# The Development of a Centrifugal Pump Nozzle for Firefighting Motorcycle

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***Abstract*—The addition of a centrifugal pump to an automatic motorcycle is the main mechanism for a fire fighting motorcycle. However, the amount of water pressure that can be sprayed by a centrifugal pump can also be affected by the nozzle attached to the end of the hose. The purpose of this research is to find out the proper nozzle model so that the performance of the motorbike developed can work optimally. By using the experimental method, the basic nozzle model to be developed is a standard nozzle which is commonly used for fire trucks. The results of the development of 10 model variations are divided into two major groups, namely nozzles that use a ball valve between the cylindrical barrel and nozzle tip and the other large groups without using a ball valve, while in each model in the two groups it is distinguished by the length of the cylindrical barrel used. The fluid pressure simulation is collected using flow simulation software, and the model chosen is having the greatest pressure at the nozzle tip. From the simulation results, the work piece is made according to the predetermined size and tested on a developed fire engine motorbike and the actual pressure is measured using the *Pitot* tube which is placed on the nozzle tip. The nozzle which has the shortest cylindrical barrel length has the largest fluid pressure measurement both in the simulation and actual measurement, while the fluid pressure value from the simulation results has a higher pressure value compared to the actual one.**

***Index Terms*—fire safety, firefighting motorcycle, centrifugal pump, water nozzle**

## I. Introduction

The phenomenon of fire disasters in densely populated settlements has a high intensity. It happens on big cities in Indonesia, especially Jakarta. The biggest contributor for this fire disaster is a short circuit or an electric short circuit as the trigger, although another trigger is an explosion from a gas cylinder also has a percentage of causing fires. This data is compiled from statistical data in each area that occurs in the Jakarta province [1]. The residences have the highest number of fires compared to fires for public buildings. Meanwhile, the industrial buildings have the smallest intensity, even if they did not occur at all in 2019. This can be seen in the picture below


Figure 1. The number of fire incidents in Jakarta residences [1]

From the picture above, it can be seen that in a period of 1 year, there were more than 1,500 residential fires recorded. This gives researchers the opportunity to create innovations that can reduce both the incidence of fires and losses caused by these fires [2, 3]. The efforts to reduce the number of losses arising from a fire disaster, especially in densely populated areas is producing a firefighter motorcycle as combining a motor engine with a centrifugal pump, which is expected to be a solution for people in urban areas. In previous studies, the main components for a firefighter motorcycle are as follows: a centrifugal pump, a pump bracket, a water hose for the inlet and outlet for placing the necessary equipment [4]. Moreover, the development stage carried out to date is a progressing of the automatic motorbike engine performance which is used as a power producer to the repair of the bracket mechanism used to connect the pump to Continuous Variable Transmission (CVT) engine [5, 6]. However, the performance of the developed firefighter motorcycle is influenced by the optimization of the engine power used, the installation mechanism for the centrifugal pump and no less important is the selection of the right nozzle as described in this study.

## II. The Literature Study

The water nozzle is used as a tool that plays an active role in splashing water to extinguish the fire as an effort to control fire. This has become an interesting topic for researchers in developing the effectiveness of nozzles as part of firefighting [7-9]. In its development, the nozzle

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for active fire protection, which is generally called a sprinkler, has various forms so that it gives a spray result in the form of droplets with certain specifications [10]. For the nozzle with the simplex solid cone type, Shrigondekar et al. [11] has investigated it. In his research, the variations in injection pressure can cause differences in the angle of the spray cone and mass flux density in the spray. Mahmud et al. [12] also stated that performance of fire extinguishment by water spray is strongly influenced by the characteristics of the sprays produced by nozzle. This can be simulated with a computational fluid dynamic (CFD) to increase the effectiveness of the nozzle model used. His research provides the option of adding orifice in this nozzle type, not only the working pressure that affects the nozzle performance, the temperature of the fluid used and the size of the orifice to produce droplets. Related with this issue, Gaytan et al [13] research, the effect of working pressure, fluid temperature, nozzle type and orifice size resulted in different nozzle effectiveness. He proved this when the fluid was added by DL-2- hydroxyl-4-(methylthio) -butanic acid.

For the nozzle used in the water cannon, the water pressure at the nozzle and the speed of water flow also depends on the water pressure acting on the nozzle. Apart from the nozzle shape, the compressible and incompressible fluid flows used as the working fluid also provide different flow rates [14]. Meanwhile, the nozzle used for fire extinguishing has a defined standard. Moreover, innovations regarding this tool are still being carried out today. The development of nozzle for fire extinguisher has been published by Galaj et al [15]. In his writing, analysis of the effect of tilt angle on water droplets for Turbo Master 52 Nozzle has been carried out. In addition to the tilt angle affecting the droplets character, it turns out that the resulting droplets are also proportional to the volume of water and the speed of water sprayed. If firefighters use this type of nozzle, the results of this study can be used as a reference.

From some of the literatures above, the water nozzle used is greatly influenced by the working water pressure. In general, the water pressure generated by the pump is high pressure. This encourages the research because in the development of a firefighter motorcycle that is used as a fast response to fires on narrow road access, the driving power of the centrifugal pump comes from the engine power of the motorbike used so that the resulting centrifugal pump pressure is limited [16] . If use the existing water nozzle in general, the resulting water pressure is felt to be less than optimal, so it is necessary to optimize the water nozzle for firefighter motorcycle.

## III. The Method of Research

The firefighting motorcycle sold using a combustion motor power to drive a centrifugal pump. This has the consequence that motorbikes must provide space to carry the combustion engine, but this model provides the advantage that the engine power can be adjusted according to the needs of the pump.

In this study, nozzle development was carried out by simulation and experimental methods. This can be explained as shown below.

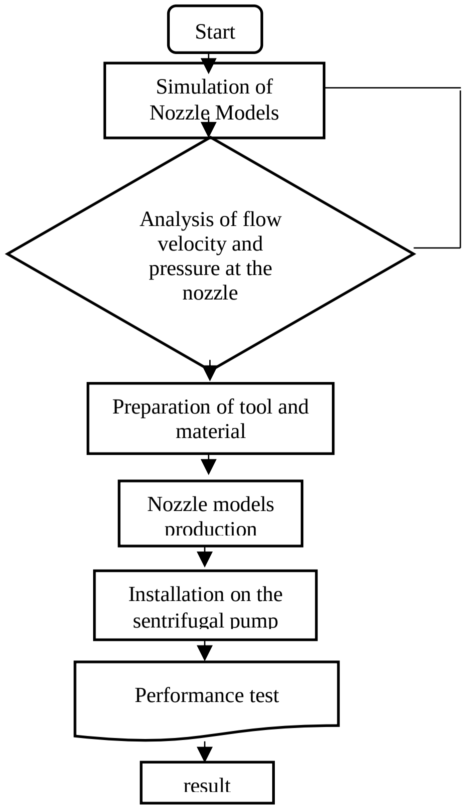



Figure 2. Research flow chart

From the picture above, the first thing the writer does is to model nozzles that are commonly used and to simulate the fluid flow using solid work software. The nozzle shape used as a comparison of the nozzle developed in Fig. 3 below. While the pump parameters used for comparison are shown in Table I.

Figure 3. Water nozzles for fire fighting

TABLE I. The Specifications of Fire Pump Engine of the Tohatsu 198CC 2 Stroke

| No | Specifications | explanations |
|---|---|---|
| 1 | Authorized output | 11.7 PS |
| 2 | Pump performance | 650 liter /min at 0.5 MPa<br>400 liter/min at 0,7 Mpa |

After the simulation data produces the fluid flow velocity and pressure in accordance with the above parameters, we make another model that is used as an alternative to get the best fluid pressure. Two other types of models are the cylindrical barrel which uses a ball valve and the cylindrical barrel without a ball valve. The purpose of using the ball valve is as a controller when spraying starts, where this will make it easier for an extinguisher to aim at a hot spot when a fire occurs and can save water. Meanwhile, variations in the length of the cylindrical barrel used as alternatives are 10cm, 15 cm, 20 cm and 25 cm. where nozzle and cylindrical barrel describe as Fig. 4.

After the cylindrical barrel length variation gets the best fluid velocity data, the simulation continues by entering the pump parameters according to the centrifugal pump attached to a fire engine motorcycle. This is to determine the effectiveness of the nozzle when tested experimentally. The types and specifications of centrifugal pumps on firefighter motorcycle are as follows in Table I.

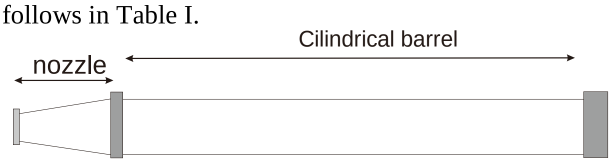



Figure 4. Nozzle and cylindrical barrel illustration

TABLE II. CENTRIFUGAL PUMP SPECIFICATIONS FOR FIREFIGHTER MOTORCYCLE

| The specifications of centrifugal pump | | |
|---|---|---|
| No | Specifications | measures |
| 1 | The hose in and out measurement | 2 inch |
| 2 | Drive system | Couple with other power |
| 3 | Water flow | 2,6 liters/seconds |
| 4 | Absorbent power | 9 meters |
| 5 | Lifting power | 6 meters |
| 7 | Pump rotation | 1400 |

From the simulation data collected, a nozzle is then made and tested experimentally to measure the fluid flow pressure at the nozzle tip from the nozzle has been selected. The spraying data collection is carried out as illustrated in the Fig. 5 below

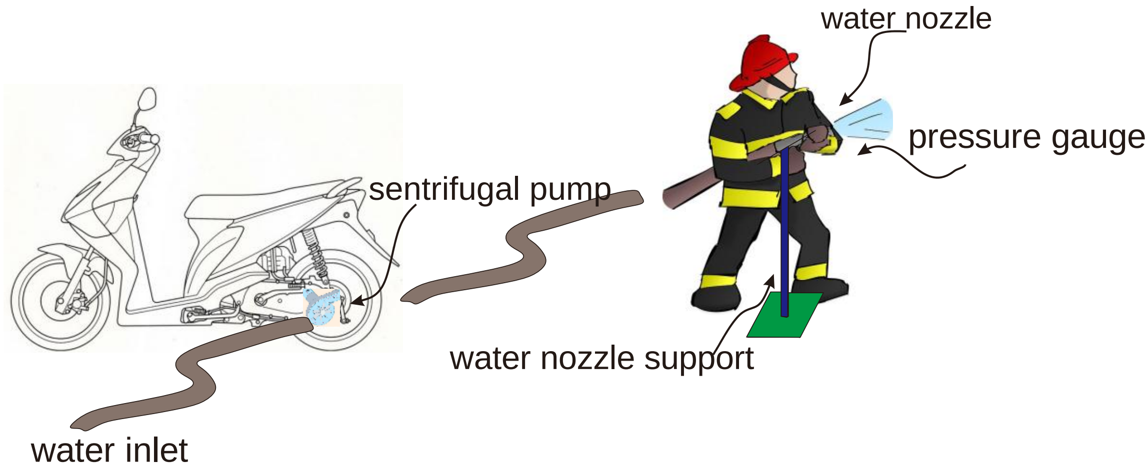



Figure 5. The illustration of the nozzle test made

## IV. DISCUSSION

According to Bernoulli's principle at the continuity of fluid discharge, the difference in cross-sectional area causes a difference in velocity and pressure at the cross section. Every fluid discharge (Q) resulting the flow velocity is (v) and the pressure is (p). This can be illustrated in the nozzle being studied as in Fig. 6 below.

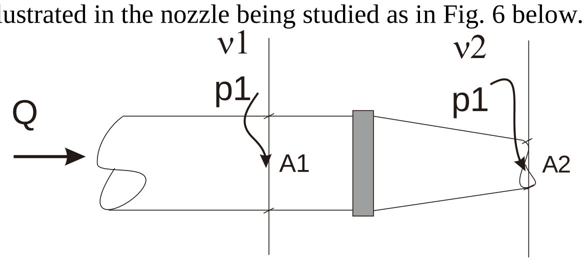



Figure 6. The equation of continuity in Bernoulli's principle

From the equation of Bernoulli's principle, the velocity of fluid flow through a cross section

$$v = Q/A \text{ And } Q = \frac{M}{\rho} \quad (1)$$

When Q = fluid discharge

A= cross-sectional area

$M$ = mass flow rate

$\rho$ = density of the fluid

While the fluid pressure equation in each cross-sectional area is

$$\frac{p1}{\gamma} + \frac{v1^2}{2\,g} + z1 = \frac{p2}{\gamma} + \frac{v2^2}{2g} + z2 + hL \quad (2)$$

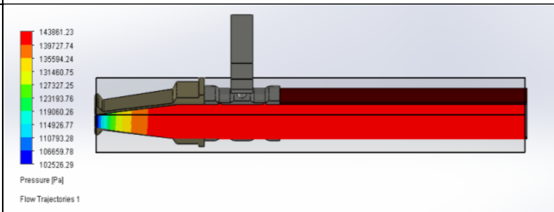
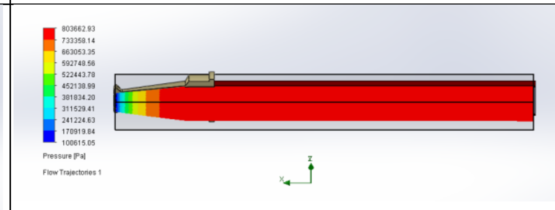
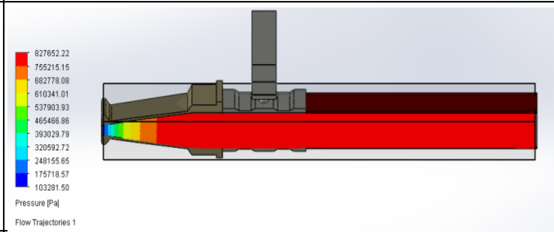
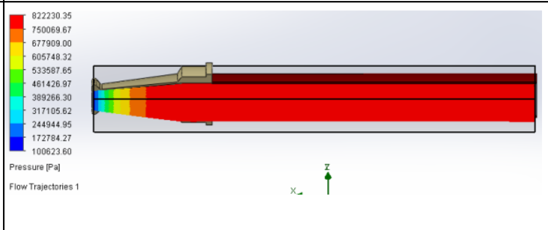
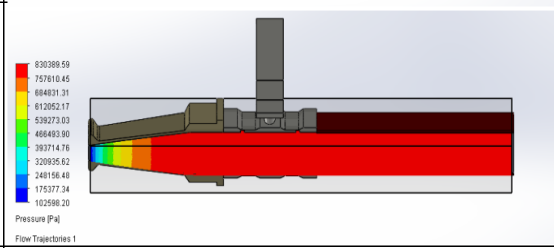
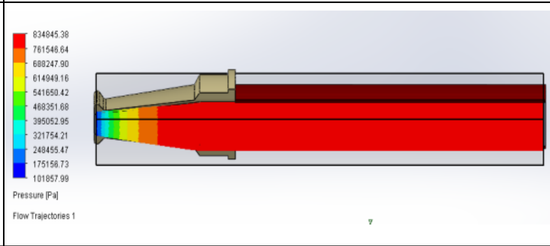
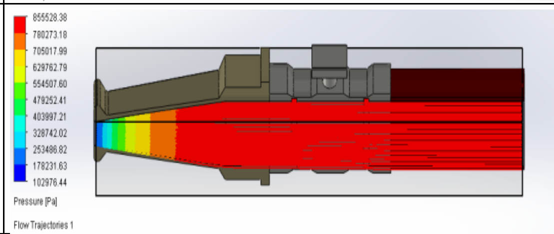
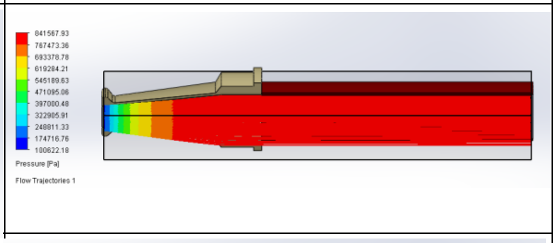
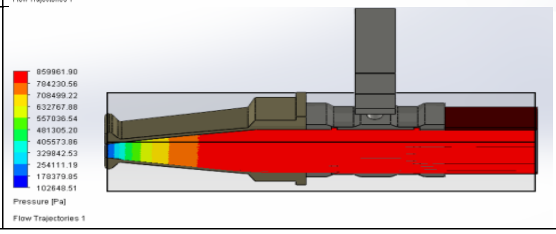
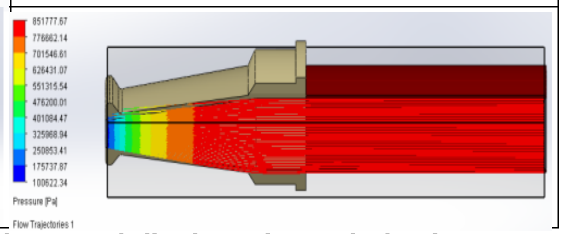
With the result

$$p2 = \gamma\ x \left[\frac{p1}{\gamma} + \frac{(v1-v2)^2}{2g} + (z1 - z2) - hL\right] \quad (3)$$

In the above equation, $v^2 / 2g$ is the velocity of the head while $hL$ is the head loss of the nozzle

The simulation results using software with several variations in cylindrical barrel length can be seen in Table III below

TABLE III. THE FLUID FLOW VELOCITY SIMULATION TABLE FOR EACH CYLINDRICAL BARREL LENGTH VARIATION

| Inlet flow rate parameter is 650 liters / minute | | | |
|---|---|---|---|
| No | Cylindrical barrel length | The images of fluid pressure with a ball valve | The images of fluid velocity without ball valve |
| 1 | 30 cm |  |  |
| 2 | 25 cm |  |  |
| 3 | 20 cm |  |  |
| 4 | 15 cm |  |  |
| 5 | 10 cm |  |  |

From the table above, according to the simulation carried out using solid work software, the shorter the cylindrical barrel, the greater the pressure on the nozzle tip. When the cylindrical barrel has a length of 30 cm, the pressure on the nozzle tip is 8.16 with an assumption of an inflow of water of 650 liters per minute. The pressure increase occurs when the cylindrical barrel is 25 cm long. At a 25 cm cylindrical barrel, the pressure at the nozzle tip is 8.21 bar or an increase of 0.05 bar. The reduction of cylindrical barrel length used as a variant getting the greatest pressure at the nozzle tip. The variant 5 (nozzle with cylindrical barrel 10 cm) is the shortest cylindrical which is determined to have the greatest pressure compared to the pressure generated by other variants. It occurs both in simulated nozzles using a ball valve as the output regulator on the nozzle or without a ball valve such as a fire extinguisher nozzle which is commonly used. The difference in pressure simulation results between a nozzle that uses a ball valve and a nozzle that doesn't use a ball valve can be seen as shown in Fig. 7 below.

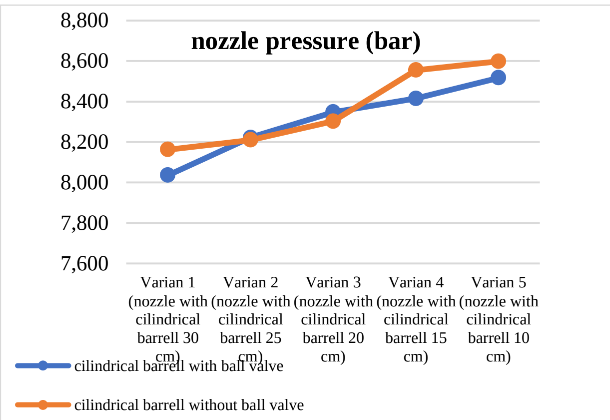



Figure 7. Simulation of nozzle pressure

From the table above, based on simulations using solid work software, the shorter the cylindrical barrel, the greater the pressure at the nozzle tip. When the cylindrical barrel has a length of 30 cm, the pressure at the nozzle is 8.16, assuming the intake water flow is 650 liters per minute. The pressure increase occurs when the cylindrical barrel is 25 cm. For a 25 cm cylindrical barrel, the pressure at the nozzle tip is 8.21 bar or an increase of 0.05 bar along with the reduction of the cylindrical barrel length which is used as a variant to get the greatest pressure at the end of the nozzle, variant 5 (nozzle with cylindrical barrel 10 cm) is the shortest cylindrical which determined to have the greatest pressure compared to the pressure generated by the other variants. This occurs both in simulated nozzles using a ball valve as the output regulator on the nozzle or without a ball valve such as a fire extinguisher nozzle which is commonly used. The difference in pressure simulation results between a nozzle that uses a ball valve and a nozzle that doesn't use a ball valve can be seen as shown below.

From the picture above, the nozzle which has the shortest cylindrical barrel can be chosen because it has the highest pressure simulation results. Meanwhile, the nozzle which adds a ball valve in its mechanism to the cylindrical barrel has a lower pressure than without using a ball valve. This can be caused by the valve flow so that the fluid flow is not optimal. The difference between the two types is less than 0.1 bars. However, the choice of using a ball valve is still used as the basis for making nozzle on firefighting motorcycle. This variant remains the variant that generates the highest pressure compared to the variant with a longer cylindrical barrel.

For a centrifugal pump that is attached to an automatic motorcycle engine on a firefighter motorcycle (table 2), it has a power of 2.2 KW, this is adjusted to the engine power of the motorbike which is capable of producing 5 HP at rotation between 1500 to 2000 rpm or in low spin range. In this range the motorbike is in a standstill condition, the power generated by the engine has not been completely transmitted by the CVT mechanism to the rotation of the motorbike wheels so that the motor does not move. In this rotation, the centrifugal pump can produce a water flow of 2.6 liters per second in accordance with the pump's technical specifications. To get a water pressure simulation for the selected nozzle type, a water flow of 2.6 liters per second is entered as a parameter in the software. This obtains the baseline pressure data. 3, 4 bars can be seen as in Fig. 8 below

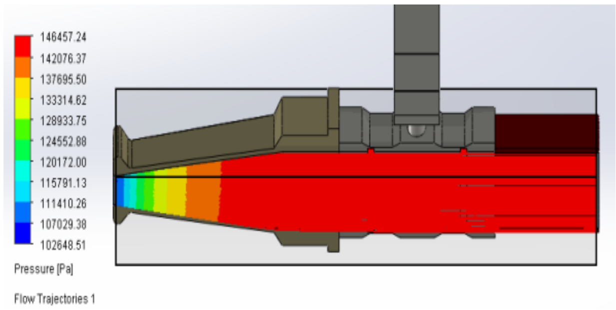



Figure 8. The simulation of selected nozzle with water discharge according to a centrifugal pump on fire-fighting motorbikes

From the simulation results above, then the pressure measurement at the selected nozzle (Fig. 9) is carried out as in Fig. 10.

Figure 9. The selected nozzle shapes for firefighting motorbikes

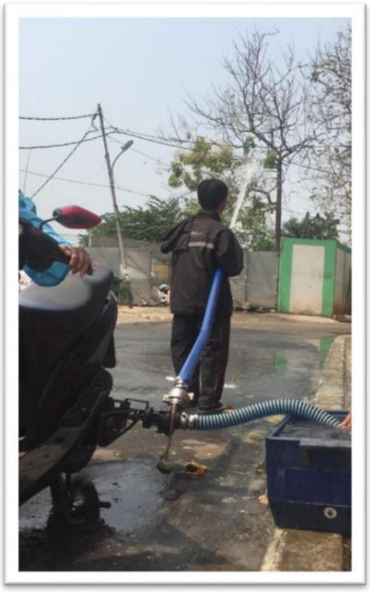


Figure 10. The nozzle testing on a centrifugal pump for a firefighting motorcycle.

From the three times testing process resulting the fluid pressure at the nozzle tip that has been made as the selected nozzle variant can be seen in Fig. 11, where every distribution test getting the average pressure value at each engine speed.

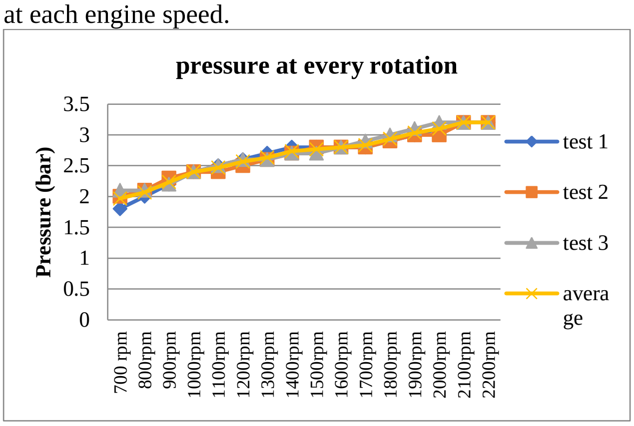



Figure 11. The graph of the nozzle pressure developed at each engine speed

From the picture above, it can be seen that at 700 rotations, the water pressure at the nozzle tip is 2.71 bars. While at 1400 rotations the resulting pressure is 3.1 bars. This water pressure continues to increase when the centrifugal pump rotates at 2400 rpm where the resulting pressure is 3.45 bars.

The similar thing is conducted with standard nozzles on the market where at each engine speed; the pressure at the nozzle tip is recorded and compared with the average pressure data from the selected nozzle. The comparison data of the average pressure of the two measured nozzles can be seen in Fig 12

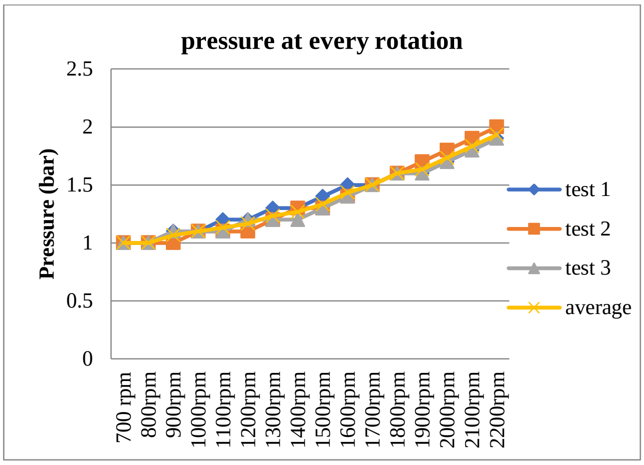



Figure 12. The comparison graph of standard comparison pressure and developed nozzle

From the graph above at each engine speed that drives a centrifugal pump for firefighting motorcycle, the developed nozzle has a pressure that is relatively higher than the pressure at a standard nozzle as seen in Fig. 13.

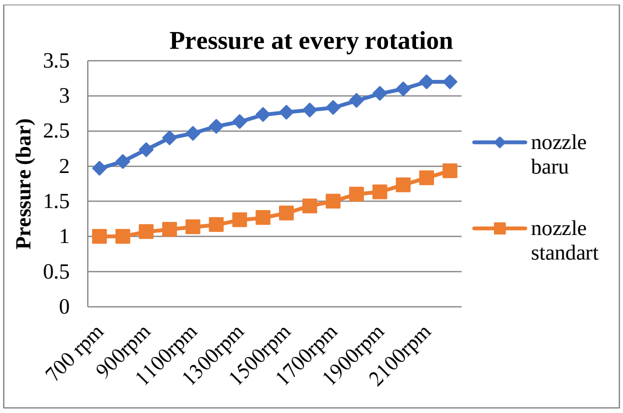



Figure 13. Differences of nozzle pressure

## V. Conclusion

The water pressure generated by the nozzle depends on the power of the pump used to equip a motorcycle engine on a firefighter motorcycle. The nozzle is made by adjusting the capacity of the centrifugal pump attached to the machine. Where the pump specifications used have smaller water discharge compared to pumps for firefighting in general. The water flow rate of 2.6 liters per second is in accordance with the specifications of the pump that is installed for a firefighting motorcycle. The simulation results show that the nozzle which has the shortest cylindrical barrel, which is 10 cm, has the largest pressure simulation result compared to other variants. This is reinforced when the experimental is also carried out in actual conditions. In this condition, the average water pressure at the nozzle tip with the shortest cylindrical barrel length is higher than the nozzle with a longer cylindrical barrel. In general, the highest pressure is the main choice so it can improve the performance of the developed firefighter motorcycle

## Conflict of Interest

The author declares no conflict of interest.

## Author Contributions

The research has been done about the development of a centrifugal pump nozzle for firefighting motorcycle, purely for the advancement of knowledge and technology from the development of firefighter motorcycles carried out by the author

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## References

[1] K. Nisa, Number of Fire Incidents and Causes of Incidents by DKI Jakarta Region in 2019, DKI Jakarta Regional Disaster Management Agency, PORTAL STATISTICS SECTORAL PROVINCE DKI JAKARTA, 2020.

[2] H. H. Sutrisno, J. Amiruddin, and Triyono, "Improving the evacuation time for 8-story office building using pathfinder simulation," *International Journal of Engineering & Technology,* vol. 7, p. 5, 2018.

[3] H. H. Sutrisno, R. Wirawan, D. Ambarwati, and A. Febriani, "Analysis of fire rate on paper coated with the silica gel from rice husk ash," *Journal of Physics: Conference Series,* vol. 1402, p. 5, 2019.

[4] H. H. Sutrisno and Triyono, "Designing a firefighter motorcycle as an effort to provide an early response to fire disaster: A study case in Jakarta special capital region," *Journal Of Mechanical Engineering,* vol. SI, p. 12, 2017.

[5] H. H. Sutrisno and Triyono, "Improvement of performance and design on firefighter motorcycle as a fast response to decrease fire disaster in a densely populated area," *International Journal of Mechanical Engineering and Robotics Research,* vol. 8, p. 5, 2019.

[6] H. H. Sutrisno, "The selection of flying roller as an effort to increase the power of scooter-matic as the main power of centrifugal pump for fire fighter motor cycle," *Materials Science and Engineering Conference Series,* vol. 324, 2018.

[7] J. Lee, "Numerical analysis on the rapid fire suppression using a water mist nozzle in a fire compartment with a door opening," *Nuclear Engineering and Technology,* vol. 51, pp. 410-423, 2019.

[8] G. Ha, W. G. Shin, and J. Lee, "Numerical analysis to determine fire suppression time for multiple water mist nozzles in a large fire test compartment," *Nuclear Engineering and Technology,* 2020.

[9] X. Huang, X. S. Wang, and G. X. Liao, "Characterization of an effervescent atomization water mist nozzle and its fire suppression tests," in *Proc. the Combustion Institute,* vol. 33, pp. 2573-2579, 2011.

[10] T. Sun, X. Huang, Y. Chen, and H. Zhang, "Experimental investigation of water spraying in an indirect evaporative cooler

from nozzle type and spray strategy perspectives," *Energy and Buildings*, vol. 214, p. 109871, 2020.

[11] H. Shrigondekar, A. Chowdhury, and S. V. Prabhu, "Characterization of solid-cone simplex mist nozzles," *Fire Safety Journal*, vol. 111, p. 102936, 2020.

[12] H. M. I. Mahmud, K. A. M. Moinuddin, and G. R. Thorpe, "Experimental and numerical study of high-pressure water-mist nozzle sprays," *Fire Safety Journal*, vol. 81, pp. 109-117, 2016.

[13] I. Gaytan, B. Nicolas, F. Gouriou, J. P. Leru, and J. Mallarach, "Effect of working pressure, fluid temperature, nozzle type and nozzle orifice size, on spray characteristics using viscous feed additive DL-2-hydroxy-4-(methylthio)-butanoic-acid," *Powder Technology*, vol. 336, pp. 383-392, 2018.

[14] Y. V. Loktiushina and A. N. Semko, "Influence of the working fluid properties on water jet cannon efficiency," *Computers & Fluids*, vol. 103, pp. 166-174, 2014.

[15] J. Gałaj, T. Drzymała, and P. Piątek, "Analysis of influence of tilt angle on the distribution of water droplets diameters in a spray generated by the turbo master 52 nozzle," *Procedia Engineering*, vol. 172, pp. 300-309, 2017.

[16] Triyono and H. H. Sutrisno, "Implementation of VDI 2221 method for firefighter motorcycle design," *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 8, p. 5, 2019.



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The author works as a researcher in the manufacturing field Department of Fire safety Engineerig Universitas Negeri Jakarta, Indonesia. In this field, knowledge of the manufacturing industry is developed for fire protection. Until now, the author has always contributed to these two fields with several publications in the fields of 5 axis milling, manufacturing, materials, and fire safety.

Dr. Ir. Himawan Hadi Sutrisno ST. MT. has intellectual property rights in the development of a firefighter motorcycle issued by the Ministry of Law and Human Rights of the Republic of Indonesia.