Oxygen Partial Pressure Environmental Correction
Computer Software Operation
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1. Introduction

This document discusses the operation of the **Partial Pressure Environmental Correction** software application by Bowling and Grippo. The software was designed to properly determine the partial pressure of ambient atmospheric oxygen for the use as a lean-range calibration standard for wide-band oxygen sensors (UEGO). However, the application can be used to determine the partial pressure of any atmospheric gas and the effects of vapor pressure and altitude.

First, an understanding of air pressure and partial pressure is in order. The pressure of ambient air (atmosphere) can be specified in several ways - the most popular term is "pounds per square inch" or "psi." (known as one atm.). At sea level elevation the average pressure exerted by the atmosphere is 14.7 psi. Pressure measurement of atmospheric pressure (i.e. barometric pressure) is used to determine the pressure at a given moment in time, and is usually provided in units of inches of mercury or Bars (note this is an absolute pressure measurement unit, not gauge pressure).

Minor changes in the atmospheric pressure occur from current weather conditions – these are reflected in the measured barometric pressure. But, changes of pressure due to change in altitude does not stem from the instantaneous weather pattern but from the change in weight of the column of air above the test elevation – higher elevations have less of a column of air above (i.e. less dense). For example, a cubic foot of air at the summit of Mt. Everest contains roughly 1/3 the number of molecules compared to a cubic foot of air at sea level.

Note that the readings of barometric pressure given by the weather bureau and/or media is a corrected barometric reading which is correlated back to sea level. So, locations close to sea level, the reported barometric pressure corresponds to the actual measured barometric pressure – they are the same. However, at high altitude locations, the reported barometric pressure represents a value that has been corrected to sea level; this is not the same as the actual measured pressure. In this case, the actual barometric pressure is lower than the reported value.

In addition to altitude affecting the barometric pressure, water vapor in the air also has an effect. Depending on the environmental situation, the relative humidity can range from 0% (dry air) to 100% (saturated air). Gas molecules, such as oxygen, are displaced by the water vapor. So, to determine the relative percentage of oxygen (and other gases) the amount of water vapor needs to be accounted for. Vapor pressure depends on humidity and air temperature.

Next, let’s look at the actual composition of air. Air is a mixture of gases, mainly oxygen (21% by volume) and nitrogen (78% by volume). The other 1% of air is made up of several other gases such as carbon dioxide (CO2), argon, krypton and neon. In any inert mixture of gases (e.g., air), the individual gases don't chemically combine with each other - the gases maintain their individual identity and percentage regardless of how much or little pressure the mixture is subjected to. This is important: the percent distribution of gas remains the same even if the pressure is increased or decreased (unless an external reaction or introduction of another air species upsets the ratio).

This is stated in Dalton’s Law: The total pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume. In other words, the pressure of any gas mixture (like air) is equal to the sum of all of the pressure exerted by each of the gas present in the mixture. Stated yet another way, the total pressure of a mixture of gas is just the addition of all of the partial pressure of each of the gas components. Think of partial pressure as “parts of pressure” – you add up all of the parts of the pressure to get the total pressure, with each gas giving a “part”.

Partial pressure is related to the fraction of a gas present multiplied by the pressure of all of the gases (excluding vapor pressure). So, if there is one atmosphere of pressure present in a mixture containing 21 percent oxygen, then the partial pressure of oxygen is 1 atm. multiplied by (21% / 100) = 0.21 atm.

Lets take this same calculation a step further: assume you are located on a elevation where the actual pressure is 0.8 atmospheres (i.e. not corrected to sea level). The same distribution of oxygen is present (21 percent). However, the partial pressure of oxygen is now 0.8 * (21% / 100) = 0.168 atm. Note that the percent oxygen is the same (i.e. 21%) but the actual partial pressure is lower (0.168 atm. compared to the 0.2 atm. value at sea level). The percent oxygen in the gas mix is the same, but the partial pressures are different – they are different because the overall pressure is different.

So, if one uses atmospheric pressure as a calibration point (i.e. free-air calibration) for a Lambda wide-band sensor (oxygen sensor), then it is very important to know the actual partial pressure of oxygen. And, equally important, is to know the amount of vapor pressure – remember, water vapor displaces oxygen.

Most curves given by Lambda sensors are based on percent oxygen tested at a specific test pressure (this yields the partial pressure) – you have to know the test environment pressure. However, by using a simple ratio, a partial pressure at a given measurement environment can be converted to a specific curve value obtained at a specific test pressure, while factoring out the effects of vapor pressure. In other words, an oxygen partial pressure of 20.95% at a barometric reading of 25.00 in Hg (roughly one mile above sea level) gives a partial pressure of (25.00*20.95/100 = 5.23 in Hg, no water vapor). To get the same partial pressure at 30.00 in Hg (where the curve for the sensor was generated), an "assumed" oxygen percent of 17.43% can be used – this gives the same partial pressure (30.00 * 17.43%/100 = 5.3 in Hg).

So, using this corrected percent oxygen value, which is really just a scaling of the percent oxygen for partial pressure's sake and not the actual oxygen ratio, you can calibrate your lean range of your lambda meter. Since the response of the sensor feedback pump current to oxygen partial pressure is linear (i.e. increase the partial pressure of oxygen and the pump current will increase by a proportional amount), one can use this adjusted percent oxygen percent value to properly calibrate the sensor at any environment.

If your sensor controller does not yield pump current as an output (it really should!) then you will have to convert the percent oxygen to a value of lambda and use this for calibration. For a Hcv ratio (hydrogen to carbon) of 2 (i.e Hexane), the following can be used:

$$\lambda = \frac{\frac{\left(\frac{X_{O2}}{100}\right)}{3} + 1}{1 - 4.76\left(\frac{X_{O2}}{100}\right)}$$

Note that as one approaches high oxygen partial pressures, the value for lambda will be extremely large – for example, at 20.95% oxygen, the value for lambda is 384.8.

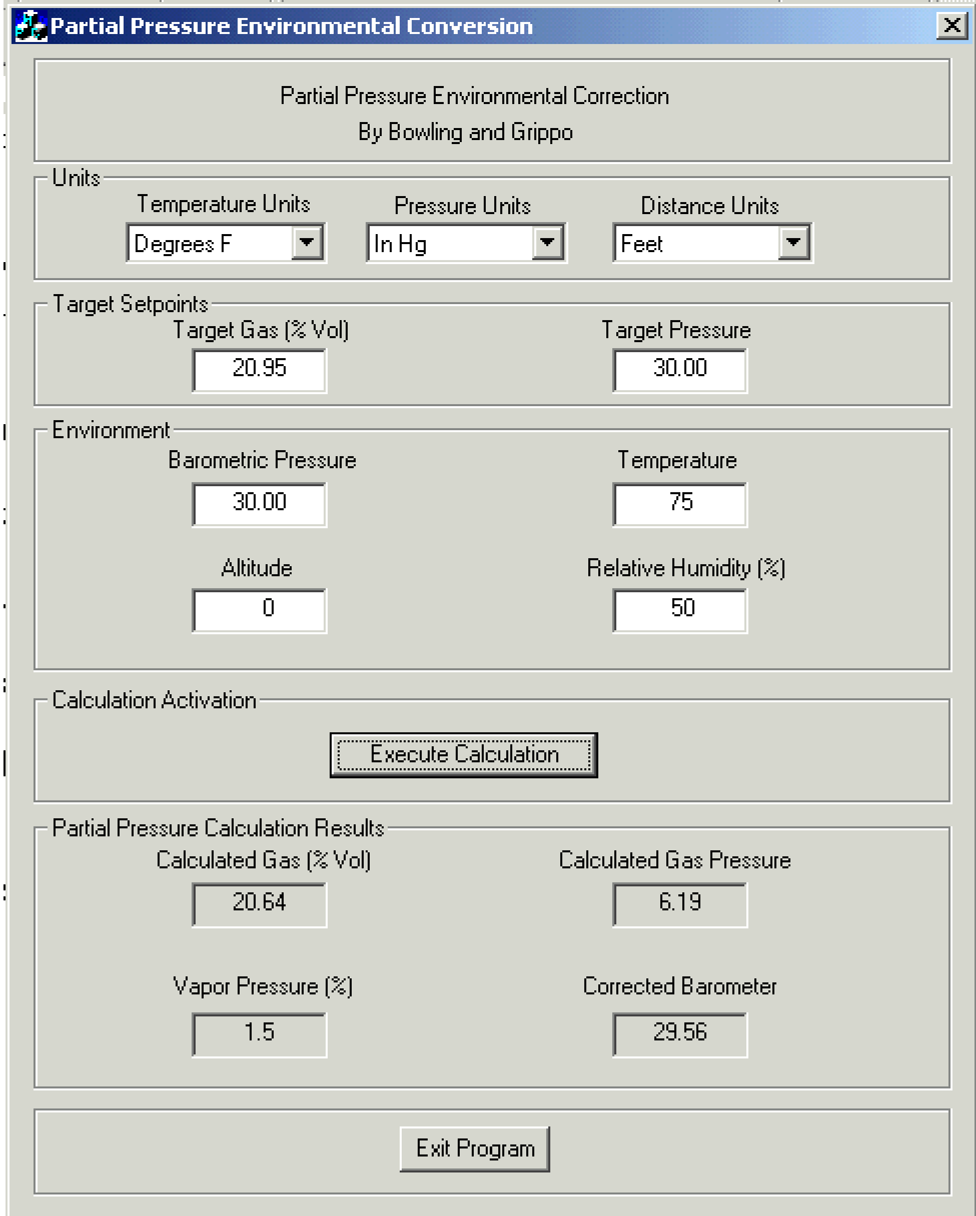
Finally, it **must** be noted that free air calibration of wide-band lambda sensors only corrects for excess oxygen measurement – i.e. the lean range of the sensor. Hence, the lean sensor range will be calibrated. The rich side of the lambda sensor will not be calibrated. The sensors used in lambda meter applications (e.g. NGK or Bosch LSU) are sensitive to O_2, NO, H_2, CO, and HC (with different sensitivity constants for each gas) and these are all present with lambda values less than 1 – for this range other calibration methods are needed.

2. Software Application Operation

Operation of the **Partial Pressure Environmental Correction** application is very simple. To install, simply unzip the application into a directory on a PC (operating systems 95/98/2K/XP/ME/NT). All files and DDL libraries are present for operation, the application does not need to be installed, and there is no installer script. Leave all files in the folder, and execute from this folder.

To delete the application, simply drag the files to the trash folder – since it was not installed, it does not requires a uninstall script operation to delete.

Double click on the application to start execution. You will see the following screen:



There are several input boxes and pull-down menus, which provide user data to the application. Each is discussed below:

- ***Units: Temperature Units***. This pull-down menu selects the temperature units for the application. Choices are degrees F or degrees C.
- ***Units: Pressure Units***. This pull-down menu selects the pressure units for the application. Choices are inches of mercury, millimeters of mercury, Bar, or Kilopascals.
- ***Units: Distance Units***. This pull-down menu selects the distance units. Choices are feet or meters.
- ***Target Setpoints: Target Gas (% Vol).*** This sets the target gas percent value, which is the value of the gas at the test atmosphere. Leave at 20.95 percent (oxygen) unless you have other specific data.
- ***Target Setpoints: Target Pressure***. This is the test pressure, defined for the measurement curve. The value of 30.00 inches of mercury is a good default,

unless you have specific datasheet values. The unit of this quantity is defined by the Pressure Units pull-down menu selection above.

- ***Environment: Barometric Pressure***. This is the current barometric pressure for your location, corrected to sea-level. This is the value that is reported by the local weather bureau. The unit of this quantity is defined by the Pressure Units pull-down menu selection above.
- ***Environment: Temperature***. This is the temperature of the air at your location. The unit of this quantity is defined by the Temperature Units pull-down menu selection above.
- ***Environment: Altitude***. This is the altitude of your location above sea level. This is used to correct the barometer reading above from sea level to your location. The unit of this quantity is defined by the Distance Units pull-down menu selection above.
- ***Environment: Relative Humidity (%).*** This is the relative humidity of your location in terms of percent.
- ***Calculation Activation: Execute Calculation***. This performs the calculation and updates the result boxes below. Note that you have to click on the calculate button in order for the calculation to execute. Updating an entry field does not automatically execute the calculations.
- ***Partial Pressure Calculation Results: Calculated Gas (% Vol).*** This is the calculation result for the percent oxygen scaling, based on maintaining partial pressures between the test environment and your actual environment, subtracting vapor pressure. This is the value that you will use to calibrate your Lambda sensor.
- ***Partial Pressure Calculation Results: Calculated Gas Pressure***. This is the actual gas partial pressure, in the units selected by the Pressure Units pull-down menu.
- ***Partial Pressure Calculation Results: Vapor Pressure (%).*** This is the percent vapor pressure in the gas quantity.
- ***Partial Pressure Calculation Results: Corrected Barometer***. This is the corrected barometer reading, corrected for altitude and vapor pressure.

To exit the program, click on the exit button located on the bottom of the application window.