Design and Performance Test of a Compressed Air Operated Reciprocating Machine

Mohammad Abdul Aziz, MM Rashid, Rupal Roy, Arifuzzaman

Abstract--- Renewable energy is an environmental friendly source of energy around the world and fossil fuel sources are the main polluting factor for global climate change. The fossil fuel reserves decreased day by day which creates environmental hazardous pollutants. Fossil fuel reserved crisis leads the researchers to find out alternative sources of energy which should be alternative solution of fossil fuel energy. In this research air compressed engine which is run by compressed air by modifying a 4-stroke petrol engine (IC engine) into two stroke air compressed piston engine where air compressor acts as a fuel source. The experimental results shows a promising maximum efficiency percentages of 53.42, 35.6, 30.4, 26.67 and 23.60 under 2 to 4.5 bar pressure with maximum load condition.

Keywords: IC Engine; Piston Engine ; Compressed Air; Power Output.

1 INTRODUCTION

As an era of global warming and civilization is growing, transportation pollutants become a part of life in our society. The world population increases very fast and number of all kind of vehicles also increases to meet up their transportation need. Carbon emission is one the major concern all over the world and the world has producing continuously 2.2 million ton of CO2 a day [1]. Moreover, rapid increasing of vehicles for transportation purposes is an indispensable controversial factor for the production of CO2. In this respect a group of researcher are try to reduce the carbon emission from transportation vehicles and for transportation purposes fossil fuel tremendously used to run the vehicles engine [2]. Fossil fuel is an non-renewable sources of energy whereas compressed air is an alternative sources of energy, which is available freely in the natural environment and it is an advanced technology for reducing carbon emission [3].The sources of non-renewable are limited around the world and typically non-renewable energy is limited whether the sources of non-renewable is limited to petrol, diesel ,gases coal and other forms of fossil fuel. The demand of non-renewable energy increasing day by day and all manufacturing industries including power plant potentially rely on fossil fuel and the majority production of power depend on non-renewable energy. Finally, if this process is going on, it is possible to end up all the sources of fossil fuel. So it is the high time, to search the definite alternate sources of energy. A new modern approach of compressed air technology essentially provides environmentally friendly solution in which air is a sources of producing fuel for running the vehicles effectively. The main advantages of this it is of clean air technology and that is effective for reducing global warming. Many research group has already been done many noble works in the field of compressed air technology for powering transportation vehicle without the use of fossil fuel.

An recent development of piston type compressed air technology on motor vehicle converts the four stroke engine to two stroke engine including valve timings of -100 to 800, -100 to 1200, and -100 to 1500 which is travel 5 km[4]. Another researcher has developed a compressed-air driven piston engine and the closing and opening angle of inlet valves 150°,during isentropic expansion leaving angle 20° whenever after the moving of exhaust valve, piston moves from 150° to 170° and exhaust valve closing point angle 340°.Due to the lower flow rates of air ,it makes lower power output of engine and shorter in valve timing [5]. A piston type air compressed engine valve timing angle of intake valve and exhaust valve 0° to 100° and 180° to 300° for open and close the valve 6 mm and 8 mm are the lifting of intake and exhaust valve[6].Other research groups modify from the petrol engine to air compressed engine and operates safely 02 km/h and two sided lobe shape of cylinder is the main factor of this research in which operating pressure of 4500 psi at weight of 18.5kg and this system requires a more air supply during operating condition [7].Moreover, a new dimensional results from compressed air technology by using single cylinder engine maximum operating vehicle speed recorded 50 km/h [8]. However, a French research based company namely motor development international launched an environmentally friendly air car for reducing city vehicle emission which i-pod [9], totally pollution free and speed of this vehicle at speed of 110 km/h and a range of 200 km. In addition, M. A. Aziz et al. design clean environmental pollution free air engine for vehicle suspension system [10].

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The main modification of this engine from conventional crankshaft to modified split crankshaft and manufacturers try to increase the time of piston in ‘’out crank’’ position which enables the degree of filling in the cylinder that is being done by compressed air for the conversion of work. This modification reduces the losses at expansion system. In split crank mechanism which provides adequate space for piston in upper extreme point. The critics of split crankshaft and piston doesn’t lie in same plane also accelerations during expansion and compression stroke, and thus inertia forces, not leaving without effect on the consumptions cooperating pairs and strength of construction. The modification of wankel rotary engine [11] to air compressed engine runs properly by the supply of air whereas original engine being operated by combustion process. The modified inlet and outlet valve timing of exhaust port is 6° (Figure 1) before closing exhaust manifold when 226° rotation of the engine crankshaft and repeats this process 5° cover phases of filling and emptying by second outlet window. JAWA 50 engine, FIAT 126P 650 Engine [12] are similar to modified wankel rotary compressed engine.

In this research a conversion of air-cooled, 4-cycle, vertical, single cylinder gasoline engine to vertical, 4-cylinder, in line, air cooled, diesel cycle in which major parts of petrol engine camshaft lobe has modify to general egg shape cam to eye shape cam and modification intake port for sufficient air supply for running the engine, special gate valve has made for supplying of air. In this proposed design performance analysis of compressed air machine by supplying compressor air to engine has already been done and compare to the performance of conventional engine. In **Fig 1** presents the modified air-cooled, 4-cycle, vertical, single cylinder gasoline engine.

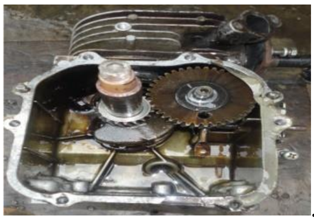

Fig. 1: Modified air-cooled, 4-cycle, vertical, single cylinder gasoline engine

2 METHODS AND CALCULATION

The materials and methods for running the air compressed engine is to design i.e. modify the camshaft of air-cooled, 4-cycle, vertical, single cylinder gasoline engine to vertical to vertical, 4- cylinder, in line, air cooled, diesel cycle compressed air engine. The main purpose of this research is to run the engine effectively without the use of fossil fuel likely diesel, petrol, gas or non-renewable fuels. However, an internal modification and performance analysis has already been done. The opening and closing of inlet and exhaust valve of the engine is maintained by the revolution of lobe as well as camshaft. The camshaft gear is messed with crankshaft gear and is driven by crankshaft gear. As crankshaft gear revolute total 720 degree and intake and exhaust valve open once, so camshaft gear must revolute 360 degrees, when crankshaft gear revolves 720 degrees. So camshaft gear must be larger than camshaft gear, and the number of teeth of camshaft gear must be twice than the number of teeth of crankshaft gear. For this reason, camshaft rotate 360 degrees while crankshaft rotate 720 degrees this is the method of opening the intake and exhaust valve once while crankshaft rotate two revolutions, suction and power and exhaust stroke. In power stroke, compressed air is supplied from the compressed air tank through intake manifold with a very high velocity and force (pressure) cause when the air is compressed, its volume decreases but pressure and temperature increases. For continuous running operation and fast response, air flow simply controlled by a proper cam design mechanism in many response CAE (Compressed air engine) system [13, 14].So here compressed air is coming through a narrow pipe (intake manifold) to a bigger space (engine cylinder). So that it tries to expand and apply a big thrust force on piston or in other word, it pushes the piston. So here compressed air is coming through a narrow pipe (intake manifold) to a bigger space (engine cylinder). So that it tries to expand and apply a big thrust force on piston or in other word, it pushes the piston with high velocity and the piston moves downward, TDC (Top dead centre) to BDC (Bottom dead centre).

As the piston begins to move downward and reaches to the BDC, we get power stroke. With this power stroke engine flywheel absorbs some energy. When the piston moves upward due to the release of absorbed energy of flywheel and kinematic momentum of the flywheel, the exhaust valve open and air get out from the engine cylinder. This is the exhaust stroke. The inlet valve open and compressed air get enter into the engine cylinder and it pushes the piston so it moves downward (TDC to BDC) and cranks begin to revolute. When the piston is at BDC, crank fulfills its 180 degrees’ revolution. After this piston begin to move upward (BDC to TDC), the exhaust valve open, compressed air get out from the cylinder and the crank finishes more 180-degree revolution and as a total one revolution (3600). So in this case, both intake and exhaust valve open and close once while cranks and crank shaft revolute 3600. Now the opening and closing of the valve is controlled by the lobe, which is attached to the camshaft. The camshaft gear is messed and driven by the crank shaft gear. The power developed by an engine at the output shaft is called brake power and given by the following relation,

$$Break\ power\ (b.p) = 2\pi NT \qquad (1)$$

Where, T is torque in Newton meter (Nm) and N is the rotational speed in revolution per second. Torque =W×R

Here, W= 9.8 × net mass (in kg) applied and R= Radius in meter Indicated power (I.P): The difference between the indicated power and brake power is the indication of the power lost in the mechanical component of the engine and forms the basis of mechanical efficiency; which is denoted as follows:

$$\text{Mechanical Efficiency} = \frac{\text{Brake Power}}{\text{Indicated Power}} \qquad (2)$$

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Mean effective pressure, Pm, is defined as a hypothetical pressure which is through to be acting on the piston throughout the power stroke. Theoretical mean effective pressure is,

$$P_m = \frac{p}{r}(1 + 2.3logr) \text{-} P_b \quad (3)$$

Whereas, Pressure supplied cylinder, expansion ratio r= V_3/V_2 Here, V3 = Total volume of the compressed air in the cylinder =clearance volume 〖(V〗 _c) + swept volume (Vs) V2 = Volume of the steam at the point of cut-off. P_(h)= Back pressure, actual mean effective pressure (Pa) is

$$Pa = Pm \times K \quad (4)$$

Where, K is the diagram factor. The value of K is usually lies between 0.65 and 0.90[15].

3 MODIFICATION OF CAMSHAFT AND WORKING PRICIPLE

In internal combustion engine camshaft is an integral part for opening and closing the valve or operating the valve of internal combustion engine. Several number of research groups were trying to modify the cam lobe for the conversion of compressed air engine. However, the camshaft gear is greater than the crankshaft gear. Let us consider T1 is for crankshaft gear and T2 for camshaft gear. The relation between crankshafts gear and camshaft gear is T2 = 2T1 so that 2N1 = N2. When crank shaft gear revolute 7200, camshaft gear revolute 3600 and from every 7200 rotation of crankshaft, single power stroke is obtained. But when the engine is run by compressed air, one power stroke at every 3600 rotation of crankshaft was obtained. An arrangement was made to get single power stroke in every 3600 rotation of crankshaft that was change of camshaft lobe shape. However, in Fig. 2 general camshaft with egg shape cam and modified cam shaft with eye shape cam are presented. In internal combustion engine the shape of cam lobe looks like egg shape but in air compressed engine cam lobe like eye shape which is shown in Fig. 3 and camshaft before and after modification shown in Fig. 4

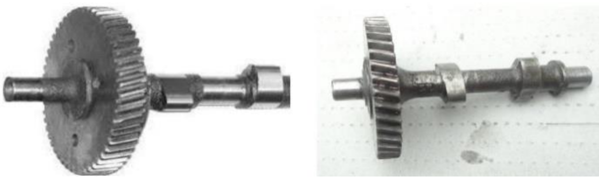

Fig. 2: General camshaft with egg shape cam and modified cam shaft with eye shape cam

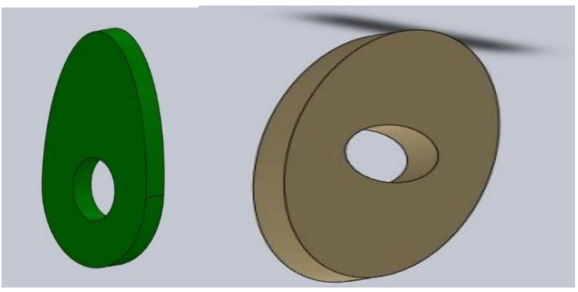

Fig. 3: General egg shape cam and modified eye shape cam

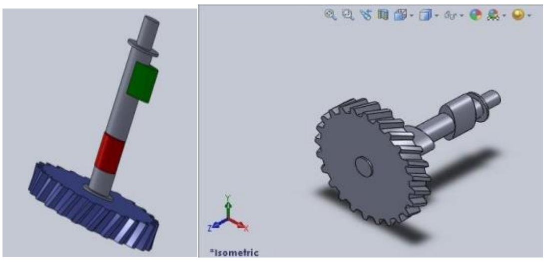

Fig. 4: General cam shaft with cam lobe and camshaft gear and Modified camshaft with cam lobe and camshaft gear

Due to the changing of camshaft lobe shape, intake and exhaust valve open twice while camshaft revolute 3600. Now from the relation 2N1 = N2, it is clear that if crank shaft gear rotates 20, camshaft rotate 10. So when camshaft gear rotates from 00 to 900, inlet valve opens once and at the same time crankshaft gear rotate from 00 to 1800 and piston moves from TDC to BDC and we get one power stroke. As the rotation of camshaft gear from 900 to 1800, inlet valve closed and opening of exhaust valve once. However, the rotation of camshaft gear 1800 to 3600 whereas piston moves from BDC to TDC and opening of exhaust stroke. This same procedure going on in which the rotation of camshaft gear 1800 to 3600 and the rotation of crankshaft gear 3600 to7200. Total rotation of camshaft and crankshaft 3600 and 7200 respectively and finally two power stroke were found during the operation. In this operation air intake path was modify for supplying air to the engine in which a narrow hose pipe was attached to the intake manifold of the air intake path. A special compressed air controlling valve was designed and the main objective of this valve is to supply compressed air to the air compressed engine.

4 EXPERIMENTAL SETUP

Compressed air engine essentially needs compressed air from compressed air storage system which acts as a high pressure energy sources and it has a tendency to rise or decrease the inside temperature of compressible gas engine[16]. It is an advanced technology for reducing gaseous emission specially in city and this technology recommends better efficiency of energy for primary user by reducing gaseous emission[17] air fuel ratio, brake power, brake thermal efficiency and specific fuel consumption [18] are the main characteristics parameter for the indication of engine performance. The engine was installed strongly on a wooded bad which is shown in Fig. 5.

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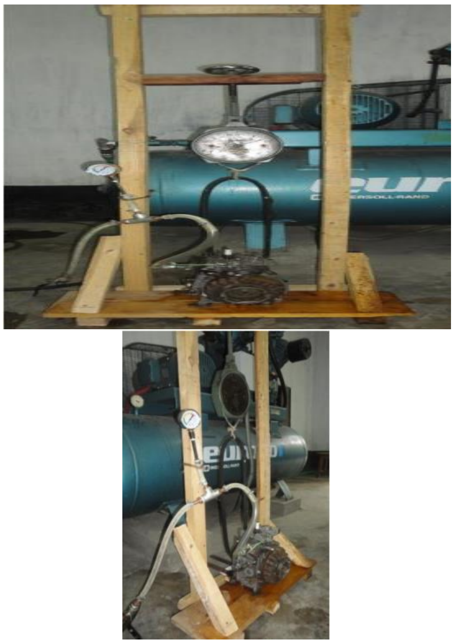

Fig. 5: Experimental setup of vertical, 4- cylinder, in line, air cooled, diesel Cycle

For proper measurement a pressure gauge was attached with inlet manifold of the engine and for coupling output shaft was connected with belt containing weight dial gauge[19]. The main purpose of weight dial gauge to indicate the amount of force which was applied on the string. The perpendicular distance from the point of application of force was applied on the string and force was calculated carefully. Torque, RPM and engine brake power was measured. In this experiment, due to lower storage capacity of compressor tank and the supply was only 5 bar pressure from air compressor and the sequence of supplying air pressure from compressor 2 bar, 3 bar, 3.5 bar ,4 bar and 4.5 bar respectively[20, 21]. In table 1 the specifications of vertical, 4- cylinder, in line, air cooled, diesel cycle (comparison) and air-cooled, 4-cycle, vertical, single cylinder gasoline engine (converted to air compressed piston engine) is shown.

Table 1: The specifications of vertical, 4- cylinder, in line, air cooled, diesel cycle (comparison) and air-cooled, 4-cycle, vertical, single cylinder gasoline engine (converted to air compressed piston engine)

Type	Vertical, 4- cylinder, in line, air cooled, diesel cycle(Comparison)	Air-cooled, 4-cycle, vertical, single cylinder gasoline engine(converted to air compressed piston engine)
Bore or diameter (mm)	76.1	51
Stroke (mm)	71.3	38
Total swept volume (cc)	1301	77.6
Compression ratio	20	6.5
Maximum torque	71 Nm at 2500 rpm	3.53 Nm at 3200 rpm
Method of lubrication	Centrifugal lubrication, contained oil mist and splash	Splashing type
Method of starting	By using starting motor	Recoil starter
Ignition system	–	Flywheel magneto type (solid state ignition)
Colling system	–	Forced air cooling
Voltage of electric installation	12 V, 21 plate	–
Injection pump	BOSCH rotary pump	–

5 RESULT AND DISCUSSION

After the modification of air-cooled, 4-cycle, vertical, single cylinder gasoline engine it was installed safely in fluid mechanics lab inside the campus of Rajshahi University of Engineering and Technology, Bangladesh and testing has done for maximum load of 44.54 N with the maximum supply of pressure from air compressor 5 bar. In this experiment operational time and torque of the modified air compressed machine were recorded and measured by a stop watch and a digital taco meter. The rating of air compressed machine performance during test operation uses the data including maximum speed, brake power and highest efficiency of the machine. In **Fig. 6** comparison of brake power(KW) Vs. efficiency,η% from 3.5 bar to 4.5 bar air pressure and maximum efficiency was 30..4 % when brake power 0.162 kW. Similarly in figure 8 with application higher load efficiency also increased. On the other hand, the maximum efficiency of this air compressed machine 53.42 % with addition of 2 bar air pressure and after maximum load addition, the highest efficiency of this air compressed machine has 23.60 % by adjusting maximum flow rate of air 4.5 bar pressure that is shown in **Fig, 7**.

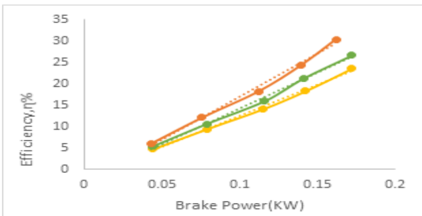

Fig. 6: Comparison of Brake power (KW) Vs. Efficiency,η% from 3.5 bar to 4.5 bar air pressure

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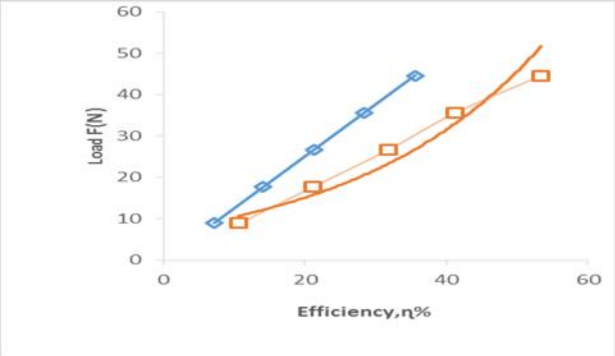

Fig. 7: Comparison of efficiency, η% vs. load from different intake valve timings up to 4.5 bar air pressure

However, in figure 8, 9 and 10, air pressure (bar) vs. efficiency, torque (Nm) vs. Efficiency η (%) and brake power (kW) and torque are shown. The maximum efficiency 53.42%, maximum air pressure 4.5 bar, maximum torque 0.888 nm and maximum speed 2372 rpm under the applying load of 44.54N. Whereas, in table 2 and 3 presents efficiency η (%) calculation using different load (N) observation and several group of researcher compressed air engine projects are shown and the maximum efficiency was 49.7% while maximum efficiency of this research 53.42% under applying 4.5 bar pressure. Yu,shi, et al 2014 and shaw et al 2013 quotes that maximum power output of engine are 0.3345 kW (7 bar) and 13.2 W respectively while mechanical efficiency is 49.7%. Moreover, Kumer et al., 2013 found that maximum mechanical efficiency 20%, maximum rpm 1483 with maximum operating pressure 10-17 bar and 10-25 bar respectively.

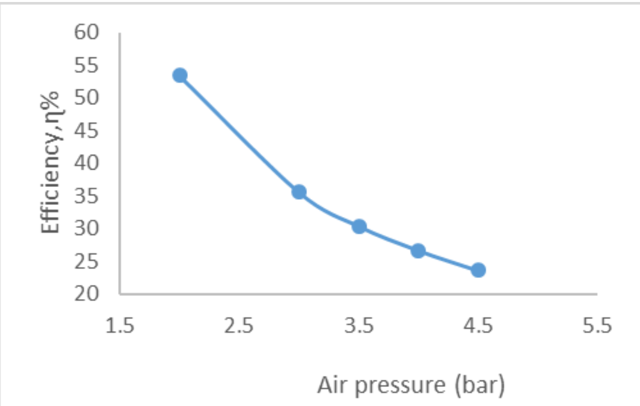

Fig. 8: Comparison of air pressure (bar) Vs. Efficiency from different air pressure

Table 2: Efficiency η (%) calculation using different load (N) observation

	Speed,N (rpm)	Force F(N)	Torque,	Brake power	Input indicated power (kW)	Efficiency, η (%)
1	1789	26.7	0.53	0.099	0.312	31.83
2	1485	35.6	0.688	0.107	0.259	41.3
3	1254	44.5	0.888	0.117	0.219	53.42

Table 3: Experimental results of different compressed air engine

power output max	Max rpm	Operating Pressure Max (bar)	Torque Max. Nm	crank speed	Working pressure(bar)	average speed km/hr
					-	
0.3345		7		400	5-9	-
kW	500	-	8.4727	-	-	16.7
13.2 W	-	10-25	-	-	-	-
	1483	10-17	-	200	-	-
	570	-	0.252	-	2-4.5	-
	-	2-4.5	-			-
	2372		0.888			

Table 3 (a): Experimental results of different compressed air engine

Mechanical Efficiency (ηm)	reduction gear ratios	Temperature Max	Researcher
	-		
-	6.1 and 3	-	[13]
-	-	-	[4]
-	-	50°C	[22]
20%	-	5 to 50°C	[22]
49.7%	-	-	[23]
53.42%		-	This research

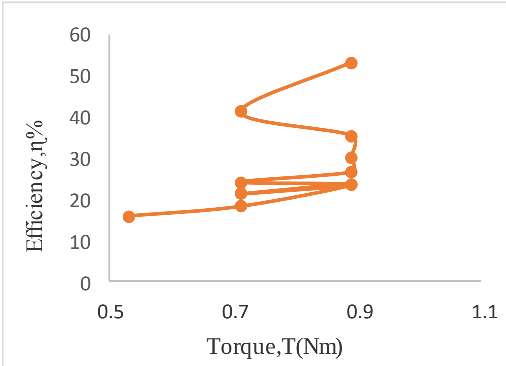

Fig. 9: Comparison of torque (nm) vs. Efficiency, η (%) from 2 bar 4.5 bar air pressure

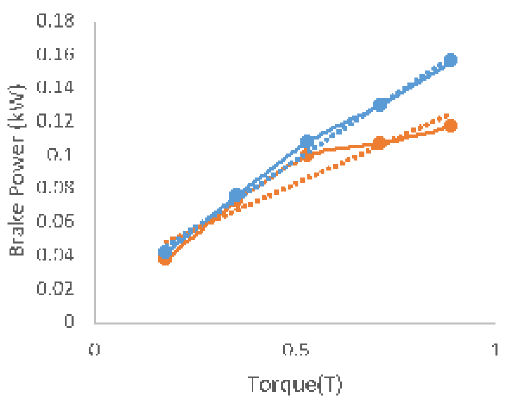

Fig. 10: Comparison of brake power (KW) vs. torque from different air pressure

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6 CONCLUSION

Today's due to the speedy design of vehicle for transportation, pollution has become a major concern for design criteria and automobile industries are trying to design a vehicle, which should be environmental friendly. This research presents the energy recovery analysis of a reciprocal compressed air engine to be installed on vehicles. Under this implementation various research groups have already been make hybrid car, electric car and hybrid air fuel engine likely France (MDI International), India (Tata Motors) and Australia (engine depiero). The main objective of this research is to redesign engine mechanism which has already run by only compressed air technology (without fuel). Some camshaft modification has done and due to the lack of high-pressurized air tank the efficiency only 53.42% that will applicable on transportation vehicles to take, the advantages of air compressed piston engine and integrate with conventional IC engine. The overall efficiency and torque output could be increased by adopting a larger intake and exhaust valve openings. The residual air pressure disposed during the exhaust process could be reused if additional cylinders are attached.

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