KINNEY®

CASE STUDY

VACUUM PUMPS FOR CHEMICAL DISTILLATION

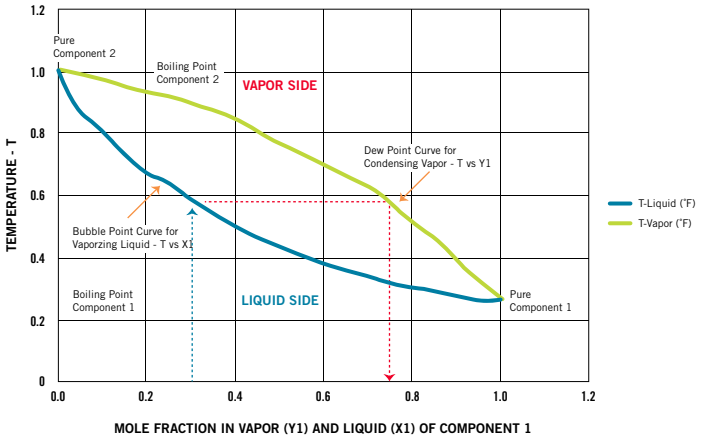
THE DISTILLATION PROCESS

Distillation is one of the many separation processes such as degassing, drying, filtration, membrane separation, adsorption, crystallization, etc. that rely upon the differences in the physical properties of substances in a mixture. Distillation relies upon the differences in the boiling point or the vapor pressure versus temperature characteristics of substances to provide a mechanism for separation. Heating, evaporation and condensing then become the tools for separation of the liquid constituents in a liquid mixture. For separating substances with differences in boiling points of less than 30°C, a fractionating column with plates or packing is normally recommended to provide repeated condensing and re-evaporation of the reflux liquid as it progresses up the column for better separation of the constituents. The more volatile liquid will have a lower boiling point or higher vapor pressure versus temperature curve, and will be more readily evaporated. The vapor phase mixture will be richer in the more volatile compounds and then can be condensed, contained and returned for further separation and purification, if necessary. The greater in difference in the volatility of a component from the mixture the more easily it is separated.

Volatility of substance i is defined as Ki = yi/xi where Ki is the volatility of the i component and yi is the mole fraction of i component in the vapor phase compared to the mole fraction of the i component in the liquid phase, xi. Since yiP = xiPvi, where P is the total pressure, yi and xi are the mole fraction in the vapor phase and liquid phase, respectively, and Pvi the pure component vapor pressure then yi/xi = Pvi/P and for two substances the relative volatility $\alpha = K1/K2 = (y1/x1)/(y2/x2) = Pv1/Pv2$ which is just the ratio of their pure component vapor pressures. For a simplified binary mixture that behaves as an ideal liquid, a phase diagram at constant pressure can be drawn with the Mole Fraction of the more volatile component on the horizontal axis and the Temperature on the vertical axis. Vacuum distillation provides a convenient and efficient format for this separation at lower temperatures without harmful reactions with other gases such as Oxygen.

For a simplified binary mixture that behaves as an ideal liquid, a phase diagram at constant pressure can be drawn with the Mole Fraction of the more volatile component on the horizontal axis and the Temperature on the vertical axis. The lower curve is normally referred to as the Bubble Point where for a given mole fraction of liquid mixture, the liquid begins to boil at a given temperature. The higher curve is normally referred to as the Dew Point which is the different temperatures where the different mole fractions of the vapor would start to condense.

BINARY DISTILLATION AT CONSTANT PRESSURE



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As an example, the phase diagram at constant pressure for a well behaved binary mixture shows that the mixture will boil at 0.59T when the more volatile component 1 represents 0.3 mole fraction of the liquid mixture and will have a saturated vapor component y1 that represents almost 0.75 mole fraction of the entire vapor. This large difference between the vapor and liquid contribution of component 1 makes it easier to distill off. In some cases, a mixture of two or more liquids at a given mole fraction of constitu ents will behave as a pure liquid where the vapor that boils off at a constant temperature has the same mole fraction in the vapor phase as in the liquid phase and no further separation of the constituents occurs. This is known as an azeotrope.

For example, a mixture of Ethanol and Water will separate through simple distillation until the mole fraction of Ethanol reaches 0.895 and no further change in concentration will occur. Some azeotropes can be separated by changing the pressure at which distillation occurs. Vacuum distillation can help in some of these cases by providing a pressure variation for shifting the azeotrope to allow for further separation. The Ethanol/Water azeotrope disappears at distillation pressures below 70 mm Hg A. As in all processes the cost of further separation dictates its feasibility.

THE MOLECULAR DISTILLATION PROCESS

Molecular distillation is a similar process but occurring at much lower pressures (normally from 0.1 to 0.0005 mm Hg A) such that collision of the distillate molecules with the condenser predominate, compared to intermolecular collisions. The use of thin film distillation process using Wiped Film Stills (WFS) and Evaporators (WFE) provides a convenient method for separating out compounds for the Chemical, Food or Pharmaceutical sectors, that have high boiling points, or high viscosity, or are sensitive to thermal degradation but are readily evaporated at modest temperatures at low pressures.

KLRC Liquid Ring Vacuum Pump

LIQUID RING VS. DRY VACUUM PUMPS

Condensers are used for knocking out most of the condensable vapors. But, for removing the permanent gases including air leakage along with the saturated vapors at the exhaust temperature of the vent condenser, for simple or fractional vacuum distillation, the most common and preferred pumps are the Liquid Ring and Dry Vacuum Pumps. For lower pressure operation, a Rotary Lobe Booster can be connected in series with either of these to provide higher pumping capacity at a lower pressure.

The Liquid Ring does not require internal lubrication and can run on most liquids such as water or low viscosity oil or many solvents that are compatible with its materials and the process in terms of vapor pressure and viscosity. It can handle liquid slugs from process upsets or a continuous flow of liquid condensate from a pre-condenser. In some cases it can perform as both a vacuum pump for non-condensables and a direct contact condenser for vapors increasing its overall pumping capacity. It is one of the most reliable and durable mechanical pumps because of its simplistic design with one rotating shaft assemblage. It is also available in 316 stainless steel for greater corrosion resistance to process effluents.

Liquid Ring Pump Advantages:	Liquid Ring Pump Disadvantages:
Can perform as both vacuum pump and direct contact condenser	Normally higher operating cost than dry
Lower purchase price	Higher power and cooling water consumption
Simplicity of rotating parts improves reliability	Larger footprint
Low maintenance	Pump performance is limited by vapor pressure of sealant
Because of pump simplicity, can be readily disassembled and reassembled on site by end user	Requires a supply of liquid sealant for makeup or change out
Lower operating temperature for thermal sensitive or polymerizable process material	Operation normally results in larger amount of hazardous waste
Liquid sealant allows for handling higher temperature inlet gases/vapors	
Can ingest liquid from process or condensater from upstream condenser	
Less sensitive to process particulate due to larger clearances	
Liquid within pump may act as quench to reduce chance of ignition from sparking	

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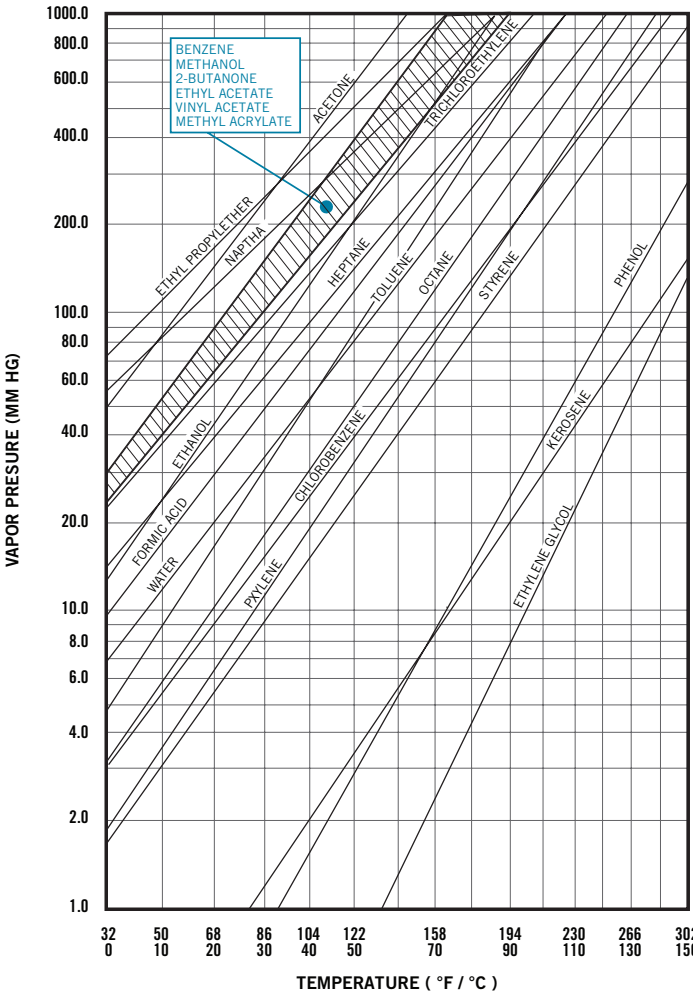
BOILING POINTS OF SOLVENTS



SDV Rotary Screw Dry Pump

The Rotary Screw Dry Pump also does not require internal lubrication and can handle some liquid carryover, but as the name implies, it is preferred to keep the pump dry for optimum performance. Knockout Pots would normally be recommended to trap out liquid slugs. Since the Dry Pump contains no liquid within its pumping chamber, it is not limited by the vapor pressure of the liquid and can achieve lower pressures without producing process contaminated waste products. The Dry Pump handles condensable vapors by keeping them in the vapor phase at an elevated temperature while traveling from suction to discharge so that they can be condensed out in an after-condenser. The Rotary Screw Dry Pump and Rotary Lobe Boosters are also available with optional protective coatings.

Because of the low pressure requirements for molecular distillation and reduced carryover, multi-stage Booster packages utilizing either Liquid Ring, Dry Rotary Screw, or Oil Sealed Rotary Piston Vacuum Pumps as the atmospheric stage can be provided.

Dry Pump Advantages:	Dry Pump Disadvantages:
Lower ultimate pressure and higher capacity at low pressure end for single-stage pump	Higher purchase price
Lower power consumption	Higher complexity effects reliability
Lower cooling water usage	More difficult to disassemble and reas-semble on site by end user
More compact footprint	Solvent handling limited by auto-ignition temperature of solvent
Can pump high vapor pressure solvents	Limited liquid ingestion
Environmentally friendly with less pollution	

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