International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 23 (2018) pp. 16327-16332
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Air Compression Presents Possibility of Generating Power from Atmospheric Air

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Abstract

A system is described whereby electric power can be generated from the atmosphere through the route of air compression. It is shown that total electrical power produced in the system can be somewhat larger than the electrical power consumed thus giving net electrical power output. This is possible because energy can be tapped from the atmosphere.

Keywords: Air compression, electric power, atmosphere.

1. INTRODUCTION:

Electricity happens to be the major source of energy for commercial and domestic/personal use. Mankind has substantially succeeded in generating electric power from sources like fossil fuels, fissionable materials, flowing water (hydro electricity), sunshine, wind, geothermal, tidal, thermoelectric and other sources. Thermal and nuclear power plants use minerals as fuel the resources of which get depleted with time. These also result in pollution. The hydel power, which in fact is solar power, on the other hand causes no pollution while producing electricity. Solar power plants are also in use; the drawback of the solar energy is that it is not available during nights and cloudy weather.

It has been thought that a system should also be possible by which the energy of the atmospheric air can be tapped. Such a system would not be subservient to any special locality (like hydroelectricity, geothermal energy), time of the day (like solar power), extremely low thermal efficiencies (like thermoelectricity), natural phenomenon (like wind and tidal energy), etc. The main aim of this publication is to describe such a possibility.

2. COMPRESSED AIR:

Compressed air is one of the common utilities in most manufacturing and production plants. It is produced by large size compressors. The phenomenon of compression by a reciprocating compressor can be represented on pressure-volume diagram as shown in fig. 1. The air compressor consists of a piston moving in and out of a cylinder which is typically provided with two valves known as inlet valve and outlet valve. The piston is in its most inward position at point 1 and in its most outward position at point 2. When the piston moves from point 1 to point 2, the air inlet valve is in the open position permitting atmospheric air to be sucked into the cylinder. A point 2 which is the most outward position of the piston the air inlet valve closes and the piston starts moving inwards. The trapped air starts getting compressed and the phenomenon is represented by the curve 2-3 in the pressure-volume diagram figure 1.

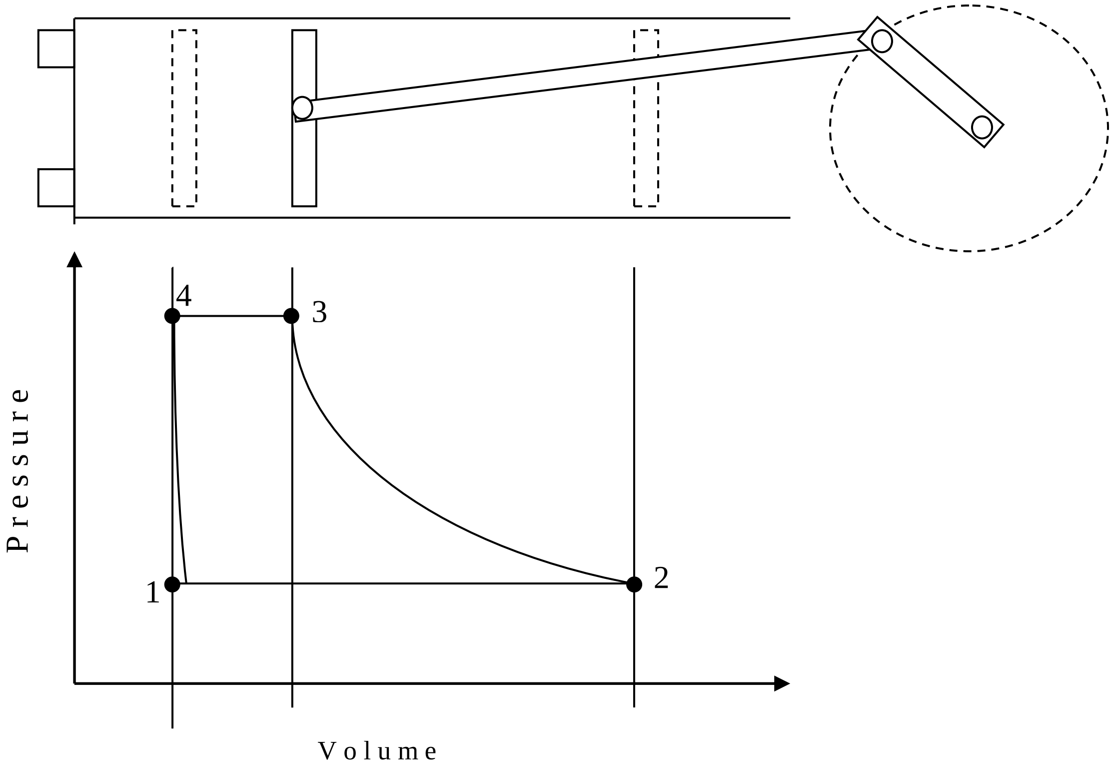

Fig.1: The pressure-volume diagram of a reciprocating air compressor.

At point 3 the outlet valve which was in the closed condition up to now, opens and lets the compressed air move into a storage vessel. The outlet valve closes at point 4 leaving a small amount of compressed air in the cylinder. The piston starts moving outwards and simultaneously the air inlet valve opens. The pressure in the cylinder falls to nearly atmospheric and fresh air is inducted into the cylinder; thus the cycle is repeated.

The performance of the air compressor can be analyzed based on well known gas laws. With reference to fig 1, processes 1-2 and 3-4 are constant pressure processes. Process 2-3 can be either isentropic or polytrophic. There are three quantities associated with the gas undergoing compression or expansion, namely, pressure (P), volume (V) and temperature (T). Since our graph is two dimensional only two parameters are shown like pressure and volume in fig. 1. It should, however, be remembered that temperature of the gas is simultaneously undergoing change. Well established thermodynamic relations govern the values of the three quantities.

Assume that the process 2-3 is adiabatic which means no heat is exchanged between the gas inside the compressor cylinder and atmospheric air. As the air is compressed, its volume is reduced, pressure increases and simultaneously the temperature also increases. Reference to any standard thermodynamics book (see reference 1, for example), shows the following relationships:

$$\frac{P_3}{P_2} = \left(\frac{V_2}{V_3}\right)^{\gamma} \quad (1)$$

$$\frac{T_3}{T_2} = \left(\frac{V_2}{V_3}\right)^{(\gamma-1)} \quad (2)$$

Where γ is the ratio of specific heats at constant pressure (C_p) and at constant volume (C_v).

It is well known that the energy W_c consumed by the compressor per cycle is given by

$$W_c = \frac{\gamma(P_2V_2 - P_3V_3)}{\gamma-1} \quad (3)$$

At point 3, the pressure is P_3, volume V_3 and temperature T_3. The thermal energy (enthalpy) of the compressed air at point 3 is

$$E = m.c_{p.}\,(T_3 - T_2) \quad (4)$$

where m is the mass of the air in the cylinder.

The gas law can be used to find m:

$$P_3V_3 = m.R.T_3 \quad (5)$$

$$\text{also}\quad P_2V_2 = m.R.T_2 \quad (6)$$

where $R = c_p - c_v$

Equation 4 can be rewritten and simplified with the help of relations 5 and 6 as follows:

$$\begin{aligned}
E &= m.c_p.\,(T_3 - T_2) \\
&= c_p.\,(m.T_3 - m.T_2) \\
&= c_p.\left[\frac{P_3.V_3}{R} - \frac{P_2.V_2}{R}\right] \\
&= \frac{c_p}{R}.\,[P_3.V_3 - P_2.V_2] \\
&= \frac{c_p}{c_p - c_v}[P_3.V_3 - P_2.V_2] \\
&= \frac{c_p/c_v}{\frac{c_p}{c_v} - 1}.\,[P_3.V_3 - P_2.V_2] \\
&= \frac{\gamma}{\gamma - 1}.\,[P_3.V_3 - P_2.V_2]
\end{aligned} \tag{7}$$

Relationships 3 and 7 are exactly similar. In other words the energy consumed by the compressor completely (repeat, completely) ends up as thermal energy of the compressed air.

3. EXCESS ENERGY:

Imagine a system as shown in fig.2. The compressor takes in atmospheric air and compresses it. The compressed air is cooled (essentially at constant pressure, just like intercoolers in multi-cylinder compressors) in heat exchanger H (for example, water gets heated up) and stored in pressure vessel S.

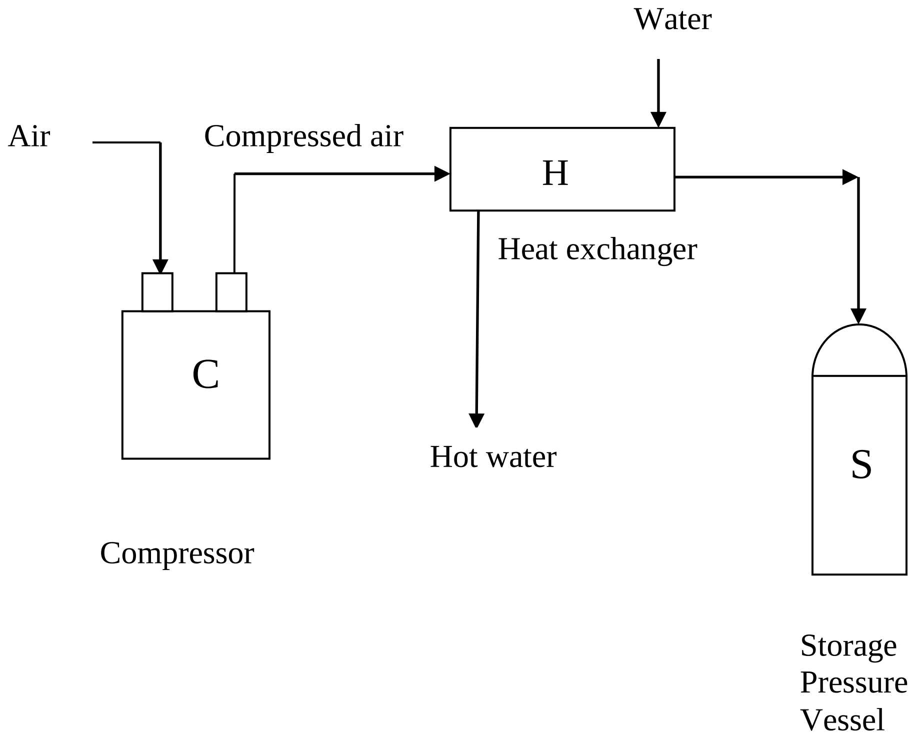

Fig.2: An air compressor system wherein all the input energy is recovered as heat of hot water.

As shown above, the energy consumed by the compressor ends up as thermal energy of compressed air which is picked up by water. Up to this point it can be said that electrical energy has been completely converted into thermal energy which has been recovered fully in the form of hot water (inefficiencies of the equipment are presently ignored). In fact, some of the major compressor suppliers do offer systems where nearly all the electrical energy consumed by the compressor is recovered as heat energy (ref 2).

The storage vessel S now contains compressed air at ambient temperature. Surely this compressed air can be used to perform work and thus must be considered as possessing energy (by definition, energy is the capacity to do work). The question is: where does this energy of compressed air come from! The system seems to generate excess energy over the input.

4. HEAT ENGINES:

Heat engines are devices that convert thermal energy into mechanical energy. Examples are internal combustion engines, steam engine, gas turbine, steam turbine etc. All these devices work on what are called cycles. A cycle consists of several processes being performed sequentially on a working fluid such that the fluid returns to its original state after every cycle. Thus internal combustion engines work on Otto cycle, Diesel cycle or dual cycle; gas turbines work on Brayton cycle, steam turbines work on Rankine cycle, etc.

Carnot cycle consists of four processes; two of these processes are isothermal processes and other two processes are isentropic processes. It is proven that for a Carnot cycle working between extreme absolute temperatures of T_a and T_b, the thermal efficiency η_c is given by:

$$\eta_c = 1 - \frac{T_b}{T_a} \tag{8}$$

It is also proven that no heat engine working on any cycle can surpass the Carnot cycle efficiency. Carnot cycle is only a theoretical cycle and cannot be realized in practice since isothermal processes need infinitely slow operation whereas isentropic processes need infinitely fast operation, both of which are unpractical. However, Carnot cycle efficiency is a good concept to evaluate the efficiency of practical cycles. We shall term the ratio of cycle efficiency to Carnot cycle efficiency as Carnot factor.

It is always possible to extract energy from a stream provided there are distinct source and sink temperatures. As an example, the Carnot cycle efficiency of a heat engine working between 373 K and 200 K would be 46.4%. Carnot efficiency indicates the maximum percentage of thermal energy available in the hot stream that can be converted into mechanical energy.

As indicated earlier, the electrical energy consumed by the compressor for raising the pressure of the air gets converted into thermal energy of the compressed air. Assuming that the compressor is fully insulated and no heat is lost through the compressor walls, all the energy is available as thermal energy of the compressed air. We can employ a suitable heat engine and extract energy from the hot compressed air as mechanical energy which can further be converted into electricity with the help of a generator.

If the source and sink temperatures are considered as T_3 and T_2, Carnot efficiency would be $1-T_2/T_3$. This fraction of the energy will be converted into mechanical energy and balance will be dissipated as thermal energy to the sink.

5. ENERGY OF COMPRESSED AIR:

Compressed air cooled to ambient temperature at constant pressure (frictional pressure drop is presently ignored) is stored in a pressure vessel. Since the complete energy input to the air compressor is available as thermal energy of the hot compressed air, it would seem that the energy of the compressed air is available for free, i.e. without any expenditure of energy.

The compressed air can be utilized to drive a turbine and mechanical work extracted. Assuming isentropic expansion takes place in the air turbine from pressure P_3 to P_2 the final temperature T_5 of the air at the outlet of the turbine will be given by:

$$T_5 = T_2 . \left[\frac{P_2}{P_3}\right]^{\frac{\gamma-1}{\gamma}} \tag{9}$$

The work done by the turbine is given by:

$$W_T = \dot{m}.c_p.(T_2 - T_5)$$

where $\dot{m}$ is the air mass flow rate. This equation can be simplified with the help of equation (9) as:

$$W_T = \dot{m}.c_p.T_2.\left[1 - \left[\frac{P_2}{P_3}\right]^{\frac{\gamma-1}{\gamma}}\right] \tag{10}$$

The temperature of the air coming out of the air turbine T_5 as given by Eqn. 9 is well below ambient temperature T_2.

Now we have the possibility of placing another heat engine between temperature T_2 and T_5 and extracting mechanical work. The Carnot efficiency of such a system would be $(1-T_5/T_2)$. This fraction of the thermal energy can be converted into mechanical work, balance being available as 'cold' which can be used to cool the atmosphere.

We now have a heat source at temperature T_3 and heat sink available at T_5 and a single heat engine working between T_3 and T_5 can be employed instead of two heat engines (one between T_3 and T_2 and another between T_2 and T_5). The Carnot efficiency of such a system would be $(1-T_5/T_3)$. The total system is shown in fig.3.

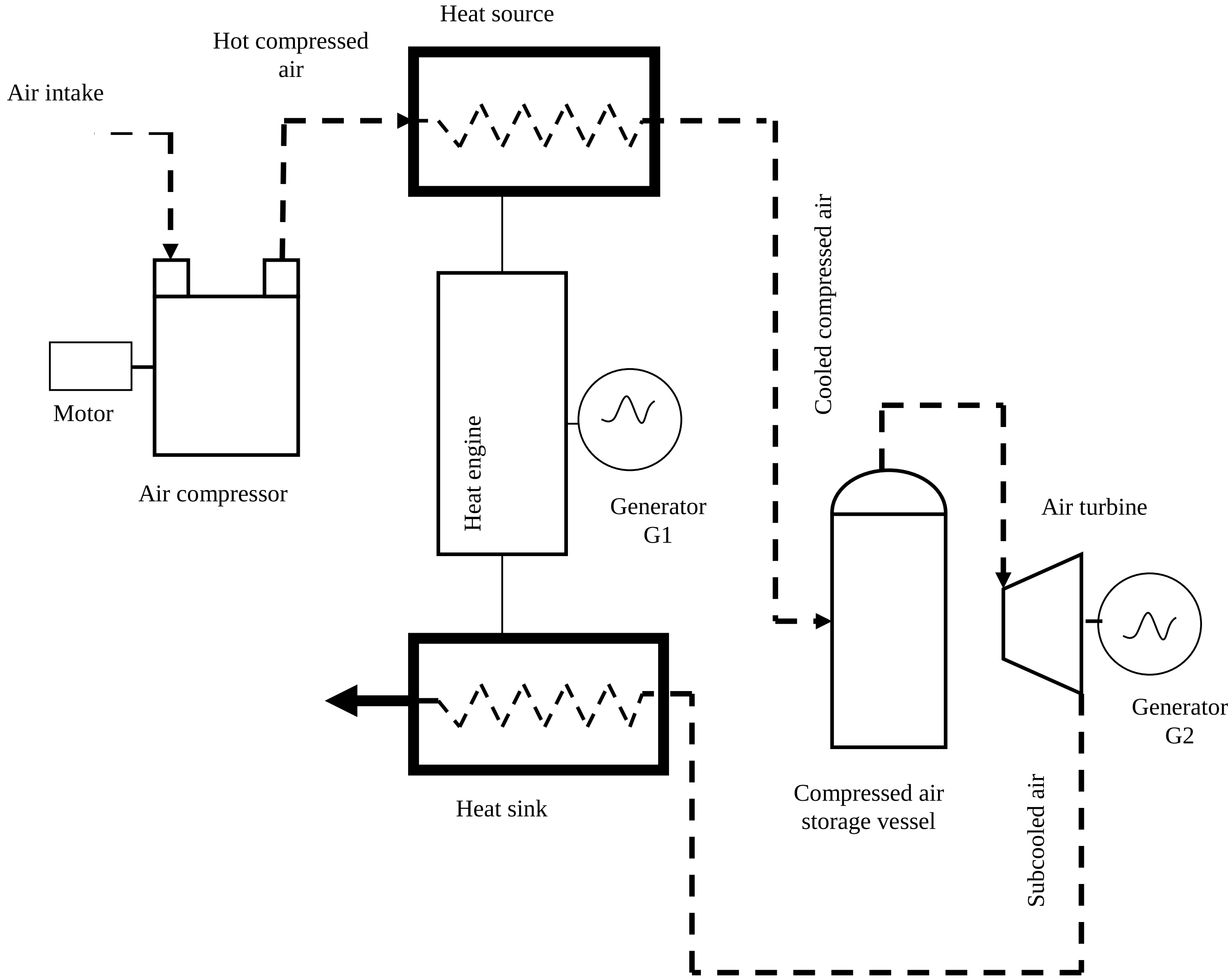

Fig.3: Schematic diagram of the atmospheric energy tapping device.

In this way, the electrical energy input to the compressor results in output as mechanical work (convertible to electrical energy) on two counts as follows:

1. Heat engine between T_3 and T_5.
2. Work of air turbine

It can be readily seen that the work of the air turbine is actually drawn from the atmosphere. In other words, the compressed air has, in fact, no energy of its own, but it facilitates conversion of atmospheric energy into mechanical energy.

6. EXAMPLE:

Consider a reciprocating air compressor with displacement of 0.018 m^3 operating at 1000 rpm. The ambient pressure and temperature are assumed as 10^5 Pa and 300 K respectively. Compression ratio is taken as 5. Compression is assumed adiabatic with γ=1.4. Average specific heats of air are taken as C_p = 1.0 kJ/kg K and C_v = 0.713 kJ/kg K; (R =$C_p - C_v$ = 0.287 kJ/kg K).

The final pressure and temperature of the compressed air are found as 9.52x10^5 Pa and 571 K respectively. Mass flow rate of air can be calculated as 0.3489 kg/s (density of air at 10^5 Pa and 300 K taken as 1.161 kg/m^3).

Power consumed by the compressor as per equation 3 comes out as 95 kW.

We will now have 0.3489 kg/s of compressed air at 9.52x10^5 Pa (at ambient temperature) after the hot compressed air has given out its thermal energy. When this compressed air is used in an air turbine, it expands back to ambient pressure (10^5 Pa) adiabatically with a final temperature of 157.6 K and gives a power output of 49.68 kW.

The heat engine works between 571 K and 157.6 K. Its Carnot efficiency will be 72.4%. Thus, theoretically 104.43 kW of electricity can be generated by this engine.

Thus the total electric power produced will be 104.43 + 49.68 = 154.1 kW against the input of 95 kW to the compressor. This way the system has become a net producer of energy. The excess energy has, as explained earlier, been tapped from the atmosphere.

7. COMMENTS ON THE EXAMPLE:

The example cited above makes some simplifying assumptions which are not strictly true. These are mentioned below:

a. The compressor is operated by an electric motor; the efficiency of the motor has not been taken into consideration. If the efficiency of the motor is 95 % the electric power consumed will become 100 kW instead of 95 kW.

b. The air turbine may not operate exactly adiabatically and isentropic efficiency will result in loss of power.

c. The heat engines have been assumed to work at Carnot cycle efficiency which is not practical. The real engines will work at a fraction of the Carnot efficiency and result in further loss of output power.

d. Efficiencies of generators have been assumed unity which may not be the case in reality.

e. Pressure drop and heat loss in the interconnecting pipelines in the system have been ignored.

Assuming 95% as motor efficiency, Carnot factor of 0.8 for the heat engine and 98 % as the generator efficiency, the energy balance comes as follow.

Input			**Output**
100 kW	Heat Engine	:	81.87 kW
	Air Turbine	:	48.68 kW
	Total		**130.55kW**

Excess Power generated = 30.55 kW (nearly 30% of input)

REALITY CHECK AND CHALLENGES:

That energy can be tapped from the atmosphere came as a surprise to most people, including the authors. The most serious objection was the nature of heat engine that would convert temperature differential at atmospheric pressure into mechanical work.

A study of various types of heat engines brought out that external combustion engines would be of relevance in the present case. Most promising external combustion heat engine is the Stirling engine. Interestingly the theoretical efficiency of a Stirling cycle is similar to Carnot cycle efficiency and practical engines have been built based on this cycle.

The challenges in realizing the ‘atmospheric energy tapping device’ (AETD) lie in developing engines (e.g. Stirling engine) that would efficiently convert thermal energy into electricity. There could be other methods of converting thermal energy into electricity that could be of relevance, for instance, the New Thermoelectric Generator by Lonnie Johnson (ref 3).

The example given above shows an output surplus of about 30% over the input. It is possible that the physical properties assumed are not accurate. There could be other minor errors and omissions in the calculations leading to a reduction in the net power produced. Further research and development of suitable heat engines is needed so that the AETD becomes a reality in the near future.

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