

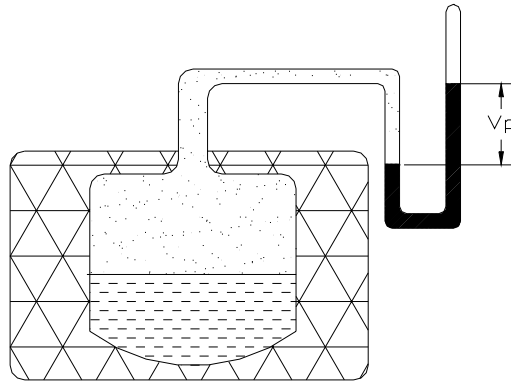
# Mechanical Vacuum Boosters for Solvent Recovery



This article has been compiled to understand the process of Solvent Recovery process generally carried out at low temperatures and vacuum. In many chemical processes solute is to be concentrated to high degrees of purity and the relatively volatile solvent is to be recovered for reuse. Initially in the solution, when the solute concentrations are low the process of solvent evaporation is relatively fast but as the solute concentration increases, the process becomes slow and demands higher temperatures or lower pressures to continue. In most of the processes the increase in temperature is limited and therefore the pressures must be reduced to continue the process. To understand the phenomenon, we start from basics.

## **Vapor Pressure: -**

Vapor pressure of liquid or solution is the pressure exerted by the vapors in equilibrium with the liquid or solution, at a particular temperature. Liquids with higher Vapor pressure have low boiling temperatures and liquids with lower vapor pressures have higher boiling points. If pure liquid or a solution is taken in an evacuated vessel placed in a thermostat, at any particular temperature, the amount of vapor in the space above keeps on increasing and finally becomes constant, on attaining equilibrium state - i.e. when rate of evaporation becomes equal to rate of condensation. The pressure '**Vp**' thus exerted is the Vapor Pressure of liquid/solution at that temperature.



Vapor Pressure largely depends upon.

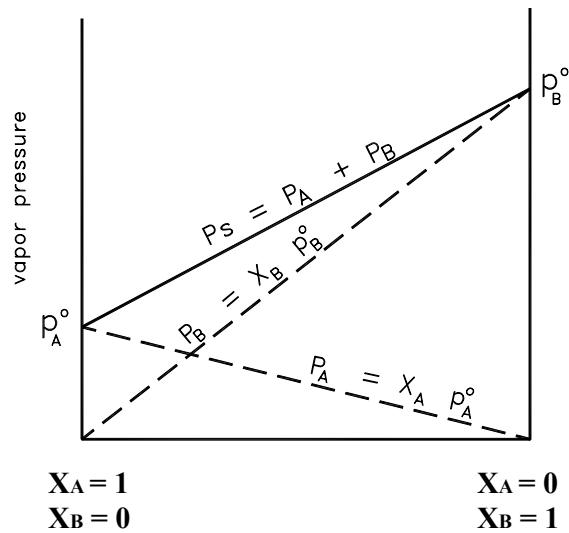
1. Nature of liquid : Volatile – Non volatile
2. Temperature.
3. Molar concentrations of a solution.

**Vapor pressure of a solution-Raoult's law.**

**a) For Volatile Solution:** Let us consider a mixture of two completely miscible volatile liquids A & B having mole fraction  $x_A$  &  $x_B$  respectively. Let their partial Vapor pressures at any certain temperature T, be  $P_A$  &  $P_B$ , and  $p_A^0$  &  $p_B^0$  be their vapor pressures in pure state, corresponding to temperature T.

According to Raoult's law: "In a solution, vapor pressure of a component (at given temp.) is equal to the whole fraction of that component in the solution multiplied by the vapor pressure of that component in the pure state". Therefore,

$$P_A = x_A p_A^0 \quad \& \quad P_B = x_B p_B^0$$



So **Ps**, Total pressure of solution (according to Daltons law of partial pressure) is equal to the sum of partial pressures.

$$\begin{aligned}
 P_s &= P_A + P_B \\
 &= x_A p_A^{\circ} + x_B p_B^{\circ} \\
 &= (1 - x_B) p_A^{\circ} + x_B p_B^{\circ} \quad (\text{since } x_A = 1 - x_B) \\
 &= (p_B^{\circ} - p_A^{\circ}) x_B + p_A^{\circ} \dots\dots\dots(I)
 \end{aligned}$$

When  $x_A = 1$  i.e liquid is pure A, then the total pressure,  $P_s = p_A^{\circ}$   
 When  $x_B = 1$  i.e liquid is pure B, then the total pressure,  $P_s = p_B^{\circ}$

In such condition where both the product are volatile, there would always be presence of vapors of both and therefore for their separation fractional distillation is required.

**b) For Non-Volatile Solution :**

For condition where solvent is relatively volatile and solute is non-volatile. In case of solvent recovery / product concentration, product A can be taken as non-volatile solute in volatile solvent B. That is, the vapor pressure  $p_A^{\circ}$ , at any given temperature is relatively very low in comparison to  $p_B^{\circ}$  or in other words the Boiling point of A is relatively higher than product B.

The equation (I) can be re written as,

**Ps =  $p_B^{\circ} \cdot x_B$**  ----- (II) Ignoring  $p_A^{\circ}$ , being relatively small.

Initially the vapor pressure,  $P_s$  of the solution, when molar concentration of B is relatively high, is close to  $p_B^{\circ}$  (vapor pressure of pure B at the specific temperature T) As the solvent evaporates, molar concentration of B drops resulting in drop of the vapor pressure of the mixture (increase in boiling temperature).

This indicates that as the process of concentration proceeds, the amount of solvent present in the solution reduces and for maintaining the same evaporation rates either the pressure must be reduced or temperature increased. In case any of the above is not done, the rate of evaporation / solvent recovery would fall drastically.

If a solution contains,  $W_A$  kg of solute of Mol Wt.  $M_A$  dissolved in  $W_B$  kg of solvent of Mol. Wt  $M_B$  have,

$$x_B = \left\{ \frac{W_B/M_B}{W_A/M_A + W_B/M_B} \right\}$$

**Where,**  
 $p_B^{\circ}$  = Vap. Pressure of Pure Solvent ,  
 $P_s$  = Vap. Pressure of Solution.  
 $W_A$  = mass of solute,  
 $M_A$  = Molecular Wt. Of Solute  
 $W_B$  = Mass of solvent,  
 $M_B$  = Molecular Wt. Of Solvent

Substituting the above in eq.II

$$P_s = \left\{ \frac{W_B/M_B}{W_A/M_A + W_B/M_B} \right\} p_B^{\circ}$$

Subtracting each side from 1 and simplifying we get

$$p^{\circ}_B - P_s = \left\{ \frac{W_A/M_A}{W_A/M_A + W_B/M_B} \right\} p^{\circ}_B \dots\dots\dots (III)$$

Since  $(P^{\circ}_B - P_s)$  = lowering of vapor pressure of solution, expression III can be expressed as “ **The relative lowering of vapor pressure of a solution, containing non volatile solute, is equal to the mole fraction of the solute in the solution**”.

**Example :** Let us take solution of Solute 'A' (Mol. Wt 45) in solvent Acetone (Mol. Wt. 58) in which the concentration of solute A is 1%. The vapor pressure of Pure Acetone at 25°C is, say, 195mm Hg.(abs).

Now Vapor Pressure of Solution  $P_s$  at temp 25° would be less than  $P_s$  by amount,

$$= \left[ 1/45 / \{1/45 + 99/58\} \right] \times 195$$

$$= 2.5 \text{ mm Hq.}$$

$$\Rightarrow P_s = 195 - 2.5 = 192.5 \text{ mm Hq.}$$

Now when the solvent evaporates, say 90gm is evaporated the concentrations then are now 1gm and 9gm for solute and solvent respectively.

The vapor pressure drop would be

$$= \left[ 1/45 / (1/45 + 9/58) \right] \times 195 = 24.4 \text{ mmHg.}$$

(The pressures must be dropped by at least 25 mmHg or temperatures raised to new boiling point levels, to enable evaporation to continue.)

Further, when say 98gm of solvent has evaporated and the concentration is 1gm of solute and 1gm of solvent, the drop in vapor pressure would be

$$\text{Drop in } V_p = \left[ 1/45 / (1/45 + 1/58) \right] \times 195$$

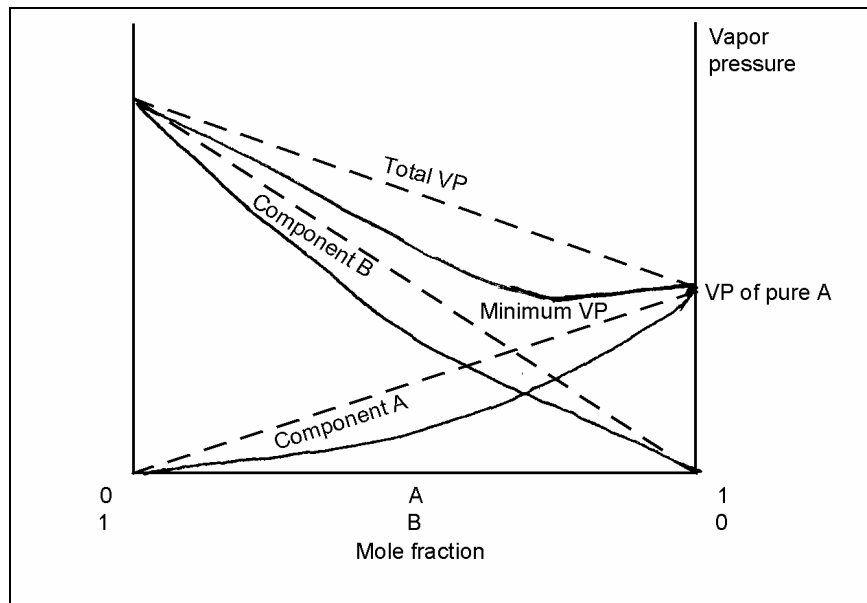
$$= 109.8 \text{ mmHq.} \quad \Rightarrow P_s = 195 - 109.8 = 85.2 \text{ mmHg}$$

This explains why lower and lower vacuums are required in a process where solvent evaporation is done to achieve fine concentrations and purity levels.

**Deviations from Raoult's law**

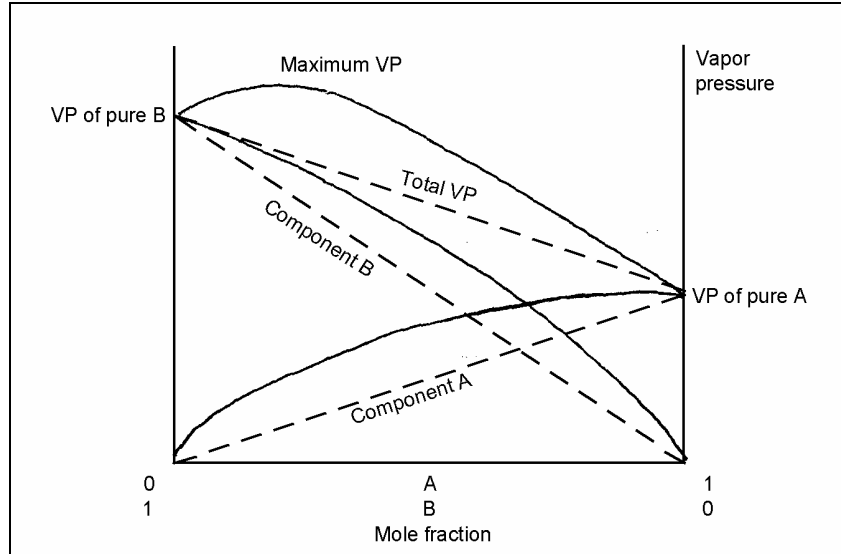
Liquid mixtures that obey Raoult's Law are quite rare. When they do exist they are made up from two components that are chemically very similar such as heptane and hexane or benzene and methylbenzene. This is because in an ideal mixture the intermolecular attraction between different molecules is the same as the attraction between identical molecules. This means that when the two liquids are mixed together there is no change in the intermolecular bonding present in either of the two pure liquids.

Sometimes when two liquids are mixed together, heat is released and the total volume is less than that of the individual components. This suggests that the two liquids attract one another quite strongly. E.g. propanone and trichloromethane.



Similarly sometimes when two liquids are mixed together, heat is absorbed and the total volume is greater than that of the individual components. This suggests that there has been a disruption of the intermolecular bonds present in one component when the liquids are mixed. E.g. water and ethanol. Ethanol interferes with the strong hydrogen bonding in the water.

Since the intermolecular bonding has been decreased each of the components will vaporize more readily, (lower boiling point), and the vapor pressure will be increased. There is a slight increase in volume when the liquids are mixed and since bonds are broken an endothermic enthalpy change is observed. This is known as positive deviation and leads to a vapor pressure composition diagram shown below. Very large positive deviations lead to a maximum vapor pressure.



**Mechanical Vacuum Boosters :-**

**Mechanical Vacuum Boosters are dry pump that meet many of the ideal pump requirements.** They work on positive displacement principle. As it's name suggests, it is used to boost the performance of water ring/oil ring/rotating vane/piston and in

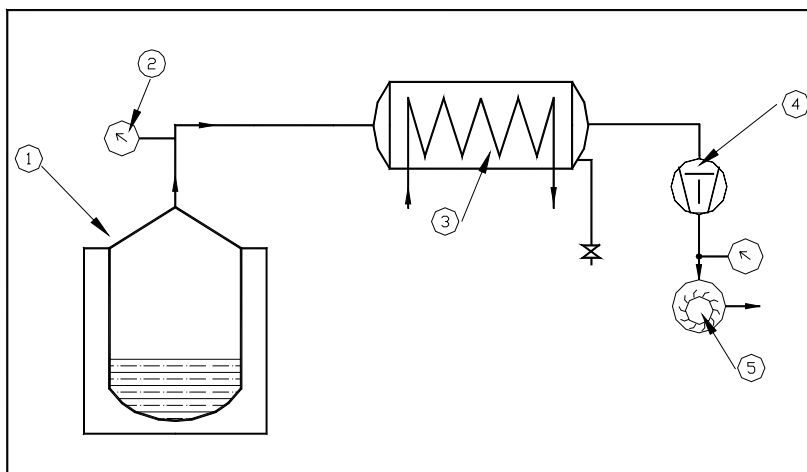
some cases even steam or water ejectors. It is used in combination with any one of the above mentioned pumps, to overcome their limitations. Vacuum booster pumps offer very desirable characteristics, making them the most cost effective and power efficient alternative.

The major advantages are:-

- 1.) The Vacuum Booster is a dry pump.
- 2.) It does not use any pumping fluid. Hence it pumps vapor or gases with equal ease. Small amounts of condensed fluid can also be pumped.
- 3.) It has very low pump friction losses, hence requires relatively low power for high volumetric speeds.
- 4.) It can be started instantly. Makes it highly suited for batch processes.

**Typically, their speeds at low vacuums are 20-30 times higher than corresponding vane pumps/ring pumps of equivalent power.** The vacuum booster can be used to generate vacuum upto the range of 0.001 Torr and yet maintain high volumetric speeds at such low pressure. At these pressures the rotary oil and water ring pumps are not effective, as their pumping speed falls drastically when approaching their ultimate levels. Mechanical boosters can be easily integrated into all existing pumping set-up to boost the process performance .

Typical arrangement is described under where the booster is installed after the condenser.



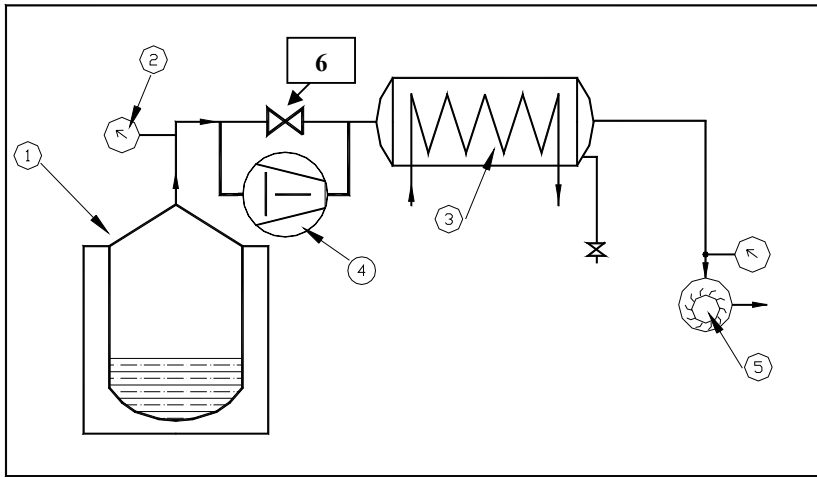
**Post – Condenser Installation**

- ( 1.) Evaporator ( 2) Gauge (3) Condenser ( 4) Mechanical Booster  
(5) backup Pump

Most often the combination of vacuum Booster and backing pump results in reduced power consumption per unit of pumping speed as they provide high pumping speeds at low pressures. With a suitable Water ring pump/water ejector as backup pump, the blank off pressure of the order of few torr can easily be achieved. However, the working pressures are, in this arrangement, governed by the condenser temperature since the working vacuum would be in equilibrium to the vapor pressures corresponding to the condenser outlet temperatures. This arrangement would be suitable for processes where there is considerable difference in the evaporator and condenser temperatures.

During selection of Booster, the pumping speed of booster selected is 3-10 times higher than the backing pump which results in gas/vapor compression at the discharge end of Booster. Due to vapor compression action at the discharge of the booster, the pressure at the discharge of booster (or inlet of backing pump) is maintained high, resulting in low back streaming of backing pump fluid. A suitable secondary condenser installed between the booster outlet and backing pump inlet would trap all the escaped vapors resulting in better solvent recovery.

For processes where lower pressures would interfere with the condensation in the condenser or demand chill water. The Booster can be installed between the evaporator and the condenser. The booster would reduce pressures at the evaporator and raise pressures at the condenser making an ideal condition since low pressures in the evaporator would enhance the evaporation process and high pressures in the condenser would increase condenser efficiency



**Pre Condenser Installation**

- (1.) Evaporator (2) Gauge (3) Condenser (4) Mechanical Booster  
 (5) Backup Pump (6) Bypass valve

High bottom product purity and maximum solvent recovery both can be effectively achieved. In cases where the evaporator temperatures are close to the boiling point of solvent, the booster can be initially bypassed, as the condenser would maintain the required differential pressures for vapor flow. However, as the concentration increases BP of the solution increases and the need for reduced pressures becomes essential for process to continue. At this stage the booster can be operated to create lower pressure in the evaporator and relatively higher pressure in the condenser creating higher differential pressures, which would speed up the entire process. Considerable reduction in process time, higher product purity and better solvent recovery can easily be achieved.

**Calculating the Pump Capacity: -**

Base on the fundamental gas laws  $PV = RT$ , an expression can be derived for Volumetric Flow Rates required for pumping different vapors/ gases at any range of pressures and temperatures.

$$V = \left[ R \cdot T_{\text{gas}} / P \right] \left\{ Q_1/M_1 + Q_2/M_2 + \dots + Q_n/M_n \right\}$$

Where V = Inlet Volume flow rate m<sup>3</sup>/hr.

R = Universal gas Constant, 83.14 mbar m<sup>3</sup>/ Kgmol x °K

T<sub>gas</sub> = Gas/Vapor abs. Temp, in °K

P = Process ab. Pressure in mbar

Q<sub>1</sub>, Q<sub>2</sub>, Q<sub>3</sub> = Gas / Vapor flow rate, in Kg/hr.

M<sub>1</sub>, M<sub>2</sub>, M<sub>3</sub> = Molar mass, in Kg/mol. of gas /vapor.

**Example:-** To calculate the size of booster capable of handling 10 kg/hr of Water vapor (mol Wt 18) and 2 kg/hr of Non-condensable gas load (Air mol wt. 29) at 69 Deg C and 10 mbar (7.6Torr) is



$$= 83.14 \times 342 / 10 \times \{10/18 + 2/29\}$$

$$= 1775 \text{ m}^3/\text{hr}$$

The booster capacity should be 1775 m<sup>3</sup>/hr in case the same is to be installed between the evaporator and the condenser and would be about 200m<sup>3</sup>/hr incase the same is installed after the condenser. (Since the condensable load would get condensed in the condenser)

On understanding the specific process requirements, various combinations can be worked out for optimum results. Proper selection of booster should ultimately result in:-

- 1.) Better product quality
- 2.) Faster process cycle
- 3.) Efficient solvent recovery
- 4.) Reduced energy consumption.

*(Article written by technical team of Everest Transmission – The only successful manufacturer of Mechanical Vacuum Boosters in India)*

## EVEREST TRANSMISSION

B-44, Mayapuri Industrial Area, Phase-1, New Delhi-110064, India.

Telefax: 91-11-28114944, 28114955, 28116307, 28117469

Email: [info@everestblowers.com](mailto:info@everestblowers.com) Web: [www.everestblowers.com](http://www.everestblowers.com)