RECEIVER SIZING:

In vacuum thermoforming it is customary to generate deep vacuum in a short period of time. A vacuum receiver is usually employed to produce this quick initial pulldown. If the installation is new, the following formula may be used to determine the size of the appropriate vacuum receiver.

$V_2 = V_1(P_3-P_1)/P_2-P_3$ Equ. 1.1

Where:
- V_2 = Applicable vacuum receiver size [Ft^3]
- V_1 = Total mold volume (forming volume + box volume) [Ft^3]
- P_1 = Initial pressure in the mold [PSIA]
- P_2 = Pressure in vacuum system [PSIA]
- P_3 = Pressure in combined system [PSIA]

Example: A vacuum receiver needs to be sized for a new installation. The forming volume is 0.8 Ft^3, and the box volume is 1.2 Ft^3. The initial pressure in the mold is 29.75" Hg (barometric pressure). The required pressure to form the sheet in the mold is 22" Hg. The pressure produced by the vacuum pump will be considered to be a maximum of 28" Hg.

First one must determine what are the appropriate variables, and then covert them to the appropriate units.

V_2 – To be determined
V_1 – 2 Ft^3 (0.8 Ft^3 + 1.2 Ft^3)
P_1 – 14.61 PSIA (29.76" Hg(A) converted to PSIA)
P_2 – 0.98 PSIA (28" Hg(G) first converted to 2" Hg(A), then converted to PSIA)
P_3 – 3.93 PSIA (22" Hg(G) first converted to 8" Hg(A), then converted to PSIA)

$V_2 = 2\ (3.93 – 14.61)/(0.98-3.93)$
$V_2 = 7.24\ Ft^3$ or times 7.48 gal/1 Ft^3;
$V_2 = 54$ gal

In this case, a 60 gal receiver would be appropriate.

Another formula is useful where an existing tank is to be used. If the receiver size is known, one will wish to calculate the pressure in the combined system.

$P_3 = (P_1V_1+P_2V_2)/(V_1+V_2)$ Equ. 1.2

Where:
- V_2 = Existing vacuum receiver size [Ft^3]
- V_1 = Total mold volume (forming volume + box volume) [Ft^3]
- P_1 = Initial pressure in the mold [PSIA]
- P_2 = Pressure in vacuum system [PSIA]
- P_3 = Pressure in combined system [PSIA]

Example: Say that a 60 gal receiver is available from stock, what will be the final pressure in the combined system?

First one must determine what are the appropriate variables, and then convert them to the appropriate units.

V_2 – 8.02 Ft^3 (60 gal * 1 Ft^3/7.48 gal)
V_1 – 2 Ft^3 (0.8 Ft^3 + 1.2 Ft^3)
P_1 – 14.61 PSIA (29.75” Hg(G) converted to PSIA)
P_2 – 0.98 PSIA (28” Hg(G) first converted to 2” Hg(A), then converted to PSIA)
P_3 – to be determined

P_3 = (14.61 * 2 + 0.98 * 8.02)/(2 + 8.02)
P_3 = 3.7 PSIA or converted to “Hg(G) (29.92” Hg(A)-3.7 PSIA (29.92” Hg(A)/14.7 PSIA))
P_3 = 22.4” Hg(G)

In most cases the system volume is equivalent to the tank volume. Generally if the pipework associated with the system is greater than 10% of the tank volume, that the volume of the pipework should be taken into account. These formulas also do not account for the collapse of the plastic in the mold. In most cases, the forming volume is so much smaller than the system volume that it does not add much to the calculations. These formulas also do not account for leaks in the system.

PUMP SIZING

- After the vacuum receiver has produced the initial quick pulldown, the vacuum pump can be used to generate the final deep vacuum. The following formula is the general pump down formula.

$t = V * LN (P_I/P_F)/Q_{AVG}$ Equ. 1.3

Where: t – Time to evacuate volume [min] LN – Natural Log
V – Total volume to be evacuated [Ft^3]
P_1 – Initial pressure (PSIA)
P_F – Final pressure (PSIA)
Q_{AVG} – Average volumetric flowrate of the pump (ACFM)

Note that this formula does not account for leaks in the system

Example: The 60 gal receiver from the previous example has been installed. The process requires that the vacuum pump should pull the combined system from 22.4” Hg to 28” Hg in approximately 10 seconds to increase the detail on the molded plastic. Will the SC-6TR be able to accomplish this?

Once again the appropriate variables need to be determined.

t = To be determined
V – 9.22 Ft^3 (1.2 Ft^3 = 8.02 Ft^3) {note that the forming volume is approximately 0}
P_1 – 3.7 PSIA (22.4” Hg(G) determined by equation 1.2)
P_F – 0.98 PSIA (28” Hg(G) first converted to 2” Hg(A), then converted to PSIA)
Q_{AVG} – 37 ACFM
The average flowrate is determined by adding the flows at different vacuum levels. The average capacity of the pump should be taken between the starting vacuum level and the ending vacuum level. For this example, the values are for the SC-6TR.

5” Hg	55 ACFM
19” Hg	47 ACFM
22” Hg	43 ACFM
25” Hg	38 ACFM
28” Hg	31 ACFM
29” Hg	21 ACFM

$$\frac{43 + 38 + 31}{3} = 37.33 \text{ or } 37 \text{ Avg. ACFM}$$

Solving for time:

t = 9.22 * LN (3.8/0.98)/37
t = 0.331 min or times 60 s/1 min;
t = 20 s

Basically the SC-6TR will take 10 seconds too long to accomplish this pulldown. Try the SC-10TR using the same parameters. All of the values remain the same, except for the average flowrate of the pump For the SC-10TR from 22” Hg to 28” Hg:

Q_{AVG} = 82 ACFM

Once again solving for time:

t = 9.22 * :N (3.8/0/98)/82
t = 0.149 min or times 60 s/1 min;
t = 9 s

In answer to the question that was posed in the example, the SC-6TR will not be able to satisfy the requirement, but the SC-10TR does satisfy the requirement.

Another way to work this problem is to determine what flowrate is required given a specific time period.

Example: The 60 gal receiver from the previous example has been installed. The process requires that the vacuum pump should pull the combined system from 22.4” Hg to 28 Hg in approximately 10 seconds to increase the detail on the molded plastic. Will the SC-6TR be able to accomplish this?

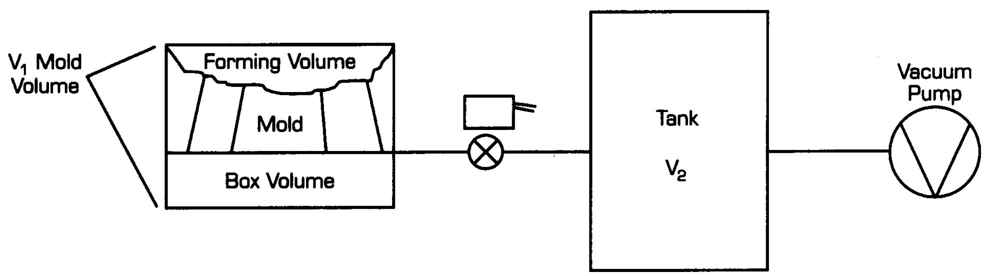
Change the formula to the following format:

$Q_{AVG} = V * LN (P_I/P_F)/t$ Equ. 1.4

From the values that been used in the previous pump down examples:

$Q_{AVG} = 9.22 * LN (3.7/0.98)/0.1667$
{t = 10 s * (1 min/60 s) = 0.1667 min}
$Q_{AVG} = 73$ ACFM

From what has been shown here, knowing the average volumetric flowrates, is that the SC-10TR will be the best choice.



Converting from SCFM to ACFM is as follows:

$V_2 = V_1(P_1/P_2)(T_2/T_1)$ Equ. 1.5

Where: V_2 – ACFM
V_1 – SCFM
P_1 – Absolute Pressure @ STP
P_2 – Absolute Pressure @ Vacuum Condition
T_1 – Absolute Temperature @ STP
T_2 – Absolute Temperature @ Vacuum Condition
MW – Average Molecular Weight

STP (Standard Temperature and Pressure) is 520^{o}R and 760 mmHg(A)

An easy way to remember is:
V that you want = V that you have x
(P that you have / P that you want) x
(T that you want / T that you have)

Converting from a mass flowrate to a volumetric flowrate is as follows:

$V = m (1/60)(379/MW)(P_1/P_2)(T_2/T_1)$ Equ. 1.6

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Where: V – ACFM
m - #/Hr

P_1 – Absolute Pressure @ STP
P_2 – Absolute Pressure @ Vacuum Condition
T_1 – Absolute Temperature @ STP
T_2 – Absolute Temperature @ Vacuum Condition
MW – Average Molecular Weight

STP (Standard Temperature and Pressure) is 520^oR and 760 mmHg(A)

Example:
Convert 20#/Hr of air to volumetric flowrate 25” Hg and 100^oF.

$V = m\ (1/60)(379/MW)(P_1/P_2)(T_2/T_1)$
m = 20#/Hr
P_1 = 760 mmHg(A) = 29.92” Hg(A)
P_2 = 25” Hg(G) = 125 mmHg(A), or 4.92” Hg(A)
$T_1 = 460 + 60^oF = 520^oR$
$T_2 = 460 + 100^oF = 560^oR$

$V = 20\ (1/60)(379/29)(760/125)(560/520)$, or $V = 20\ (1/60)(379/29)(29.92/4.92)(560/520)$
V = 29 ACFM @ 25” Hg and 100^oF (Volumetric flowrates should be described at a specific pressure and temperature

Converting from a volumetric flowrate to a mass flowrate is as follows:

$M = V\ (60/1)(MW/379)(P_2/P_1)(T_1/T_2)$,
using the same symbols as above. Equ. 1.7

Example:

Convert 300 ACFM of air @ 28.5 Hg and 60^oF to a mass flowrate.

$m = V\ (60/1)(MW/379)(P_2/P_1)(T_1/T_2)$
V = 300 ACFM
P_1 = 760 mm Hg = 29.92” Hg
P_2 = 28.5” Hg = 36 mmHg, or 1.42” Hg(A)
$T_1 = 460 + 60^oF = 520^oR$
$T_2 = 460 + 100^oF = 520^oF$, note that since $T_1 = T_2$, the division is 1, and it may be neglected

$m = 300\ (60/1)(29/379)(36/760)$, or $m = 300\ (60/1)(29/379)(1.42/29.92)$
m = 65#/Hr

Note that all calculations involving pressure and temperature should be performed at absolute conditions.