
PARAMETRIC ANALYSIS OF AN AIR DRIVEN ENGINE: A CRITICAL REVIEW

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ABSTRACT

As the world is suffering with energy and fuel crisis, and is being contaminated with harmful exhaust pollutants. Consequently, it becomes difficult to live a healthy life on earth. Therefore, any technology that can help in reducing these crisis and pollution are most welcomed and are widely accepted these days. One of such technology that can provide solution to this problem is compressed air driven engine. The literature has been reviewed to analysis the different effects of various parameters on the air engine such as air pressure from the compressor, capacity of compressor tank, number of strokes of the engine, number of cylinders, number of storage tank, number of inlet and exhaust ports, pneumatic guns, and use of electrical devices like piezometer, solenoid valves, etc. In the review, it was found that engine speed of 3000 rpm was obtained at a maximum pressure of 8 bar and also high power gain of about 0.95 kW was achieved at 9 bar and 1320 rpm. At small pressure of 10 bar with varying injection angle from 10° before top dead centre to 15° after top dead centre, the rotating speed was found to be 715 rpm to 965 rpm whereas, at higher pressure of 25 bar with varying injection angle the speed ranged from 1191 rpm to 1422 rpm. At lower pressure of 5 bar the maximum speed was 28.9 kmh⁻¹ with a travelling distance of 2.5 km, whereas at high pressure of 9 bar the maximum speed attained was 36.5 kmh⁻¹ travelling 1.7 km.

Keywords: Compressed Air Engine, Emission, Fuel Consumption, Spark Ignition Engine, Two/Four Stroke Engine.

1. INTRODUCTION

As we know that internal combustion engines have been used in automobiles for several decades and in order to obtain power, a very complicated process is carried in the engine. Fossil fuels are used to produce the required energy, which leads to many environmental disasters like global warming, greenhouse effect, ozone depletion along with the pollution of the air and environment.

Moreover, the fossil fuels are non-renewable and are at the verge of extinction. So, in this world of energy crisis there is an urgent need to shift from fossil fuels to a non-conventional source of energy which causes no or very less pollution and is feasible in terms of cost, availability and ease of installation. Thus, compressed air as a fuel for engine is the best option under this context. Also compressed air is non-combustible, non-polluting, safe, simple and efficient, and there are no harmful by-products of air used as a fuel. As there is no combustion taking place in the engine, so its non-polluting and requires lighter metals since there are no high temperatures in the engine. The air driven engine operates on compressed air, which do not need to undergo combustion and so no polluted emissions, thus making it an eco-friendly engine. The process is quite simple as compared to that of internal combustion engine. Air compressed into a cylinder possesses energy which is utilized for running the engine. As the compressed air expands, it releases energy which is used to move the piston of the engine. Recently MDI (Motor development international) has developed a new car based on compressed air engine that can run at 56 kmph. The TATA Motors have also announced an air car to be launched in 2015. The car is named as AIRPOD and can run on a minimum air pressure of 20 bar and can attain a maximum speed of 70 kmh^{-1} [1].

2. RECENT STUDIES

Numerous reviews on air compressed engine have been studied and some performance characteristics such as emission characteristics, fuel consumption, power, revolutions per minute (rpm), torque and pressure has been analysed. The extensive literature review on air compressed engine is as follows:

In the study of Singh et al. [1], it was observed that for compressed air two stroke spark ignition engine, high pressure would be the driving force. The parameters considered while doing analysis on compressed spark ignition engine were 10.45 Nm torque and 6.85 HP horse power ranged from 5500 to 7500rpm. An air motor with double inlet and exhaust were designed to get 5500 to 7500 rpm.

Lal [2] introduced a design of a compressed air engine with no start-up power that led to more power to weight ratio. In the modified version, power stroke was obtained at every 180° rotation of crank shaft.

Addala et al. [3] observed that air car propelled with compressed air motor or a pneumatic wrench hold compressed air to about 11.3 bar pressure. The process flow was compressor-reciprocating compressor-single stage-hermetically sealed-1, 5 HP, 3000 rpm. Rotary vane motor performed satisfactorily in high temperature areas up to 93°C and air stored in tank at 11.03 bar pressure.

In the study of Haung et al. [4], the compressed air engine was reformed from a four stroke engine to a two stroke engine using cam gear and crank shaft modifications. Power of about 0.95 kW was achieved at 9 bar and 1320 rpm. At same pressure, the maximum torque of 9.99 Nm was obtained at 465 rpm. Due to improved cam gear system, the inlet valve opened at 0° crank angle and closed at 150° crank angle, and the exhaust valve opened at 170° and closed at 360° .

Keste et al. [5] made a prototype of a vehicle operating on compressed air on the concept of inversed slider crank mechanism. The piston attached with the pinion of the double acting pneumatic cylinder was used to generate the rotary motion.

Kumar et al. [6] used an existing two stroke engine in order to convert into a two stroke compressed air engine. The flywheel, cylinder head and intake port of the engine were modified whereas the carburettor was removed from the system. At small pressure of 10 bar with varying injection angle from 10° before top dead centre to 15° after top dead centre, the rotating speed was found to be 715 rpm to 965 rpm, whereas at higher pressure of 25 bar with varying injection angle, the speed ranged from 1191 rpm to 1422 rpm.

In the study of Ravi [7], the reciprocating movement of the piston inside the cylinder was achieved by the pressure energy of the compressed air. The proposed air engine had two 180° opposite cylinder with piston set in opposite phases to each other. The crankcase was fabricated with cast iron material and 8 mm square rods. In order to jolt the bearing of the crankshaft, a 47 mm hole was bored through the central axis of the crank case.

In the study of Yadav et al. [8], compressed air was used as fuel to run an engine. The compressed air engine was modified with pneumatic cylinder, pneumatic solenoid valve, and compressor. In the proposed model, the input was connected with air compressor. The study showed that about 3m³ air at 30 bar pressure gave a mileage equal to 1 litre petrol and cost of production of compressed air was much lower than that of petrol, this proved it less costly. The engine designed was thus eco-friendly, pollution free and also economical.

The study of Wang et al. [9] presented the applications of compressed air on an engine to run a motorcycle. A 100cc four-stroke internal combustion engine was revised to a two-stroke air compressed engine. The compressed air engine motorcycle was examined at different valve timings, gear reduction ratios and different air pressures. At lower pressure of 5 bar, the maximum speed was 28.9 kmh⁻¹ travelling 2.5 km, whereas at high pressure of 9 bar the maximum speed attained was 36.5 kmh⁻¹ travelling 1.7 km.

In the study of Thipse [10], an air compressed engine was proposed with special crankshafts and piston that remained at top dead centre for 70° of crankshaft rotation, which allowed more power. About 90 m³ of air was stored in a carbon fibre tank at around 4500 psi.

In the review of Parashar et al. [11], an analysis of compressed air engine was done. Engine gave uniform turning effort as compared to four stroke engine. It was concluded that the changing of cam lobes setup from two lobes to four lobes, an engine could be run on compressed air.

Vishal et al. [12] proposed that air powered engine could be an alternative of internal combustion engine. Two stroke engine gave 18 mph maximum speed while running on compressed air. Experiment showed that air powered engine was efficient and contributed to pollution free environment.

In the study of Verma [13], an analysis on problems related to compressed air engine was done. Zero emission of harmful gases was the greatest advantage. Results of analysis showed that compressed air vehicle was a bit distant dream for actual practice, but in laboratories researches were very rigorously going on.

Shirke et al. [14] established a simple micro air engine. The air driven engine worked as a pneumatic actuator, which was used for expanding compressed air. The pressure measured was between 0.6 bar to 10 bar. Forces at advance stroke and return stroke was 620 N and 754 N respectively.

In the study of Kumar et al. [15], a compressed air engine was proposed which used the energy of reciprocating piston to rotate the output shaft. Simulation showed inlet pressure was directly proportional to velocity and inversely proportional to cycle time.

Shaw et al. [16] designed a pneumatic motor system which was driven by compressed air. It was observed that the efficiency was better for the engine at low temperature. Difference in theoretical and experimental efficiency was observed to be 0% - 3.4%.

In the study of Sharma et al. [17], a single cylinder engine was modified to make it work on compressed air. Pneumatic cylinder and solenoid valve were the main components introduced to the modified engine. The study showed that indicated power was directly proportional to load.

The study of Agarwalla et al. [18] proposed the estimation of run time parameters for an air driven engine. Compressed air entered seven directional control valves and limiting switches. A prototype was developed with operating pressure of 10 bar. It was found that pressure was directly proportional to speed.

Amardeep et al. [19], proposed an engine that worked on compressed air. A compressor with capacity of 30 litres, pressure 8 bar and a solenoid controlled 5/2 way valve was used for controlling an output air. It was observed that this engine was less robust as compared to internal combustion engine.

Boddapati et al. [20] modified a four stroke engine to a two stroke engine. The first stroke was suction/power stroke while the second was exhaust stroke. A cam was designed to set the inlet air timing for an air engine. Furthermore, 5 bar of pressure gave 850 rpm with mechanical efficiency of 80%.

Jandhayala et al. [21] proposed the design of a compressed air engine in which the connecting rod was replaced by a link mechanism that did not link the piston straight to the crank shaft. Air was supplied through the inlet at 20 bar pressure and 400°C.

In the study of Yu et al. [22], a compressor tank of 300 litre capacities was used in which the density of air was 491.6 kJ/kg and equivalent to the energy density of a lithium ion battery. To optimize energy efficiency, a compressed air engine was developed with a simple electromagnetic distribution arrangement.

In the experiment by Bohac [23], a two stroke tier one locomotive engine of 1973 year was modified to decrease the emission as initially there were no emission limits in this engine. The inlet valve timings were varied from 5 notches to 8 notches and it thus increased the efficiency of the two stroke engine.

In the study of Tembhurkar et al. [24], a piston was designed with special feature to run an air engine without carburettor. Two pistons of different sizes were used. The air stored in tank at 300 bar was supplied to the inlet, as the piston reciprocated.

In the study of Ghazal et al. [25], it was observed that the emission of the carbon dioxide (CO₂) and nitrogen oxides (NO_x) decreased with the change in the valve timing of the engine. It also increased the thermal efficiency of the engine.

In the study of Sardeshpande et al. [26], the efficiency of the compressor was increased by decreasing the leakages, avoiding wastages and misuse. As the flow rate of air was small as compared to that of the overall compressed air flow in system, thus the use of these equipment increased the performance of the compressor.

Briggs et al. [27] proposed a design of a direct injection system that used pressurized air blast for its working. The air rail supplied the compressed at a pressure of 600 kpa and the fuel at a pressure of 650 kpa. The blast valve was used to inject the fuel that was being actuated by an electrical solenoid valve.

In the study of Qin et al. [28], the influence of stroke to bore ratio on combustion performance was discussed. It was observed that when the stroke to bore ratio was increased, the oxides of nitrogen (NO_x) emission increased and decreased when the engine speed increased.

In the study of Balashanmugam et al. [29], it was analysed that by using a turbocharger in a two stroke petrol engine, reduction in fuel consumption and emission could be achieved along with the increase in the power output and torque of the engine that led to better thermal efficiency.

In the literature of Lande et al. [30], an experimental investigation on efficiency of two stroke petrol engine was discussed using blending of ethanol with petrol. The emissions of carbon monoxide (CO) and hydrocarbons (HC) were lowered as the percentage of ethanol was increased in the petrol.

In the experiment of Thakur et al. [31], a two stroke engine was run at different rpm, load and the percentage of different pollutants were checked. A nano sized copper catalytic converter was used which resulted in the reduction of the percentage of pollutant.

Sapatel et al. [32] proposed a design of a two stroke engine to control the precise amount of fuel at all operating speed of the engine by fitting the Gasoline direct injection system in two stroke petrol engine. Gasoline direct injection improved the quality of combustion and output of the engine.

In the study of Blanchard et al. [33], it was suggested that instead of using a simple two stroke engine, a two stroke direct injection engine could be used in order to increase the efficiency of a two stroke engine. Reduction in emission, like quantity of hydrocarbon (HC), oxides of nitrogen (NO_x) and carbon monoxide (CO) were observed in comparison to simple two stroke engine. Fuel consumption were also 10 to 20% lesser than 4 stroke engine with same carburettor capacity.

In the study of Obodeh et al. [34], engine power output and emission out from engine were improved by using a tuned adjustable exhaust pipe system. The fuel economy of engine was improved by 12%. HC emissions maximum reduction of 34.6% occurred at 3000 rpm and minimum 27.8% at 600 rpm. Emission of CO was also reduced by maximum 15.9% at 600 rpm and minimum 10.7% at 2400 rpm.

In the study of Kumar et al. [35], it was found that by the use of oxy hydrogen blended fuel, emission of engine was improved as compared to the conventional fuel. During combustion maximum temperature of 2800°C was achieved. An increase in efficiency of about 10% was obtained.

Chakraborty et al. [36] made a test rig on which 2 stroke petrol engine tested at different load conditions. For better consumption of fuel, at 5 kg load time taken for consumption of 5cc fuel was 58.60 seconds at 232 rpm of engine in 4th gear in main jet of size 90 as compared to others. For more rpm at same condition, the same parameters took as 5cc, 28.12 seconds, 528 rpm and main jet size of 85 as compared to others.

In the study of Jeevanandha et al. [37], a street moped of 49cc engine which produced 39 bhp and maximum speed of 50 kmh^{-1} was converted into racing bike of 70cc engine which produced 9 bhp power and maximum speed of 100 kmh^{-1} . At maximum speed of 10,000 rpm 9.5 bhp of power was found.

In the experiment by Singh et al. [38] a vane type novel air turbine was used to run a motor bike. A 300 psi air compressor was used to make impact on the vanes of the turbine and a power of 6.50 to 7.20 HP was gained at initial speed of 500 to 750 rpm at 4-6 bars air pressure to the running speed of 2000 to 3000 rpm at 2 to 3 bar pressure. It was observed that the efficiency of the turbine varied from 72 to 97%.

Bossel [39] did an analysis of compressed air vehicle propulsion. A 300 litre compressor tank was used, which carried energy of about 51 MW at 20°C and 300 bar pressure. In the analysis of the compressed air, an ideal isothermal compression was approached by multistage processes backed with intercooling.

In the study of Chavda et al. [40], a single cylinder Hero Honda CD-DAWN-100cc engine was modified from a four stroke to a two stroke engine by changing the number of teeth of the cam shaft gear and crank shaft gear. The engine used with a compressor of 300 litre capacity at 300 bar air pressure and 300 K temperature gave work output of 222.8 kJ/kg to 284.2 kJ/kg.

In the study of Singh et al. [41], three different experiments were done by using a vane type turbine as prime mover with different casing diameters of 50 mm, 100 mm, 150 mm, at 2500 rpm speed and 6 bar air pressure and 60° of constant injection angle. This experiment showed that optimum shaft power of the turbine was obtained when the ratio of rotor diameter to casing diameter was 0.70 to 0.75 and vane angle was $30-45^\circ$ and the efficiency of the light vehicle thus would be around 75-97%.

In the study of Robinson et al. [42], an analysis on electronic fuel injection of a 2 stroke spark ignition engine was done. It suggested that at same air fuel ratio the engine with injection mode produced more brake power than the carburettor mode engines because of the stable ignition by injection mode.

Singh et al. [43] suggested that electric fuel injection systems improved the level of overall pollution and increased the performance factors of engines. The fuel consumption could be

decreased by improving the air fuel ratio, bore stroke ratio, and delivery ratio in the combustion chamber.

Murthy [44] carried out an experiment on combustion parameters of two stroke copper coated spark ignition engine whose brake power was 2.2 kW at 3000 rpm and connected with two zone and multi zone combustion model. Air cooled Bajaj's two stroke engine with compression ratio of 7.5:1 was used.

In the study of Mishra et al. [45], a four stroke internal combustion engine was transformed to an air driven engine along with some modification in the compressor tank. The tank was modified to decrease the energy utilization while the output work remained unaffected.

In the study of Baig et al. [46], a 100cc internal combustion engine was modified to an air compressed engine. The engine was improved from a four stroke engine to a two stroke engine. Engine speed of 3000 rpm was obtained at a maximum pressure of 8 bar and temperature of 15°C.

In the study of Agarwal et al. [47], a research was performed on a diesel engine to review the exhaust emission. The pollutants from the tailpipe were mainly nitrogen oxides, carbon monoxide, hydrocarbons and particulate matter. It was observed that the emissions of pollutants varied with engine speed.

In the literature of Andre et al. [48], the various vehicles were examined for exhaust pollutant emissions on different roads. The study revealed that the emission of carbon monoxide pollutant was directly proportional to engine rpm whereas the other pollutants decreased when engine rpm increased by 40%.

In the study of Tsang et al. [49], fuel utilization and tailpipe emissions on urban, sub-urban and hilly roads in Hongkong were analyzed in case of euro-4 gasoline vehicles. It was observed that emitted pollutants like carbon monoxide, hydrocarbons as well as fuel consumption were highest on the hilly roads.

Cullinane et al. [50] analyzed the maritime transport for emission control areas. In April 2008, Marine Environmental Protection Committee (MEPC) revised the extent of sulphur content permitted in fuel for ships. There was a need for special norms and regulatory actions for the control of SO_x and NO_x emissions.

3. CONCLUSION

This paper provides the review of an air driven engine, its design, fabrication techniques, analysis and developments over the year. Air is renewable and thus is a very good alternative to be used as a fuel in automobile as it will help in reducing the pollution as well as help in controlling the prices for running vehicles. The main key content was this research study is as follows:

- High power gain of about 0.95 kW was achieved at 9 bar and 1320 rpm. At same pressure the maximum torque of 9.99Nm was obtained at 465rpm.
- At lower pressure of 5 bar the maximum speed was 28.9 kmh⁻¹ with a travelling distance of 2.5km, whereas at high pressure of 9 bar the maximum speed attained was 36.5 kmh⁻¹ travelling 1.7km.
- When the intake valve timing was -10° to 80° the motorcycle could travel the longest distance of up to 544 km with an average speed of 16.7 kmh⁻¹.
- Engine with a compressor of 300 litre capacity at 300 bar air pressure and 300 K temperature gave work output of 222.8 kJ/kg to 284.2 kJ/kg.
- Power gain of 6.50 to 7.20 HP was obtained as an output at initial speed of 500 to 750 rpm at 4-6 bars air pressure to the running speed of 2000 to 3000 rpm at 2 to 3 bar pressure with turbine efficiency of 72-97%.
- Engine speed of 3000 rpm was obtained at a maximum pressure of 8 bar and temperature of 15°C.

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