APPLICATION OF COMPRESSED AIR AS AN ALTERNATIVE ENERGY SOURCE TO RUN AIR TURBINE AND TO OVERCOME CHALLENGES OF 21ST CENTURY- GLOBAL WARMING

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Abstract — *Worldwide extensive transportation requirements are resulting in greater consumption of hydrocarbon fuel in transport sector. This is causing serious threat to availability of fossil fuels due to their fast depletion. Since last two decades major thrust has been given on the search of alternatives to fossil fuel, amongst various options the atmospheric air also appears to be one of the cost effective working fluid for energy conversion system. The compressed air also offers to be a potential zero pollution working fluid if the air turbine is runs using it. Such air turbine can be utilized for producing shaft work to run the motorcycles or light vehicles.*

This paper details the application of compressed air in a novel vaned type air turbine as an alternative engine to produce shaft work. Parametric evaluation of a small capacity compressed air driven vaned type air turbine is done using a mathematical model. The effect of expansion power and flow power due to high pressure air for varying range of rotor lengths, rotor to casing ratio, injection angle and vane angle of the turbine have been considered and analyzed here. Study shows that the thermodynamic expansion power has significant contribution with respect to total power output in comparison to flow power. Implementation of such projects may overcome the challenges of global warming to some extent

Keywords — *environment, global warming, compressed air, vaned type air turbine.*

NOMENCLATURE

d	diameter of rotor (2r) in meter
D	diameter of outer (2R) cylinder in meter
L	length of rotor having vanes in meter
n	no. of vanes= (360/θ)
N	no. of revolution per minute
p	pressure in bar
p_1, v_1	pressure and volume respectively at which air strike the Turbine,
p_4, v_4	pressure and volume respectively at which maximum expansion of air takes place,
p_5	pressure at which turbine releases the air to atmosphere.
v	volume in cu-m
w	theoretical work output in Nm
W	theoretical power output (Nm/s)
X_{1i}	variable extended lengths of vane at point 1
X_{2i}	variable extended lengths of vane at point 2
bar	(1 / 1.0132) atmospheric pressure
rpm	revolution per minute

Subscripts

1, 2.3, 4, 5	subscripts – indicates the positions of vanes in casing
e, exp	expansion
f, flow	flow
min	minimum
max	maximum
t, total	total

Greek symbols

α	angle BOF
α_1	angle LOF (=180-ϕ)
α_2	angle KOF(=180-θ-ϕ)
β	angle BAF
γ	1.4 for air
θ	angle between 2-vanes (BOH)
ϕ	angle at which compressed air enters into rotor through nozzle
ξ_d	eccentricity *(R-r)*

1.0 INTRODUCTION

Globally, as pace of civilization is increasing, uses of transport have become essential part of life and increasing pollution significantly. Thus the greater consumption of hydrocarbon fuel in the transport sector is causing serious challenges to the availability of oil resources, thereby creating environmental problems such as global warming, health hazards and ecological imbalances.

In 1956, a US based Chief Consultant and Oil Geologist Marion King Hubbert [1] predicted that if oil is consumed with high rate, US Oil production may peak in 1970 and thereafter it will decline. He also predicted that other countries may attain Peak Oil day within 20-30 Years and many more may suffer with oil crises within 40 years, first, small ones later.

A study was conducted in the city of Lucknow, India from 1998-2002.The area of Lucknow City is 50 sq. km and total numbers of vehicles were found to be about 423 thousands, out of which 337 thousands were only motorcycle. Due to presence of only two wheelers such as motorbikes the contribution in the pollution was found to the order of 77.8 %. India's vehicular pollution estimated to have increased eight times over the last two decades. This source alone is estimated to contribute about 70 per cent to the total air pollution. With 243.3 million tons of carbon released from the consumption and combustion of fossil fuels in 1999, India is ranked fifth in the world behind the U.S., China, Russia and Japan. India's contribution to world carbon emissions is expected to increase in the coming years due to rapid migration of rural population to urban area thereby increasing vehicular usage, continued use of older and more inefficient coal-fired and fuel power-plants. The peak oil year may be the turning point for mankind which in turn leads to the end of 100 years of easy growth, if sustainability of energy [2] is not maintained on priority.

On account of fast depletion of oil resources major thrust is being given to the search of alternatives resources It is also learnt that atmospheric air can also be one of the cost effective energy conversion system and compressed air can be utilized as potential zero pollution working fluid when the vaned type air turbine is used. Such novel air turbine can be utilized for producing shaft work and running as prime-mover to the motorcycles or light vehicles.

This paper details the application of compressed air for running a vaned type air turbine as an alternative to fossil fuel run engine to produce shaft work. A mathematical model has been developed for analyzing the vaned type air turbine and the parametric evaluation is done and presented here. Ultimately if such compressed air turbines are used in the light vehicles especially in urban area, there will be substantial reduction in the pollution.

2.0 SUSTAINABILITY TO ENERGY SOURCE

It is fact that '*Sustainability is nothing but meeting the needs of current and future generations through simultaneous environmental, social and economic improvement*' [3], and the Sustainability to energy source is nothing but to preserve the oil and to make the future of mankind brighter by adding alternative energy sources such as Non-Conventional and Renewable Energy, which is going to help current problem to some extent. Now, all over the world, researchers and inventors are paying full attention to this issue. The Energy Storage System or Power Conversion System is the only solution for 21st century energy sustainability.

From above it is evident that on account of heavy consumption of fossil fuel, there are two distinct reasons to go for the search of alternatives to fossil fuel and make sustainable energy source: the first one is depletion of oil reservoirs and the other one is higher rate of emission due to rapid use of hydrocarbon fuel.

3.0 COMPRESSED AIR - TWENTY FIRST CENTURY ENERGY STORAGE SYSTEM

The air engine technology is very old and was in process of development parallel to combustion technology. It is on record that Sterling air engine was developed in 1790-1810, but due to some limitations much work was not carried out. The uses of such engines are limited such as in Coalmines where fire problems are predominant and other high flammable places where fossil fuel vehicles are not advisable to be used. The technology again took its rolling pace in 1979 when cost of petroleum product had gone very high, but from 1979 to 1998 much work did not take place.

Since the last two decades lots of researches are being carried out to tap down air freely available in atmosphere and compressing it into storage 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. The air engines so far developed [11, 12] are basically running on hybrid such as compressed air and gases and are not 100% zero pollution.

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. The 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 adverse weather effect. Once compressed air is stored into cylinder, it can be utilized at any time without loss of pressure. Thus preventive cost on compressed air is low as compared to other available alternate to fossil fuel; e.g., battery needs constant maintenance even for charging and discharging cycle, hydrogen cell is very costly due to its storage problems, photo voltaic cells also need some storage devices may be of high bank capacitors or batteries that 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.

3.4 Cost Comparison

In case the compressed air is being used in place of fossil fuel, the air is freely available in atmosphere and offers zero cost of basic working fluid and the cost involvement in its compression is also nominal. The costing analysis for the vaned air turbine based engine under study is as detailed below:

- Cost of 7.5 to 10 HP electric motor coupled with 2-3 stage compressors: Rs. 25,000.00
- Cost of electricity for filling the compressed air cylinder once: *{Rs. 5.00 to Rs. 7.00}
- *Consumption of electric power for running it for 5-10 min** to fill the cylinder of 1.2 m long and 0.65 m diameter at 15-20 bar (225 – 300 psi) may cost [(10 kWh X Rs 4.00# to 5.00#) / 7min**]=*{Rs.5.00 to 7.00} including depreciation, running and maintenance of compressor devices.
- [#] - Cost of electricity per unit in Rupees
- Once filed compressed air cylinder can run vehicle up to: 40 km
- Cost of running vehicle per km using compressed air: Re. 0.12 to Rs. 0.17
- Present cost of running vehicle per km using hydrocarbon fuel : Re. 0.62 to Rs. 0.75

This shows that the motor bike may run 40 km in Rs.5.00 to Rs. 7.00, whereas cost of same travel distance with hydrocarbon fuel may be around between Rs. 25.00 to Rs.30.00 and hence compressed air cost is almost one fifth of fossil fuel cost [13]. On the other hand, in the absence of fossil fuel combustion, air as working fluid offers advantage of giving zero pollution engines. Thus the use of compressed air is economical too, apart from being environment friendly.

3.5 Energy Storage

Air is available in atmosphere in abundance without any cost. This air can be compressed either through conventional or non conventional devices such as: wind mill, solar energy motor, and human or animal power etc. The compressed energy can be stored in tank and may be utilized to run other domestic appliances such as grinders / mixies, air cleaners, exhaust fans, small generator set when power supplies are not available. Compressed air tank can be used for running vaned type air turbine as energy storage device.

4.0 UTILIZATIONS OF COMPRESSED AIR AS AN ALTERNATIVE TO FOSSIL FUEL

India is a developing country and its average per person income is very low to meet out the minimum requirement of person. Maximum population of the country is still living in villages where means of transport is either bi-cycle or motorbike. Currently prices 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 possible alternatives for fossil fuel to make environment free from emission and pollution, and make the future healthy.

4.1Model of Air Turbine

Many studies have been made to examine the functions of various types of turbines and their improvement of efficiency [14-18]. A vaned type air turbine as shown in Figure 1a has been considered, which works on the reverse of working principle of vane type compressor. In this arrangement total shaft work is cumulative effect of an isobaric admission of compressed air jet on vanes and the adiabatic expansion of high pressure air. In earlier studies conducted by authors, a prototype of air turbine was developed and its functionality was ensured [19-22]. Vanes of novel air turbine were placed under spring loading to maintain their regular contact to the elliptical casing wall to minimize leakage.

The present objective of this paper is to investigate the performance of an air turbine with the variation of rotor / casing dimension. The air turbine considered has capability to yield output of 5.50 to 6.80 HP at 4-6 bar air pressure and for speed of 2000–2500 rpm, which is suitable for a motorbike. A cylinder for the storage of compressed air with a minimum capacity of storing air for the requirement of 30 minutes running at initial stage and maximum pressure of 20 bar is used as a source of compressed air. Compressed air storage cylinder is attached with filter, regulator and lubricator to release clean air and regulated constant pressure to admission through inlet passage to the air turbine for developing desired torque at even small volume of compressed air.

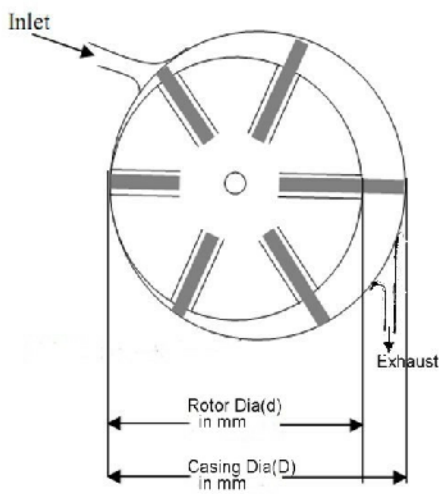

FIGURE 1a
AIR TURBINE-SCHEMATIC DRAWING

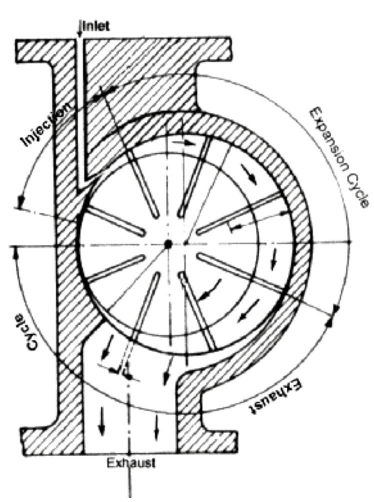

FIGURE 1b
AIR TURBINE- MODEL

4.2 Mathematical Modeling

The high pressure of air at ambient temperature drives the rotor in novel air turbine shown in Figure 1a. When high pressure air enters through the inlet passage and impinges upon the vanes it produces impulse. Also the high pressure air entering the rotor in consecutive vanes is gradually expanded up to exit passage. This impingement action and the expansion of high pressure air both contribute in producing the shaft work from air turbine.

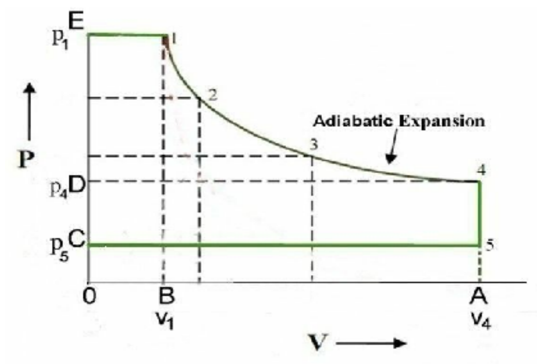

FIGURE 2
THERMODYNAMIC PROCESS (ISOBARIC, ADIABATIC AND ISOCHORIC EXPANSIONS)

From Figure 2, it is seen that work output is due to isobaric admission (E to 1), and adiabatic expansion (1 to 4). Thus, total work done due to thermodynamic expansion process may be written as:

[Area under (E145CE)] = [Area under (E1BOE) +Area under (14AB1) – Area under (5AOC5)]

Total Work output $= p_1.v_1 + \left(\frac{p_1.v_1 - p_4.v_4}{\gamma - 1} \right) - p_5.v_4$

$$w = \left[\left(\frac{\gamma}{\gamma - 1} \right) . \left(p_1.v_1 - p_4.v_4 \right) \right] + \left[\left(p_4 - p_5 \right) . v_4 \right] \qquad (1)$$

w = [Thermodynamic expansion work (w_1)] + [Exit flow work (w_2)] (2)

For adiabatic process, $v_4 = \left(\frac{p_1}{p_4} \right)^{\frac{1}{\gamma}} . v_1$

Thus thermodynamic expansion work output can be written as

$$w_1 = \left(\frac{\gamma}{\gamma - 1} \right) . p_1 . v_1 . \left\{ 1 - \left(\frac{p_4}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right\} \qquad (3)$$

After the expansion process during exit the pressure p_4 cannot fall below atmospheric pressure p_5. Thus, the net work output will be:

$$w = (w_1 + w_2) = \left(\frac{\gamma}{\gamma-1}\right).p_1.v_1.\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} + (p_4 - p_5).v_4 \quad (4)$$

When air turbine is having n number of vanes, then shaft output can be written as,

$$w_n = n.\left(\frac{\gamma}{\gamma-1}\right).p_1.v_1\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} + n.(p_4 - p_5).v_4 \quad (5)$$

where w_n is work output (in Nm), for complete one cycle. Therefore, the total power output (work done per unit time) W for speed of rotation N rpm will be mentioned as:

$$W_{total} = n.(N/60).\left(\frac{\gamma}{\gamma-1}\right).p_1.v_1.\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} + n.(N/60).(p_4 - p_5).v_4 \quad (6)$$

Where $W_{exp} = n.(N/60).\left(\frac{\gamma}{\gamma-1}\right).p_1.v_1.\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}$

and $W_{flow} = n.(N/60).(p_4 - p_5)v_4$

Figures 1a, 1b show that if vanes are at angular spacing of θ degree, then total number of vanes will be n = (360/θ). The variation in volume during expansion from inlet to exit (i.e. v_1 to v_4) can be derived by the variable extended length of vane as shown in Figure 3 at every point of movement between two consecutive vanes.

From Figure 3, it is seen that when two consecutive vanes at OK and OL moves to position OH and OB, the extended vane lengths varies from SK to IH and LM to BG, thus the variable length BG at variable α_i is assumed as $X_{at\,'variable'\,\alpha}$ can be written from the geometry:

$$X_{variable} = R\cos\left[\sin^{-1}\left\{\left(\frac{R-r}{R}\right)\sin\alpha\right\}\right] + (R-r)\cos\alpha - r \quad (7)$$

and variable volume of cuboid (B-G-I-H-B):

$$v_{cuboid} = L\left\{\frac{(X_1 + X_2)(2r + X_1)}{4}\right\}\sin\theta \quad (8)$$

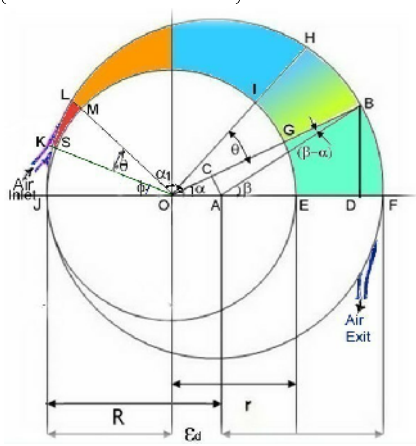

FIGURE 3

VARIABLE LENGTH BG AND IH AND INJECTION ANGLE ϕ

(3)

The volume at inlet v_1 or $v_{\min}$ will fall between angles $\angle$ LOF= $\alpha_1 = (180 - \theta - \phi)$ and $\angle$ KOF= $\alpha_2 = (\alpha_1 + \theta) = (180 - \phi)$, when air is injected at angle $\angle$ KOJ = ϕ into air turbine. Applying above conditions into equation (7), then

$$X_{1\min} = R\cos\left[\sin^{-1}\left\{\left(\frac{R-r}{R}\right)\sin(180-\theta-\phi)\right\}\right] + \left[(R-r)\cos(180-\theta-\phi) - r\right] \quad (9)$$

$$X_{2\min} = R\cos\left[\sin^{-1}\left\{\left(\frac{R-r}{R}\right)\sin(180-\phi)\right\}\right] + \left[(R-r)\cos(180-\phi) - r\right] \quad (10)$$

Applying values of X_{1min} and X_{2min} to equation (8), then volume at entrance v_1 or $v_{\min}$ will be

$$v_1 = L\left\{\frac{(X_{1\min} + X_{2\min})(2r + X_{1\min})}{4}\right\}\sin\theta \quad (11)$$

The volume at exit v_2 *or* $v_{\max}$ will fall between angles $\angle$ BOF and $\angle$ HOB, when OB touches OF [i.e. $\alpha = 0$ and $(\alpha + \theta) = \theta$]. It can be seen from Figure 3. Applying above conditions into equation (7), then

$$X_{1\max} = 2(R - r) \Rightarrow (D - d) \quad (12)$$

$$X_{2\max} = R\cos\left[\sin^{-1}\left\{\left(\frac{R-r}{R}\right)\sin\theta\right\}\right] + \left\{(R-r)\cos\theta\right\} - r\sin^{-1}\theta \quad (13)$$

Applying values of X_{1max} and $X_{2\,max}$ to equation (8), then volume at exit v_2 *or* $v_{\max}$ will be

$$v_2 = L\left\{\frac{(X_{1\max} + X_{2\max})(2r + X_{1\max})}{4}\right\}\sin\theta \quad (14)$$

Applying values of v_1 and v_4 from equations (11) and (14) to equation (6), the total power output available W_{total} , can be written as:

$$W_{total} = n\left[\frac{N}{60}\right].\left(\frac{\gamma}{\gamma-1}\right).\left\{1-\left(\frac{p_4}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}p_1.\left[L.\left\{\frac{(X_{1\min} + X_{2\min}).(2r + X_{1\min})}{4}\right\}.\sin\theta\right] \quad (15)$$
$$+ n\left[\frac{N}{60}\right].(p_4 - p_5).\left[L.\left\{\frac{(X_{1\max} + X_{2\max}).(2r + X_{1\max})}{4}\right\}.\sin\theta\right]$$

5.0 ASSUMPTIONS AND PARAMETERS FOR INVESTIGATION

Various input parameters are considered and listed in Table-1 for investigation of effect of rotor length and its optimization. It is assumed that rotor will have 8 numbers of vanes and hence angle between two consecutive vanes would be 45°. It is also considered that high pressure air (2-6 bar) will enter into two consecutive rotor vanes at an angle of 30°, that is 2/3rd of the vane angle. Rotor to casing diameter ratios for study was considered 0.65, for casing diameter 150 mm and rotor diameter approx. 100 mm. Exit air pressure is considered as atmospheric pressure (1.0132 bar) and at different rotor length as 25mm, 50mm, 75mm, 100mm and 125mm i.e., different rotor length / diameter (L/d) ratio 0.25, 0.5, 0.75, 1.0 and 1.25 for this study.

TABLE 1
INPUT PARAMETERS

Symbols	Parameters
Rotor to Casing diameters (d/D)	Casing diameter (D)=150 mm and Rotor Diameter (d)=100 mm, when rotor to casing diameter ratio=0.65
p_1	Inlet pressures 2 bar(≈30 psi), 3 bar(≈45psi), 4bar(≈60psi), 5bar(≈75psi), 6bar(≈90psi)
p_5	1.0132 bar- exit pressure
p_4	*1.0 to 1.1 p_5 =1.05 bar
N	2500 rpm
L	Length of rotor, 25mm, 50mm, 75mm, 100mm, 125mm [i.e. L/d ratio; 0.25, 0.5, 0.75, 1.0, 1.25]
γ	1.4 for air
θ	**45° angle between 2-vanes, (i.e. rotor contains correspondingly 8 number of vanes)
ϕ	**30° angle at which compressed air through nozzle enters into rotor

***** For optimum output, exit pressure may fall up to atmospheric pressure (i.e. ≈1 bar).
** 45° angle between 2-vanes (assumed) and 30° angle at which compressed air through nozzle enters into rotor, for ease of rotation.

6.0 RESULTS AND DISCUSSION

Various input parameters considered for study are listed in Table-1. Based on the mathematical model the effect of rotor length to diameter ratio, speed of rotation and injection pressure 2-6 bar on the expansion power, flow power and total power output from air turbine is studied. Here the vane angle θ, injection angle ϕ of the air turbine are considered to be constant as 45°, 30° respectively for whole study. The results obtained are plotted as shown in Figures 5 to 9.

Figure 4 shows the variation of expansion power at different rotor length / diameter ratio, vane angle θ =45 deg, air injection angle ϕ =30 deg, air injection pressure 2-6 bar and at speed of rotation 2500 rpm. It is evident that the shaft power due to expansion *(W_{exp})* is low at 2 bar for rotor length / diameter ratio and thereafter it gradually increases with increase in L/d ratio from 025 to 1.25. Also expansion work is seen to be larger for higher injection pressures which are attributed to the large power capacity.

The similar variation of expansion power with different rotor length/ diameter ratio and injection pressures 2-6 bar is found for different speeds of rotation 500, 1500 rpm. It is seen that expansion work is directly proportion to higher speed of rotation as well as rotor length / diameter ratio for all injection pressures 2-6 bar.

Figure 5 shows the variation of flow power at different rotor length / diameter ratio, vane angle θ =45 deg, air injection angle ϕ =30 deg, air injection pressure 2-6 bar and at speed of rotation 2500 rpm. It is evident that the shaft power due to flow power *(Wflow)* is low for rotor length / diameter ratio 0.25 and thereafter it gradually increases with increase in L/d ratio from 025 to 1.25. Also flow power is seen to be larger for higher L/d ratio as 0.5 to 1.25.

The similar variation of expansion power with different rotor length/ diameter ratio and injection pressures 2-6 bar is found for different speeds of rotation 500, 1500 rpm. It is seen that flow power is directly proportion to higher rotor length / diameter ratio.

Figures 6 to 7 show the percentage contribution of expansion power to the total power output at different rotor length / diameter ratio. It is evident that percentage contribution of expansion power is small at 2 bar when the rotor length / diameter ratio 0.25 and constant from 025-1.25 rotor length / diameter ratio. At further higher injection pressures of 3 to 6 bar the contribution of expansion work is higher but it is found constant for the L/d ratio from 0.25 to 1.25 for a particular injection pressure. The contribution of expansion work is found to follow same trend at low speeds of rotation 500, 1500 rpm. The similar situation is also observed for percentage contribution of flow power but exactly into reversed position.

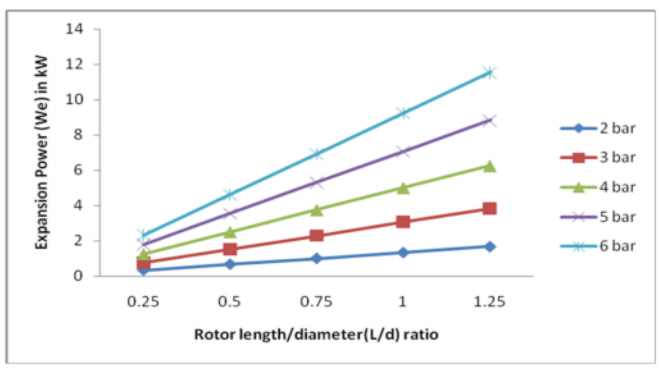

FIGURE 4
ROTOR LENGTH / DIAMETER (L/d) RATIO VS EXPANSION POWER

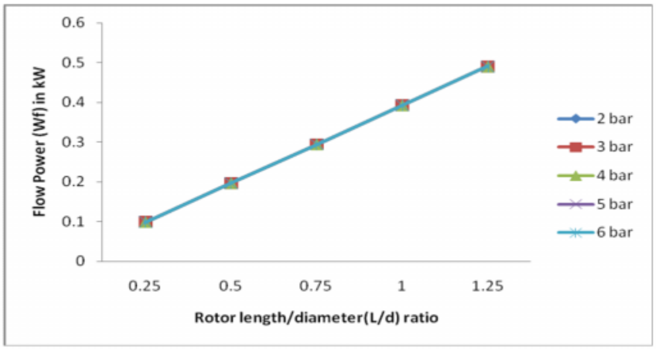

FIGURE 5
ROTOR LENGTH / DIAMETER (L/d) RATIO VS FLOW POWER

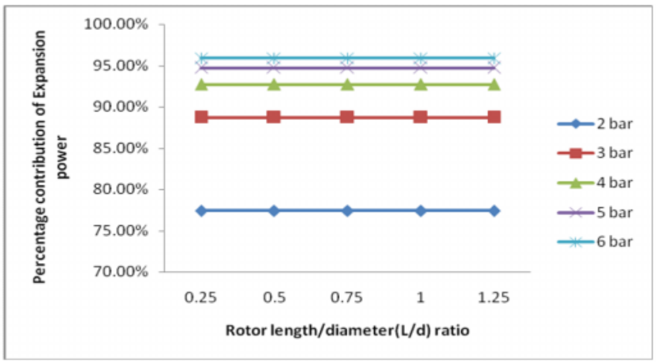

FIGURE 6
ROTOR LENGTH / DIAMETER (L/d) RATIO VS PERCENTAGE CONTRIBUTION OF EXPANSION POWER

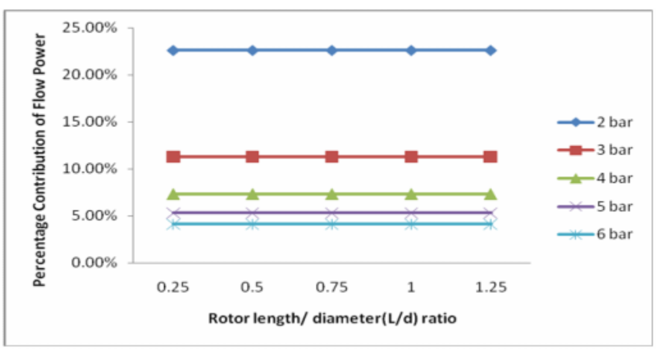

FIGURE 7
ROTOR LENGTH / DIAMETER (L/d) RATIO VS PERCENTAGE CONTRIBUTION OF FLOW POWER

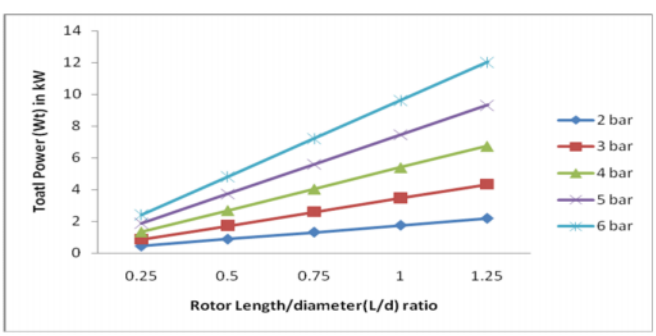

FIGURE 8
ROTOR LENGTH / DIAMETER (L/d) RATIO VS TOTAL POWER

Figure 8 shows the variation of total power at different rotor length / diameter ratio when vane angle θ =45 deg, air injection angle ϕ =30 deg, air injection pressure 2-6 bar and speed of rotation is 2500 rpm. It is evident that the shaft power due to total *(Wtotal)* is low at 0.25 rotor length / diameter ratio for all injection pressure 2-6 bar and thereafter it gradually increases with increase in L/d ratio from 025 to 1.25. Also total work is seen to be larger for higher injection pressures which are attributed to the large power capacity. The similar variation of total power with different rotor length / diameter ratio and injection pressures 2-6 bar is found for lower speed of rotation 500, 1500 rpm. It is seen that total power output is directly proportional to the higher injection pressure as well as higher rotor length / diameter ratio which is deciding factor for a particular power output.

7.0 CONCLUSIONS

Following conclusions are drawn from the above study:

- The large power is available when rotor length / diameter (L/d) is higher and injection pressure is also larger (i.e. at 6 bar).
- The rotor diameter and turbine rotor length can be adjusted as per requirement of power and minimum air flow rate.
- An interpolation can easily be done from the graph between L/d ratios vs. total power for particular or desired dimensions of air turbine.

Hence this study is very useful for designing a vane type air turbine considering its various parameters. The efficient air turbine can be utilized as prime-mover to the motor bike which can cut down substantial amount of pollutant released from hydrocarbon fuel vehicles.

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