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Performance review of a four Cylinder Petrol Engine –A Case Study

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ABSTRACT
Modern civilization relies heavily on internal combustion (IC) engines, which power various applications, including aircraft, automobiles, motorcycles, marine vessels, railway locomotives, spacecraft, and more. To ensure efficient fuel utilization and minimize pollution, optimizing engine performance is crucial. This paper aims to investigate the optimal operating conditions of a practical ISUZU engine.Through detailed performance calculations and analysis of test results, it was determined that the engine achieved maximum efficiency (31.28%) at an air-fuel ratio of 16.4:1, slightly leaner than the stoichiometric mixture. This condition, coupled with an engine speed of 1578 RPM and a brake horsepower (BHP) of 9.98, represents the most economical operating point.The engine produced maximum power (12 HP) at an air-fuel ratio of 12.4:1, slightly richer than the stoichiometric mixture, and an engine speed of 1245 RPM.
Key words: *Petrol engine, engine performance, air fuel ratio, lean mixture and stoichiometric mixture*

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Nomenclature

BP	Brake Power
A:F	Air fuel ratio
T	Torque in Kgm
IP	Indicated Power
N	Speed of the turbine in RPM
ɳ	Efficiency
HP	Horse Power

I. Introduction

Internal combustion (IC) engines, such as petrol engines, derive power from the combustion of fuel (typically a fossil fuel) with an oxidizer (usually air) within a combustion chamber. This combustion process generates high-temperature, high-pressure gases that exert force on engine components like pistons, converting thermal energy into mechanical work.Research has explored the impact of water injection on spark ignition engines fueled by LPG. Results indicate that increasing water injection levels can enhance engine performance by increasing the percentage of useful work, reducing specific fuel consumption, and improving thermal efficiency.Theoretical studies have also investigated waste heat recovery strategies in IC engines powered by both internal combustion and electric motors to further optimize fuel efficiency. IC engines find widespread application in various sectors, including transportation (road vehicles, locomotives, ships, aircraft), power generation (portable standby units), and agriculture (tractors, lawn mowers, concrete mixers, motorboats).This paper aims to delve deeper into the optimal performance conditions of a specific IC engine, the ISUZU engine.

II. Materials and Methods

Figure 1 and Figure 2, respectively, depict the schematic diagram and original image of the experimental setup employed for this study. The experiments were conducted at the I/C Engine Laboratory in the Department of Mechanical Engineering at Durgapur Institute of Advanced Technology and Management, Durgapur. The test rig was designed and supplied by M/s. Technical Teaching (D) Equipment, Bangalore, India.The specifications of the engine used in the experiment are as follows:

Brake Horse Power	: 10HP
No of cylinder	: 4
Compression ratio	: 8.5:1
Bore Diameter	: 84mm
Stroke length	: 82mm
Types of cooling	: water cooling
Air drum orifice diameter	: 24mm
Speed	: 1500rpm
Load arm	: 320mm

Maker : ISUZU

The test rig primarily comprises a digital temperature indicator for thermocouple readings, a digital RPM indicator, a burette with a 3-way manifold for fuel consumption measurement, and a differential U-tube manometer with an appropriate orifice for air intake measurement.

The engine and hydraulic dynamometer are secured on a 3-inch M.S. channel frame and further stabilized using anti-vibration mounts. The engine panel board accommodates the starter, an analog ammeter connected to the battery, a burette with a 3-way cock, a digital temperature indicator with a selector switch, a digital RPM indicator, and a U-tube manometer.

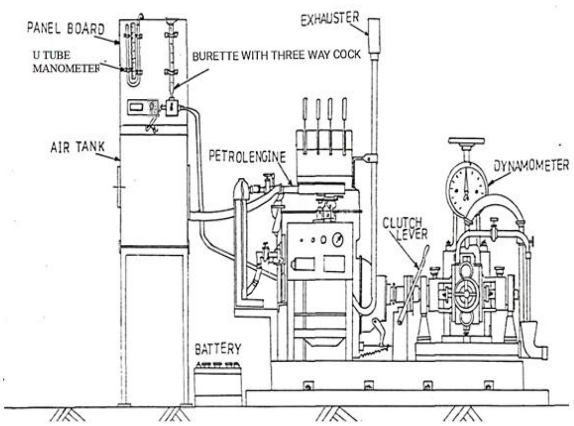

Fig 1 Schematic diagram of the experimental test rig of Petrol Engine (ISUZU Engine)

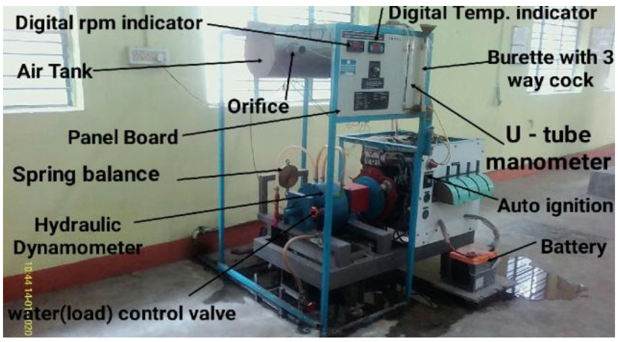

Fig2 Original image of ISUZU Engine

3.1 Analysis of engine performance

Engine performance is evaluated using efficiency (η), which measures the conversion of heat energy into power. Indicated Power (IP) represents the power generated to drive the piston, while Brake Power (BP) refers to the useful power available at the shaft.Fuel consumption is quantified by specific fuel consumption (SFC), expressed in kg of fuel per kilowatt-hour. A lower SFC indicates better engine performance.The intricate interplay between engine speed, power output, and specific fuel consumption ultimately determines overall engine performance.

3.1.1 Important Formulae Used

Power and Mechanical Efficiency
Brake Power (BP) is the power output measured at the engine's crankshaft.It is typically calculated using the following formula:
BP = (2πNT)/60,000
Where:

- BP: Brake Power in horsepower (hp)
- N: Engine speed in revolutions per minute (rpm)
- T: Torque in pound-feet (lb-ft)

Volumetric Efficiency
Volumetric efficiency is a crucial parameter in engine performance, indicating how effectively an engine fills its cylinders with air-fuel mixture during the intake stroke. A higher volumetric efficiency generally leads to better engine performance.
Volumetric efficiency (η_v)

$$= \frac{\text{Mass of charge actually sucked in}}{\text{Mass of charge corresponding to the cylinder intake } P \text{ and } T \text{ conditions}}$$

Fuel-Air Ratio (*F*/*A*)

The fuel-air ratio is a critical factor influencing combustion within an engine. It directly impacts:

- Flame Propagation Velocity: The speed at which the flame front travels through the combustion chamber.
- Heat Release Rate: The rate at which heat energy is released during combustion.
- Peak Combustion Temperature: The maximum temperature achieved during the combustion process.
- Combustion Completeness: The extent to which the fuel is fully oxidized.

A stoichiometric mixture, where the fuel and air are present in the ideal ratio for complete combustion, is often targeted. However, deviations from this ratio can occur, leading to lean or rich mixtures. These deviations impact engine performance, emissions, and fuel economy

Specific Fuel Consumption

Specific Fuel Consumption (SFC) is a key metric used to evaluate the fuel efficiency of an engine. It represents the amount of fuel consumed per unit of power output per unit of time.A lower SFC value indicates better fuel efficiency. In other words, the engine is able to produce more power from a given amount of fuel.

$$\textit{Specific fuel consumption (sfc)} = \frac{\textit{Fuel consumption per unit time}}{\textit{Power}}$$

Table1:Experimental and calculated data

RPM	Manometric Head(mm)	Water thrust Kg	BHP	Mass of fuel Kg	η_{Bth}	Actual vol m^3 /hr	Swept vol m^3 /hr	$\eta_{vol(\%)}$	A:F
692	36	6.4	2.03	1.45	8.97	24.35	37.62	64.92	21.35
937	43	8.4	3.57	1.62	13.17	26.67	50.68	53.2	19.44
1158	40	15	7.90	3.43	14.69	26.03	63.77	41.21	9.58
1578	41.5	14	9.98	1.95	31.38	26.03	85.79	30.44	16.4
1241	54	21.4	11.91	2.9	24.26	67.37	67.38	46.12	12.27

Table-1 exhibits the experimental data and calculated performance data.

4.1 Results and discussions

The following paragraphs discuss the experimental results obtained from the petrol engine under five different load conditions, applied in the form of water thrust.

4.1.1 Variation of efficiency with variation of air fuel ratio

Figure 3 illustrates the relationship between engine efficiency (η) and the air-fuel ratio (A:F). The efficiency initially rises linearly with increasing A:F ratio, reaching a peak of 31.38% at a slightly lean mixture of 16.4:1. This optimal A:F ratio is crucial for both fuel economy and reduced emissions. Complete fuel combustion is achieved at this point, with an engine speed of 1578 RPM and a brake horsepower (BHP) of 9.98.

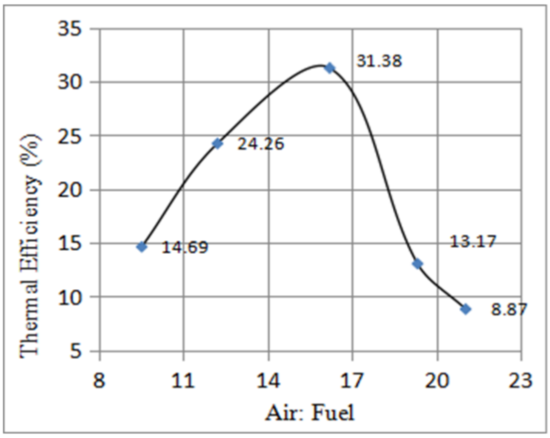

Fig 3 Variation of efficiency(η) with the variation of air fuel ratio

4.1.2 Variation of power output with variation of air fuel ratio :

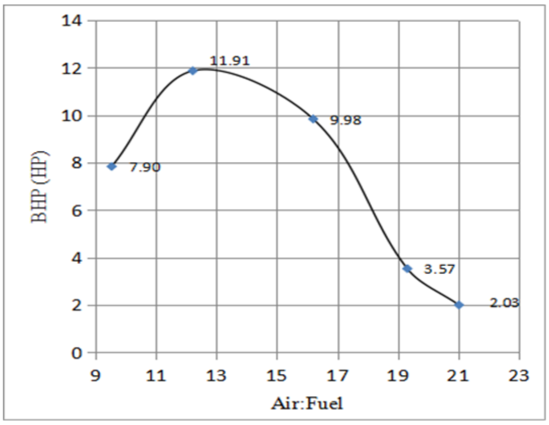

Fig 4 Variation of power output (HP) with the variation of air fuel ratio(A:F)

Figure 4 depicts the relationship between engine power output (HP) and the air-fuel ratio (A:F). The A:F ratio significantly impacts engine power. Initially, in fuel-rich conditions, limited oxygen availability restricts complete combustion, resulting in lower power output. As the A:F ratio increases, more oxygen becomes available, leading to improved combustion and increased power. Peak power of 12 HP is achieved at an A:F ratio of 12.4:1, slightly richer than the stoichiometric mixture. At this point, the limited oxygen within the cylinder is fully utilized for combustion, and dissociation is minimized due to the presence of CO in the combustion products. Therefore, to maximize engine power, it should be operated at an A:F ratio of 12.4:1.

4.1.3 Variation of volumetric efficiency with variation of Power output

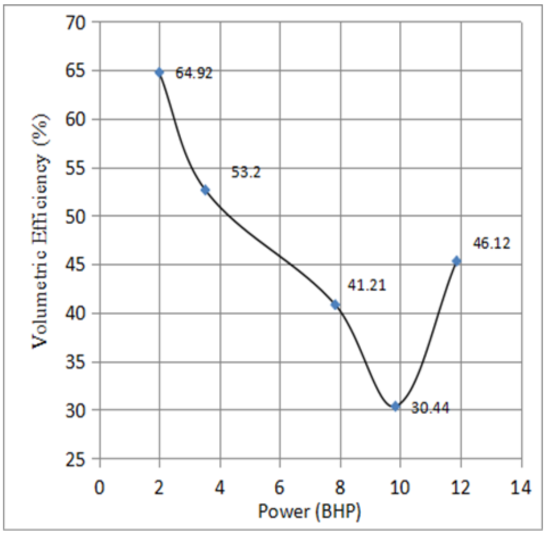

Fig 5 Volumetric efficiency versus power

Volumetric efficiency, a critical factor in engine longevity and health, reflects the engine's "breathing" capacity. At low engine speeds (around 2 HP), where valve operation is less frequent, maximum volumetric efficiency is observed. This is because valves have ample time to fully open and close, allowing for optimal cylinder filling.As engine speed increases, the reduced cycle time limits the valve's ability to fully open and close, hindering complete cylinder filling and diminishing volumetric efficiency. Additionally, at maximum power (12 HP), the fully open throttle valve, combined with the inertia of air velocity, allows for increased airflow and a moderate volumetric efficiency of 45.03%.Therefore, while operating at lower power levels promotes engine longevity, higher power output can be achieved at the expense of reduced volumetric efficiency.

4.14 Variation of Power output with variation of RPM

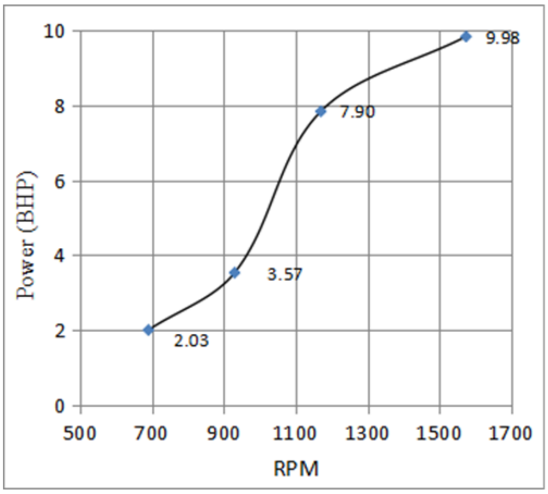

Fig 6 Power output with the variation of speed (RPM)

Figure 6 illustrates the relationship between engine power output (HP) and engine speed (RPM). The brake power output exhibits a nearly linear correlation with engine speed. As RPM increases, the number of power cycles per unit time also increases, resulting in a corresponding increase in power output. In this experiment, the maximum brake power of 9.85 HP was achieved at an engine speed of 1568 RPM. It's important to note that all engines have specific operating limits, and exceeding these limits can lead to damage. Therefore, it's crucial to operate the engine within its designated speed range.

V. CONCLUSION

The following conclusions were drawn from this investigation:

A. The engine achieved its peak efficiency of 31.38% at an air-fuel ratio (A:F) of 16.4:1, which represents a slightly lean mixture. This condition, characterized by an engine speed of 1578 RPM and a brake horsepower (BHP) of 9.98, is the most fuel-efficient operating point.

B. The engine produced maximum power (12 HP) at a slightly rich air-fuel ratio (A/F) of 12.4:1. At this point, the limited oxygen within the cylinder is fully utilized for combustion, minimizing dissociation due to the presence of CO in the combustion products. This optimal A/F ratio results in peak power output.

C. Volumetric efficiency exhibits a linear decline from 64.92% to 30.44% as engine speed increases. This decrease is attributed to the limited time available for valves to fully open and close at higher speeds, resulting in incomplete cylinder filling. While at maximum power (12 HP), the fully open throttle valve and air inertia contribute to increased airflow and a moderate volumetric efficiency of 46.12%.

D. The brake horsepower (BHP) increases linearly with engine speed (RPM). As RPM rises, the number of power cycles per unit time also increases, leading to a corresponding increase in power output.

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