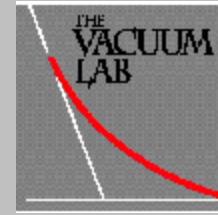


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## Will RGAs Replace Ion Gauges?

*Pressure measurement in high vacuum can be important, but is an ion gauge good enough, or do you need a residual gas analyzer?*

The requirement to measure the pressure within a vacuum system is one of the important parameters that is common to all vacuum systems. There are myriad techniques and instruments to fulfill this universal need that spread across the entire range of pressures from atmospheric pressure to ultrahigh vacuum. The technique and instrument of choice is usually dictated by the process application in terms of both the pressure range and degree of accuracy and precision of measurement to fit the process requirements. In general, the lower the pressure that the process requires, the more important the pressure measurement becomes, and the fewer the choices of both techniques and instruments. Processes that require pressures in the high vacuum (less than  $10^{-3}$  torr) or lower regimes are usually dominated by ionization gauges (IG) and residual gas analyzers (RGA).

Within the common verbal usage of the vacuum community, IG's are said to measure total pressure and RGA's are said to measure partial pressures. Since the residual gas within any vacuum system is almost never a single gas, total pressure would be a summation of the pressures of each specific gas within the chamber. If, then, you install an IG on a system and read the meter, you'd be safe in calling the meter reading the total pressure according to common usage terminology. Accordingly, the output of an RGA would be interpreted as providing partial pressures of the various residual gases. This is one of the examples where common, or sloppy, terminology can cause important misunderstandings. You have read a number, but it probably isn't really the total or partial pressure(s) in the real sense. To clarify this, we need to look further into the instruments and sensors themselves.

### The Ionization Process

An IG or RGA tube (sensor), mounted on the vacuum system, provides a source of electrons in sufficient quantity (current) and energy (voltage) to impact the neutral gas molecules and knock an electron, or electrons, loose to leave a positively charged gas ion. At a fixed, and controlled, current and energy, the electrons will impact a statistical portion of the gas molecules and cause ionization. The ionized gases are collected on an anode where the dc current generated as they give up their charge is measured. This current is proportional to the number of ions formed which is, in turn, proportional to the number of gas molecules in the system. The readout on the IG controller, then, is the ion current of any

and all positive ions formed, but it is displayed as pressure with a sensitivity factor such as amps/torr applied. Although IG's are divided into two main groups (hot cathode and cold cathode), the ionization formation and ion collection mechanism is the same. In hot cathode tubes, the source of electrons is from a hot wire of refractory metal, usually tungsten (W), or a thoria (ThO<sub>2</sub>)-coated Iridium (Ir). A cold cathode tube provides electrons that are trapped and constrained within a magnetic field. There are many other differences between the two IG's, but those differences are a subject unto themselves, and we only need to consider them together here. The same ionization process occurs in an RGA, but an additional array is interposed between ionization and collection electrodes to separate the ions by mass and/or energy before collection and measurement.

In the simplest sense, an electron will impact a neutral gas molecule and knock an electron away from the gas molecule to leave a positively charged ion according to the equation:  $e^- + \text{Gas} \rightarrow \text{Gas}^+ + 2e^-$ . This would seem to be straightforward enough, but each gas species will be ionized with a different efficiency. This effect is usually referred to as the ionization cross-section. It's a lot like shooting at targets with different diameter bulls-eyes. Thus, the number of gas ions produced will vary depending upon the identity, and attendant ionization cross-section, of the residual gas. This then, in turn, will produce an ion current that will depend upon the gas's identity. Some gases will also become doubly as well as singly ionized:  $e^- + \text{Gas} \rightarrow \text{Gas}^+ + \text{Gas}^{++} + 3e^-$ , and this effect will also change the collected ion current. Since diatomic gases such as nitrogen (N<sub>2</sub>), oxygen (O<sub>2</sub>), and hydrogen (H<sub>2</sub>) are common in vacuum systems, it's necessary to realize that they will ionize into both monatomic and diatomic ions such as  $\text{N}_2 \rightarrow \text{N}_2^+ + \text{N}^+$  where differing ionization efficiencies will occur due to the need to break the diatomic bond. This effect becomes more complex as more complex molecules are ionized. For example, methane (CH<sub>4</sub>), a common residual gas, will fragment into  $\text{C}^+ + \text{CH}^+ + \text{CH}_2^+ + \text{CH}_3^+ + \text{CH}_4^+$ . As the neutral molecules' complexity increases, the ionization process's complexity increases. Long-chain molecules such as solvents or pump oils that are common within vacuum systems will fragment during ionization to produce groups of fragments that are particular to the gas being ionized, and these are commonly referred to as fragmentation patterns.

Relative Ionization-sections	
H <sub>2</sub>	0.42
He	0.14
CH <sub>4</sub>	1.57
N <sub>2</sub>	1.00
CO	1.07
O <sub>2</sub>	1.02
Ar	1.19
CO <sub>2</sub>	1.36

*Relative ionization cross-sections normalized to N<sub>2</sub> show the differences in ionization efficiency during the ionization process.*

All of these differences that arise from the ionization process of the various gases in a vacuum system can and will lead to inaccuracies in the measurement of either total or partial pressure. Whether these inaccuracies really matter or not depends upon the application and process being undertaken, and decisions must be made somewhere along the line about the possible problems and whether an IG or an RGA is the best instrument to use.

## Ion Gauges

Establishing process parameters can be a difficult undertaking, and many processes are provided with hit-or-miss pressure parameters. If, for example, a process requires that some ultimate

IG reading be attained before starting the process, it might well be that there is enough forgiveness built into that reading to ensure that the process will be within specs if the reading is anywhere close to the spec. In a batch system, the amount of water vapor at the process ultimate will vary from day-to-day as well as seasonally. With higher summer humidity, it is expected that longer pumpdown times will be required to reach the same pressure than in mid-winter. In some cases, it's safe to assume that the main residual gas is water vapor, but in many other cases, it isn't. Due to the variations in the ionization process, the same IG reading might represent only one of several mixtures of residual gases. Whether this is a problem or not depends upon the process.

IG applications where a process gas is purposely admitted to the chamber as the predominant gas in the mixture, a different situation exists, and IG readouts are almost always calibrated for N<sub>2</sub>. In these applications, the practitioner can turn to correction factors that have been determined for that gas, and if no large quantities of other gases are present as contaminants, a fairly true pressure reading can be achieved. In general, you can't believe an ion gauge reading without calibration.

## Residual Gas Analyzer Applications

RGA's have the same problems in accuracy stemming from the ionization process as IG's, and they have an additional problem in that the array used to separate the ions by mass and/or energy can also introduce differences. Quadrupole mass filters are arguably the most prevalent in the field, and they result in variations in ion transmission due to mass discrimination as the ions are being sorted. Since the normal terminology refers to the RGA as giving partial pressure measurements, it's necessary to constantly remind ourselves that what we are seeing on the readout device is really peaks of ion current at mass readings. They are not to be taken as partial pressure readings or measurements.

### Relative Ion Gauge Sensitivity For Single Gases

H <sub>2</sub>	0.48
He	0.18
CH <sub>4</sub>	1.50
N <sub>2</sub>	1.00
CO	1.05
O <sub>2</sub>	0.85
Ar	1.20
CO <sub>2</sub>	1.40

*Divide Gauge Reading by Sensitivity for True Pressure (Gauge Readouts are in N<sub>2</sub> Calibration)*

RGA's do, however, provide vast amounts of useful and sometimes essential data that is not available with an IG alone. Comparison of peak heights at the same mass position from day-to-day or run-to-run can help spot incipient problems before they get out of hand. For example, an increasing peak height at some position can often give early warning to a build-up of some problem contaminant. Additionally, problems such as leaks can be easily spotted before a process is initiated, and then the RGA can be tuned to lock onto a probe gas such as helium to help locate the leak. At this point we can begin to see the separation in the two main uses of RGA's. They can be used as a system and process monitor where relative readings can be compared, or they can be used as a true measuring device for partial pressures. In both cases, calibration is important.

## Calibration

Calibration of both IG's and RGA's is only as important as the amount you need to rely upon their readings. In some cases, only occasional calibration is required, but if they are to be used for true quantitative readings, daily or better calibration is often required. There are a number of acceptable techniques, but on a continual basis, the most acceptable is usually using a calibrated leak that will allow you to introduce a known amount of a single gas or gas mixture into the system for the IG or RGA to measure. These can be purchased and installed permanently on a system if required. For RGA's a known gas mixture that includes some of the common residual gases over the entire mass range of the instrument is probably best.

## Ion Gauge or RGA?

There is no single answer. you have to carefully consider the application. In most systems, an IG and an RGA are often both used. There are usually total pressure readouts on RGA's but they are only a rough indicator, and shouldn't be relied on as more than that. RGA's provide a lot of information, but that can be a problem too in that they can overwhelm you with information. Consider carefully what you need to accomplish with your application and make your choice(s), but don't accept the reading provided by either.

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