A STUDY TO OPTIMIZE THE OUTPUT OF VANED TYPE NOVEL AIR TURBINE

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ABSTRACT

Worldwide high rate of emission is creating environmental & ecological imbalances. USA, China, Russia, Japan & India are major players due to utilization of large number of vehicles for transport. This source alone is contributing to about 70% of the total air pollution. In view of the ongoing search for alternative energy sources the compressed air has been considered as a potential working fluid for generating shaft work. This paper deals with the optimization of the output of a very small capacity air turbine with vane type rotor. Mathematical model for optimization is prepared and the results of the proposed novel air turbine have been given here. It is observed that this air turbine could be successfully used as a prime mover to run light vehicles / motor bikes having inbuilt compressed air storage tank of small capacity.

KEYWORDS: emission, pollution, alternate energy, air turbine, shaft work

1.0 INTRODUCTION

In developing and developed countries, as civilization is growing transport has become essential part of life. The larger utilizations of transportation vehicles causing release of high rate of tale pipe emission. This has entirely affected the environmental and ecological imbalances. The India is rated 5th country after USA, China, Russia, and Japan for releasing high rate of pollutant. The transport vehicles for transport alone are contributing to about 70% in respect of the total air pollution. The reason for this current situation is primarily the transport technology based on combustion using hydrocarbon (fossil) fuel. About 100-150 years ago, the major source of energy shifted from solar to fossil fuel and now civilization is becoming vulnerable due to depletion of oil resources. The current study made (Aleklett K. and Campbell C.J) in the year 2004, predicted that if the oil is consumed at the current rates, then by 2010 most of country will pass through peak oil day and by 2020, 80% of the entire available resource will be consumed. This necessitates the search for alternative of oil as energy source or preserving it by tapping some other alternatives such as Non-conventional energy like battery operated vehicles, wind mills, photovoltaic vehicles etc. and to convert their output into mechanical energy, which may alternatively preserve oil source.

Thus, it is advantageous for the energy storage system of a Zero Pollution Vehicle (ZPV) to have low initial cost, be quickly and economically recharged, and to provide driving performance comparable to that of conventional automobiles. Currently, the battery-powered electric vehicles and hydrogen cell vehicles (Knowlen et al. - 1998) are the only commercially available technology that can meet ZPV standards; however, these vehicles have not captured market & sold well due to their limited range, no proper facilities for recharge, and high initial cost. Though the worldwide researches are also going on for other alternatives such as use of Hydrogen Fuel Cell (Honton-2004, Rose & Vincent-2004), which is presently very costly, use of Bio-Diesel (Singh B.R. & Singh Onkar-2006a) or use of compressed air for Vehicle engines (Singh & Singh-2006b).

All of these issues have forced researcher to invent the compressed air energy technology and its utilization in transport vehicles and other domestic utilities. The "Guy Negre", a French technologist and inventor has developed 4- cylinder compressed air engine, which can run the vehicle at 60-80 miles per hour speed without tail pipe emission. So far about 52- patents (Guy & Negre-2004) were made during 1998 to 2006. Recently MDI and Tata Motors entered into an agreement to develop such vehicles in commercial use. These highly compressed air energy storage systems (Rocha -2005) with 300 psi, which can be filled within 15-20 minutes, may remain the dominant technology in the electric and hydrogen cell vehicle market.

In this paper the optimization of the output of a very small capacity air turbine with vane type rotor has been presented. Mathematical model for optimization is prepared and the results of the proposed novel air turbine have been given here. It is observed that this air turbine could be successfully used as a prime mover to run light vehicles / motor bikes having small capacity inbuilt compressed air storage tank.

2.0 USE OF COMPRESSED AIR AS AN ALTERNATIVE TO FOSSIL FUEL

India is developing country and income of average person is very low to meet out the minimum requirement of person. Maximum population of country is still living in villages where transport is either bi-cycle or motorbike. Current hike of fossil fuel are increasing tremendously up to 30-40 % every year. With this pace by 2010 prices may go double than what is today and by 2030-40, it may touch to Rs.1000 per litre. A time will come when common person would not be able to purchase fuel to run the motorbike. It is not only due to rate of increase of vehicles in India, but it is a worldwide problem due to the 80 % of fossil fuel being consumed in transport with increasing mobility of persons and transportation of daily consumable materials through road transport. Thus, it is the need of the day to explore possibility of alternatives for fossil fuel to make environment free from emission & make children healthy.

Since the last two decades lot of researches are being made to tap down air freely available in atmosphere and compressing it for storage in cylinders for its further use. This compressed air can be used to run combustion engine with mixture of gas and air getting fired at compression stroke at TDC. Compressed air helps for fire stroke when ignition takes place. Thus efficiency of IC engine gets improved and without running all four stroke cycle it runs on two stroke cycles. But air engines so far developed are basically running on hybrid such as compressed air and gases and are not 100% zero pollution.

3.0 AVAILABILITY, SUSTANABILITY, EFFECT ON ENVIRONMENT AND COST EFFECTIVNESS OF COMPRESSED AIR

3.1 Availability of Air

Air is natural source and available freely in atmosphere, which can be stored after compressing it to desired pressure such as 90- 350 psi. This is the only source, which can be stored at very high pressure and can be retained without any loss after lapse or with passage of time. Compressed air can drive many domestic appliances such as vacuum cleaner, mixers, pumps, electric generator when electric power fails instead of using inverter to have clumsy arrangements of battery etc.

3.2 Sustainability, Economics and Advantages

Compressed air is most sustainable. It has no volatility or temperature or much weather effect. Once compressed air is stored through compressor, it will be available at any time without any loss of pressure. Thus sustainability of compressed air is much better compared to other available alternate of fossil fuel. Battery needs constant maintenance even for charging & discharging cycle. Hydrogen Cell (Rose et al. -2004) is very costly due to its storage problems. Wind Mills (ABI Research-2004), Photo Cells also need some storage devices may be of high bank capacitors or batteries, which will need constant and recurring expenditures on its upkeep.

3.3 Influences on Environment and Ecology

The light vehicles presently running on fossil fuel releases tail pipe emission and creates imbalances to ecology, ultimately hazardous to public health. Compressed air as an alternate for running light vehicles using air turbine will have no ill effect on ecology and reduce the health hazards.

4.0 MODEL OF AIR TURBINE

Present objective is to develop an air engine using air turbine with output of 6.85 HP to 7.50 HP at 500-750 rpm for meeting starting torque requirements at 4 - 6 bar air pressure and required torque at normal speed of 2000 - 2200 rpm at 2-3 bar air pressure, which is suitable for a motorbike. Various steps involved in the development of engine are as given separately. A cylinder of compressed air is proposed to have minimum capacity of storing air for requirement of 30 min running at initial stage and maximum pressure of 200-300 psi. The Air Turbine with dual inlet and exhaust has been taken into consideration to produce high rpm to match 2500-3000 rpm. Compressed air storage cylinder is designed so that it produces constant pressure for minimum variation of torque at low volume of compressed air. The Air Turbine is designed with spring-loaded vanes to maintain regular contact with elliptical bore, to produce optimum torque (Fuglsang -2004, Selig-2004, Gorla & Reddy -2005, and Schreck & Robinson-2004). Above air turbine is being designed to meet out the all-minimum parameters of motorbike to have efficient and fossil fuel free running.

4.1 Input Parameters for Air Turbine

Required Air pressure:	60-150 psi (assumed)
*Speed:	3000 rpm (maximum)
*Torque:	9.6-10 Nm
P-V Ratio:	4 / 5

Note: - *Data based on Performance of commercially available motorbike (7.2 HP)

4.1.2 Principle

For novel air turbine (see Fig.1), the high pressure air drives the rotor at ambient temperature. The impulse and dynamic action of high pressure air are responsible for the shaft work from the air turbine.

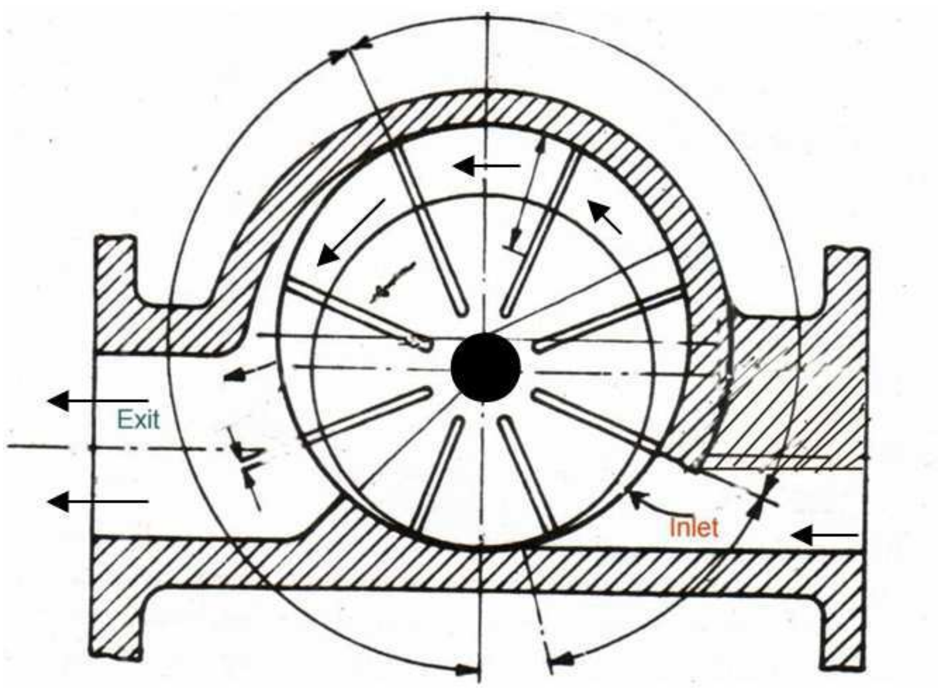


Fig. 1 Air Turbine - A Concept

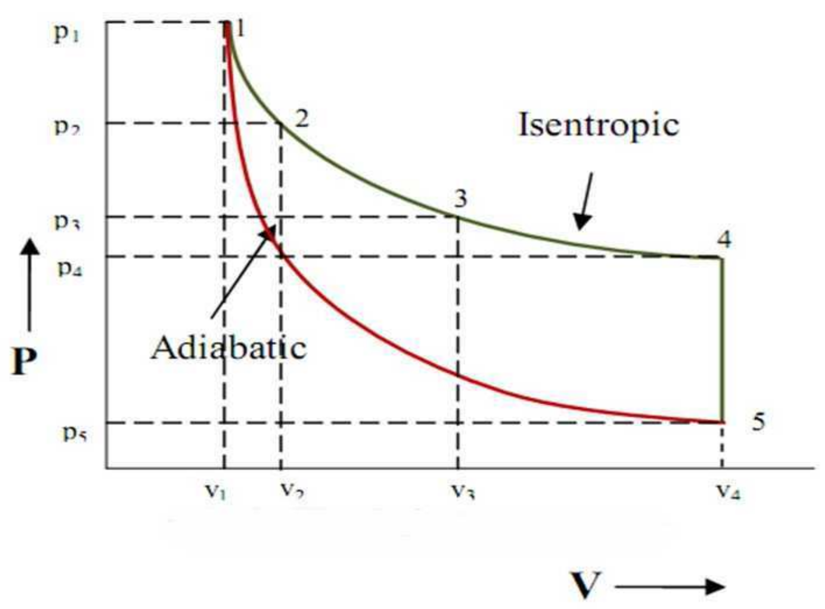


Fig.2 Expansion in Air Turbine – An Isentropic cycle

It is reverse process of vane type air compressor. Considering the isentropic expansion (see Fig.2) air entering the Air Motor having "*n*" vanes, theoretical work is given as under: -

$$w = n\left(\frac{\gamma}{\gamma-1}\right)p_1 v_1\left\{\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\} - n\left(p_4 - p_5\right)v_4 \qquad (1)$$

Where w = Theoretical Work done,

p_1 & v_1 are Pressure & Velocity respectively at which air strike the Turbine,

p_4 & v_4 are Pressure & Velocity, respectively at which maximum expansion of air takes place,

p_5 is the Pressure at which Turbine releases the air to atmosphere.

In order to meet the initial design requirements (cylinder diameter, rotor diameter and number of vanes), optimization methods are adopted as below:-

From equation (1)

Let $\frac{\gamma-1}{\gamma} = k$ (constant)

$$w = \frac{n.p_1.v_1}{k}\left\{\left(p_4{}^{k}.p_1{}^{-k}\right) - 1\right\} - n\left(p_4 - p_5\right)v_4 \qquad (2)$$

Applying Lagrange's Multiplier to find out Optimum value of Shaft-Work,

$$\frac{\partial w}{\partial v_4} = 0 \qquad (3)$$

$$\frac{\partial w}{\partial p_4} = 0 \qquad (4)$$

Applying Equations (3) to (2);

$$\frac{\partial w}{\partial v_4} = -n\left(p_4 - p_5\right) = 0$$

or $\boxed{p_4 = p_5 \cong 1.0 Nbar \Leftrightarrow 1.03 Atmospheric\ \mathrm{Pr}essure}$ (5)

Applying Equations (4) to (2)

$$\frac{\partial w}{\partial p_4} = n.\frac{p_1.v_1}{k} p_1^{-k}.k.p_4^{\ k-1} - n.v_4 = 0$$

$$or \quad n.p_1^{1-k}.v_1.p_4^{\ k-1} - n.v_4 = 0$$

or $p_1^{1-k}.v_1.p_4^{\ k-1} = v_4$

Therefore $\boxed{p_4 = \left(\frac{v_4}{v_1}\right)^{1-k}.p_1}$ (6)

From the above, it is evident that for optimal shaft work, p_4 has direct relation with p_1, v_1 & v_4.

5. 0 Results and Discussions

From the theoretical calculations, results obtained at different pressure and rpm relations between "Air Consumption & Speed" as well as "Torque & Speed" are drawn (see Fig.3 & Fig.4). Here it is evident that better speed can be achieved at lower consumption of air, if the negative forces acting due to higher difference in pressure between p_4 to p_5 are almost eliminated.

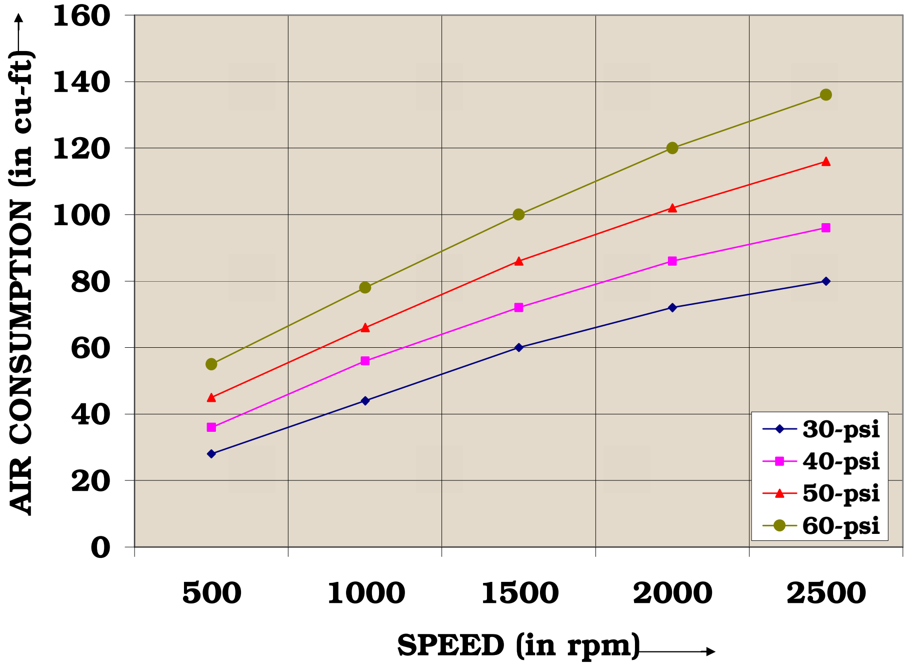


Fig-3 Air Consumption versus Speed in the Air Turbine

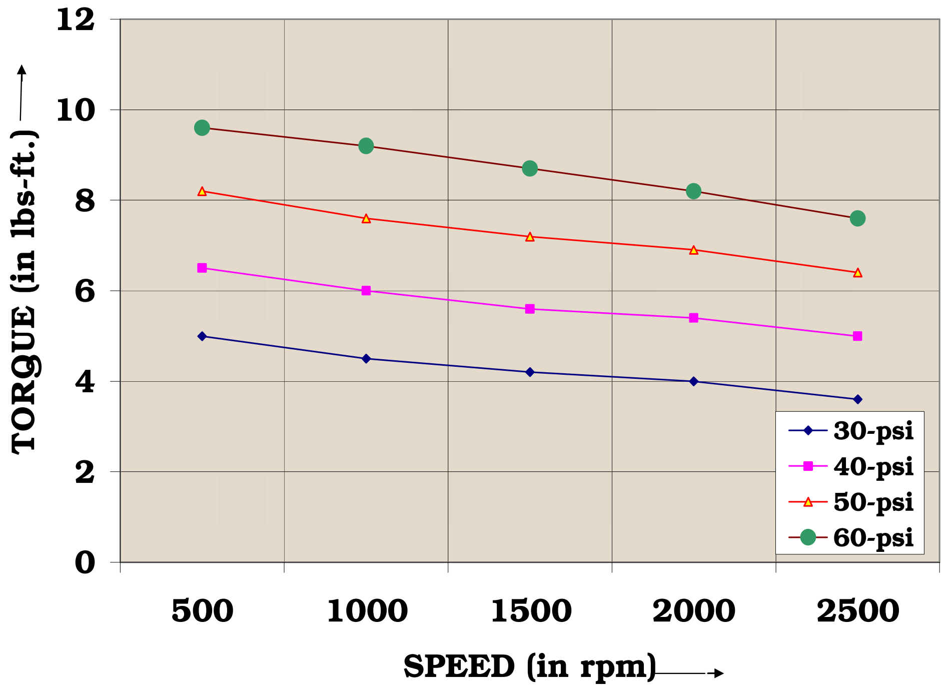


Fig-4 Torque versus Speed in the Air Turbine

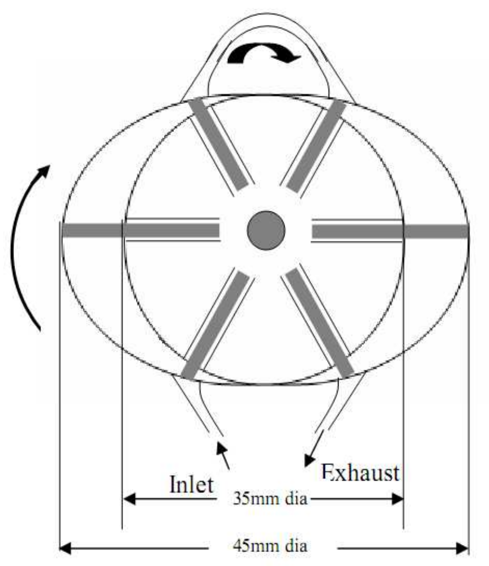
6.0 ONGOING DEVELOPMENT

For maximizing the work output from air turbine following designs have been conceived and are being developed:-

6.1 To develop dual / triple inlet and exit air turbine

Dual inlet & exhaust Air Turbine (see Fig.5) is under fabrication and concept is introduced as dual elliptical cylinder having spring loaded vanes as designed above wherein negative effect as indicated in Eq. (1) is almost reduced which enhances the shaft work and make the Turbine most efficient and novel in its functions.

When the exit compressed air pressure of first stage is fed into second stage inlet of Air Turbine, the expansion of residual compressed air is further expanded from V_4 to $V_{4'}$ and pressure P_4 is substantially reduced to $P_{4'}$ and closer to the P_5 (see Fig. 6). From the Equation (1), it is evident that if $P_{4'} \geq P_5$ the negative effect will almost vanish and shaft output would become optimum.



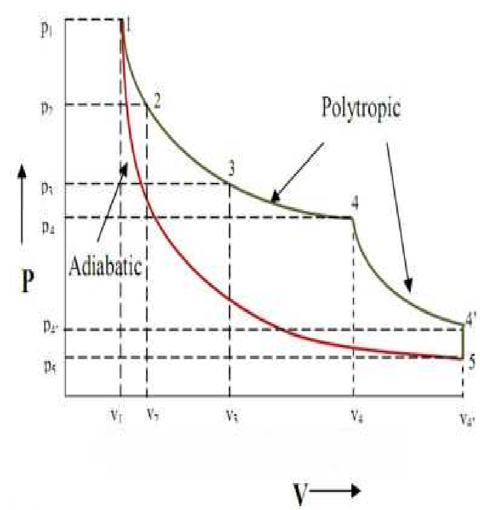


Fig.5 Dual inlet & exhaust Air Turbine **Fig. 6** Air Turbine – Polytropic Cycle

6.2 To develop variable size air nozzle to strike air jet on vane at different angle to create impulse and then expansion cycle

In this approach variable nozzle size and angle on which air jet strikes will develop impulse force and thereafter at the end of v_1, expansion will take care for further work

Thus wordone would be as shown in Equ. (7);

w = impulse force x displacement $(f_{imp}).l_1$ + expansion force x displacement $(f_{exp}).l_2$

Thus, $$w = f_{imp} . l_1 + f_{exp} . l_2 \qquad (7)$$

7.0 CONCLUSIONS

In view of the enormous potential of air as working fluid, an Air Turbine having dual inlet and exhaust is designed to run on compressed air. The compressed air is to be contained in a portable cylinder at 300-psi air pressure. This Air Turbine is under close test run and expected to be more efficient than the currently available one, as negative workforces are tried to be almost eliminated and ultimately it is going to be the best alternate to the fossil fuel driven prime-mover / engine.

NOMENCLATURE

γ	1.4 for air
d_1	diameter of rotor
d_2	diameter of outer cylinder
f_{imp}	impulse force
$f_{\exp}$	expansion force
k	constant
l	length of rotor having vanes
l_1	displacement due to impulse force
l_2	displacement due to expansion force
m	metre
n	no. of vanes
p	pressure
v	specific volume
w	specific work output
atm	atmospheric
bar	(1 / 1.0132) atmospheric pressure
cu. ft.	cubic foot
cu-m	cubic metre
HP	horse power
IC	internal combustion
km	kilo-metre
kwh	kilo-watt hour
lbs. ft.	pound foot
min	minute
MDI	moteur development international
Nm	newton metre
psi	pounds square inch
rpm	revolution per minute
Rs.	Indian rupees
TDC	top dead centre
ZPV	zero pollution vehicle
1, 2...4, 5	subscripts - states position of vanes corresponding to specific pressure & volume

REFERENCES

[1] Aleklett K. and Campbell C.J., 2004, "The Peak and Decline of World Oil and Gas Production," Oil Production, Feb.2004.

[2] Fuglsang P., Bak C., Gunna M., 2004, "Design and verification of the Ris0-B1 Airfoil-family for Wind Turbines," ASME- Nov'2004, Vol.126 pp 1002-1008.

[3] Gorla, R., and Reddy, S., 2005, "Probabilistic Heat Transfer and Structural Analysis of Turbine Blade," IJTJE, Vol. 22, pp 1- 11.

[4] Guy and Negre Cyril, 2004, "Compressed Air - The Most Sustainable Energy Carrier for Community Vehicles"– Speech in front of assembly at Kultur gathered for "Fuel Cells World" Tuesday 29th June '2004.

[5] Honton E. J., 2004, "Hydrogen Fuel Cell Car," presented at 15th Annual US Conference & Hydrogen Expo, April'2004, USA.

[6] Knowlen C., Bruckner A. P., Mattick A.T., and Hertzberg A., 1998, Society of Automotive Engineers, Inc., "High Efficiency Energy Conversion Systems for Liquid Nitrogen Automobiles"-AIAA 98-1898.

[7] Rose Robert, William J. Vincent, 2004, "Fuel Cell Vehicle World Survey 2003"-Break through Technologies Institute, February' 2004, Washington, D.C.

[8] Rocha Beau de (Otto), 2005, Quasiturbine zero pollution cars using gasoline, 25th Sept'2005, at Korea.

[9] Schreck S. & Robinson M., 2004, "Tip Speed Ratio Influences on Rationally Augmented Boundary Layer Topology & Aerodynamic Force Generation," Journal of Solar Energy Engg., ASME-Nov' 2004-Vol.126 pp1025-1033.

[10] Selig Michel S., 2004, "Wind Tunnel Aerodynamics Tests of Six Airfoils for use on Small Wind Turbines," ASME-Nov'2004.

[11] Singh B.R. & Singh Onkar., 2006, "Necessity & Potential for Bio-Diesel Use in India," Proceedings of International Conference on Bio-Fuel Vision-2015, October'13th -15th, 2006 at Bikaner, India Page 71.

[12] Singh B.R. & Singh Onkar., 2006, "Compressed air as an alternative to Fossil Fuel for Automobile Engines," International Conference on 10th-11th June, 2006 at Lucknow, India-Proceedings pp 179-191.