Exhaust Manifold Assessment for Backpressure Minimization

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Abstract: Engine exhaust back pressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system to discharge the gases into the atmosphere. Minimizing the level of backpressure will improve the overall performance of the engine as proven by various literature. The aim of this study was to study the effects of manipulating the exhaust manifold's diameter of a spark ignition (SI) engines with respect to its backpressure. The exhaust manifold's diameter tested were 46mm, 49mm and 52mm respectively. The bending radius for the manifold was fixed at 50mm. The 3D-model of the exhaust manifolds were developed via Computer Aided Design (CAD) with the use of SolidWork software. Computational Fluid Dynamics (CFD) was then conducted via ANSYS Workbench 2021 R1. The exhaust manifold was designed in reference to the KTM 690 motorcycle. The results showed that the pressure at the bent for the 46mm specification was 270.2Pa, while, the pressure before and at the outlet which was similar at 101.7Pa for both. Identical pattern of data was also obtained for the 49mm exhaust manifold's diameter, albeit, the pressure at the bent was 194.4Pa and 34.02Pa for pressure at the bent and outlet respectively. Contradicting to these, the 52mm exhaust manifold's diameter had shown constant pressure reading throughout the manifold at 170.4Pa. From these data, the lowest average backpressure was determined. Thus, the 49mm diameter is found to be optimal with the average backpressure of 87.48Pa throughout the exhaust manifold. This is a novel finding since the effects given by the diameter towards the average backpressure of this specific exhaust is determined. For future studies, assessment on the effects given by the bending radius with respect to the backpressure is recommended to be explored.

Keywords: Exhaust manifold, Backpressure, Internal combustion engine

1. Introduction

Engine exhaust back pressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system to discharge the gases into the atmosphere (Nor et al., 2019). Minimizing the level of backpressure will improve the overall performance of the engine as proven by various literature. Greater backpressure lowers engine power and torque output. The fuel intake will also increase due to the increase in backpressure. The existence of the backpressure in the exhaust system particularly in the exhaust collector is critically affected by the collector's design features. The development of back pressures on the exhaust system directly impacts design parameters, such as diameter, weight, bending angle and bending radius. Therefore, the specification specifications for a collector are very critical if the back pressure is to be minimized and engine performance increased.

Joardder, Uddin and Roy, 2011 noted that extreme back-up of the exhaust system produces excessive heat in the engine cylinder, decreased engine power and a fuel load that can harm engine components and low performance. The variation of thermal brake efficiency with the backpressure engine. At engine speeds of 600, 950 and 1200 rpm thermal efficiency is expressed in figure 1 (a), (b) and (c), respectively. For short, medium, and high loads, thermal braking efficiency at a short engine speed of 600 rpm was almost constant. It decreased slightly at 950 rpm for low, medium, and moderate loads. Backpressure reduces at 1200 rpm. Medium and high load conditions were not tested because of excessive black smoke.

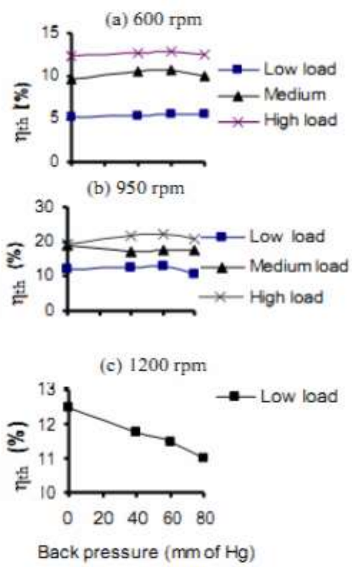

Figure 1. Line Graph of Backpressure Effect on brake Thermal Efficiency with various loads (Joardder, Uddin and Roy, 2011)

Figure 1 demonstrates the change of the brake specific fuel consumption (bsfc) at various engine loads and speeds with backpressure. The BSFC backpressure effect is illustrated in the Figure 1. It was revealed that the meaning of bsfc for low-speed conditions of 600 rpm at 950 rpm bsfc does not change, for all load conditions (note: the term ‘load’ here is in reflection to the working operation of the engine by means of the revolution per minute) here the backpressure rises. At 1200 rpm, bsfc also increased with low load backpressure. There are also no significant impacts up to a certain speed and backpressure cap on engine performance. Excessive backpressure limits engine power and fuel penalty at extremely high operating conditions.

The aim of this study was to study the effects of manipulating the exhaust manifold’s diameter of a spark ignition (SI) engine with respect to its backpressure. Exhaust manifold are used to collect the exhausted gas that produce from the internal combustion engine and direct away from the engine. The diameter of the manifold will directly affect the performance of the engine performance due to the backpressure.

The fluid flow in smaller diameter pipe will have higher velocity and when the diameter pipe is enlarged, the fluid will travel in a slower speed (Qin & Duan, 2017). Backpressure is a force that will resist toward the desire flow fluid, this will decrease the power output, or the fuel consumption will be increase to deliver the desire output. The engine backpressure is a production that is to overcome the hydraulic resistance of the exhaust system to release the gases into the atmosphere, in theory the backpressure should be reduce in order to improve the overall performance of the engine, as observed from various study and research. An engine with higher efficiency of power output, will need to have lower backpressure, to decrease the restriction toward the fluid flow.

2. Methodology

Figure 2 shows reference manifold design for KTM DUKE 690CC. Experimental parameters are indicated in Table 1. The exhaust manifold's diameter tested were 46mm, 49mm and 52mm, respectively. The bending radius for the manifold was fixed at 50mm. The 3D-model of the exhaust manifolds were developed via Computer Aided Design (CAD) with the use of SolidWork software. Computational Fluid Dynamics (CFD) was then conducted via ANSYS Workbench 2021 R1. The exhaust manifold was designed in reference to the KTM 690 motorcycle.

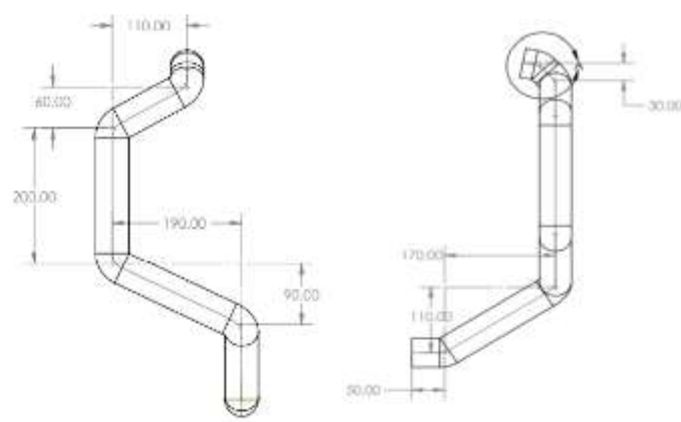

Figure 2. Reference Manifold Design for KTM DUKE 690CC

Table 1. Experiment Parameters

Constant Variable	Manipulated Variable	Responding Variable
Exhaust Manifold KTM Duke 690cc	Diameter 2	Backpressure
Diameter 1	Bending Radius 6	
Bending Radius 1		
Bending Radius 2		
Bending Radius 3		
Bending Radius 4		
Bending Radius 5		
Fuel: Gasoline		
Inlet Velocity: 17.03		
Turbulence: 10%		
Wall Temperature: 300K		
Inlet Temperature: 1477.59 K		

3. Result and Discussion

Pressure contour for 46mm, 49mm and 52mm diameter radius is shown in Figure 3.

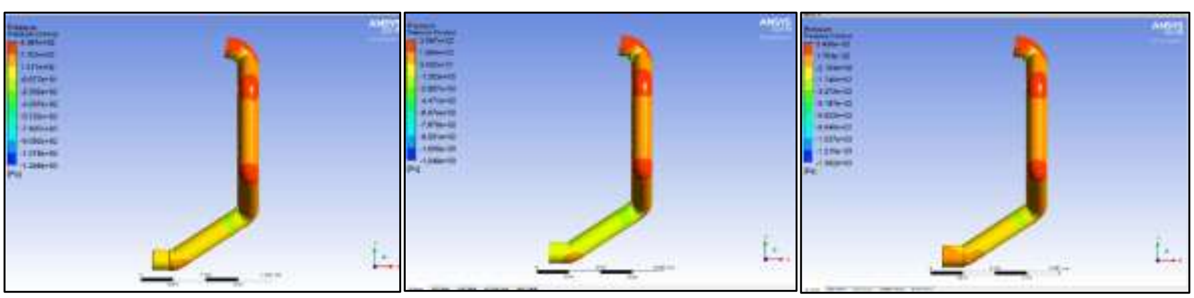

Figure 3. Pressure contour for (a) 46mm (b) 49mm and (c) 52mm diameter radius

Table 2. Stage 2 Results

Design	Diameter (mm)	Bending Radius (mm)	Pressure before Bent (Pa)	Pressure at Bent (Pa)	Pressure at Outlet Diameter (mm)
a	46	50	101.7	270.2	101.7
b	49	50	34.02	194.4	34.02
c	52	50	170.4	170.4	170.4

The results showed that the pressure at the bent for the 46mm specification was 270.2Pa, while, the pressure before and at the outlet which was similar at 101.7Pa for both. Identical pattern of data was also obtained for the 49mm exhaust manifold's diameter, albeit, the pressure at the bent was 194.4Pa and 34.02Pa for pressure at the bent and outlet respectively. Contradicting to these, the 52mm exhaust manifold's diameter had shown constant pressure reading throughout the manifold at 170.4Pa. From these data, the lowest average backpressure was determined. Thus, the 49mm diameter is found to be optimal with the average backpressure of 87.48Pa throughout the exhaust manifold.

Backpressure is a pressure that are push back into the exhaust pipe, when the pressure of the fluid is lower than the atmospheric pressure outside the exhaust. As shown in Table 2, bigger pipe diameter does not necessary mean that it will produce less backpressure. A large diameter of exhaust pipe will lower the fluid flow velocity of the gases that is exhausted. If the gases travel at higher velocity flow, hence a low pressure will be created behind the gases, this helps to suck out the gases at an extreme high rate. Hence if there is unburned air or fuel mixture, it will escape. Hence waste the fuel in the engine. This show that the proper and balance size of diameter is needed to ensure that the performance of the engine will operate at it optimum or deliver the power efficiency.

4. Conclusion

Conclusively, the 49mm diameter is found to be optimal with the average backpressure of 87.48Pa throughout the exhaust manifold. This is a novel finding since the effects given by the diameter towards the average backpressure of this specific exhaust is determined. For future studies, assessment on the effects given by the bending radius with respect to the backpressure is recommended to be explored. This shall facilitate towards continuous improvement with respect to design optimization. Design optimization shall lead towards overall increment in product performance and sustainability.

References

Akhil Teja, M. *et al.* (2016) Analysis of Exhaust Manifold using Computational Fluid Dynamics, *Fluid Mechanics: Open Access*, 03(01), pp. 1–16.

Allawi, M. K., Oudah, M. H. and Mejbel, M. K. (2019) Analysis of exhaust manifold of spark-ignition engine by using computational fluid dynamics (CFD), *Journal of Mechanical Engineering Research and Developments*, 42(5), pp. 211–215.

Bajpai, K. *et al.* (2017) CFD Analysis of Exhaust Manifold of SI Engine and Comparison of Back Pressure using Alternative Fuels, *IOSR Journal of Mechanical and Civil Engineering*, 14(01), pp. 23–29.

Benajes, J. *et al.* (1998) Pre-design criteria for exhaust manifolds in I.C. automotive engines, *SAE Technical Papers*, (724).

Bolt, J. A., Bergin, S. P. and Vesper, F. J. (1973) The influence of the exhaust back pressure of a piston engine on air consumption, performance, and emissions, *SAE Technical Papers*.

Crawford, N. M., Cunningham, G. and Spence, S. W. T. (2007) An experimental investigation into the pressure drop for turbulent flow in 90° elbow bends, *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, 221(2), pp. 77–88.

Deshmukh, D. S., Modak, J. P. and Nayak, K. M. (2010) Experimental analysis of backpressure phenomenon consideration for C.I. engine performance improvement, *SAE Technical Papers*.

Joardder, M., Uddin, M. and Roy, M. (2011) Effect of engine backpressure on the performance and emissions of a CI engine, in *The 7th Jordanian International Mechanical Engineering Conference 27-29 September 2010, Amman, Jordan*, pp. 27–29.

Nor, M.I., Rishan, M., Lim, J.W., Mohd Amir Shazwan, H., Girma, T.C. and Chai, C.E., 2019. A Short Review on Factors that Impact the Backpressure of exhaust manifold of spark ignition engine. *INTI JOURNAL*, *2019*(20).

Qin, Ruqiong & Duan, Chunyi. (2017). The principle and applications of Bernoulli equation. Journal of Physics: Conference Series. 916. 012038. 10.1088/1742-6596/916/1/012038.

Sriyanto, J. *et al.* (2019) Effects of Fuel Injection Pressure to Fuel Consumption and Exhaust Gas Emissions of SI Engine, *Journal of Physics: Conference Series*, 1273(1).

Subramaniam, M. *et al.* (2020) Numerical and experimental investigation on capture of CO2 and other pollutants from an SI engine using the physical adsorption technique, *Heat Transfer*, 49(5), pp. 2943–2960.

Taguchi, G., Chowdhury, S. and Wu, Y. (2007) Taguchi's Quality Engineering Handbook, *Taguchi's Quality Engineering Handbook*.

Wang, Y., Dong, Q. and Wang, P. (2015) Numerical investigation on fluid flow in a 90-degree curved pipe with large curvature ratio, *Mathematical Problems in Engineering*, 2015. doi: 10.1155/2015/548262.timing system', *Energies*, 11(1545), pp. 1–16.