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A study on a swirl type multi-hole fuel injector for a PFI system to improve air-fuel mixture formation

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Abstract. This paper described the development and simulation works that were conducted on an injector that has a combined swirl spray and multi-hole injection functions. It was expected that those two functions would provide beneficial effects to the fuel injector, in order to provide better fuel and air mixing, especially for Port Fuel Injection (PFI) application. The combination of both functions was aimed for achieving high quality spray formation, which might be useful in cases when the combustion time is limited. Swirl spray pattern is known for fine droplets production with relatively smaller SMD and bigger coverage area in the combustion chamber. On the other hand, a multi-hole injector has the advantages of simplicity in manufacturing and operation. Preliminary results on the simulation works that were done separately, demonstrated the ability of the injector's design to produce swirl spray as well as injecting near-symmetrical sprays from the four holes at the injector's end. Nevertheless, these findings must be improved further in the future, especially on simulating the benefits of having a combined swirl and multi-hole functions inside a single injector. Furthermore, detailed assessment on manufacturability and cost effectiveness of this injector must also be addressed.

1. Introduction

According to BP 2016 Statistical Review of World Energy [2] energy consumption for emerging economies accounted for up to 97% of the increase in global energy consumption. Notable emerging economies countries [3] are forecasted to have increase access to transportation: either for commercial or personal usage [1]. As light duty vehicles such as motorcycles and compact cars are among the primary types of vehicles for personal transport, works on improving the fuel economy and reducing hazardous emissions for these types of engines and vehicles are always relevant and important.

A good air-fuel mixture is imperative for achieving efficient combustion for better fuel economy and emissions control, especially for a port fuel injection (PFI) system where the fuel delivery occurs a



distance away from the intake port. The quality of the mixture is highly influenced by the injection characteristics as well as the quality of mixing with the entrained air. For a PFI system, spray coverage and penetration are known to be the issues associated with conventional fuel injector. In this paper, the findings from a preliminary CFD work on the operation of a fuel injector with a swirl effect nozzle, which is designed to be used with small engines (capacity below 250cc), are presented, concerning the injector's fuel delivery characteristics: spray and penetration.

2. Literature review

The conventional understanding of spray formation are described by Sazhin (2014) [6] to follow these stages: 1) development of a jet; 2) conversion of a jet into liquid sheets and ligaments; 3) disintegration of ligaments into relatively large droplets (primary break-up) and 4) break-up of large droplets into smaller ones (secondary break-up). The successful transformation achieved by the injected fuel, upon leaving the injector nozzle, in accordance to the abovementioned stages will ensure the achievement of an efficient combustion.

Prior to that, Mitroglouet *al.* (2006) [4] also emphasised the importance of also assessing the quality of spray structure, tip penetration and fuel droplets distribution, velocities and diameters as a function of nozzle design, as well as the value of the fuel delivery pressure. In their work, on the spray characteristic of a multi holes injector under different spray pressures, they found that the spray angle remains constant and is almost independent of injection and chamber pressures. In addition, they deduced that injector with a multi-hole and central hole will produce uneven flow distribution and consequently created over-penetration and unstable spray pattern.

For port fuel injection engines, mixture formation process starts with the injection of liquid fuel into the intake ports. The fuel droplets interact with the air inside the intake manifolds, as well as intake port walls and intake valves, creating fuel vapour and wall films. Therefore, injector design and intake port geometry are also influential to the fuel injection spray quality [5]. Their findings showed that, as the fuel pressure increased, both jet velocity and spray cone angle increased and as a result it makes the diameter of droplets much smaller and a better atomization was achieved. A better understanding of spray characteristics of port injector is also very important in matching spray parameters with different engine designs and targeted operations.

Recent researches, studies and experiments on the mixture formation and spray pattern are mostly done by using numerical analysis and computational fluid analysis as these methods are more detailed and provide more complete data for analysis. By carrying out the analysis using the correct operating boundaries and practical geometries, injection spray and mixture formation quality can be assessed and further recommended for actual physical experiment could be recommended. For the current work described in this paper, the proposed fuel injector will function using a central injection hole surrounded with swirl channels.

3. Methodology

The study was initiated with the design of the new injector nozzle, which has a central hole with swirl channels using CAD Software, *Solidworks*. The basic injector design was based on combination of a single path flow with swirl paths, which will converge into four outlets at the end of the injector. Then, using FLUENT software, the fluid flow simulations inside the injector were carried out. Based on this preliminary CFD works, the initial design will be improved and upon achieving an optimum performance through simulations, a prototype will be fabricated for future physical experiments.

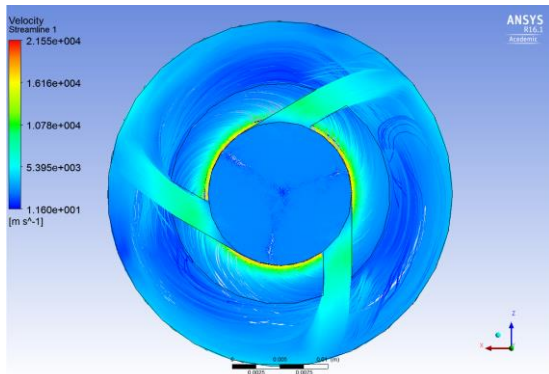


Figure 5. Plan view of the swirling flows with 90° angle.

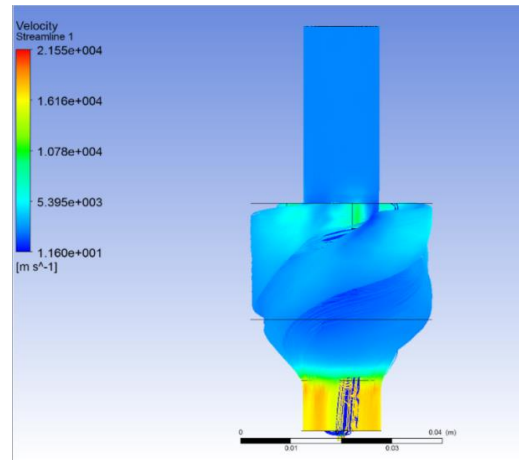


Figure 6. Side view of the swirling flows with n-octane as liquid.

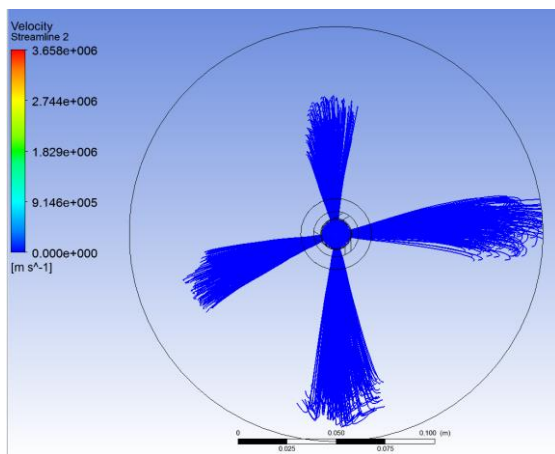


Figure 7. Simulation of the injected fuel from the four outlets – view facing the outlets.

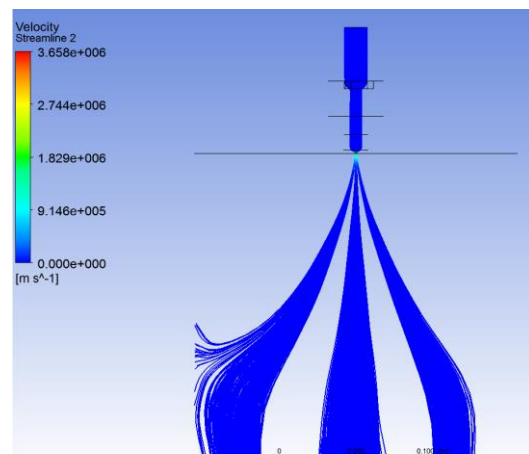


Figure 8. Side view of the injected fuel from the injector.

High velocity flows were observed inside the swirl paths and the selected angle were able to eliminate stagnation points in between the swirl paths. The flows encircled the single injection path and moving downwards towards the four injector's outlets. Nevertheless, the simulations were unable to simulate the combined flows from the swirl paths and the single injection path. High velocity streamlines were observed, as in figure 6, which could be due to the pressure difference between the inlet and outlet conditions, and they were too high in comparison to actual physical events. This observation will be subjected to further refinement in the future. In figure 7 and 8, the fuel flows exiting the four outlets were observed as expected. Even though the flows from the outlets are distinct and almost symmetrical, in accordance to the location of the outlets, the effects from having swirling paths inside the injector are not clearly demonstrated from these simulations.

The results obtained must be benchmarked in the future against simulations from the conventional multi-hole injector and also from swirl-only type injector. Those shortcomings will need to be investigated for future works for this type of fuel injector. Moreover, the positive effects of combining the swirl paths with the single injection must also be examined closely, in order to ascertain the influential factors for better fuel mixing inside the combustion chamber. Another aspect that must be

considered will be from the manufacturing perspective and the cost effectiveness of having this type of fuel injector as opposed to the conventional fuel injectors.

5. Summary

In this current work, a new configuration of fuel injector, which has a combined swirl spray and multi-hole functions had been successfully designed and investigated via simulations using CFD. Although the preliminary simulation works were carried out separately for the swirl paths flows and the single injection path flow, the results were useful to serve as the benchmarks for future works on this type of fuel injector. Swirling behaviour was observed and near-symmetrical flows were obtained at the outlets of the injector. It is recommended that for future works on this type of injector, the CFD simulations must attempt to combine and elucidate the benefits of having swirl spray function with the multi-hole injection. Furthermore, detailed assessment on manufacturability and cost effectiveness of this injector must also be addressed.

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References

- [1] Asif M and Muneer T 2007 *Renewable and Sustainable Energy Reviews*, **11**
- [2] Dudley B 2016 *BP Statistical Review*
- [3] Hoskisson R E, Eden L, Chung M L and Wright M 2000 *The Academy of Management Journal*, **43** 3
- [4] Mitroglou N, Nouri J M, Gavaises M and Acroumanis, C 2006 *International Journal of Engine Research* **7** 3
- [5] Movahednejad E, Ommi F and Nekofar K 2013 *EPJ Web of Conferences*, **45**
- [6] Sazhin S 2014 *Droplets and Sprays* (London: Springer)