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An analysis of the inlet air temperature and humidity influence on the power of an internal combustion engine modeled as an otto cycle

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Abstract. *The growing concern for the environment, as the sustainable use of non-renewable resources and the desire in reducing fuel consumption by consumers, comes against the constant increase of demand on emission standards and new creations programs. The Innovate-Auto, which has in its objectives, support the protection of the environment and promote energy efficiency through tax incentives to the automotive industry. Thus, it becomes essential to the need for the development of more efficient engines. Thus, some parameters to be observed during a calibration of an internal combustion engine are the temperature and humidity of the intake air. Since this temperature may influence during combustion, which can result in loss of power and /or increased fuel consumption. This study evaluates one of the influences of air admitted into an engine, which works on Otto cycle temperature. Thus, it was analysed the power of the engine through the test results through variation and control of air admitted to the same temperature. The tests were conducted using a small counter dynamometric based on the concept applied the Prony brake connected to an internal combustion engine with a cylinder, four-stroke Otto cycle running at maximum output of 5.5 hp, and a control device for temperature variation of air admitted.*

Keywords: *Temperature of the air, Otto cycle, Power, Combustion engine*

1. INTRODUCTION

The engines currently applied in the automotive industry have been developed for over a century. The majority of technological innovations, thermodynamic studies and improvements in the overall efficiency of internal combustion engines happened throughout the history of motorized road transport (Belli, 2013).

The idea of building an engine, taking advantage of the expansive force of gases from the combustion of gunpowder in a closed cylinder was proposed by Father Hautefoille at 1652, but did not record information about it. At 1794, Robert steet obtained a patent of an internal combustion engine consisting of two horizontal cylinders, where a pump cylinder produced energy that would be used to drive a power cylinder. These cylinders were connected by means of a chain transmission comprising a crankshaft provided with a differential (Varella, 2013).

The inventor of the gas lighting, Phillip Lebenob had a patent for a combustion engine at 1801, which worked based on the principle of expanding gases from the combustion of a mixture of air and gas ignited (Varella, 2013).

At 1860, Belgian Jean Joseph Etienne Lenoir used the concept of Barsanti and Matteucci to create a two-stroke engine that used explosive gas using a spark plug to initiate combustion. At 1863, Lenoir created a motorized three-wheeled carriage equipped with the engine he designed for burning oil (Belli, 2013).

Created and patented by Nikolaus August Otto, around the year 1866, the Otto cycle internal combustion engine is a machine that works with the principles of thermodynamics and the concepts compression and expansion of gaseous fluid to generate power and rotary motion. The concept of a four-stroke Otto motor would become the standard for most of the developments that would follow. Karl Benz, who at 1879 created a two-stroke engine based on the Otto cycle, again used this concept and created his own four-stroke engine, which was used in the famous Benz Motorwagen of 1885, the first commercially produced car with cycle engine Otto, released to the public officially in 1886 (Belli, 2013).

The mechanical efficiency studies of the engines continued to grow. At 1912, Fiat introduced its first engine with dual overhead cams, in their models with two or four valves per cylinder, followed by Peugeot with hemispheric camera configuration with four valves per cylinder, later that year, and the Alfa Romeo at 1914 (Belli, 2013).

During the next several years, the technologies involved in the internal combustion engine performance were focused on aviation, especially during the period of World War II. The special needs of aeronautical use technologies brought to the car years later. The overfeeding was a common feature for high-performance engines, widely used in aviation because of the loss of income of naturally aspirated engines at high altitudes. The innovations also occurred in the areas of materials, light and resistant, fuels with higher calorific value and how to feed the combustion chamber with vaporized fuel. The carburetors were becoming increasingly efficient, but there was still much to improve. In 1952, Mercedes introduced the 300 SL model, equipped with the first automobile engine that used direct mechanical fuel injection Bosch system. Before this, only aircraft engines had this power system, such as Daimler-Benz DB 601 that fitted the German fighters Messerschmitt Bf 110. Several variations of this engine were created by equipping of light fighters to heavy bombers such as the Heinkel He177 (BELLI, 2013).

Prior to the 70s, what mattered most was a car's performance, acceleration, power and speed. Then, because of the oil crisis, the client also wanted a car that consumed little fuel. At the end of the 70s, the pollution reducing would be a major concern of the automotive and oil industry, due to the pressure exerted by legislation. With use of electronic easier control of external variations. In Brazil, the innovation has come through the Bosch with the VW Gol GTI, launched in January 1989 (Ferraresi, 2011).

Therefore, due to all concerns on engines performance, this research aims to measure the impact on power in an internal combustion engine running on the Otto cycle, related to the variation of the air admitted to the engine temperature.

This research was divided in tests using a 5.5 hp four strokes motor in a small dynamometer bench and theoretical survey of possible impacts on power of the intake air temperature variation in engines with Otto cycle.

2. MATERIALS AND METHODS

2.1 Otto cycle

According to Bosch (2005), the engine has spark ignition (SI or motor) is an engine that uses piston, with internal or external formation of air/fuel mixture. These engines have little freedom of operation regarding to poor air/fuel mixture. Thus, it should be implement a load control mode, which sets the mass flow of the fuel-air mixture.

According to Chollet (1981), one four-stroke engine has the primary cycle in neutral piston and is related to four successive courses that require two revolutions of the crankshaft. The valves command the entry and exit of gases. The strokes are:

1. Admission: Driven by the connecting rod and the crankshaft, the piston moves away from the head and causes the suction certain amount of gas. The intake valve stays open during the entire course allows the gas to penetrate the cylinder.
2. Compression: When starting this compression stroke, the intake valve closes causing the compressed gases present in the cylinder undergo great compression. At the end of the second stroke, the crankshaft has already completed a rotation, wherein the valves are hermetically closed and the gases are compressed in the compression chamber and combustion chamber.
3. Combustion: The pressure relating to the end of the second stroke, where the explosion takes place, causes considerable rise in temperature, and therefore, increase in pressure. This transmits a favorable driving force rotation to the crankshaft.
4. Escape: The total expulsion of the gases occurs as the piston makes its return, in which the exhaust valve is closed and immediately after the inlet is opened starting a new cycle.

The four-stroke internal combustion engine can be observed schematically in figure 1.

Bauer, Westfall and Dias (2013) explain that the Otto cycle is based on two adiabatic processes and two constant volume processes. These processes are also exposed in figure 1, both the theoretical and real pressure x volume diagram for an Otto cycle.

The processes of each stage are:

0-1: isobaric Admission;

1-2: adiabatic compression;

2-3: Isovolumetric heating;

3 - 4: adiabatic expansion;

4-1: Isovolumetric rejection of heat.

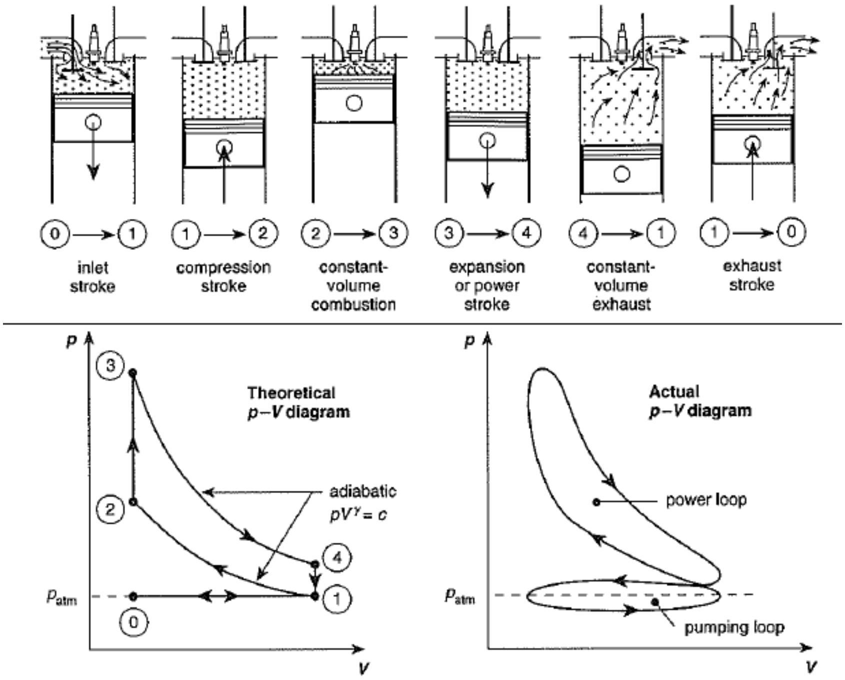

Figure 1. Four stroke Otto cycle and its respective Pressure x Volume diagrams

2.2 Power and torque

This power definition is related to the ability of an engine or other machine to perform mechanical work or generate energy in a given time interval. (Gray, Constanzo and Plesha, 2014)

According Bosch (2005), the power refers to the amount of work performed per unit time. Therefore, the power equivalent to a change in speed occurs in a power system or a time taken to perform work.

According to Beer and Russell (1991), the power is the criterion in selecting a motor or engine since, although a job can be effected by motors of various sizes, the time for a larger engine would run a job It would be short compared a smaller engine would need a longer time to reach the same result.

Everything that generates or tends to cause rotation or twist, and the intensity is measured by the product of force and the perpendicular distance the force line of action of the rotation axis.

The Torque always occurs in a plan. It is also applied around an axis. The greater the distance of the force application point to axis of rotation is greater the torque. If the force is acting on the shaft alignment, the value of the torque produced will be zero. (Training Division Publication, 2004).

2.3 Dynamometer measurements

One way to perform the measurement of power of an engine, is to use the concept applied in the Prony Brake, developed at 1821, which is the oldest device power measurement used to the present, this concept can be seen in figure 2 (Palczuk, J., Reinhardt, L. and Pedro, V., 2013).

The method in question is to restrict the motor shaft rotation by a brake. This restriction to the rotation generates a rotating a lever coupled to the brake trend. To measure torque, weights are added at the end of the lever until the system is in equilibrium, it becomes difficult to control in all load or engine speed changes, or using a load cell, where the applied force can be displayed.

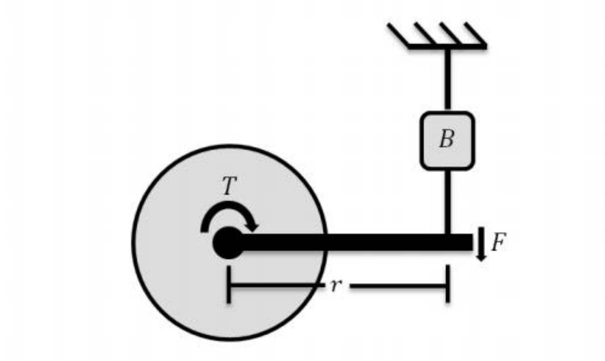

Figure 2: Prony brake scheme

After reading the force applied to the end of the lever, knowing the engine speed and knowing the arm length, the generated power can be determined by using the Eq. (1).

$$P = B \cdot r \cdot \omega \cdot \frac{\pi}{2250} \tag{1}$$

Where P is the power in cv, B is the force applied to the end of the lever in kgf, r is the lever arm length in m and ω is the engine rotation speed in rpm.

3. EXPERIMENTS

For the realization of the tests it was used a small dynamometer based on the Prony brake, which was the result of a course conclusion research (Palczuk, J., Reinhardt, L. and Pedro, V., 2013). The engine installed on the dynamometer used for testing was a B4T-5.5H from the White engine manufacturer, available at Universidade Positivo. The engine has a maximum power of 5,5cv at 3600 rpm.

It is informed by the manufacturer that every increase of 5,6ºC in the engine inlet temperature there is a loss of 1% for each increase horsepower and 305 meters of altitude loss is 3.5% of the engine power. Also reports that for continuous regimen available power must not exceed 85% of maximum power (Branco, 2014).

To increase the temperature of the air at the engine intake, an infrared sterilizer Marconi MA-1201 was used, as illustrated in figure 3, adapted to the engine intake pipe. This apparatus had a 20mm duct diameter and 120mm length, which allowed the passage of air where it was heated. The sterilizer was capable to attain a temperature up to 800 ° C. The air passage pipe connecting the heater to the engine had a hole for measuring the temperature of the intake air as shown in figure 3. This measurement was performed with a thermometer Minipa MT-510. The speed rotation reading was performed with an automotive multimeter Minipa MA-128. This device was connected to an inductive clamp connected to the engine spark plug wire.

Figure 3. Dynamometer bench with heater and thermometer

To perform the control of the test, it was pre-establish a working speed for the measurements. The control of this rotation, was performed using the brake and the engine with working arrangements at full load, ie full throttle. After stabilization of the measurements on the brake load cell, the inlet air temperature was elevated by the infrared heating device. For each variation of 10 ° C it was record the measurement performed by the load cell. As the dynamometer arm measured 200mm, the power was measured.

4. RESULTS

In order to collect the values of force applied to the load cell, the engine was set to a constant speed of 2,400 rpm. This rotation was adjusted by application of the brake dynamometer with the engine running at full load, ie with the throttle butterfly 100% open.

As the rotation was stabilized, the temperature variation was started in the infrared sterilizer heater duct. As to the environment temperature on the day the test is 17 ° C, the values observed on the load cell were started at 20 ° C, and it was recorded a new measurement at each 10 ° C variation. It was performed 3 experiments following this procedure.

The average results of the experiment can be seen in Tab. 1.

Table 1. Results acquired during experiment controlling temperature

Temperature(°C)	20	30	40	50
Load cell (kgf)	5.29	5.21	5.16	5.06
Power (cv)	3.5	3.5	3.5	3.4
Torque (kgf m)	1.06	1.04	1.03	1.01

From the results obtained in the tests and considering the engine manufacturer's information that is lost on average 1% of the power for each increase of 5.6 ° C. It was noticed that there is an average power reduction to 1.64% per 10 °C increase.

The reduction in power can be explained, among other reasons, by the air characteristic in which there is a decrease in air density with increasing temperature, causing the amount of oxygen existing in the same volume is reduced. As the oxygen needed to combust was decreased to the same inlet air portion, the spent fuel will be less, resulting in a lower power, since the required air-fuel ratio for combustion may be considered fixed.

This indicates that during the operation, the admitted air temperature is an important factor and affect the performance and the motor power.

This result still has to be analyzed regarding the humidity. The temperature increase causes a humidity reduction. This effect can be observed in the psychrometric chart exposed in Figure 4. As the dry bulb temperature increases from 30°C to 40°C, as the red arrow indicates, the air relative humidity decreases from 60% to less than 40%.

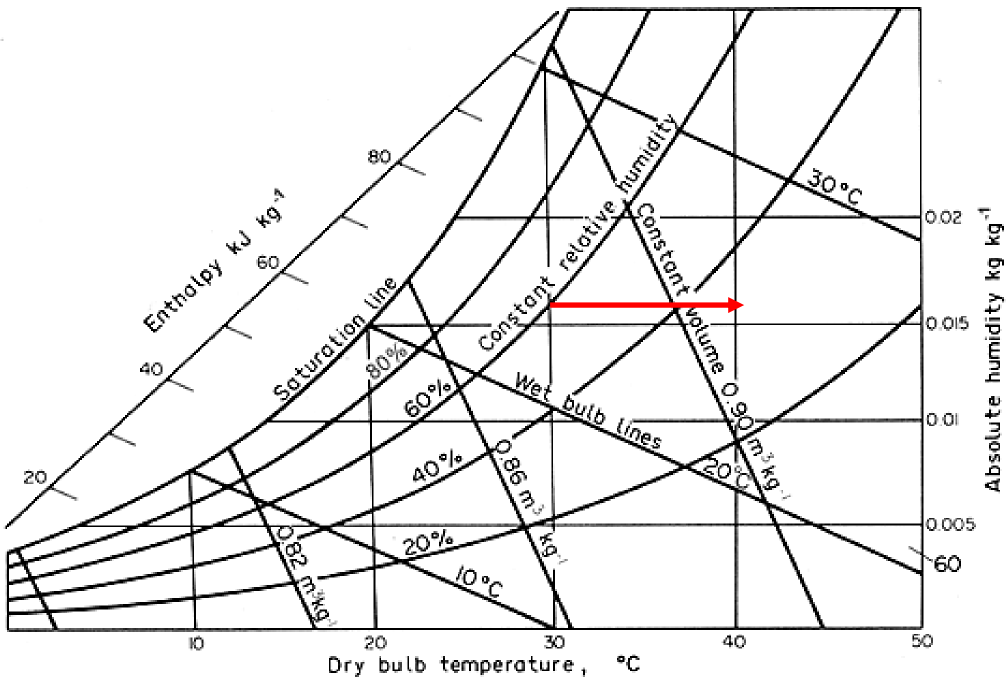

Figure 4. Psychrometric chart and temperature increase operation

Therefore, it is necessary to study the effects of humidity in the motor performance. A new experiment was set up, varying the relative air humidity keeping the temperature constant. The experiment was based on a control volume box, where the inlet air humidity was controlled using a humidifier, as exposed in Figure 5. When the experiment was performed, the control box was closed. The humidity was measured with a thermo-hygrometer equipment. All the experiments were realized in triplicate.

Figure 5. Experiment setup to control humidity

The rotation was set in 2200 rpm and the humidity was varied from 23% to 72%. The results are exposed in Table 2.

Table 2. Results acquired during experiment controlling humidity

Temperature	25° C			
Rotation (rpm)	2200			
Relative humidity	23%	50%	60%	72%
Load cell (Kgf)	5.25	5.20	5.10	5.00
Torque (Kgf.m)	1.05	1.04	1.02	1.00
Power (cv)	3.27	3.24	3.18	3.12

It is noticed that the motor performance reduced as the humidity increased. That is the same trend found in the temperature, however, when the temperature was increased, the humidity was decreased, inducing contradictories effects in the performance. This result was somehow expected, since whenever the humidity is increased, there is more vapor in the air and less available oxygen to the combustion process.

From the analyzed data, it is possible to affirm that the humidity increase induces a performance loss in the motor. It was not possible, however, to affirm that the temperature increase has the same effect. It is necessary, therefore, to study the temperature controlling the humidity, which will be studied in future researches.

5. CONCLUSION

It was possible to measure the influence of the admitted air temperature in a motor performance. It was not possible, however, to affirm that the temperature increase caused a performance loss, since when the temperature increases, the humidity decreases. The humidity influence was studied and both the motor performance and power are reduced by the increase of the humidity. This research indicates that the admitted air humidity is an important factor and should be taken in account when designing and calibrating a motor. For future works, it is suggested to evaluate the temperature controlling the humidity.

6. ACKNOWLEDGEMENTS

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