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THE EFFECT OF DISCHARGE COEFFICIENT OF INTAKE AND EXHAUST VALVE FOR DIRECT INJECTION ENGINE

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ABSTRACT
This paper presents the effect of the coefficient of discharge of intake and exhaust valve for direct injection engine. The main purpose of the present work is to determine the discharge coefficient of intake and exhaust valves in the engine cylinder head of a 406 cm^3. The experiment has been conducted using a flow bench model Superflow SF-1020. It is required to know such discharge coefficients, as a function of lift and pressure ratio in the mathematical modelling process at each juncture during the open cycle. Accuracy can be obtained for the mass flow rates of gases, the magnitude of pressure waves and the in-cylinder thermodynamics. The obtained results are dependent on test pressure.

Keywords: Engine Design, Coefficient of Discharge, Diesel Engine, Test Pressure, Valve Lift.

1. INTRODUCTION
The important parameters in diesel engine performance are geometrical properties, engine efficiencies and other related engine performance parameters. The engine efficiencies are indicated thermal efficiency, brake thermal efficiency, mechanical efficiency, volumetric efficiency and relative efficiency [6]. A wide variety of inlet port geometries patterns is used to accomplish this over the diesel size range [1, 3, 4, 5]. The engine ratings usually indicate the highest power at which manufacturer expect their products to give satisfactory of power, economy, reliability and durability under service conditions.

The diesel engines port flow coefficient of discharge for a particular flow discontinuity is defined as the ratio of actual discharge to ideal discharge. In an engine environment, ideal discharge considers an ideal gas and the process to be free from friction, surface tension, etc. Discharge coefficients are widely used to monitor the flow efficiency through various engine components and are quite useful in improving the performance of these components [7]. This paper presents experimental results for coefficient of discharge the small four-stroke direct-injection diesel engines using SuperFlow flow bench.

The SuperFlow flow bench is designed to measure the air-flow resistance of engine cylinder heads, intake manifolds, velocity stacks, and restrictor plates [8]. In the SuperFlow flow bench, for four-cycle engine testing, air is drawn in through the cylinder head into the machine, through the air pump and exits through the vents at each side of the flow bench. The amount of flow is displayed in cubic feet per minute (*cfm*), liters per second (*lps*) or cubic meter per hour (*cmh*). The flow meter measures the pressure difference across an adjustable flow orifice in the flow bench. By selecting different ranges, the flow meter can be used to obtain high accuracy over reads 5 to 100% of any flow range selected in either intake or exhaust flow direction. The full scale flow measurement range of SuperFlow SF1020 can be varied from 25 to 1000 cfm or 12 to 470 lps.

A flow test in SuperFlow flow bench consists of blowing or sucking air through a cylinder head or other component at a constant test pressure. Then the flow rate is measured at various valve lift. A change can be made and then the component can be re-tested. Greater air flow indicates an improvement. If the tests are made under the same conditions, no corrections for atmospheric conditions or machine variations are required. The results of the experiment investigation may be compared directly. For more advanced tests, it is possible to adjust and correct for all variations so test results may be compared to those of any other head, tested under any conditions on any other SuperFlow flow bench. Further calculation can be made to determine valve efficiency and various recommended port lengths and cam timing. The port length and valve size are shown in Figure 1. The calculations can be cumbersome without a small electronic calculator, preferably with a square root key.

The total flow through the diesel engine is ultimately determined by the valve diameters. While well-designed smaller valves will out-perform larges valves on occasion, a good, big valve will always out-flow a good, smaller valve. Valve size is limited by the diameter of the engine bore. According to SuperFlow Technologies Group [25], that in practice the ideal flow is never

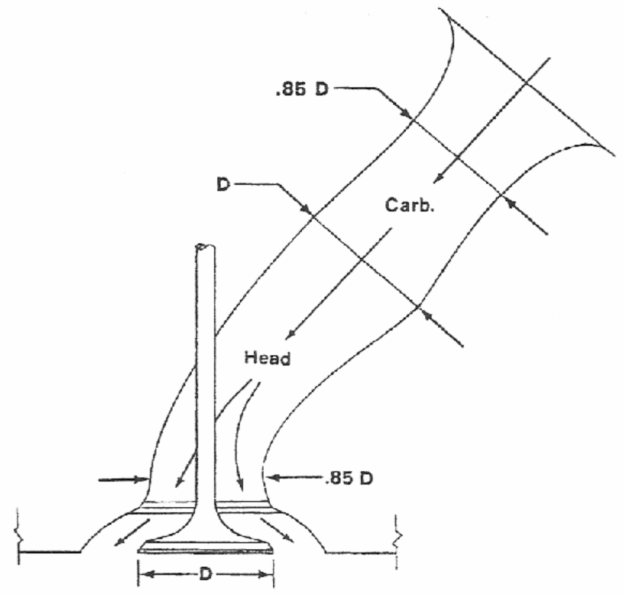

Fig 1: Intake port area and shape [8]

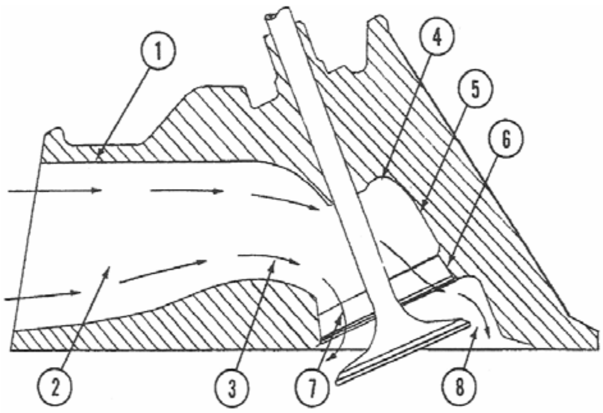

Fig 2: Source of flow losses in the port [8]

Table 1: Percentage of losses in the port [8]

Source of flow loss		% of loss
1.	Wall friction	4
2.	Contraction at push-rod	2
3.	Bend at valve guide	11
4.	Expansion behind valve guide	4
5.	Expansion 25 degrees	12
6.	Expansion 30 degrees	19
7.	Bend to exit valve	17
8.	Expansion exiting valve	31
	Total	100

achieved but it does provide a guide-line for what an efficient port would be like. If air flow losses are caused by port expansions, not contractions, it may wonder why the port should be necked down above the valve seat. The reason is the air must both turn 90 degrees and expand as it flows out the valve into the engine cylinder. Humping the port inward just above the seat allows the air to make the turn outward toward the valve edge more gradually, reducing the total flow loss. Source of flow losses in the port are wall friction, contraction at push-rod, bend at valve guide, expansion behind valve guide, expansion in 25 degrees, expansion in 30 degrees, bend to exit valve and expansion exiting valve. The source of flow losses is shown in Figure 2 and the percentage of loses is shown in Table 1.

2. MATERIALS AND METHODS

An experiment investigation to measure and analyze the discharge coefficient of small diesel engines using SuperFlow flow bench is presented in this paper. The specification of the selected diesel engine is shown in Table 2. The diesel engines cylinder heads are mounted onto the SuperFlow flow bench by a cylinder adapter. The adapter consists of a tube about 4 inch or 10 cm, long with the same bore as the engine and a flange on one end. The flange is bolted to the flow tester and the upper flange is bolted or clamped to the test cylinder head. The flanges must be flat or gasketed to make an airtight seal. The adapter tube may be 0.06 inch or 1.5 mm, large or smaller than the actual diesel engine cylinder.

Table 2: Specification of small diesel engine

Engine Parameters	Value
Bore (mm)	86.0
Stroke (mm)	70.0
Displacement (cc)	407.0
Number of cylinder	1
Maximum intake valve open (mm)	7.095
Maximum exhaust valve open (mm)	7.095
Intake valve diameter (mm)	35.54
Exhaust valve diameter (mm)	29.04
Intake valve stem (mm)	7
Exhaust valve stem (mm)	7
Intake valve effective area (sq. cm)	9.53
Exhaust valve effective area (sq. cm)	6.24

A device must be attached to the diesel engine cylinder head to open the diesel engine valves to the various test positions. The usual method is to attach a threaded mount so the end of the threaded part contacts the end of the valve stem. In this experiment the adaptor and the thread are developed using CNC machine. As the thread is rotated, it pushes open the valve. In this experiment, in one rotation of the thread the valve is open in 0.5 mm. Dial indicator may be mounted to the same fixture with its tip contacting the valve spring retainer to measure the amount of valve opening. The original valve springs are used in this experiment.

On the intake side of a four-cycle cylinder head, it is strongly recommended a radiused inlet guide be installed to lead the air straight into the head. The guide should be about one port width in thickness and be generously radiused on the inside all the way to the head of the diesel engine. The intake manifold of the diesel engine can also be used in the experiment.

All experiment test data may be recorded on the SuperFlow test data sheet forms. Before beginning a experiment test, record the test data setup. The test data setup are head description, valve stem, valve diameter, valve area, stem area and net valve area.

Net valve area = 0.785(valve diameter^2 – stem diameter^2) (1)

All diesel engine valves in this test should be performed at the same ratio of valve lift to valve diameter or L/D ratio.

$$L/D\ \text{ratio} = \frac{\text{valve lift}}{\text{valve diameter}} \tag{2}$$

Then the flow efficiencies of any valves can be compared, regardless of size. In this research, the constant of L/D ratios used are 0, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30. Then the valve lift test points can be obtained.

Initially, the flow bench is calibrated using test orifice plate. Then turn on the flow bench motor, make sure the flow rate match the value stamped on the test plate. Remove the test orifice plate from the flow bench and install the test head, cylinder adapter and valve opener for the actual flow investigations. In this research the dial indicator is set in zero with the valve closed. Then install either the intake manifold or an air inlet guide on intake port. In this research, the test pressure is set on 65, 55, 45, 35 and 25 of inch H_2O or 1651, 1397, 1143, 889 and 635 mm H_2O. The cylinder head leakage is determined with the valves closed. The actual test flow value will be deducted with the leakage value to get the corrected test flow value. The valve is lifted to 0, 1.78, 3.55, 5.33, 7.11, 8.89, and 10.66 mm for intake valve, and lifted to 0, 1.45, 2.90, 4.36, 5.81, 7.26 and 8.71 mm for exhaust valve.

For the analysis of the experiment results data, it is necessary to measure the corrected test flow. The corrected test flow can be compared to other experiment of the same head with the same setup without further calculations. In this experiment there is no atmospheric corrections needed. To obtain the valve efficiency, it is necessary to calculate the flow in cfm/square inch or lps/cm^2 of the valve area and then to compare that flow to the best yet achieved. The test flow calculation is as below:

$$\text{Test flow} = \frac{\text{correction test flow}}{\text{effective valve area}} \tag{3}$$

$$\%\ \text{Potential flow} = \frac{\text{test flow}}{\text{potential flow}} \tag{4}$$

The % potential flow can be used as an indicator of the remaining improvement possible. To determine the valve coefficient of discharge (C_d), the test flow per unit area is divided by the maximum potential flow per unit area for the test pressure. The calculation is shown below:

$$C_d = \frac{\text{test flow}}{\text{potential orifice flow}} \tag{5}$$

The flow results of this experiment investigation are plotted on graphs as shown in Figure 4 to 8. Square symbol is used to indicate the intake experiment test points, diamond symbol is used to indicate the exhaust test points and triangle symbol is used to indicate the potential theoretical points.

3. RESULTS AND DISCUSSION

In this experiment investigation, the intake valve lift is opened up to 10.66 mm. This value is more than original maximum intake valve lift which is 7.095mm. The maximum exhaust valve lift in this experiment is opened up to 8.71 mm, this value is also more than the original maximum exhaust valve lift which is 7.095mm.

The air flow through the engine is directly controlled by the valve lift. The farther the valve opens, the greater the flow, at least up to a point. In order to discuss a wide variety of valve sizes, it is helpful to speak in terms of the ratio of valve lift to valve diameter, or L/D ratio. Stock engines usually have a peak lift of 0.25 of the valve diameter and for racing engines open the valves to 0.30 of the valve diameter or even 0.35 of the valve diameter [8]. Graph in Figure 3 shows how flow varies with lift for a well-designed valve and port. Up to 0.15 of the valve diameter, the flow is controlled mostly by the valve and seat area. At higher lifts the flow peaks over and finally is controlled by the maximum capacity of the port. Wedge-chamber intakes have lower flow at full lift due to masking and bends, and are port-limited at a 15% lower level. These valve flow potential graphs on the Figure 3 can be used as a guide for judging the performance of any valve. To determine the flow rate for a particular valve, simply multiply the flow/area from the graph by the valve minus the valve stem area. The flow rate obtained is not the expected flow rate, but rather the maximum potential flow rate for a particular head at the test pressure. If the flow reaches a maximum value at a lift of about 0.30d, it may wonder why some cams are designed to open the valve farther, even as high as 0.37d. The answer is in order to open the valve more quickly and longer at lower lifts, it is necessary to over-shoot the maximum head-flow point. The extra flow is gained on the flanks of the lift pattern not at the peak.

The head flow figures in Figure 1 and 2 are for the cylinder head alone with just a radiused inlet guide on the inlet port. When the introduction system is installed, the total flow will drop of from 5% to 30% depending on the flow efficiency of the system. By measuring the flow at each valve lift with and without the induction system, it is possible to accurately measure the flow efficiency. Frequently, the induction system will have even more room for improvement than does the cylinder head.

Figure 4 shows result of valve flow versus valve lift to diameter ratio at 1651 mm test pressure. The intake and exhaust valve flow graph are increasing linearly with the increment of valve lift to diameter ratio from 0 to 0.2. The value of L/D = 0.2 is the value for valve maximum lift. (7.1mm). Both graphs will joint at L/D = 0.25. After this value, the intake graph shows decrement compared to exhaust graph in term of valve flow. The potential flow graph in Figure 4 is calculated theoretically. From these three graphs, the information gained that intake and exhaust valve flow can be increased up to potential flow subjected to L/D < 0.25 by using valve floating process. Figure 5 to 8 show results of valve flow versus valve lift to diameter ratio at different test pressure. The results show that the graph trend almost similar with each others. The intake and exhaust flows in Figure 4, 5, 6, 7 and 8 can be increased up to potential flow subjected to L/D < 0.25, 0.25, 0.26, 0.26 and 0.28 respectively.

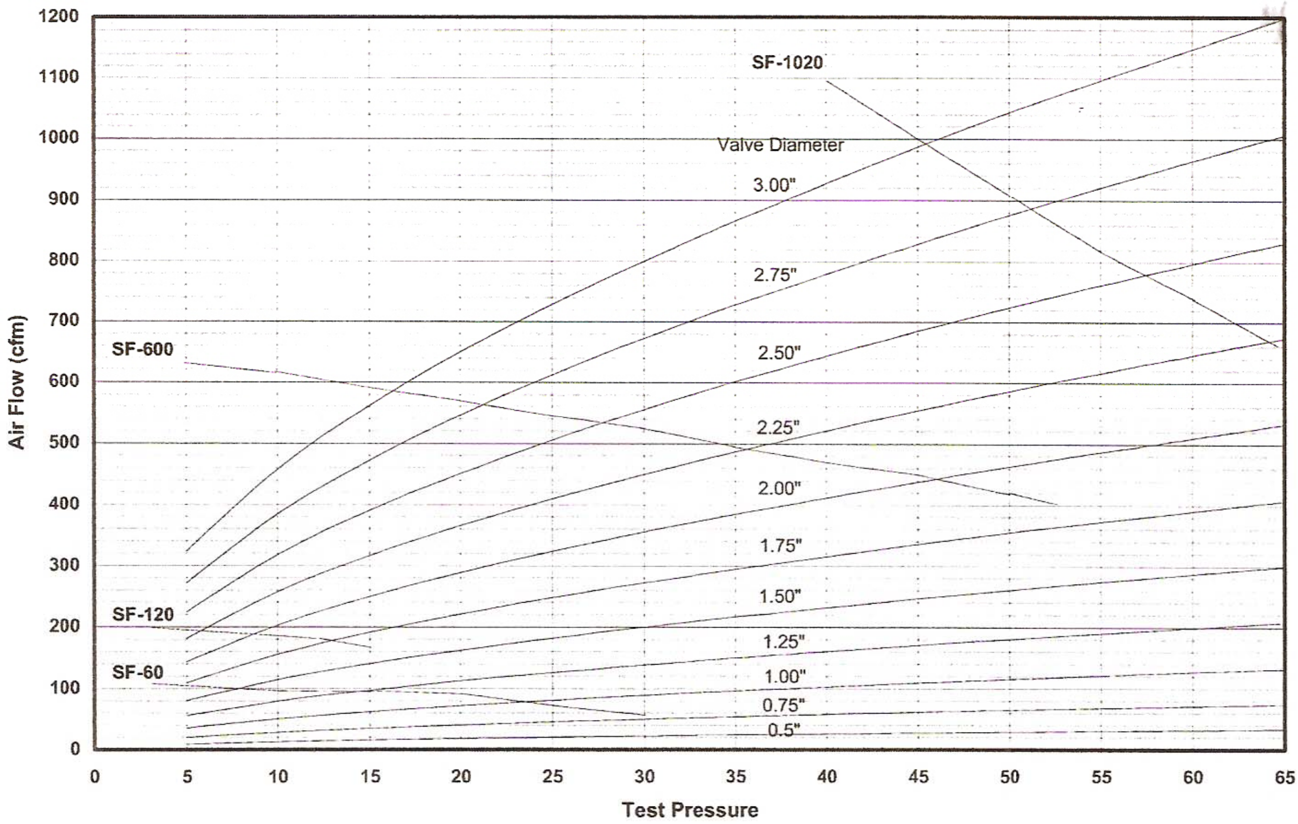

Fig 3: Valve flow potential vs test pressure [8]

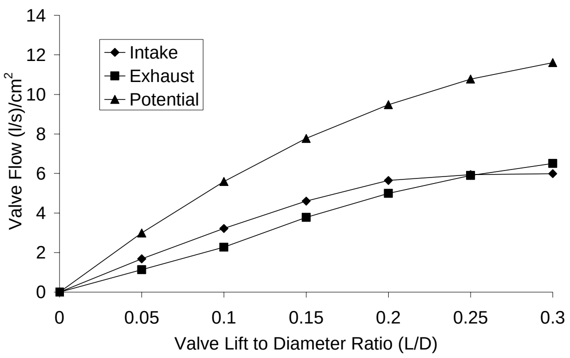

Fig 4: Valve flow at 1651 mm test pressure

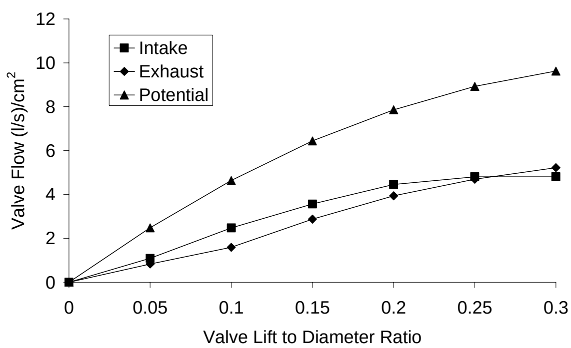

Fig. 6: Valve flow at 1143 mm test pressure

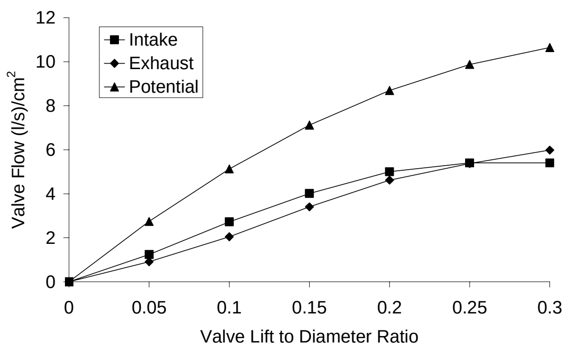

Fig 5: Valve flow at 1397 mm test pressure

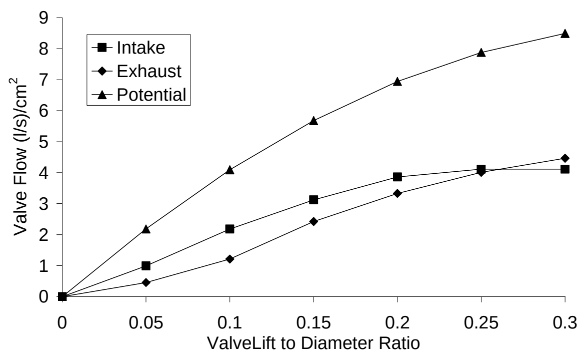

Fig 7: Valve flow at 889 mm test pressure

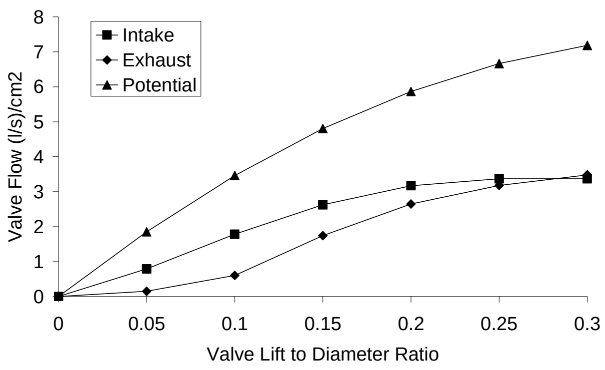

Fig 8: Valve flow at 635 mm test pressure

Figure 9 shows the discharge coefficient versus valve to diameter ratio at different pressure for intake. Test pressures being used in this experiment are 635, 889, 1143 1397 and 1651 mm H_2O. The graphs show the equality in term of curve for each others. The increment of discharge coefficient is linearly dependent with the increment of valve lift to diameter ratio until L/D=0.2 which is the maximum valve lift for intake valve. After this value, the increment in valve lift to diameter ratio will cause the discharge coefficient to achieve the peak value.

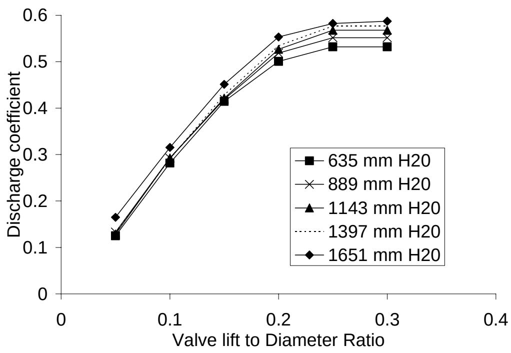

Fig 9: Discharge coefficient vs valve lift to diameter ratio at different test pressure for intake

Figure 10 shows the discharge coefficient versus valve to diameter ratio at different pressure for intake. Test pressures being used in this experiment are also 635, 889, 1143 1397 and 1651 mm H_2O. The graphs also show the equality in term of curve for each others. The increment of discharge coefficient is not linearly dependent with the increment of valve lift to diameter ratio as in intake case. This is because of back pressure effect in the cylinder. After L/D=0.25 which is the maximum valve lift for exhaust valve, the graphs seem to become flat.

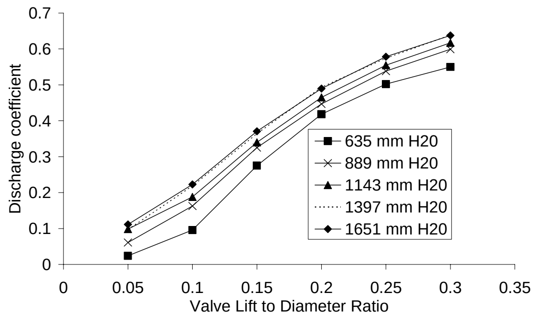

Fig 10: Discharge coefficient vs valve lift to diameter ratio at different test pressure for exhaust

4. CONCLUSION

The valve lift has been successfully examined in various test pressures and the result shows that the air flow in the intake port and exhaust port of the small diesel engine can be optimized up to specific potential flow subjected to valve lift to diameter ratio and test pressure. From this experiment also, the discharge coefficient has been successfully calculated theoretically and its value varies depending to test pressure and valve lift to diameter ratio. Further simulation research such as using Star-CD will be conducted to verify these results.

5. ACKNOWLEDGEMENT

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