Answer on Question #84161 - Physics – Mechanics|Relativity

If I have an air tight structure measuring 10m high X 1m wide and 1m deep and I place a 1 tonne mass on top of a plunger at the top of the structure how would I calculate the psi and flow rate of the air coming out of a hole at the bottom of the structure measuring 10 cm X 10 cm? (Assuming no air is escaping anywhere else)

How quickly will the plunger with the mass on top fall?

How does this change when the size of the hole at the bottom is changed?

Solurion. So, we have next situation. The area on which the mass weighs one ton is: S=1× 1=1 m^2. The piston pressure will be: P=$\frac{1000kg\times 10\frac{N}{kg}}{1m^2} = 10000\ Pa$. That is, in general, the gas will be in this tank under pressure: 101300Pa+10000=111300 Pa or 11130 $\frac{kg}{m^2}$. We translate this value in interest: 1 pound is 0.45 kg, then p_1= 111130 $\frac{kg}{m^2}$ =24733 $\frac{pound}{m^2}$; 1 m^2 is 1550 square inches, then 24733 $\frac{pound}{m^2}$=15.95 $\frac{pound}{inches^2}$.

The tank is large, and the hole is small. Then we can apply the Bernoulli formula. We assume that the outside air pressure is p=101300 Pa. Take the temperature at 20 degrees Celsius, then the air density will be ρ= 1.288 $\frac{kg}{m^3}$. Find the flow rate of air, given that the adiabatic index for air is k= 1.4, then v=$\sqrt{\frac{2k}{k-1}\times\frac{p_1}{\rho}\times[1-\left(\frac{p}{p_1}\right)^{\frac{k-1}{k}}]}$ = $\sqrt{\frac{2\times 1.4}{1.4-1}\times\frac{111300}{1.288}\times[1-\left(\frac{101300}{111300}\right)^{\frac{1.4-1}{1.4}}]}$=135 $\frac{m}{s}$.

The cross-sectional area of the hole is: S_0= 0.1×0.1=0.01 m^2.

Air consumption will be: m=S_0× $\sqrt{2\times\frac{k}{k+1}\times(\frac{2}{k+1})^{\frac{2}{k-1}}\times\frac{p_1^2}{R\times T}}$=0.01× $\sqrt{2\times\frac{k}{k+1}\times(\frac{2}{k+1})^{\frac{2}{k-1}}\times\frac{111300^2}{R\times 293}}$=2.6 $\frac{kg}{s}$, where R for air R=287 $\frac{J}{kg\times K}$ and T=293 K.

The time it takes for the piston to go down is calculated by the formula: t=$\frac{2SH}{\mu\times S_0\sqrt{2gH}}$, where S=1 m^2, S_0=0.01 m^2, H=10 m, g=10 $\frac{N}{kg}$, μ=$\frac{1}{1.23+\frac{58\times H}{Re\times s}}$=$\frac{1}{1.23+\frac{58\times 10}{Re\times 0.1}}$. Re=$\frac{Q\times s}{S_0\times\nu}$=$\frac{1.96\times 0.1}{0.01\times 1.51\times 10^{-5}}$=1298013, where Q=m× $R\times\frac{T}{p_1} = 1.96\ \frac{m^3}{s}$, and s-width, m; and ν for air (kinematic viscosity at 20 degrees Celsius)=1.51× 10^{-5} $\frac{m^2}{s}$, μ=0.81, then t=175 seconds.

As the linear dimensions of the hole increase from below, the area also increases, then, as can be seen from the formula for time, it will decrease.

Answer: 15.95 psi; 2.6 $\frac{kg}{s}$; 175 seconds; as the linear dimensions of the hole increase from below, the area also increases, then, as can be seen from the formula for time, it will decrease.