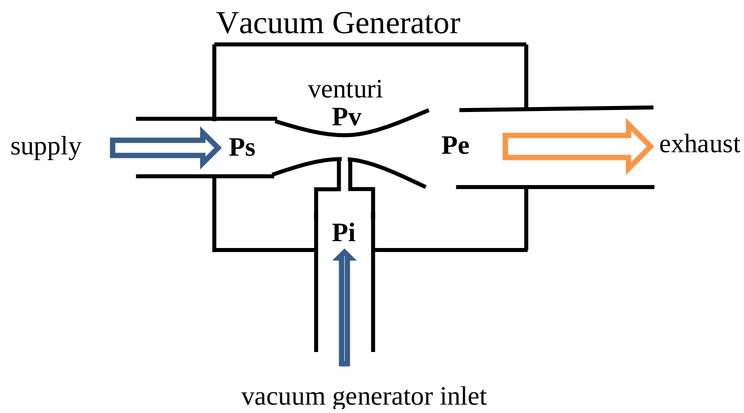
Product Note, PN 434, Revision 1
Vacuum Generator Exhaust

May 22, 2014



AP Tech recommends using the shortest and simplest possible exhaust plumbing to achieve optimum vacuum generator performance, such as 3 feet of 3/8 inch diameter exhaust line. Why is this necessary?

According to Bernoulli's Principle, a fluid stream's total energy is conserved. Vacuum generators use the conservation of energy principle and the venturi effect to develop useful vacuum. The pressure differential between supply pressure, ***Ps*** and exhaust pressure, ***Pe*** accelerates supply gas through a short narrow passage called a venturi. ***Ps*** must be sufficient to ensure choked flow in the venturi throat. Choked flow is present for gases with k=1.4 when the absolute pressure ratio ***Pe/Ps*** < 0.528 (critical pressure ratio). Choked flow maximizes gas velocity and results in the lowest achievable ***Pi***. If not maintained, **Pi** becomes unstable with loss of vacuum. When accelerated, much of the gas potential energy (pressure) is converted to velocity. Due to conservation of energy, a low pressure zone, ***Pv*** is created in the venturi. This zone is tapped to the vacuum inlet port. Inlet gases at pressure, ***Pi*** are drawn into the exhaust stream due to the pressure differential between ***Pi*** and ***Pv***. The inlet gases are entrained and exhausted at pressure, ***Pe***. Most vacuum generators use an inert supply gas such as N2 to generate vacuum. This enables the dilution of evacuated gases and safe transport from a process gas system.

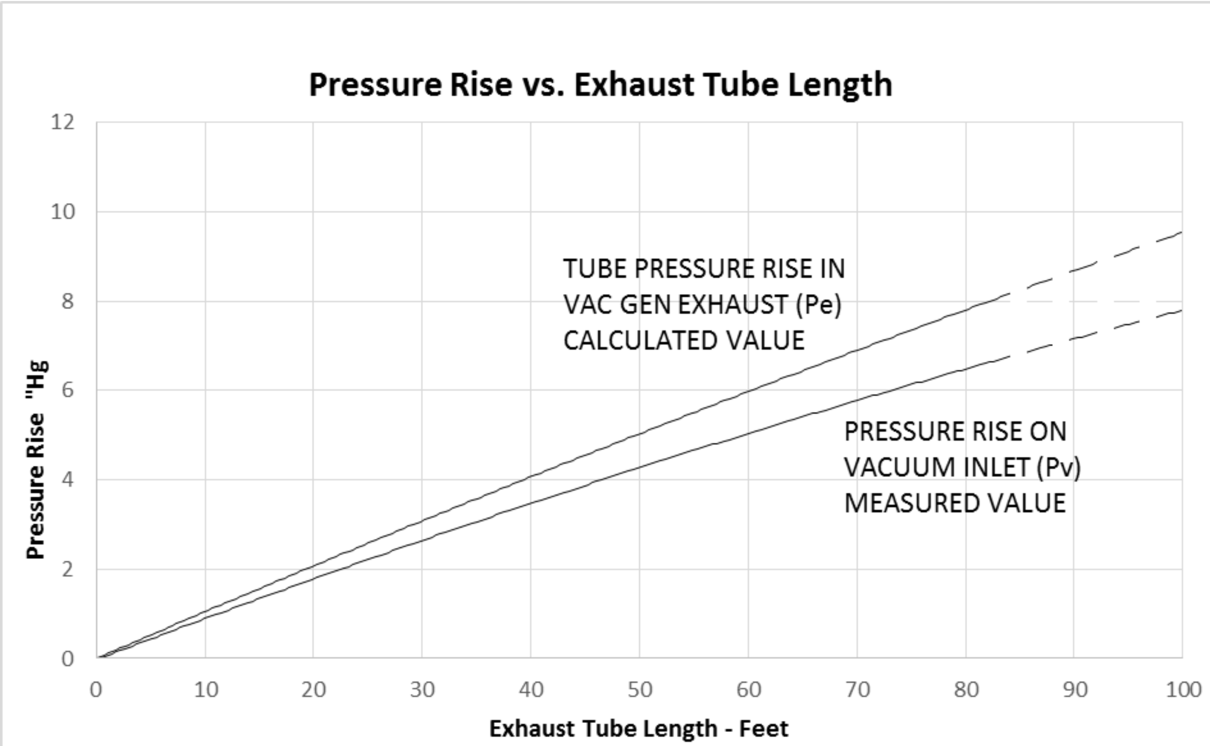
How does exhaust pressure impact the performance of the vacuum generator? Longer and more complex exhaust systems result in higher ***Pe*** due to frictional losses. Under pumping conditions, ***Pe*** > ***Pi*** due to differences in gas velocity and other factors. However, in accordance with the conservation of energy principles, the *total* vacuum generator inlet gas energy ***is*** coupled to *total* exhaust stream energy. It is known that when ***Pe*** rises above atmospheric pressure, ***Pi*** rises by a similar amount at no inlet flow conditions. While the exact relationship between ***Pe*** and ***Pi*** is complex and beyond the scope of this analysis, it is accurate to suggest that ***Pe*** and ***Pi*** are interrelated. To investigate the relationship between ***Pe*** and ***Pi*** the following analysis is provided.

Data regarding the tube geometry, supply gas pressure, temperature, and flow are entered into a calculator spreadsheet. Vacuum generator flow is viscous and turbulent (Reynolds number >> 2,000), so the Darcy-Weisbach equation shown below is used to calculate ***Pe*** as a function of exhaust tube length. Other elements (e.g. bends, tees, valves) in the exhaust tubing add to the pressure drop, but for simplicity, the analysis was conducted with straight electropolished 3/8" X .035" wall tubing of length L.

$$P_e = P_{atm} + \frac{f \times L \times \bar{v}^2 \times \bar{\rho}}{2 \times d_e \times g_c}$$

f = Darcy friction factor, L = exhaust tube length, $\bar{v}$ = mean exhaust gas velocity,
$\bar{\rho}$ = mean exhaust gas density, d_e = exhaust tube diameter, and g_c = gravitational constant

With negligible inlet flow, ***Ps*** is set at 80 psig with 65 slpm of nitrogen at 60°F and is exhausted to atmospheric pressure. The Sutherland equation is used to estimate gas viscosity and Haaland equation used to estimate the friction factor enabling an accurate calculation of the Reynolds number (further calculator spreadsheet details not included here for brevity). The resulting vacuum generator pressure dependency on exhaust tube length is graphed below. A vacuum generator was tested for pressure rise in ***Pi*** as a function of rise in exhaust tube pressure, ***Pe*** with no inlet flow. The experimental pressure rise data is graphed along with the calculated exhaust pressure. The data was collected with controlled laboratory conditions and with accurate laboratory instrumentation. Different piping configuration, gases, and operating conditions will yield different results.



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For example, a vacuum generator is installed to evacuate process gas. The initial rough installation is done with no exhaust tube, exhausting directly to atmosphere (***Pe***=0"Hg). Vacuum inlet pressure (***Pi***) is measured to be -26"Hg with no inlet flow. To safely exhaust process gases to a scrubber, 10 feet of straight 3/8" exhaust tube is added. Exhaust pressure rises to 1"Hg (0.53 psig) at the generator and Pi rises by a similar amount delivering nearly -25"Hg with no inlet flow.

In summary, long and/or bent exhaust tubing decreases vacuum. A pressure rise due to frictional losses in the exhaust path will lead to degradation in the achievable vacuum (***Pi***) level. Further, it was shown that for practical tube lengths, the exhaust pressure (***Pe***) rise associated with frictional losses in exhaust tubing approximates the pressure rise found at the vacuum generator inlet.

In conclusion, long and/or complex exhaust tube lengths may result in poor or unstable vacuum generator performance, so are not recommended. To optimize vacuum generator performance and achieve the lowest possible generator inlet pressure, AP Tech recommends operating the vacuum generator in accordance with optimum performance conditions that include installation with the shortest and simplest possible exhaust tubing.