Relation between the Otto engine rpm and the exhaust gas speed

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Abstract: - This work examines the correlation between the exhaust gas speeds in the exhaust system with operation rounds of an internal combustion engine. For this purpose it has been used a four-stroke, single cylinder, air cooled gasoline motorcycle linked to idraulic brake. For the measurement of the exhaust gas speed, it has been used a tube of Pitot, who was connected to the exhaust tube. Through to the Pitot tube, the measured differential pressure combined with the temperature of exhaust gas was reduced by a special unit signal processing speed exhaust. The recording of measurements was made using the software Vijeo Look Scada, which recorded the measurements from the unit PLC, which controls the brake. From the results of the measurements it was correlated the engine rounds under without load and with load operation with the gas emission speed. From the correlation it derived linear equations through which it can be calculated the engine speed (rpm) from the gas emission speed (m/s) and vice versa.

Key-Words: - Gas emissions speed, Engine rpm, Pitot tube, Internal combustion engine, Four stroke engine

1 Introduction

The gasoline Otto is an internal combustion engine, in which power is produced by the combustion of the mixture of gasoline and air (in particular analogy). The combustion is caused by spark, which ignites the mixture. The petrol engines are the most common internal combustion engines. Their size and strength can vary from less than one horsepower for use in small portable devices up to 35000 horsepower for airplanes. While most are used in cars they represent less than half of the total number of engines used on a global scale. There are single cylinder and multi-cylinder gasoline engines, which use for their cooling either air (air-cooled) or liquid (liquid cooled). Also they are divided into two-stroke and four-stroke engines depending on how they operate[1]. The petrol engines typically used in motorcycles. Smaller motorcycles use single-cylinder engines, while biggest usually use two or four cylinder engines. Previously, it was very popular (mainly in smaller cubic capacity) two-stroke engines, but in recent years their use has been limited due to increased exhaust emissions (hydrocarbons). The exhaust system is composed from metal structures, piping and other components. Its main aim is the management of the engine exhaust emissions[2]. By saying the term “gas management” we perceive that the exhaust system has to perform many basic functions such as:

- To remove the exhaust from the combustion chamber and the vehicle to the environment.
- To limit the noise of the engine exhaust.
- To contribute in the improvement of the efficiency of the engine either alone or incorporating provisions such as the exhaust turbocharger.
- To accommodate the sensors of the engine management system that is related to functions prepared fuel mixture (i.e. lambda sensors and sometimes one or more pyrometers).
- To incorporate the provisions for cleaning the exhaust (catalytic converters, particulate filters etc).
- To accommodate auxiliary systems such as valves and circuits of recycling exhaust etc.

The exhaust system firstly incorporated in different vehicles that brought engines of internal combustion to protect them from the exhaust, integrating all the components needed for cleaning and converting them into harmless to humans and the environment, gas. The other side has to do with noise. Even the smallest internal combustion engine is capable of producing too much noise; if it does not have an effective from the side of subsidence exhaust system[3]. Apart from individual and public health the exhaust system primarily serves the needs of the engine. In a typical gasoline engine the 35 – 40% of the energy contained in fuel is lost in the export in the form of thermal, kinetic and acoustic energy. The exhaust system arranges to take advantage of this energy for the benefit of engine performance, increasing the volumetric efficiency by improving the rate of the cylinder. This is done through the design and specifically the first part of it to exploit the wave nature of the exhausts (the main design feature from the side of performance). The flow of exhaust gases in the exhaust system is a complicated and complex phenomenon that it is influenced by many factors. Even on the same engine with the same exhaust system, the exhaust flow is constantly changing. Then an attempt is made to describe the basic principles and phenomena that are appeared. During the phase of export in a four-stroke cycle operation, the piston moves to the top of the cylinder reducing the total volume of the combustion chamber. At some point, the exhaust valve opens and the exhaust gases escaping into the exhaust system with high pressure and temperature. When the piston reaches the highest point, the exhaust valve is closed; thus creating an exhaust pulse (shock wave) which through the exhaust system escapes into the environment at speeds sometimes exceeding 100 m/sec and temperature to several times exceeding 1000^{o}C. The part of the pulse which precedes (head of pulse) moves outwards from the exhaust system with pressure greater than atmospheric. The middle part of the pulse (body) has almost the same pressure to atmospheric, while the rear (tail) has lower pressure than atmospheric. The low pressure tail of the pulse attracts the high pressure head of the follow pulse, pulling it effectively to the exterior environment. Then as the pulses move downstream in the system, their speed is reduced[4]. This is due to the differential pressure of the head of the pulse and the environment is reduced while the same time the temperature decreases due to their losses. Then the roles are reversed and the high pressure heads of pulses that follow push the intuitive pulse efficiently to the exit. The exhaust system is specially designed in order to allow pulses to align as much as possible so that the phenomenon described above to be more intense and effective[5]. This process helps beyond the efficient removal of exhaust gases from the exhaust system, to pay for the cylinders of the engine with fresh air and fuel as far as the exhaust and intake valves are at the same time open[6,7].

2 Instrumentation and experimental results

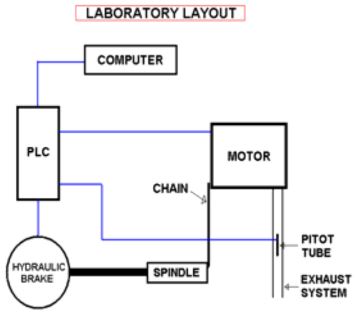
It has been used a four-stroke air cooled gasoline engine, named LIFAN type Smart 125(1P52FMI), volume 119,6cc with one cylinder and max power 7,5hp/7500rpm. The engine is used to propel the motorcycle. The engine was function under different, revolutions and there was a continuous monitoring of the exhaust gases CO, NO, HC and the gas emissions flow for each number of rpm separately. The flow meter that was used is a Pitot static tube type L, which was placed into the exhaust pipe of the engine and transfers the differential pressure of the gas flow, to a pressure transmitter placed at the PLC unit. The transmitter uses this pressure, in combination with the gas temperature, in order to calculate the exhaust gas speed. The PLC unit was also controlling the motor and hydraulic brake operation. The recording and storage of measurements, taken from all sensors placed, were realised via the software Vijeo Look Scada. From the test data resulted linear equations, which relate the engine speed (rpm) with the exhaust gas speed, under both no load and load operation of the engine. The purpose was to discover a relation between engine speed (rpm) and the exhaust gas speed under load and no load conditions of the engine.

The first series of experiments took place with the silencer of the exhaust system fitted and the engine running without load. In these conditions it was found that the exhaust gas speed was unable to calculate. This was due to increased backpressure provoked by the exhaust silencer, especially in high rpm. Increased backpressure prevented the Pitot tube transfer the static pressure of the gas flow to the pressure transmitter.

In the second series of experiments, measurements were taken in both load and without load operation of the engine, having replaced in the silencer with a straight tube. During the measurements it was found that while in no load engine operation were no problems, when load applied there was no gas speed calculation. It was estimated that these problems were the result of turbulent flow conditions created in the exhaust tube. This phenomenon prevented (as in the first series of experiments) the transfer of static pressure to the pressure transmitter. The measurement of rounds/min of the engine was made by a portable tachometer (Digital photo/contact tachometer) named LTLutron DT-2236

In order to calculate the exhaust gas speed under load operation of the engine, in the third series of experiments the prevailing static pressure inside the tube was considered to be equal to the atmospheric. This was implemented by removing the hose carrying the static pressure from the Pitot tube to the transmitter. Note that the actual static pressure in an exhaust pipe was found in previous experiments to be a little bigger (at the level of mbar) than the atmospheric.

For all measurements were conducted under load, was selected the third gear of the engine, which gives us a total final gear 0,24. Also note that the estimated exhaust gas speed was the maximum flow speed, as the. Pitot tube was placed at the center of the diameter of the exhaust pipe.



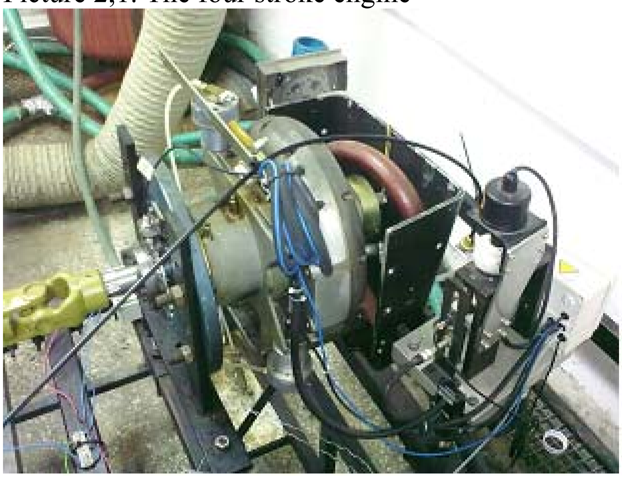
Picture1. Experimental layout

Picture1,1. Experimental layout

Picture1,2. Experimental layout

Picture 2. The four stroke engine

Picture 2,1. The four stroke engine



Picture 3. The idraulic brake

Picture 4. The Pitot tube

Experimental results:

At the first series of experiments that have been done it was placed a silencer in the exhaust system without engine load. During execution of the measurements it has been observed that when the engine was operated at low rounds (rpm), the engine speed could be calculated by the measuring instruments, as the rate of rotation of the engine went up this calculation could not be done, the value of speed was reduced and eventually set to zero (Figure 1).

This is not an expected situation after considering the increase in the volume of supply of exhausts at high speeds, expected increase in speed for the given section of tube.

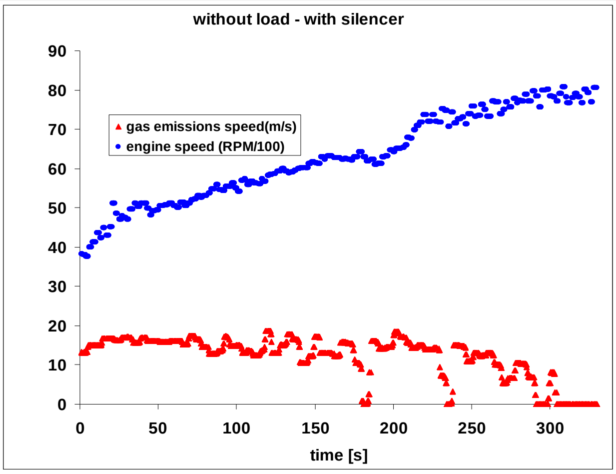


Figure 1. The engine speed and the gas emissions speed variation without load and with silencer

This result is due to the fact that the silencer of the exhaust system caused increased backpressure. In such a situation there are increased returned pulses in the exhaust system. These pulses affect the possibility of transfer the real pressures that prevail from the Pitot tube in to the processing unit of pressures in order to calculate the gas emissions speed. From figure 1 it can be observed that until 4000 rpm the engine speed is increased and from that point and then is declined until to clear completely at about 8000 rpm. This observation led to the decision to replace the silencer with a straight tube from steel with length of 1000mm and internal diameter of 30mm. During the execution of the second series of experiments it has been noticed that while the engine is without load operation there was a linear relationship between engine speed and the gas emissions speed, at the load engine operation there was a failure mode of calculation speed similar to the one of the previous paragraph.

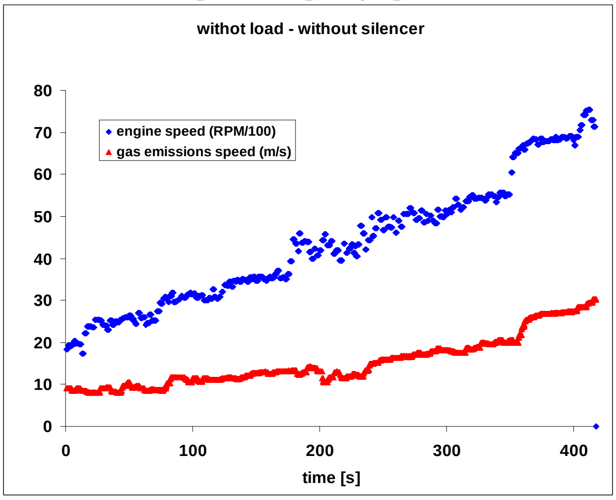


Figure 2. The engine speed and the gas emissions speed variation without load and without silencer

As it can be seen from figure 2, during this process, as the engine speed is increased, the gas emission is increased too.

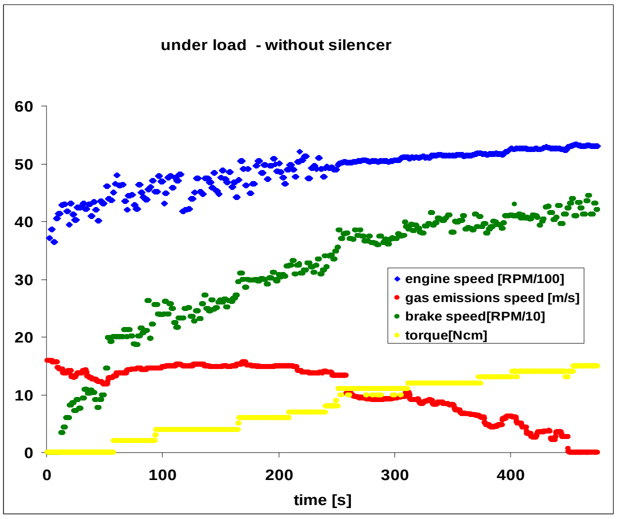


Figure 3. The engine speed, the gas emissions speed, the brake speed and the torque variation, under load and without silencer.

In the measurement of the engine under load, it has been seen that as the engine speed is increased the gas emissions speed is reduced to zero eventually (Figure 3). The difficulty of calculating the gas emission speed under these conditions is probably due to turbulent flow phenomena that occur during the measurement under load but also because of any backpressure by increasing the gas emission speed. As a result it could not be transferred the prevailing static pressure around the head of the Pitot tube pressure in the processing unit. Since the aim was to relate the engine speed and the gas emission speed and having found from previous measurements that under load conditions there was no proper record of the growing gas emission speed in the exhaust system, it has been decided to be regarded as a prevailing static pressure within the exhaust system the atmospheric. This was implemented by removing the elastic tube, which transferred the static pressure from the Pitot tube to the processing unit of pressure. Thus as static pressure was transferred the atmospheric. The gas emission speed under these circumstances could be calculated (and showed a linear relation with engine speed) without load and with load operation. The measured values differ from the actual but the correlation with the engine speed is real and can be calculated.

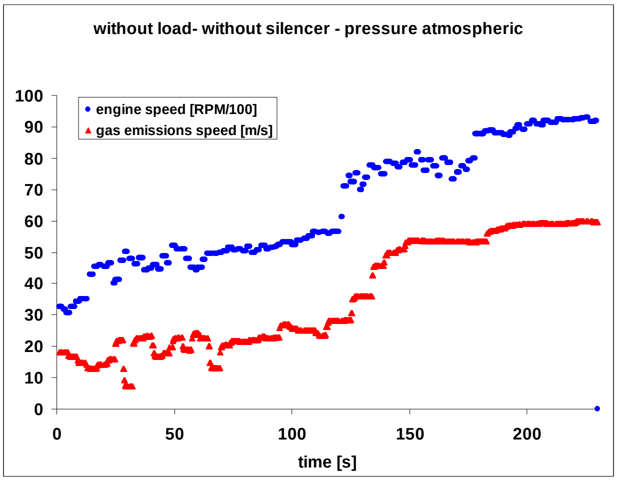


Figure 4. The engine speed, the gas emissions speed, the brake speed and the torque variation, without load, without silencer and pressure atmospheric

As expected the two sizes displayed in figure 4 can be correlated. It is also expected that the absolute measured values of gas emission speed appear greater than those measured in the case where the static pressure transferred to the processing unit of pressure, the prevailing pressure in the exhaust tube.

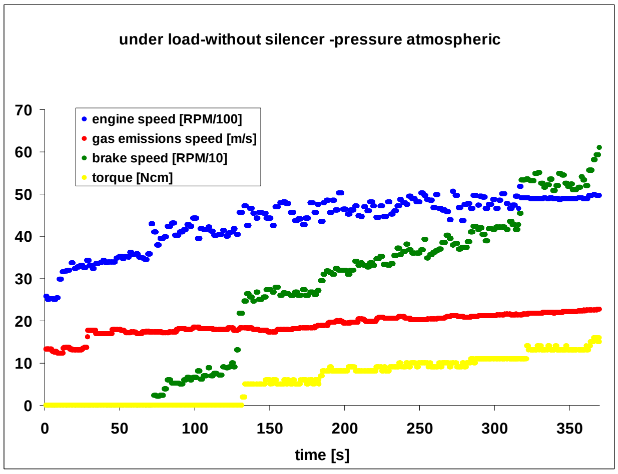


Figure 5. The engine speed, the gas emissions speed, the brake speed and the torque variation, under load, without silencer and pressure atmospheric

From figure 5, it can be observed that under these measurement circumstances there is analogy of gas emission speed and engine speed.

In order to eliminate the phenomena of backpressure and at the same time to take from the processing unit of pressure the static pressure rather than atmospheric, a number of measurements were made under load, with tube of Pitot placed on the end of the exhaust system. Given the fact that at the end of the exhaust system the phenomena of backpressure occurred only because of the impact of gas emissions in still atmospheric air, it was found that under low loads there was a proportional relation between the gas emission engine and speed engine (Figure 6).

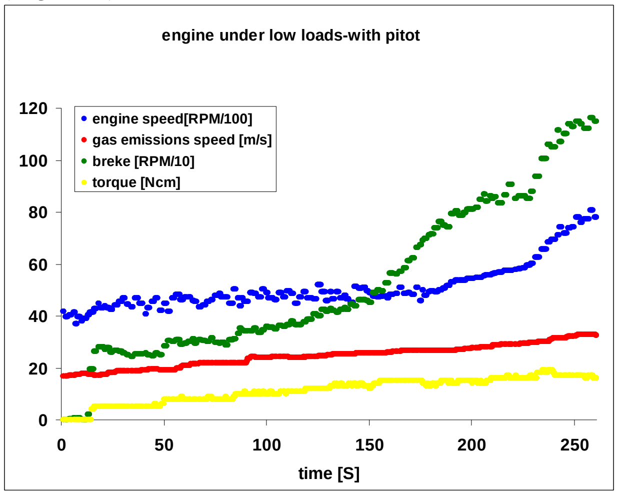


Figure 6. The engine speed, the gas emissions speed, the brake speed and the torque variation, under load, without silencer and with tube of Pitot

As you can see from figure 7, when the loads have been increased to 100% of the engine operation, this proportional relation has been lost.

ISBN: 978-1-61804-062-6

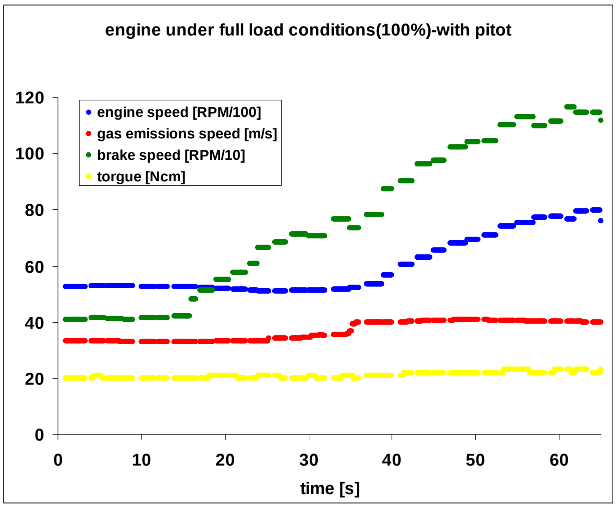


Figure 7. The engine speed, the gas emissions speed, the brake speed and the torque variation, under full load(100%), without silencer and with tube of Pitot.

This observation led to the decision all the other measurements to be made with the unique selection which was to measure the gas emission speed with reduction of the static pressure of gas emissions to atmospheric pressure. Under these circumstances it became possible to identify the relation between gas emission speed and engine speed for all loading of the engine. Below you can see the relation between gas emission speed and engine speed for the cases of measurement:

1) with silencer,
2) without silencer
3) with static reference pressure to Pitot tube to atmospheric pressure.

All the measurements that appeared in figure 8, were made in engine operation without load.

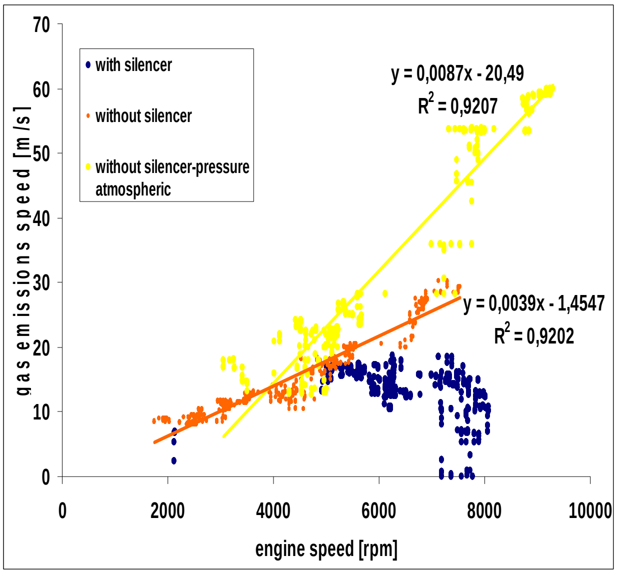


Figure 8. The engine speed, the gas emissions speed, without load, with and without silencer and with tube of Pitot, when the pressure is atmospheric.

It is evident that in the case of measurement with the silencer in the exhaust system is not possible to determine the relation between the gas emission speed and engine speed. But in the other two cases of measurement it can be identified linear relations with indicator of cross correlation as shown in the following analytical relations.

- *Without silencer:*

Gas emissions speed = 0,0039 x Rpm-1,45
Rpm=237,76 x (Gas emissions speed)+705,92
with indicator of cross-correlation:

$$R^2 = 0{,}92$$

- *Without silencer and pressure atmospheric:*

Gas emissions speed = 0,0087 x Rpm - 20,49
Rpm=104,65 x (Gas emissions speed)+2720,6
with indicator of cross-correlation:

$$R^2 = 0{,}92$$

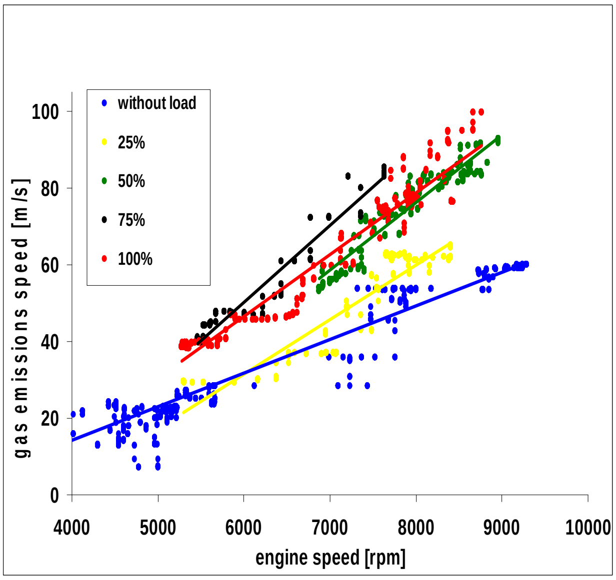


Figure 9. The engine speed, the gas emissions speed, with different loads (25%, 50%, 75%, 100%, without silencer and with tube of Pitot, when the pressure is atmospheric

From figure 9 it can be seen the gas emission speed in relation to engine speed under engine load 0%, 25%, 50%, 75% and 100% in these conditions. It is observed an increase in speed as the rounds of engine are increased for all loads that were made the measurements. Also for each measurement with different load it can be extracted a different linear relation for the engine speed.

The mathematical relations that are associated the gas emission speed and the gas speed under engine load are:

- *Engine under 25% load:*

Gas emissions speed = 0,00142 x Rpm - 53,718
Rpm=57,997 x (Gas emissions speed)-4408,9

ISBN: 978-1-61804-062-6

with indicator of cross-correlation:

$$R^2 = 0,82$$

- *Engine under 50% load*:

Gas emissions speed = 0,0175 x Rpm - 63,808
Rpm=51,151 x (Gas emissions speed)-4092,1
with indicator of cross-correlation:

$$R^2 = 0,89$$

- *Engine under 75% load*:

Gas emissions speed = 0,02 x Rpm - 69,818
Rpm=46,893 x (Gas emissions speed)+3658,2
with indicator of cross-correlation:

$$R^2 = 0,93$$

- *Engine under 100% load*:

Gas emissions speed = 0,0161 x Rpm -49,631
Rpm=58,746 x (Gas emissions speed)+3302,4
with indicator of cross-correlation:

$$R^2 = 0,93$$

From figure 9 it can be observed that there is a tendency to increase the gas emission speed as the load increases. The only situation in where this is not true is when the engine loads 75%, which generally have higher rates of speed from 100% load.

3. Conclusion

From the execution of above experiments exported mathematical relations that associate the gas emission speed with the engine speed, without silencer and: i) without load conditions, ii) without and under load conditions.
In order to calculate the gas emission speed from these measurement instruments under load conditions, the prevailing static pressure rather than the atmospheric, it should be eliminated completely the turbulent phenomena in the narrow layer of the tube Pitot.
Considering the fact that the measurements were made in a close laboratory room and the engine which is air cooled was placed at a fixed immovable basis, future research will be the installation of a cooling system to prevent overheating after some period of operation.

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