THE ROLE OF THE PRESSURE GAUGE IN HEPA-FILTERED CLEAN AIR DEVICES

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Abstract: HEPA-filtered clean air devices – systems containing both a fan and a HEPA filter – are prevalent today in many modern applications. They include laminar flow / biological safety cabinets (hoods) for laboratory applications, in addition to cleanroom equipment such as fan filter units. This technical paper outlines the theory of operation of the pressure gauge, which is commonly used in the industry as an indicator on HEPA-filtered clean air devices. Most significantly, common misconceptions as regards the functionality of pressure gauges with regards to HEPA-filtered clean air devices are discussed in detail. Proper usage practices are also recommended.

1. INTRODUCTION AND THEORY OF OPERATION

The pressure gauges found on all HEPA-filtered clean air devices, are, at the most fundamental level, indicators of differential pressure. In a HEPA-filtered clean air device, for air to move across a HEPA filter, there must be a difference between the pressures of the plenums (an enclosed air space in which the pressure at multiple points is almost uniform) before and after the filter. Air will then move from a region of higher pressure across the filter to a region of lower pressure. A fan is used to create this pressure difference.

For example, a fan may be used to pressurize air positively (with respect to the ambient environment) in a plenum. Air is then forced from a region of high pressure before the filter, across the filter, into a region that has a pressure roughly equal to that of the ambient atmosphere. This last region may be, for example, the work zone of a laminar flow cabinet. In theory this region may be defined to be under slight positive pressure (due to “velocity” pressure or the pressure “exerted” by the laminar air stream) but in practice it may be considered to have a pressure equivalent to that of the ambient environment. In this scenario the fan can be thought of as "blowing" air across the filter. It is also possible for a fan to be "sucking" air across a filter - fundamentally this is the same and a pressure difference also exists. The pressure difference is also referred to a "pressure loss across the filter" or a "pressure drop across the filter".

Therefore, a pressure gauge indicates the difference in pressure between the plenums present before and after the filter. In the example above ("blowing"), the pressure gauge indicates the difference between the region of high pressure before the filter, and that of the ambient environment (atmosphere). Practically this value is derived by subtracting the ambient pressure value from the actual value of the positive pressure plenum before the filter. Note that on all HEPA-filtered clean air devices the pressure gauge only reads in one direction (i.e. its value cannot be negative).

When a pressure gauge is present on a HEPA-filtered clean air device it indicates pressure as follows: one sampling tube will be connected to the plenum just before the filter and the other sampling tube will be connected to the plenum just after the filter. The gauge then indicates the pressure difference between both plenums. In the case of a laminar flow cabinet, for example, a sampling tube will be connected to the positive pressure plenum just before the filter, and the other tube connected to the exterior of the cabinet to sample ambient pressure. In the case of Esco laminar flow cabinets, the second tube is connected to the region of negative pressure that is before the fan but after the pre-filters. Hence on Esco cabinets the pressure gauge indicates the pressure difference not only across the main HEPA filter but across the entire fan system (taking into consideration the drop across the pre-filters).

Differential pressure gauges (also called a manometer) are available in different display units. Common display units include inches of water, millimeters of water, or Pascal’s. The most common pressure gauge suitable for indicating the relatively low differential pressures present on HEPA filters is unequivocally the Minihelic / Magnehelic series of gauges manufactured by Dwyer Instruments Inc. Esco products make use of a gauge displaying in terms of inches of water ("Inches W.C.").

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2. USING THE GAUGE ON HEPA-FILTERED CLEAN AIR DEVICES

A HEPA filter when new and unused has a certain pressure drop to produce a certain amount of airflow. For example, new Esco filters are rated at less than 125Pa / 0.5" W.C. to produce an linear air velocity (across the filter) of 0.45m/s or 90fpm. Most manufacturers try to optimize the performance of their HEPA-filtered clean air device by minimizing this initial pressure loss. The lower the initial pressure loss value, the less "work" the fan has to "do" to maintain airflow and the more efficient the fan system.

However, as a filter "loads" during the normal course of operation, to maintain the same air velocity across the filter, the pressure loss will increase. For example the pressure drop required to maintain 0.45m/s or 90fpm on an Esco filter may increase from 125Pa / 0.5" W.C. to 150Pa as the filter "loads". This is due to the fact that during the normal course of operation the filter will "collect" fine particulate matter in the media bed causing greater resistance to airflow. In practical terms all manufacturers would recommend that the user adjust a variable speed control regularly to increase the speed of the fan system (above its initial speed setting) to compensate for this increase in resistance and maintain airflow in the system. This adjustment must in most cases be validated by a true airflow velocity meter. Adjustments CANNOT be performed using the pressure gauge. This is because the pressure drop across the filter, to maintain the SAME amount of airflow, is NOT a constant and depends on the "health" of the filter. It is only a known constant when the filter is new.

In any HEPA-filtered clean air device the user's concern is undoubtedly to maintain a proper quantity of airflow in the system. On a laminar flow cabinet the user's goal will be to maintain a laminar airflow velocity of approximately 0.45m/s or 90fpm for example. On a Class II biosafety cabinet the user will try to maintain certain downflow and inflow setpoints / velocities which in turn translate to a certain amount of airflow across the entire filtration system. Airflow, NOT pressure loss across the filters, is the primary factor that translates into performance and/or safety (apart naturally from other aspects such as filter integrity and efficiency).

The pressure loss across the filter as indicated by the differential pressure gauge may be thought of as an indicator of the "health" of the filter or the efficiency of the entire blower system, provided that airflow is maintained by (a) speed control adjustments and (b) validation with a true airflow velocity meter. The higher the operating pressure loss of the filter, the "poorer" its health and the less efficient the blower system.

The user will note that on every filtration system there are two operating pressure points that can be determined. When the filter is new there will be a certain operating point to maintain a certain airflow setpoint. As the filters become loaded and the speed of the fan is increased to maintain airflow the filtration and fan system will soon reach another operating value - this operating value can be thought of as a "maximum" beyond which the fan cannot work any "harder" to deliver airflow. Hence, a theoretical application of the pressure gauge is, provided that airflow is maintained and measured with an independent meter, as a linear "scale of filter loading" - a scale ranging from the initial value explained above to the final value. That is, as the reading on the gauge increases from the initial value the user will know how much "pressure capacity" the fan has left to maintain airflow. As the reading on the gauge approaches the "known maximum" the user will know that the filter must soon be replaced. In practice this is hard to apply because for every single unit the initial and final operating points may be different.

Practically though the pressure gauge has some useful applications. On Esco cabinets, the initial operating pressure corresponding to the required airflow setpoint is recorded at the factory during initial commissioning. If the setting on the variable speed control has been accidentally reset or adjusted before actual use the user may, upon actual use, adjust the variable speed control so as to operate the filters at the same pressure point.

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In general the pressure gauge can also indicate very roughly airflow across the filter. On a new filter an operating point of 125Pa or 0.5" W.C. corresponds to a filter velocity of roughly 0.45m/s or 90fpm. Although this operating pressure point may increase as the filter loads, under all conditions, an increase in pressure across the filter (in the same operating "health" condition) corresponds to an increase in airflow. The pressure gauge may hence be used as a relatively inaccurate airflow meter that is "true in itself".

In pharmaceutical applications, to meet GMP requirements, a pressure gauge is useful from the point of view that is allows the user to record operating conditions in terms of the pressure loss across the filter. In many cases, a pressure gauge is the only airflow meter available economically, and may be though of as "better than nothing" (although it is far from ideal). If there is a pressure loss across the filter, the user knows that there is airflow across the filter (although he or she will not know the airflow velocity).

Remember that a pressure gauge is not an indicator of airflow (as much as manufacturers may like to lead you to believe otherwise) and should not be used as such under any circumstances. Esco has encountered in the industry many false recommendations such as "the filters should be changed when the pressure exceeds 1.5 inches W.C." (yes, this is correct, PROVIDED that airflow is maintained with an independent meter - this is something that is often unstated). Other recommendations read in such a manner as to lead (in our opinion) the user to think of the pressure gauge as an airflow meter.

Increasingly, pressure gauges are being replaced by "true" electronic airflow meters on higher-end equipment (such as biosafety cabinets). At Esco, pressure gauges have already been replaced on all higher-end Esco Labculture horizontal and vertical laminar flow cabinets, in addition to all biosafety cabinets.

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