle of the spray it is important to consider to two points which are point A and point B and their flow energy is given as $\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B$. Their respective velocities at inlet and exit V1 and V2 are computed from the equation of continuity given as V2 = (A1V1/A2). To compute the optimal velocity and discharge during spray of the nozzle, the change in pressure from the nozzle can be computed as

$$\Delta P = \frac{\rho}{2}\left(V_A^2 - V_B^2\right) = \frac{\rho}{2}\left(V_1^2 - V_2^2\right) = \frac{\rho}{2}\left(V_1^2 - \left(\frac{A_1 V_1}{A_2}\right)^2\right) \qquad [3]$$

where A1 is the inlet of the spray nozzle and A2 is the area of the spray nozzle at the exit. The different velocity at the inlet and exist can be defined form the equation of Bernoulli given as

$$V = \frac{Q}{\frac{\pi}{4} \times D^2} \qquad [4]$$

Where Q is the flow rate, D is the spray nozzle diameter (mm), V is the velocity (m/s). From equation (4) the discharge through a spray nozzle can be computed. The relationship between the spray nozzle flow rate and the spray nozzle diameter given as

$$Q = \frac{K \times D \times \sqrt{\Delta P} \times 10^{-6}}{60} \qquad [5]$$

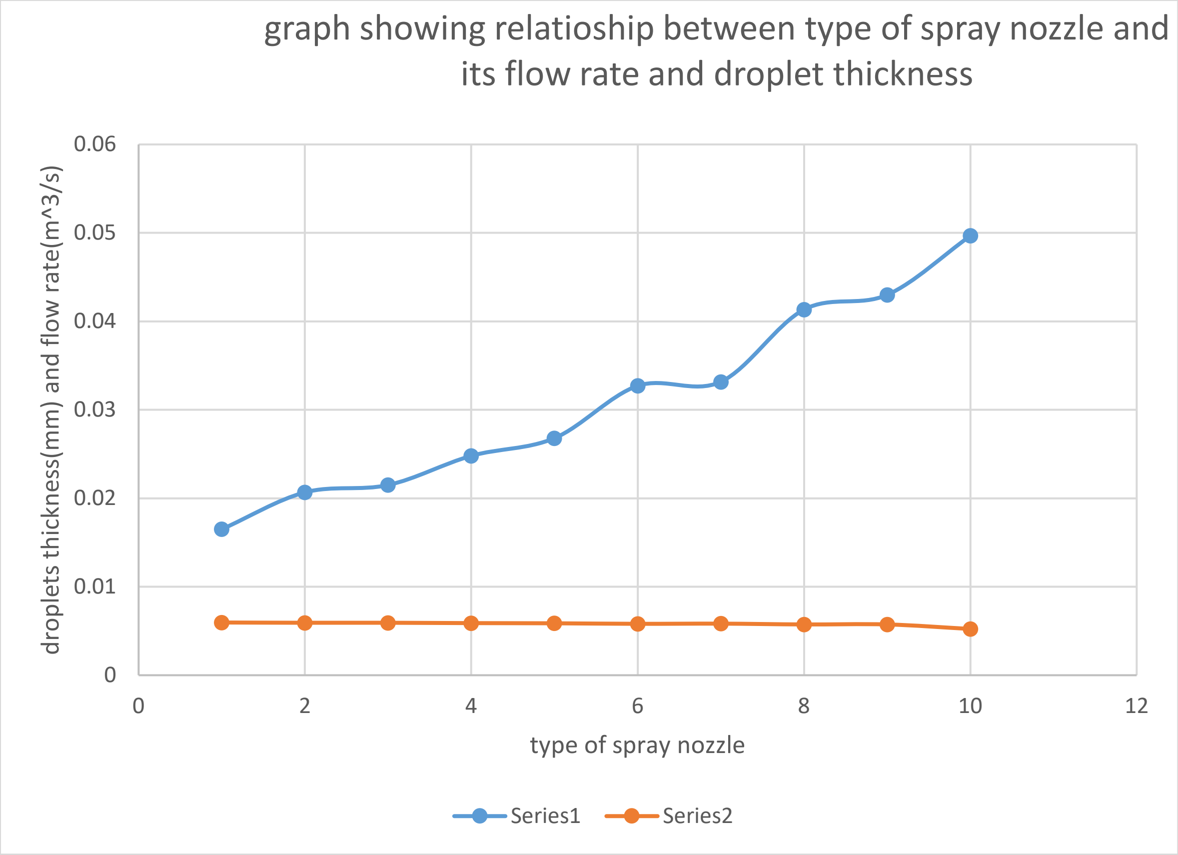
Where K is the test coefficient, P is the water pressure (MPa). The results in table 1 revealed the performance of BJ flat fan spray nozzles with different flow rates and BJ flat fan spray nozzle at a Pressure of 2Bar, Diameter of 9.65mm and at a Spray angle of 110o

Table 1: the performance of BJ flat fan spray nozzles with different flow rates

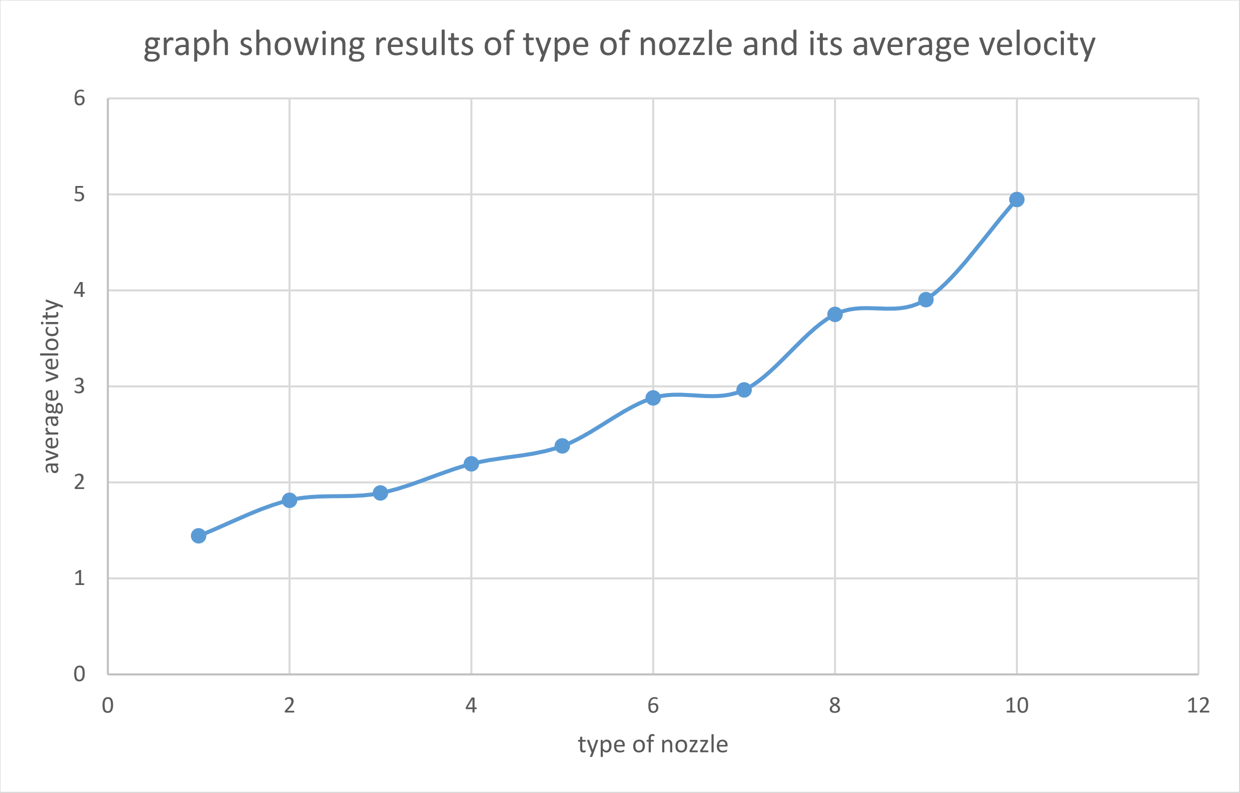
Spray nozzle	k-value	Q(L/m)	Q(m3/s) ×10-3	Velocity(m/s)	Average velocity(m/s)	Droplet thickness(mm)
1	0.702	0.99	0.0165	0.226	1.443	0.00596
2	0.877	1.24	0.0207	0.283	1.815	0.00593
3	0.912	1.29	0.0215	0.294	1.889	0.00593
4	1.053	1.49	0.0248	0.339	2.193	0.00589
5	1.139	1.61	0.0268	0.366	2.379	0.00587
6	1.367	1.93	0.0322	0.439	2.880	0.00581
7	1.404	1.99	0.0332	0.454	2.963	0.00583
8	1.755	2.48	0.0413	0.565	3.749	0.00574

9	1.823	2.58	0.0430	0.588	3.905	0.00574
10	2.106	2.98	0.0497	0.679	4.947	0.00523

From table 1 it is revealed that an increase in spray nozzle led to an increase k-value, discharge, and velocities of flow through the spray nozzle. It is shown that as these parameters increases during operation the droplet thickness decreases during operation. This is due to the fact an increase in velocities and discharge led to an increase in pressure which causes molecular breakdown of droplet. At very high pressure the droplet thickness gets more smaller due to more random breakdown of molecules of water. Therefore, an increase in velocities of flow led to an increase in discharge during spray nozzle operation. The graph below shows the relationship between types of spray nozzles flow rate and droplet thickness. An exponential increase of droplet thickness, flow rate and type of spray nozzle is revealed in Fig.1 (a). It increases to an optimal droplet thickness and flow rate during operation. However, the increment is not smooth due to air pressure or variation of pressure during operation that impacts the flow trajectory. A similar result was observed for average velocity and type of spray nozzle as shown in Fig.1 (b)



(a)The graph below shows the type of spray nozzle and its average velocity



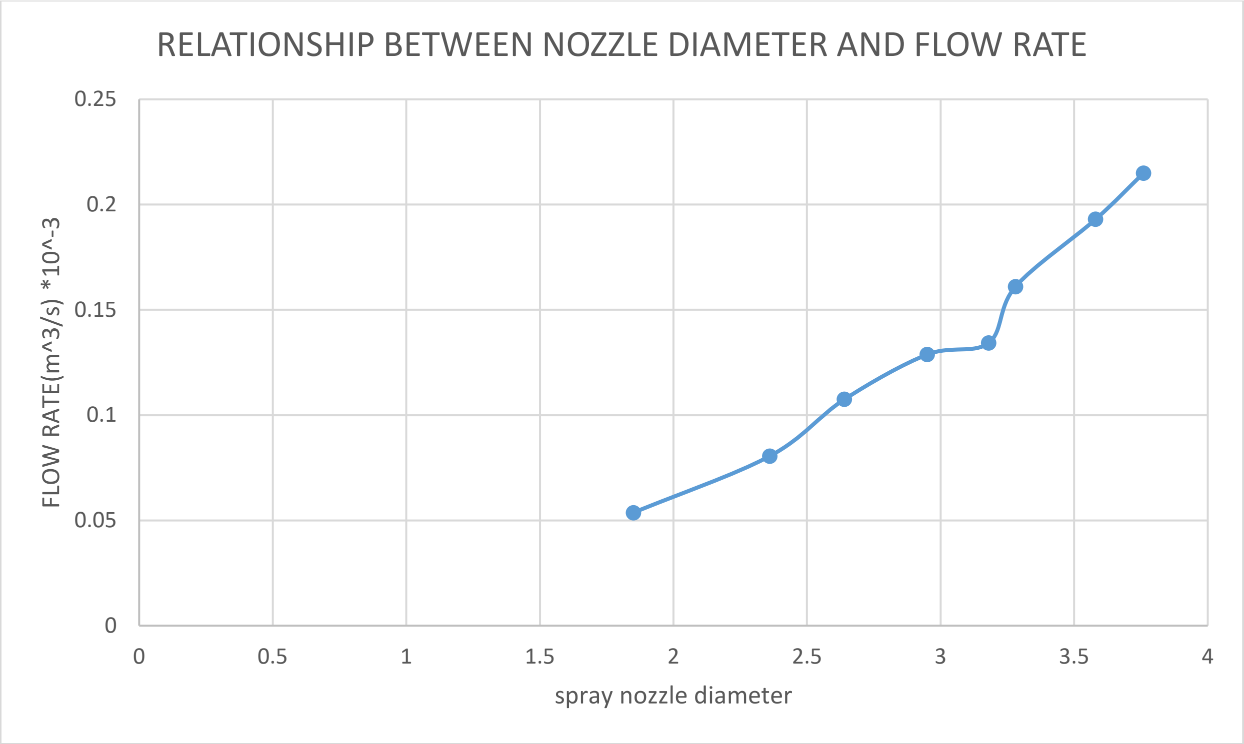
(b)

Figure:1 (a) droplet thickness to spray nozzle type (b) average velocity to type of spray nozzle

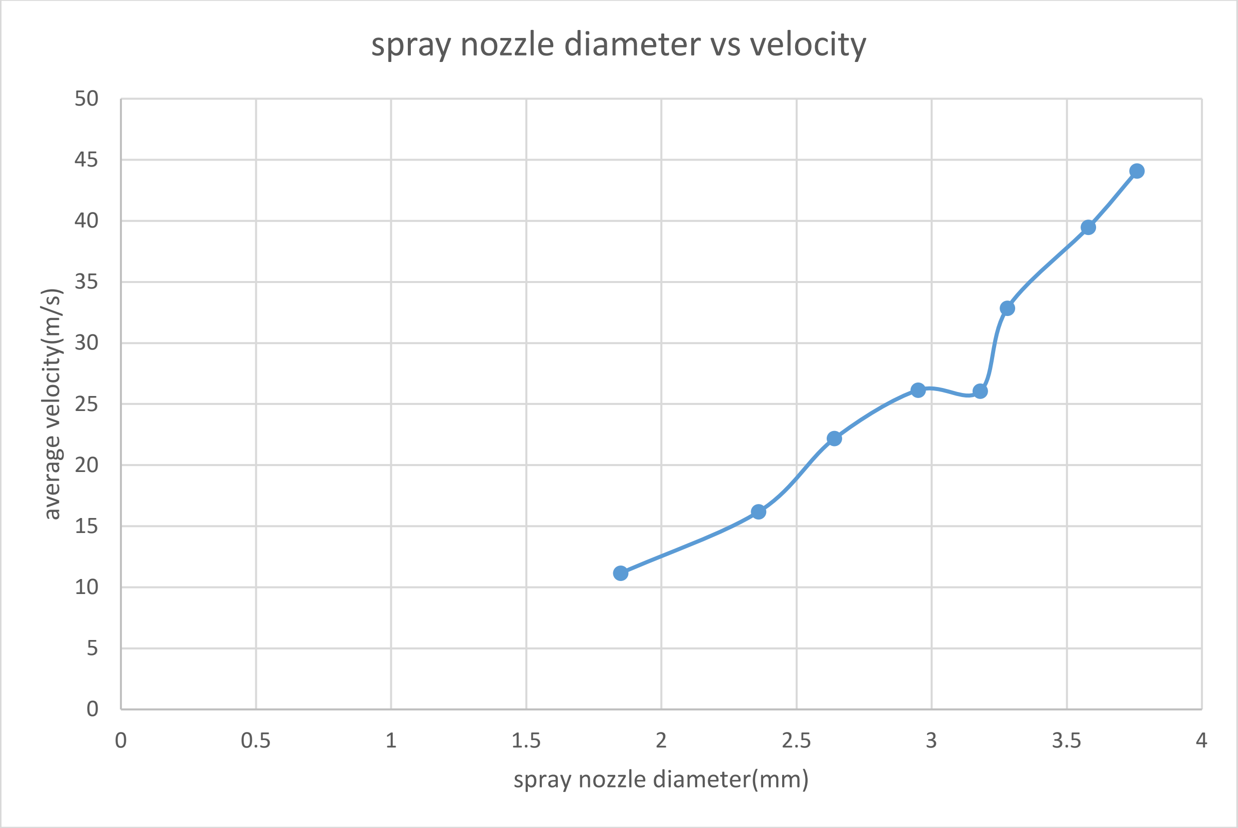
Table 2: the performance of FF deflection wide angle spray nozzle

SPRAY TYPE	DIAMETER (mm)	k-factor	Q(m3/s) ×10-3	Velocity(m/s)	Average velocity(m/s)	Droplet thickness(mm)
FF073	1.85	2.28	0.05367	19.966	11.162	0.00189
FF093	2.36	3.42	0.0805	18.403	16.187	0.001965
FF104	2.64	4.56	0.1075	19.639	22.1706	0.001915
FF116	2.95	5.47	0.1288	18.844	26.1441	0.001946
FF125	3.18	5.70	0.1343	16.9095	26.064	0.002036
FF129	3.28	6.84	0.161	19.054	32.842	0.001937
FF141	3.58	8.20	0.193	19.173	39.473	0.001932
FF148	3.76	9.12	0.215	19.363	44.081	0.001927

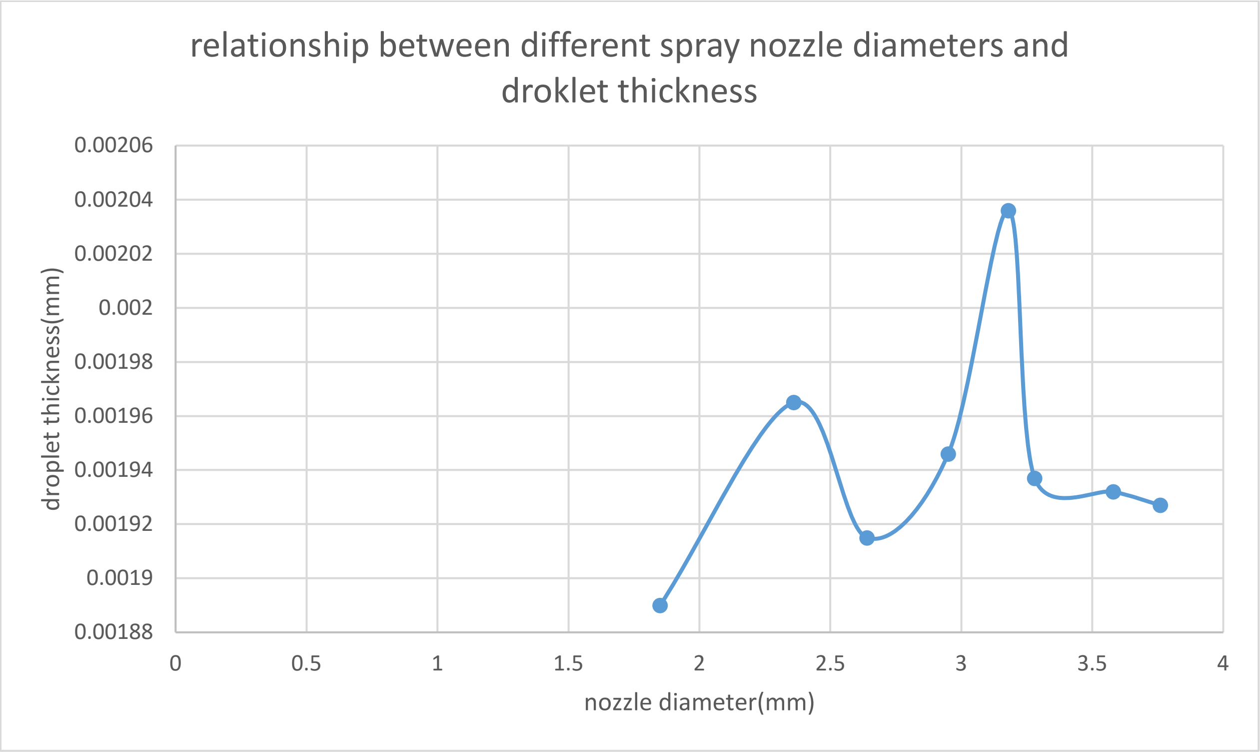
The performance of FF deflection wide angle spray nozzle revealed an increase in velocities and discharge when the diameter increase. It was also revealed that the droplet thickness decreases when the velocities and discharge increases. The obtained results in Fig.2 is like the obtained result revealed in Fig.1. Further investigation was needed to get the optimal velocity and discharge that gave optimal performance during operation. The obtained results revealed in table 2 is revealed in Fig.2 (a-c) as shown below.


RELATIONSHIP BETWEEN NOZZLE DIAMETER AND FLOW RATE
FLOW RATE(m^3/s) *10^-3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
spray nozzle diameter

(a)


spray nozzle diameter vs velocity
average velocity(m/s)
50
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
spray nozzle diameter(mm)

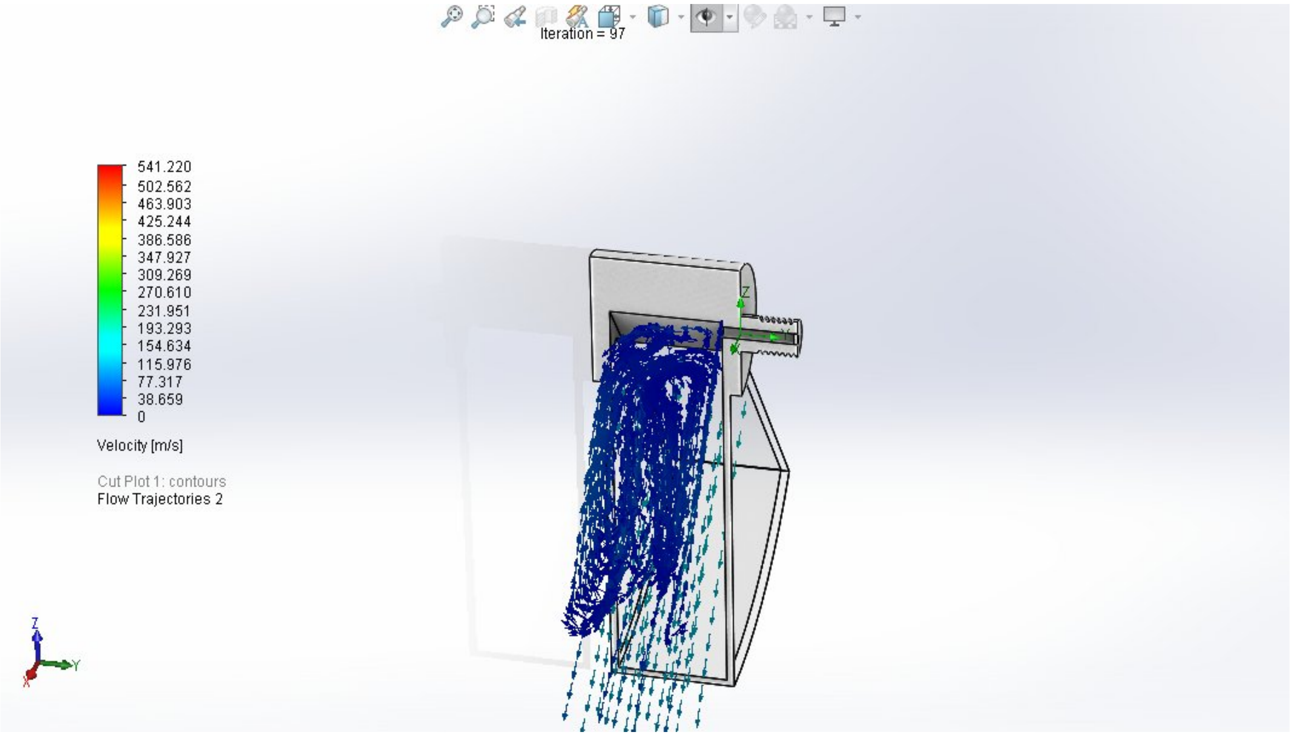
(b)



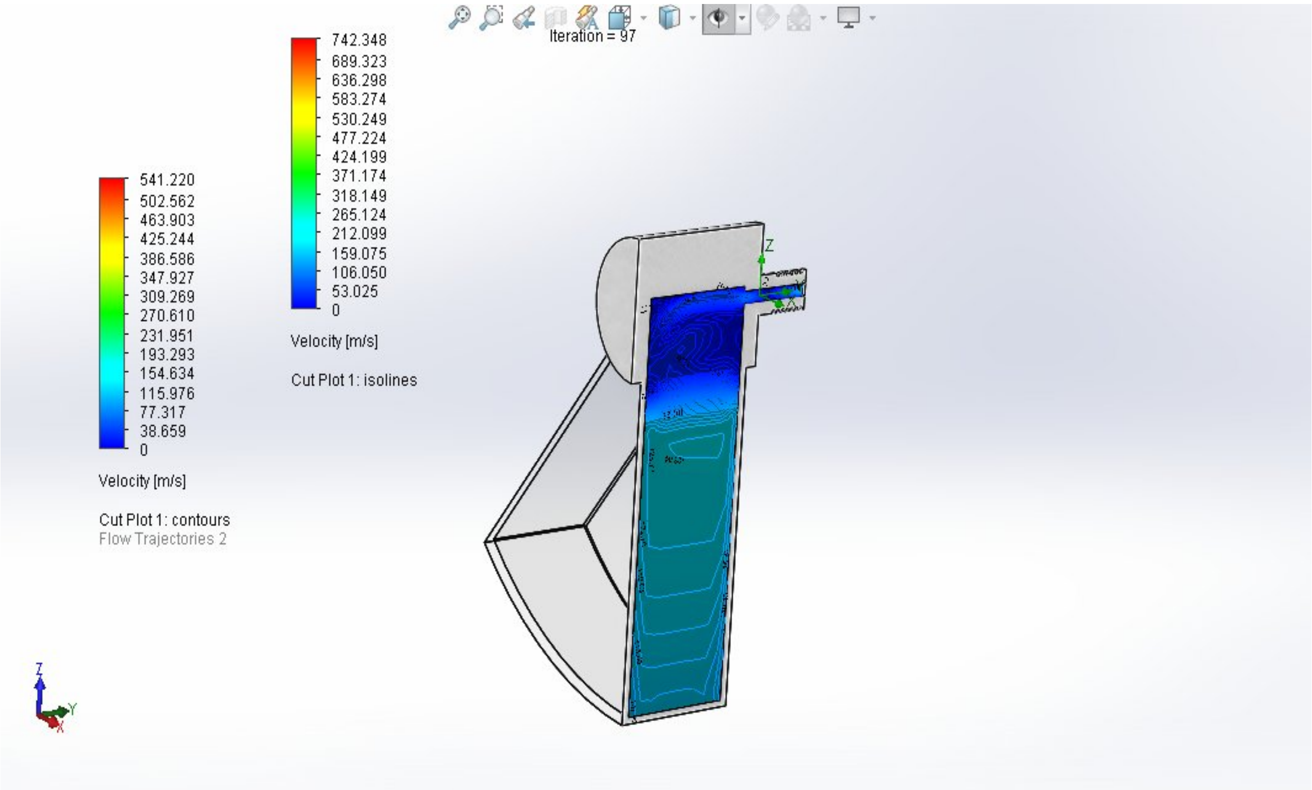
(c)

Figure 2 (a) Nozzle diameter and flow rate during operation (b) spray nozzle diameter to average velocity (c) nozzle diameter to droplet thickness

The results in Fig. 2(a) revealed an increase in flow rate as the spray nozzle increases. A similar observation is also observed in Fig.2 (b) which revealed an increase in average velocity and spray nozzle diameter during operation. It is observed that the flow is impacted by air which was reported to impacts the droplet thickness as velocity and flow rate increases. The result in Fig. 2 (c) revealed the optimal nozzle diameter and droplet thickness that gave the optimal discharge and velocity of the spray nozzle during operation. This is impacted by the varying direction of velocities in the system during operation given in Fig.3 (a-c) as revealed by solid works. The system Velocity in Z-direction of the spray nozzle design such that it is has a greater velocities of up to +46.311m/s in the Z-direction that is the optimal speed (velocity) needed for proper washing of the aggregate. The velocity in the Z-direction is a vector quantity and it can be positive or negative. The negative sign is only indicating the direction of the flow during operation. Therefore, the fluid velocity that is needed for efficient washing of aggregates during solid work simulation was found to be 117.639m/s. The system velocity in the X-direction is the velocity entering the spray nozzle at a diameter of 3mm. The maximum simulated velocity that can enter the system was revealed in the simulation to be 346.423m/s. But the one entering the spray nozzle at the assigned pressure was simulated to be 108.018m/s. it could be observed that the real velocities seem to be greater than the theoretical velocities.


Iteration = 97
541.220
502.562
463.903
425.244
386.586
347.927
309.269
270.610
231.951
193.293
154.634
115.976
77.317
38.659
0
Velocity [m/s]
Cut Plot 1: contours
Flow Trajectories 2
Z
Y
X

(a)


Iteration = 97
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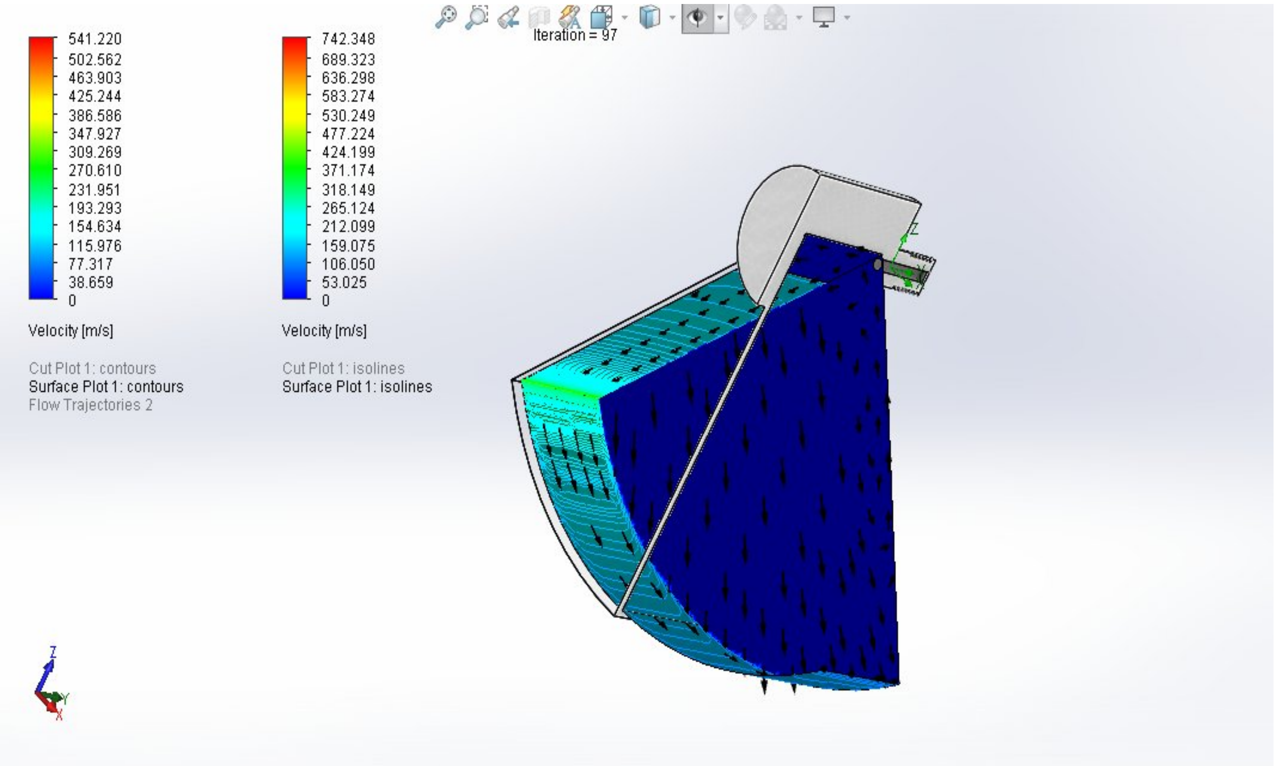
689.323
636.298
583.274
530.249
477.224
424.199
371.174
318.149
265.124
212.099
159.075
106.050
53.025
0
Velocity [m/s]
Cut Plot 1: isolines
541.220
502.562
463.903
425.244
386.586
347.927
309.269
270.610
231.951
193.293
154.634
115.976
77.317
38.659
0
Velocity [m/s]
Cut Plot 1: contours
Flow Trajectories 2
Z
Y
X

(b)



(c)

Figure. 3: Flow velocities in directions of X, Y and Z

From the obtained results shown in Fig.3, it is revealed that 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 an optimal maximum flow velocity of 541.220m/s. This is greater to what was expected and therefore the system will be more efficient during washing of aggregates. The solid works simulation shows that the designed spray nozzle can operate at greater velocities which can have positive pulsating effect on the crushed of aggregates. Such greater velocities are what is expected on the designed spray nozzle. By comparing the theoretical obtained results and simulated obtained results it is revealed that the diameters of the spray nozzle can operate to its maximum and at this maximum diameter the spray nozzle will have a greatest flow velocity of water and pressures as shown in table 3. These results are all from constant diameter of 3mm

Table 3 comparing theoretical and simulated results

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

By correlating the theoretical obtained results and simulated results, the velocity of the water flowing in the spray nozzle revealed that the simulated nozzle will have a range of velocities from 38.659m/s to maximum velocity of 77.314m/s. This is the range that the theoretical obtained results fall within the simulated results. Therefore, there is a close correlation which means that the velocity of the simulated spray nozzle and the theoretical spray nozzle results revealed a close correlated. The calculated pressure at which the spray nozzle can be operation was computed to be

6MPa and the simulated results was simulated to be between 0.226MPa to maximum of 595.698MPa. From this observation, the computed pressure falls within the simulated values. The simulated spray nozzle has the greatest velocity of flow and the greatest pressures can be used. This mean that the design can function efficiently at optimal velocity and flow rate during operation.

3. Conclusion and Recommendation

The study was aimed at optimizing the velocity and discharge produced by a spray nozzle for efficient washing of aggregates in mining industry. To achieve this objective the principles of fluids mechanics and the relevant simulation was performed by solid works. The following results was revealed in the study. it is revealed that an increase in spray nozzle led to an increase k-value, discharge, and velocities of flow through the spray nozzle. It was also revealed that the flow is impacted by air which was reported to impacts the droplet thickness as velocity and flow rate increases. It was also revealed that the optimal nozzle diameter and droplet thickness gave an optimal discharge and velocity of the spray nozzle during operation. Varying direction of velocities in the system during operation given was revealed by solid works to have different impacts on flow velocity and discharge. The correlation between theoretical obtained results and simulated results from solid works revealed that the velocity of the water flowing in the spray nozzle have a range of velocities from 38.659m/s to maximum velocity of 77.314m/s as shown in the simulated result. The obtained results revealed close correlation in both modeling and simulation. It could be concluded that the design will function efficiently at optimal velocity and flow rate during operation.

References

Arnold, C. M. & Holden, M., 1972. spray nozzle orifice member. united states, Patent No. 3647147 axminster, 2019. axminster.

Babinsky, E. & Sojka, P., 2002. modeling drop size distribution. progress in energy and combustion science, 22 february, pp. 303-329.

Bahadir, S., 2015. turkish journal of agriculture and forestry. [Online] Available at: http://journals.tubitak.gov.tr/agriculture/

Butller, e. M., Tuck, C. & Miller, P., 1997. the effect of some adjuvants on sprays produced by aggricutural flat fan nozzles. crop protection, 16 (1), pp. 1-5.

Clarence, D. F., 1937. spray ano.et noaale. 5 may, pp. 1-5.

Dennis, B. W. & Des, M., 1977. low drift flat spray nozzle and method. 801(836), pp. 1-10.

Dennis, M. & Stuart, F., 2006. high impact waterjet nozzle. united state, Patent No. 7100844 B2.

Dennis, M. & Stuart, F., 2006. HIGH impact waterjet nozzle. US, Patent No. 7100844 B2.

Eckardt, T. M. et al., 1985. two dimensional echocardiographic findings in double mitral valve. JACC, 6(2), pp. 383-387.

Essien, S., Archibong, E. & Lao, L., 2019. discharge coefficient of high viscosity liquids through nozzles. experimental thermal and fluid science, pp. 1-8.

Fred, K. N., 2003. handbook for dust control in mining. In: F. N. kissell, ed. handbook for dust control in mining. columbia parkway cincinnati: NIOSH, pp. 5-32.

Freeman, J. J., 1928. hose nozzles. united states, Patent No. 1813733.

Fuyi, L., 1986. spray nozzle. united states, Patent No. 4629152.

Ghobad, A., 2016. liquid flow in a simplex swirl nozzle. international journal of multiphase flow, 30 september, pp. 225-235.

Glenn, W. S. et al., 1986. multiple pattern spray nozzle. united states, Patent No. 4618100.
Guijun, G., ChangJiang, W. & Ziming, K., 2018.

Henderson, G. W. & Pasadena, C., 2003. independent flow rate and droplet size control system for sprayer. Europe, Patent No. 0847307 B1.

Kiaoulias, D., Travis, T., Moore, J. & Risha, G., 2019. evaluation of orifice inlet geometries on single liquid injectors through cold-flow experiments. experimental thermal and fluid sciences, pp. 78-88.

Lan, Z. et al., 2013. experimental study on spray characteristics of pressure-swirl nozzles in pressurizer. Annalas of nuclear Energy, 28 july, pp. 215-227.

Mat, R. M. S. F., Hamid, A. H. A., Sheng, O. C. & Ghaffar, Z. A., 2012. International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012). s.l.:s.n.

Miller, miller , P. & Butller , m., 2000. effects of spray formulation on spray nozzle performance for applications, silsoe bedford UK: silsoe research institute.

Miller, P. & Ellis, B. M., 2000. effects of formulation on spray nozzle performance for applications from ground based boom sprayers. In: Crop protection. bedford UK: silsoe research institute , pp. 609-615.

Qun, Z. et al., 2019. effects of droplets formation patterns on the atomization characteristics of a dust removal spray in a coal cutter. power technology, 5 december, pp. 570-580.

Quy, D. B., 2006. nozzle with flow rate and droplet size control capacity. united states, Patent No. 7124964 B2.

Shenghao, Y. et al., 2019. an experimental comparison of the elliptical and circular nozzles spray and mixing characteristics under different injection pressures. Fuel, pp. 1474-1482.

Tao, Z. et al., 2017. spray characteristics of pressure-swirl nozzles at different diameters. applied thermal engineering, 21 april, pp. 985-991.

Tao, Z. et al., 2017. spray characteristics of pressure-swirl nozzles at different nozzle diameter. applied thermal engineering, 21 april, pp. 984-991.

Wen, N. et al., 2016. a novel spraying/negative pressure secondary dust suppression device used in fully mechanized mining face:a case study. Elsevier, 103(103), pp. 126-134.

P.C.H. Miller, M.C. Butler Ellis and C.R. Tuck, Entrained air and droplet velocities produced by agricultural flat-fan nozzles, Atom. and Sprays, vol. 6, pp. 693-707, 1996

C.R. Tuck, M.C. Butler Ellis and P.C.H. Miller, Techniques for measurement of droplet size and velocity distributions in agricultural sprays, Crop Prot., vol. 16, pp. 619-629, 1997.