Global Journal of Researches in Engineering
Automotive Engineering
Volume 13 Issue 1 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Latest Developments of a Compressed Air Vehicle: A Status Report

By S. S. Verma
S.L.I.E.T., Longowal

Abstract - Compressed air as a source of energy in different uses in general and as a non-polluting fuel in compressed air vehicles has attracted scientists and engineers for centuries. Efforts are being made by many developers and manufacturers to master the compressed air vehicle technology in all respects for its earliest use by the mankind. The present paper gives a brief introduction to the latest developments of a compressed-air vehicle along with an introduction to various problems associated with the technology and their solution. While developing of compressed air vehicle, control of compressed air parameters like temperature, energy density, requirement of input power, energy release and emission control have to be mastered for the development of a safe, light and cost effective compressed air vehicle in near future.

Keywords : compressed air vehicle, technological trends, energy input, energy released, emission control, storage & fueling, temperature.

GJRE-B Classification : FOR Code: 090299

Latest Developments of a Compressed Air Vehicle: A Status Report

S. S. Verma

Abstract - Compressed air as a source of energy in different uses in general and as a non-polluting fuel in compressed air vehicles has attracted scientists and engineers for centuries. Efforts are being made by many developers and manufacturers to master the compressed air vehicle technology in all respects for its earliest use by the mankind. The present paper gives a brief introduction to the latest developments of a compressed-air vehicle along with an introduction to various problems associated with the technology and their solution. While developing of compressed air vehicle, control of compressed air parameters like temperature, energy density, requirement of input power, energy release and emission control have to be mastered for the development of a safe, light and cost effective compressed air vehicle in near future.

Keywords : compressed air vehicle, technological trends, energy input, energy released, emission control, storage & fueling, temperature.

I. Introduction

Compared to batteries, compressed air is favorable because of a high energy density, low toxicity, fast filling at low cost and long service life. These issues make it technically challenging to design air engines for all kind of compressed air driven vehicles. To meet the growing demand of public transportation, sustainable with environmental consciousness, people are in the search for the ultimate clean car with zero-emissions. Many concept vehicles were proposed that run on everything from solar power to algae, but most of them are expensive and require hard-to-find fuels. Compressed air vehicle project in the form of light utility vehicle (LUV) (i.e., air car in particular) has been a topic of great interest for the last decade and many theoretical and experimental investigations [1-19] have appeared on the subject in the literature. Many largest car manufacturers [5-8, 11-13, 19] all over the world have taken up the lead in this direction based on the initial technological concept of the pioneer-the French company Motor Development International (MDI) in the field. In 2008, India's largest car manufacturer also announced that it would begin production of world's first commercial vehicle to run on nothing but compressed air.

Author : Department of Physics, S.L.I.E.T., Longowal; Distt.-Sangrur (Punjab)-148 106, India.

Fig. 1 : Model of air car by Tata Motors

The car was said to achieve speeds of up to 68 mph with a range of 125 miles between fill-ups, all for less than $13,000. Unfortunately, the dates for the air car's much-publicized release in both Indian and American markets have come and gone with no word about when the vehicle might actually hit the streets. Tata says that the first "proof of the technical concept" phase of the program is now complete with "the compressed air engine concept having been demonstrated in two Tata Motors vehicles." Phase two, which involves, "completing detailed development of the compressed air engine into specific vehicle and stationary applications," is now underway and, "the two companies are working together to complete detailed development of the technology and required technical processes to industrialize a market ready product application over the coming years."

II. Techological Trends

- In Europe inventors have made a simple air engine, thus opening a new field for compressed air car technology. These engines allow cars to run on compressed air instead of fuel. The air, super compressed and powerful, pumps the pistons in the car instead of small gas explosions. Pumping air instead of exploding gasoline means these cars have zero emission motors–no pollution, no oil. In addition, current average family cost of fuel is 60 dollars a week and half that for a hybrid car. The new air engines will give a whole week of driving for a few dollars. The company, MDI plans to sell this clean fuel vehicle and a compressed air hybrid in Europe for less than 15,000 dollars in near future.

- To refit scooters with an air-compression motor that is about three-quarters of a foot in diameter. In the engine's schematics, a tank of compressed air fires into the chambers of a turbine whose axis is set off-center from its housing. The vanes of the turbine extend as they rotate, allowing the chambers to accommodate the volume of air as it expands and contributes to the drive. Unlike the Air Car, the retrofitted scooters would run off the pressure it takes to fill a tire at the gas station. Although they are hoping to eventually solve engineering problems related to torque and range for the scooters (which currently only hold enough air to travel 18 miles), it might be a while until they can really solve the emissions problem.
- An inventor in California (USA) has made a car running on compressed air, stored in scuba diving tanks. He modified an engine used on the Honda RC51 998 cc Superbike. He blocked off one of the cylinders of the engine and used the spark plug hole on the other cylinder to feed the compressed air. The compressed air drives the piston down as the power stroke. At the end of the power stroke, the compressed air is released through the exhaust valves and the exhaust is only air. The pistons were connected to the wheels through the Honda bike's six-speed transmission. This modified engine was mounted on a tubular frame and a body that looked like a curious crossbreed of a motorbike with a racing car. A bank of three scuba tanks was used to store compressed air at 3500 psi and throttled it to 250 psi at the engine inlet with a self-designed throttle valve, linked to the accelerator pedal. The three tanks were sufficient for the test run over the 2 mile, where an average speed of 46.723 mph was achieved with a top speed of 54.058 mph. Further, a speed to the level of 300 mph is expected with compressed air. However, several issues like large size and heavy model due to the use of a number of tanks still remain before this concept can translate into a usable idea.
- Another inventor in Uzbekistan has modified a car to run it with compressed air, stored in a tank and claims that as the car runs, it will take in air and store it in the tank at pressure, resulting in a perpetual motion machine. Perpetual motion machines are, of course, not possible under the known laws of physics but the idea is not being dismissed as crank. The concept of compressed air being regenerated while the car is in motion is intriguing. It is akin to batteries of electric vehicles using regenerative charging and even a part regeneration of compressed air would be an advance from the present understanding of the technology.

III. Developers and Manufacturers

Various companies are investing in the research, development and deployment of compressed air cars. Overoptimistic reports of impending production date back to at least May 1999. Most of the cars under development also rely on using similar technology to low-energy vehicles in order to increase the range and performance of their cars. Here is a brief list of few leading manufacturers who are putting their concerted efforts towards making compressed air vehicle a reality for public use.

- APUQ (Association de Promotion des Usages de la Quasiturbine) has made the APUQ Air Car, a car powered by a quasiturbine.
- MDI (Motor Development International), France has proposed a range of vehicles made up of AirPod, OneFlowAir, CityFlowAir, MiniFlowAir and MultiFlowAir. One of the main innovations of this company is its implementation of its "active chamber", which is a compartment which heats the air (through the use of a fuel) in order to double the energy output.
- Tata Motors, India, as of January 2009 had planned to launch a car with an MDI compressed air engine in 2011. In December 2009 Tata's vice president of engineering systems confirmed that the limited range and low engine temperatures were causing problems. Tata Motors announced in May 2012 that they have assessed the design passing phase 1, the "proof of the technical concept" towards full production for the Indian market. Tata has moved onto phase 2, "completing detailed development of the compressed air engine into specific vehicle and stationary applications".
- Air Car Factories South Africa is proposing to develop and build a compressed air engine.
- The Energine Corporation, a South Korean company claimed to deliver fully assembled cars running on a hybrid compressed air and electric engine. These cars are more precisely named pneumatic-hybrid electric vehicles. Engineers from this company made, starting from a Daewoo Matiz, a prototype of a hybrid electric/compressed-air engine. The compressed-air engine is used to activate an alternator, which extends the autonomous operating capacity of the car.
- A similar concept using a pneumatic accumulator in a largely hydraulic system has been developed by U.S. government research laboratories and industry. It uses compressed air only for recovery of braking energy, and in 2007 was introduced for certain heavy vehicle applications such as refuse trucks.
- K'Airmobiles vehicles were intended to be commercialized from a project developed in France in 2006-2007 by a small group of researchers.

However, the project has not been able to gather the necessary funds. In the meantime, the team has recognized the physical impossibility to use on-board stored compressed air due to its poor energy capacity and the thermal losses resulting from the expansion of the gas.

- Engine-air is an Australian company which manufactures small industrial vehicles using an air engine of its own design.
- In 2010, Honda presented the Honda Air concept car at the LA Auto Show.

IV. Problems with Compressed Air

A compressed air vehicle is a type of alternative fuel vehicle which uses a motor powered by compressed air. Compressed air cars are not yet available in most places but the technology behind them is being perfected so that they can be introduced into the market. These cars can be powered solely by air or by a combination of air and fuel, such as diesel, ethanol, or gasoline which is how a hybrid electric vehicle runs. Compressed air car engines are fueled by a tank of compressed air, instead of an engine that runs with pistons and an ignited fuel air mixture. Basically, compressed air cars are powered by the expansion of compressed air. Vehicles that run on compressed air sound like a fantastic idea on paper, but bringing this technology to the masses have proven, well, a difficult road to travel because of some inherited technical problems with compressed air [2-4, 14, 18]. The present article gives a brief report to highlight such problems so that some methods can be designed to counter to improve the efficiency of compressed air vehicle.

a) *Engine Technology*

The air-powered car runs on a pneumatic motor that is powered by compressed air stored onboard the vehicle. Once compressed air is transferred into the onboard storage tank, it is slowly released to power the car's pistons. The motor then converts the air power into mechanical power. That power is then transferred to the wheels and becomes the source of power for the car. The engine that is installed in a compressed air car uses compressed air which is stored in the car's tank at a pressure as high as 4500 psi. The technology used by air car engines is totally different from the technology that is used in conventional fuel cars. They use the pressure generated by the expansion of compressed air to run their pistons.

b) *Air Storage & Refuelling*

The cars are designed to be filled up at a high-pressure pump and thus the tanks must be designed to safety standards appropriate for a pressure vessel. The storage tank may be made of metal or composite materials. The fiber materials are considerably lighter than metals but generally more expensive. Metal tanks can withstand a large number of pressure cycles, but must be checked for corrosion periodically. It may be possible to store compressed air at lower pressure using an absorption material within the tank. Absorption materials such as activated carbon, or a metal organic framework is used to store compressed natural gas at 500 psi instead of 4500 psi, which amounts to a large energy saving. One company stores air in tanks at 4,500 pounds per square inch (about 30 MPa) and hold nearly 3,200 cubic feet (around 90 cubic metres) of air. The tanks may be refilled at a service station equipped with heat exchangers, or in a few hours at home or in parking lots, plugging the car into the electrical grid via an on-board compressor. The Tata/MDI air car version had 4,350 psi in its tanks, which would require stations to install new high-tech air pumps, a difficult investment for station owners. As thought by engineers and designers, the storage tank would be made up of carbon fiber to reduce the car's weight and prevent an explosion, in case of a direct collision. Carbon-fiber tanks are capable of containing air pressure up to 4500 psi, something the steel tanks are not capable of. For fueling the car tank with air, the compressor needs to be plugged into the car, which would use the air that is around to fill the compressed air tank. This could be a slow process of fueling; at least until air cars are commonly used by people, after which high-end compressors would be available at gas stations that would fuel the car in no time at all.

c) *Input Energy*

Compressed air to very large pressures is extremely expensive to produce and it is very inefficient to use. Of the energy required to produce compressed air, less than 20% of input energy is left for use. That means 80% of what is paid for is used up before compressed air is put in the distribution system. In order to use air storage in vehicles or aircraft for practical land or air transportation, the energy storage system must be compact and lightweight. Energy density is the engineering term that defines these desired qualities. Compressed air has a low energy density. In 300 bar containers, about 0.1 MJ/L and 0.1 MJ/kg is achievable, comparable to the values of electrochemical lead-acid batteries. While batteries can somewhat maintain their voltage throughout their discharge and chemical fuel tanks provide the same power densities from the first to the last litre, the pressure of compressed air tanks falls as air is drawn off. A consumer-automobile of conventional size and shape typically consumes 0.3-0.5 kWh (1.1-1.8 MJ) at the drive shaft per mile of use, though unconventional sizes may perform with significantly less. It is important to take into consideration that the energy needed to compress the air into the tanks comes from the electrical grid. Such electric grids are generally supported with use of fossil fuels. However, efforts are going on to make use of non-conventional sources of energy like solar and wind to compress air. Compressed air has relatively low energy density. Air at 30 MPa (4,500 psi) contains about 50 Wh of energy per liter (and normally weighs 372g per liter). From figure 2, it is very clear that power input requirement depends directly on the mass flow rate of the air to be compressed at a desired compression pressure [14, 16-17].

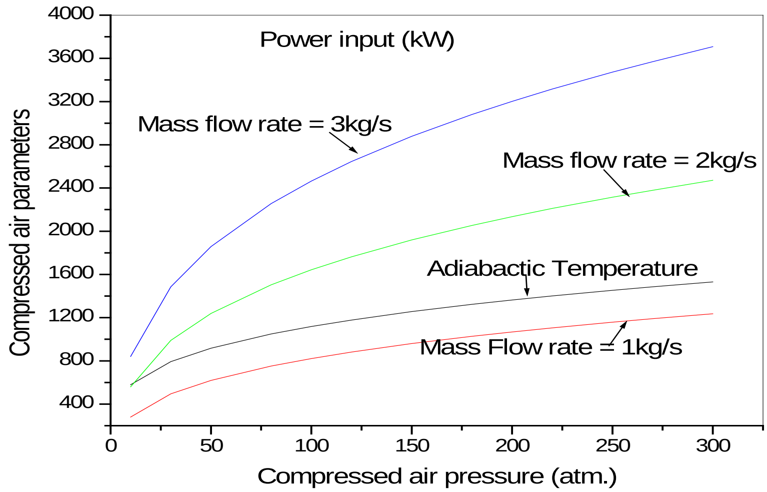

Fig. 2 : Power input requirement for compressed air as a function of compressed air pressure

d) Temperature Control

In adiabatic process of compression of air [15], the heat of compression is retained, that means, there is no heat exchange resulting in zero entropy change, so the compressed air becomes very hot. Compressed air would experience a temperature rise due to the energy that has been added to the gas by the compressor (Figure 2) which can be controlled with isothermal or adiabatic compression processes. In an isothermal compression process, the gas in the system is kept at a constant temperature throughout. This necessarily requires removal of heat from the gas. This heat removal can be achieved by heat exchangers (intercooling) between subsequent stages in the compressor. To avoid wasted energy, the intercoolers must be optimized for high heat transfer and low pressure drop. Naturally this is only an approximation to an isothermal compression, since the heating and compression occurs in discrete phases. Some smaller compressors can approximate isothermal compression even without intercooling, due to the relatively ratio of surface area to volume and the resulting improvement in heat dissipation from the compressor body itself. An adiabatic process is one where there is no heat transfer between the fluid and the surroundings: the system is insulated against heat transfer. If the process is furthermore internally reversible (smooth, slow and frictionless, to the ideal limit) then it will additionally be isentropic. An adiabatic storage system does away with the intercooling during the compression process, and simply allows the gas to heat up during compression, and likewise to cool down during expansion. This is attractive, since the energy losses associated with the heat transfer are avoided, but the downside is that the storage vessel must be insulated against heat loss.

e) Multistage Compression

Power requirement can be controlled through multistage compression of air [16-17]. The compression generates heat, the compressed gas is to be cooled between stages making the compression less adiabatic and more isothermal. The inter-stage coolers typically result in some partial condensation that is removed in vapor-liquid separators. By cooling the compressed air between each stage, the compression curve moves to near isothermal. The work done by the compressor is less if it is multi-staged. A multi-stage compressor is one in which there are several cylinders of different diameters. The intake of air in the first stage gets compressed and then it is passed over a cooler to achieve a temperature very close to ambient air. This cooled air is passed to the intermediate stage where it is again getting compressed and heated. This air is again passed over a cooler to achieve a temperature as close to ambient as possible. Then this compressed air is passed to the final or the third stage of the air compressor where it is compressed to the required pressure and delivered to the air receiver after cooling sufficiently in an after-cooler. Figure 3 indicates the power required is highest for single stage compression and lowers with multistage compression. Table 1 gives the Lorentz fit equation (Fig. 3) constants for a ready hand calculation of power requirement with multistage air compression.

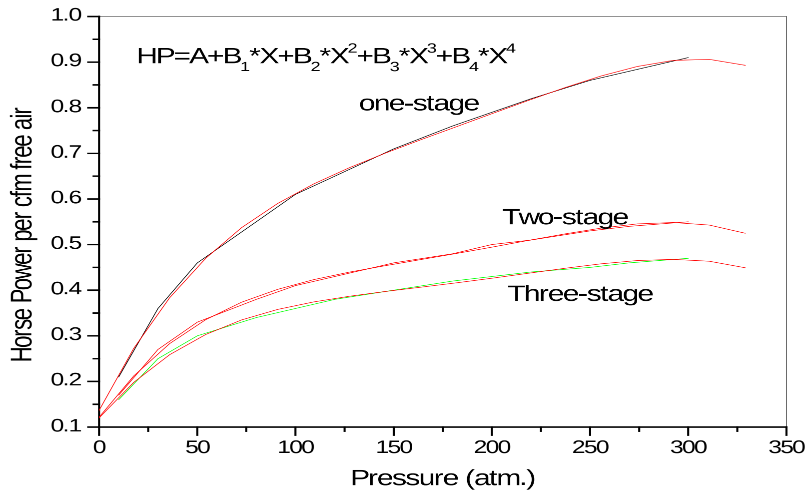

Fig. 3 : Multi-stage power requirement for air compression

Table 1 : Power input Lorentz fit equation constants

Constants	Value of constants		
	Single-stage	Two-stage	Three-stage
A	0.13677	0.12183	0.12042
B_1	0.00862	0.00582	0.00501
B_2	-5.5601×10^{-5}	-4.2453×10^{-5}	-3.7148×10^{-5}
B_3	1.95142×10^{-7}	1.54986×10^{-7}	1.33957×10^{-7}
B_4	-2.57×10^{-10}	-2.0780×10^{-10}	-1.7669×10^{-10}

f) Properties of compressed air

Compressed air energy storage is a way to store energy generated at one time for use at another time. Air driven motors use the energy of a compressed gas to do useful work. The power output is simply the inlet enthalpy minus the discharge enthalpy times your mass flow rate. The variation of some of its thermo dynamical and physical properties like enthalpy, internal energy and density with compression pressure is shown in figure 4. The inlet enthalpy is a known state which we can calculate knowing the inlet pressure and temperature [15, 16-17]. Internal energy gives the energy contained in the compressed air and the idea about how much work can thus be extracted from it. Similarly, density of the compressed air can indicate the volume level to which the air can be compressed corresponding to a desired value of pressure.

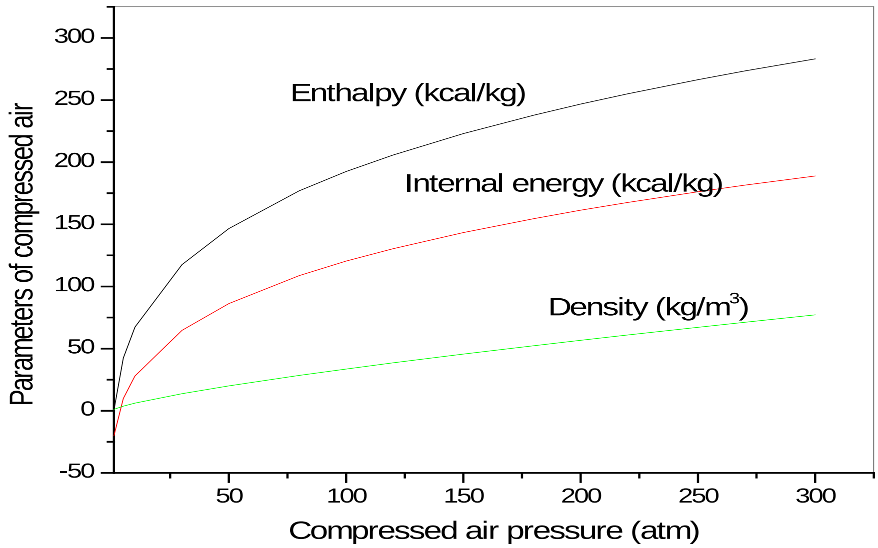

Fig. 4 : Variation of enthalpy, internal energy and density of compressed air

g) Energy Released

Compressed air is more expensive than many other utilities when evaluated on a per unit energy delivered basis. Therefore, energy released by the compressed air is very important and thus are the factor like volume of compressed air, compressed air pressure and expansion flow rate under isothermal or adiabatic conditions of expansion on which it depends [14, 16-17]. Figure 5 shows the typical control characteristics of energy release by the compressed air on its isothermal or adiabatic expansion as a function of compressed air pressure, volume of compressed air and flow rate. Applying best energy release management and control practices, the desired energy can be achieved. Figure 5a,b, c indicate that energy released for isothermal expansion is always higher than adiabatic expansion when volume of compressed air and flow rate are controlled at a particular pressure of compression. However, when compression pressure is fixed with respect to flow rate and volume of air, then adiabatic expansion gives more energy release as compared to adiabatic expansion.

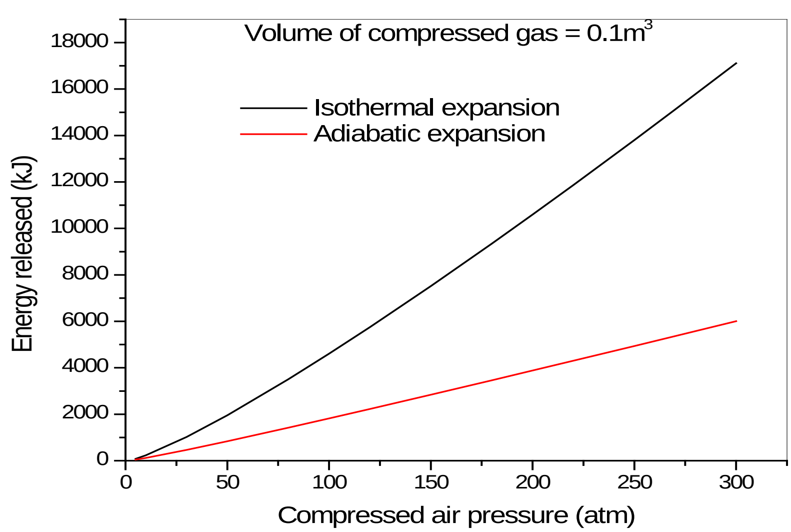

Fig. 5a : Energy released as a function of compression pressure at constant volume of compressed air

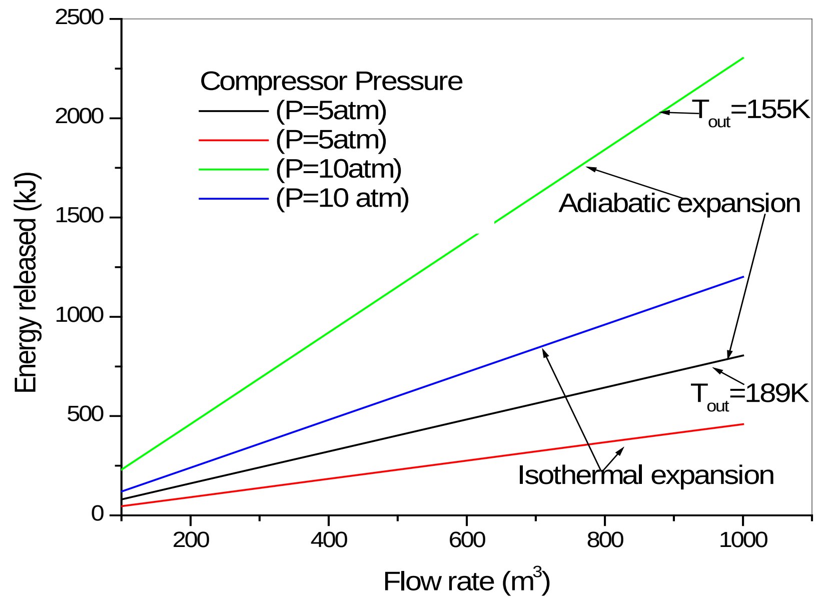

Fig. 5b : Energy released as a function of air flow rate at a particular compression pressure for isothermal and adiabatic expansion

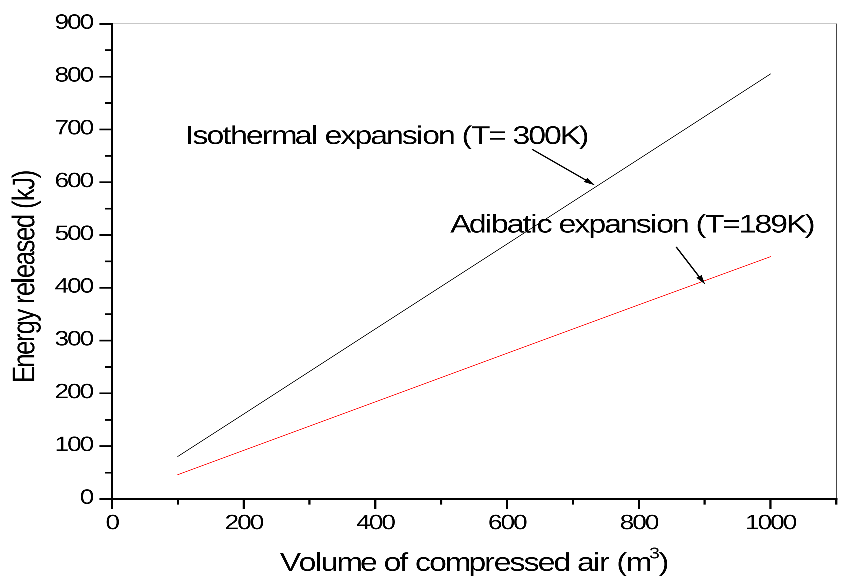

Fig. 5c : Energy released as a function of volume of compressed air at a particular compression pressure and flow rate for isothermal and adiabatic expansion

h) Adiabatic Expansion

Compressed-air vehicles operate to a thermodynamic process as air cools down when expanding and heats up when being compressed [14-17]. It is said that the compressed air vehicle project is facing difficulties in terms of vehicle range and cooling as excessively low engine temperature caused by the adiabatic expansion of the compressed air is a major problem. Typical air engines use one or more expander pistons or rotary expander. Figure 6 clearly shows a sharp decrease in temperature of the air at the outlet under adiabatic expansion conditions. The cooling of air is very large in case of higher compression pressure. It is necessary to heat the air or the engine during expansion. As it is not possible in practice to use a theoretically ideal process, losses occur and improvements may involve reducing these, e.g., by using large heat exchangers in order to use heat from the ambient air and at the same time provide air cooling in the passenger compartment. At the other end, the heat produced during compression can be stored in water systems, physical or chemical systems and reused later.

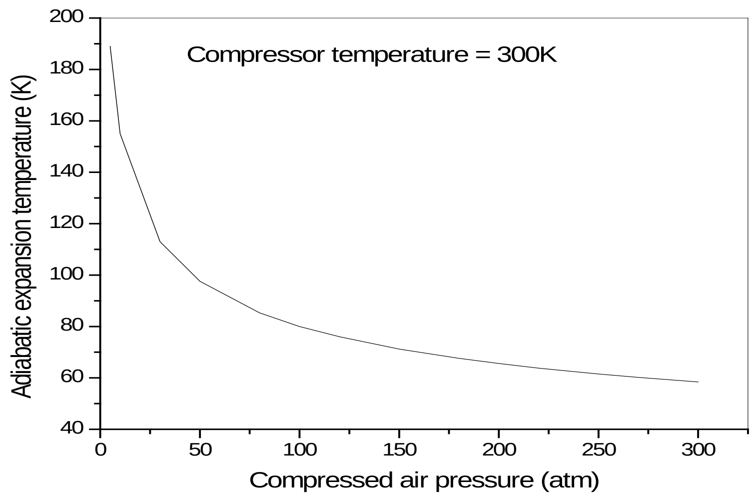

Fig. 6 : Compressed air temperature after adiabatic expansion

i) Pollutant Emissions

Like other non-combustion energy storage technologies, an air vehicle displaces the emission source from the vehicle's tail pipe to the central electrical generating plant. Where low emissions sources are available, net production of pollutants can be reduced. Emission control measures at a central generating plant may be more effective and less costly than treating the emissions of widely dispersed vehicles. Since the compressed air is filtered to protect the compressor machinery, the air discharged has less suspended dust in it, though there may be carry-over of lubricants used in the engine. The air-powered car would normally emit air, as it's what it would solely use. But it would totally depend on the purity of air that is put into the air tank as well as the temperature maintained inside the storage tanks during the process of compression. The rise in temperature of the compressed air as a function of compressed pressure [14-17] is shown in figure 7. As can be seen from the figure 7, temperature rises significantly if the air is compressed single stage without providing any facility in the tank to absorb the heat produced. This increase in temperature can lead to the dissociation of air nitrogen part and its chemical reaction with oxygen to produce unwanted gaseous compounds like NO, N_2O and NO in significant concentrations. This type of emission can increase if impure air is filled in the tank.

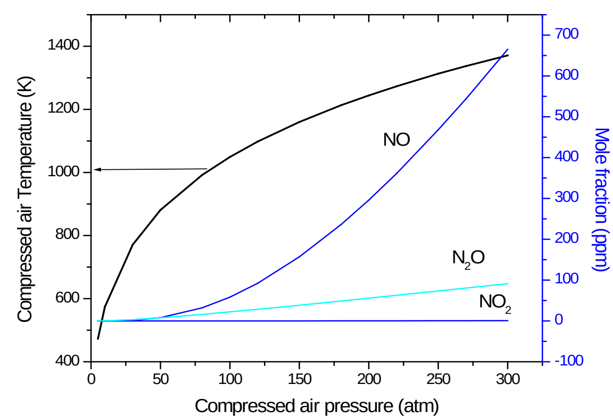

Fig. 7 : Concentration variation of NO, N_2O and NO_2 with compression air temperature rise as a function of compressed air pressure

V. Conclusion

It's important to remember that while vehicles running on only compressed air might seem like a distant dream, but they still have public interest due to their environmental friendly nature. Efforts should be to make them light, safe, cost effective and economical for deriving. The storage of compressed air (initially as well as during journey) with all benefits like no heating, high energy density and provisions to make use of cooling produced during adiabatic expansion during the energy release have to be taken care off in a much more controlled manner. Electric-powered cars and bikes already available on the market put a strong competition to compressed air car not only in terms of cost but also their environment friendly role. The technology still looks distant but that has not deterred inventors from working on it.

References Références Referencias

1. Matt Sullivan, World's First Air-Powered Car: Zero Emissions by Next Summer, Popular Mechanics (June 2008 issue) http://www.popularmechanics. Com/automotive/new cars/4217016.html
2. SS Verma, Air Powered Vehicles, The Open Energy and Fuels Journal, 2008, 1, 54-56.
3. Andrew Papson, Felix Creutzig and Lee Schipper, Compressed Air Vehicles, Drive-Cycle Analysis of Vehicle Performance, Environmental Impacts, and Economic Costs, J. of Transportation Research Board (TRB) 2010 Annual Meeting CD-ROM, Volume 2191 / 2010, pp.67-74, 2011, (http:// www.user.tu) berlin.de/creutzig/Papson_ Creutzig_ Schipper_2010.pdf)
4. Caroline Baggott and Shawn McMullen, Riding on Air: a Technical Review of the Air-Powered Car" University of Pittsburgh, Swanson School of Engineering, Twelfth Annual Freshman Conference, April 14, 2012 (assessed November 2012)
5. Graham Kozak, Make way for air-powered cars-maybe, http://www.autoweek.com/article/20120821/ green/120829984 (assessed November 2012)
6. Soon, air-powered cars to debut in India, http://zeenews.india.com/business/news/technolog y/soon-air-powered-cars-to-debut-in-india_774556. html (assessed November 2012)
7. John Metcalfe, Forget Electric Cars, This One Runs on Compressed Air, http://www.theatlanticcities. com/commute/2012/08/forget-electric-cars-one-runs-compressed-air/2967/ (assessed November 2012)
8. Larry Greenemeier, Compressed-Air Car Winds Way to Market http://www.scientificamerican.com/ podcast/episode.cfm? id=compressed-air-car-winds-way-to-mar-12-03-29 (assessed November 2012)
9. Compressed air car http://en.wikipedia.org/wiki/ Compressed_air_car (assessed November 2012)
10. Christopher Lampton, How the Air Car Works http://auto.howstuffworks.com/fuel-efficiency/ vehicles/air-car.htm (assessed November 2012)
11. A car that runs on air, in India soon http://www. rediff.com/money/2007/mar/21car.htm (assessed November 2012)
12. Gizmag Team, Tata Motors enters second phase of air-car development http://www.gizmag.com/tata-motors-air-car-mdi/22447/ (assessed November 2012)
13. The Air Car http://www.milnermotors.com/aircar.htm (assessed November 2012)
14. Compressed air energy storage calculations: http:// www.tribology-abc.com/abc/thermodynamics. htm (assessed November 2012)
15. Gaseq software: A Chemical Equilibrium Program for Windows (http://www.c.morley.dsl.pipex.com/) (assessed November 2012)
16. Horsepower required to Compress Air: http://www. engineeringtoolbox.com/horsepower-compressed-air-d_1363.html (assessed November 2012)
17. Power Cycle Components/Processes Online Calculator: http://www.engineering-4e.com/calc4. htm (assessed November 2012)
18. Peter Fairley, Deflating the Air Car, IEEE Spectrum (November 2009), http://spectrum.ieee.org/energy/ Environment/deflating-the-air-car/0(assessed Nove-mber 2012)
19. Compressed air motor runs car, http://www. panacea-bocaf.org/compressedair.htm (assessed November 2012).