VACUUM SCIENCE AND ITS APPLICATIONS

Abstract

The subject matter explains the requirement for a strong vacuum as well as the basic principles of vacuum science and the main gas sources present inside a vacuum system. For scientific inquiry and present high technology, vacuum science is a must. This introduction to vacuum science presents the essential notions of an atom-and-molecule-composed gas. The vacuum is defined as a volume that is only partially filled with the mentioned gas particles. The basic concepts of vacuum, historical understanding, measurement of vacuum, Uses of Vacuum, Advantage of vacuum driers, principal of operation vacuum, classification of vacuum pumps, and application of vacuum drier are discussed.

Keywords: Vacuum, Measurement of vacuum, Uses of vacuum, Advantage of vacuum driers, Principal of vacuum, Classification of vacuum pumps, and Application of vacuum**.**

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I. INTRODUCTION

The term vacuum is derived from the Latin vacuus, which means "empty," and is related to the verb vacare, which means "to be empty," and implies "an empty space, vacuum." This article is about the lack of matter, often known as physical vacuum. See vacuum for further information. Vacuuming (disambiguation) is used for a number of applications. The phrase "free space" here is a redirect. There are numerous methods to use free space (disambiguation). A vacuum is a space that is devoid of any substance, including air. A vacuum prevents sound from travelling around. Even in space, a small quantity of dust is always present; therefore no location is entirely vacuumed. A vacuum is also a zone that has only a tiny amount of air removed. Despite the fact that most of the air is still present, the pressure in the space diminishes **(Boi, 2011).**

A partial vacuum's quality is determined by how near-perfect it is to a fully vacuum. Lower gas pressure equates to better hoover, everything else being equal. In order to reduce air pressure by about 20%, a conventional hoover cleaner, for instance, provides enough suction. Vacuums of a higher caliber are however conceivable. In chemistry, physics, and engineering, ultra-high vacuum chambers are frequently used to operate at pressures less than one trillionth of that of the atmosphere (100 nPa), where they can achieve particle densities of up to 100/cm3. The vacuum in space is even better than that found on Earth, with only a few hydrogen atoms per cubic meter on average in intergalactic space. (**Lensing, 2007**).

Although the vacuum has been a topic of discussion in philosophy since the time of the ancient Greeks, it wasn't scientifically explored until the 17th century. Other experimental approaches emerged as a result of Evangelista Torricelli's atmospheric pressure theories, which were implemented in the first laboratory vacuum in 1643. A tall glass container that is closed at one end and filled with mercury can be used to create a Torricellian vacuum by inverting it in a bowl to confine the mercury. **(Maier, 2005)**.

The introduction of incandescent light bulbs and vacuum tubes in the beginning of the 20th century transformed vacuum into a useful industrial device. Since that time, a broad variety of vacuum technologies have become available. The advancement of human spaceflight technology has increased interest in how vacuum impacts life in general and human health in particular.

Vacuum drying is currently regarded as one of the best drying techniques due to its remarkable performance in maintaining the quality of dried materials. **(Kumar *et al.,* 2023).** In comparison to conventional drying, vacuum drying is faster, more consistent, and uses less energy. In recent years, vacuum-drying has been researched as a potential method for producing high-quality dried food products such as fruits, vegetables, and pharmaceuticals. The low temperature and fast mass transfer provided by vacuum in combination with the rapid energy transfer produced by freeze-drying very rapid low temperature drying has the potential to increase energy efficiency and product quality. **(Kumar *et al.,* 2022).**

II. HISTORICAL UNDERSTANDING

The existence of a vacuum has long been contested. In the context of atomism, which considered empty and atom as important explanatory components of physics, ancient Greek philosophers argued for the existence of a vacuum, or void. Even Plato's abstract concept of a featureless void was met with scepticism after Plato because it could not be perceived by the senses, it could not provide additional explanatory power beyond the physical volume with which it was commensurate, and, by definition, it was nothing at all, which could not be rightly said to exist. According to Aristotle, no void could exist naturally because any imminent event that would result in a void would be quickly filled by the denser surrounding material continuum.

Aristotle provided various arguments against the vacuum in Book IV of his Physics, including the fact that motion across an open medium may last forever and that there was no reason why something should come to rest anywhere specific. Hero of Alexandria attempted but failed to build an artificial vacuum in the first century AD, however Lucretius stated for the existence of vacuum in the first century BC. European academics such as Roger Bacon, Blasius of Parma, and Walter Burley gave considerable attention to the concept of a vacuum in the 13th and 14th centuries. Scholars began to deviate from the Aristotelian perspective in the 14th century in favour of a supernatural emptiness outside the boundaries of the cosmos itself, a conclusion that was widely accepted by the 17th century and served to distinguish natural and theological difficulties. Stoic physics was ultimately affected in this case.

(Chambers, 1998).

René Descartes presented a geometrically based alternative theory of atomism almost two thousand years after Plato, avoiding the challenging void/atom/nothing dilemma. Despite his agreement that a vacuum does not exist in nature, the success of his namesake coordinate system and, more subtly, the spatial-corporeal part of his metaphysics would come to define the philosophically contemporary notion of empty space as a quantified extension of volume. In the old paradigm, however, magnitude and direction were conceptually distinct.

According to mediaeval thought experiments on the concept of a vacuum, when two flat plates were quickly separated, a vacuum could have existed. There was great debate regarding whether the air entered rapidly enough when the plates separated, or whether, as Walter Burley argued, a "celestial agent" prevented the vacuum from forming. The term "spectre vacui" related to the widely held belief that nature despised vacuum cleaners. The 1277 Paris condemnations of Bishop Étienne Tempier, who insisted on no limitations on God's abilities, led to the conclusion that God could, if he so desired, create a vacuum. Some even questioned God's ability to construct a hoover if he so desired. When the port was blocked, teams of ten horses were unable to open bellows, according to testimony provided by Jean Buridan in the 14th century. The first attempts at quantifying partial vacuum readings date back to the 17th century. The existence of a partial vacuum was demonstrated by both Blaise Pascal's investigations and Evangelista Torricelli's mercury barometer from 1643.

Otto von Guericke designed the first vacuum pump in 1654 and conducted the well-known Magdeburg hemispheres experiment, which revealed that teams of horses could not separate two hemispheres from which the air had been partially evacuated due to atmospheric pressure outside the hemispheres. Guericke's design was refined by Robert Boyle, who also revolutionized vacuum pump technology with the help of Robert Hooke. The pursuit of the partial vacuum fell out of favour until August Toepler devised the Toepler pump in 1850 and Heinrich Geissler invented the mercury displacement pump in 1855, both of which produced a partial vacuum of about 10 Pa (0.1 Torr). At this vacuum level, a variety of electrical features become visible, reviving interest in future research.

Later, in 1930, Paul Dirac proposed the Dirac sea theory, which pictured the vacuum as an infinite sea of particles with negative energy. This idea contributed in refining the predictions of his earlier-formulated Dirac equation and accurately predicted the presence of the positron, which was proven two years later. Werner Heisenberg's uncertainty principle, proposed in 1927, anticipated a fundamental constraint in measuring instantaneous location and momentum, or energy and time. This has a significant impact on the "emptiness" of space between particles. The existence of 'virtual particles,' or subatomic particles that appear out of nowhere, was verified in the late twentieth century. **(Boi, 2009).**

III. MEASUREMENT OF VACUUM

Because the amount of matter in a system impacts the quality of a vacuum, a high-quality vacuum has very little matter left in it. The absolute pressure of a vacuum is used to assess it, but other parameters, such as temperature and chemical composition, are required for a complete analysis. One of the most important measurements is the mean free path (MFP) of remaining gases, which shows the normal distance that molecules would travel before colliding. The continuum assumptions of fluid mechanics do not remain true as the gas density decreases and the MFP increases when the MFP is longer than the chamber, pump, spacecraft, or other elements present. This vacuum condition is known as high vacuum, and the study of fluid movements in this range is known as particle gas dynamics. The MFP of air at atmospheric pressure is quite small—70 nm—whereas at 100 mPa (10-3 Torr), the MFP of room-temperature air is around 100 mm, on the scale of commonplace things like vacuum tubes. The Crookes radiometer rotates when the MFP is greater than the width of the vanes.

Vacuum quality is categorized into ranges according on the technologies required to manufacture or measure it. Table-2 compares these ranges to ISO 3529-1:2019. (100 Pa = 0.75 Torr, a non-SI unit):

Table 1: Vacuum Ranges

Vacuum Ranges	Pressure (Pa)
Low vacuums	$1x10^{5}$ to $3x10^{3}$
a medium vacuum	$3x10^{3}$ to $1x10^{-1}$
High vacuum	$1x10^{-1}$ to $1x10^{-7}$
Ultra-high vacuum	$1x10^{-7}$ to $1x10^{-10}$
Extremely high vacuum	$1x10^{-10}$
Perfect vacuum	0

$1x10^{-4}$ to $3x10^{-15}$ in outer space (**Source: Kumar, 2009**)

Table 2: The Rationale for Defining the Ranges

Pressure range	Definition	The reasoning for the ranges is as follows (typical circumstances):
Prevailing atmospheric pressure (31 kPa to 110 kPa) to 100 Pa	low vacuum (rough)	Simple materials (such as ordinary steel) and positive displacement vacuum pumps can reach pressure; viscous flow regime for gases
<100 Pa to 0.1 Pa	High vacuum (HV)	Expensive materials (such as stainless steel) and positive displacement vacuum pumps can produce pressure; transitional flow regime for gases
<0.1 Pa to 1×10^{-6} Pa	medium vacuum (fine)	Expensive materials (such as stainless steel), elastomer sealing, and high vacuum pumps can produce pressure; molecular flow regime for gases
<1×10^{-6} Pa to 1×10^{-9} Pa	UHV (ultra-high vacuum)	Expensive materials (such as low-carbon stainless steel), metal sealing, extensive surface preparations and cleaning, bake-out, and high vacuum can all be used to generate pressure.
below 1×10^{-9} Pa	XHV stands for extremely high vacuum.	Pressure can be obtained using complex materials (for example, vacuum burned low-carbon stainless steel, aluminium, copper-beryllium, and titanium), metal sealing, particular surface preparations and cleaning, bake-out, and supplementary getter pumps; molecular flow regime for gases.

Source: Hanlon (2003).

- Although **atmospheric pressure** varies, common standard or reference pressures are 101.325 k Pa (760 Torr) and 100 k Pa (1000 mbar).
- **Deep space** is significantly emptier than any artificial vacuum. It may or may not fulfill the standards of high vacuum above, depending on the region of space and astronomical bodies researched. For example, the MFP of interplanetary space is smaller than the size of the Solar System but larger than minor planets and moons. As a result, whereas solar winds exhibit continuum flow on the Solar System scale, they must be regarded as particle bombardment with respect to the Earth and Moon.
- **Perfect vacuum** is an ideal state in which no particles exist. It cannot be done in a laboratory; however tiny quantities containing no particles of matter for a short period of time may exist. Even if all matter particles were eliminated, photons and gravitons would still exist, as well as dark energy, virtual particles, and other quantum vacuum properties.

Table 3: Examples

Pressure (Pa or kPa)	**Pressure (Torr, atm)**	**Mean free path**	**Molecules per cm^3**	
Standard atmosphere, for comparison	101.325 kPa	760 torrs (1.00 atm)	66 nm	2.5×10^{19}[54]
Intense hurricane	approx. 87 to 95 kPa	650 to 710		
Vacuum cleaner	approximately 80 kPa	600	70 nm	10^{19}
Steam turbine exhaust (Condenser backpressure)	9 kPa			
liquid ring vacuum pump	approximately 3.2 kPa	24 torrs (0.032 atm)	1.75 µm	10^{18}
Mars atmosphere	1.155 kPa to 0.03 kPa (mean 0.6 kPa)	8.66 to 0.23 torrs (0.01139 to 0.00030 atm)		
freeze drying	100 to 10	1 to 0.1	100 µm to 1 mm	10^{16} to 10^{15}
Incandescent light bulb	10 to 1	0.1 to 0.01 torrs (0.000132 to 1.3×10^{-5} atm)	1 mm to 1 cm	10^{15} to 10^{14}
Thermos bottle	1 to 0.01 [1]	1×10^{-2} to 1×10^{-4} torrs (1.316×10^{-5} to 1.3×10^{-7} atm)	1 cm to 1 m	10^{14} to 10^{12}
Earth thermosphere	1 Pa to 1×10^{-7}	10^{-2} to 10^{-9}	1 cm to 100 km	10^{14} to 10^{7}
Vacuum tube	1×10^{-5} to 1×10^{-8}	10^{-7} to 10^{-10}	1 to 1,000 km	10^{9} to 10^{6}
Cryopumped MBE chamber	1×10^{-7} to 1×10^{-9}	10^{-9} to 10^{-11}	100 to 10,000 km	10^{7} to 10^{5}
Pressure on the Moon	approximately 1×10^{-9}	10^{-11}	10,000 km	4×10^{5}[55]
Interplanetary space				11[1]
Interstellar space				1[56]
Intergalactic				10^{-6}[1]

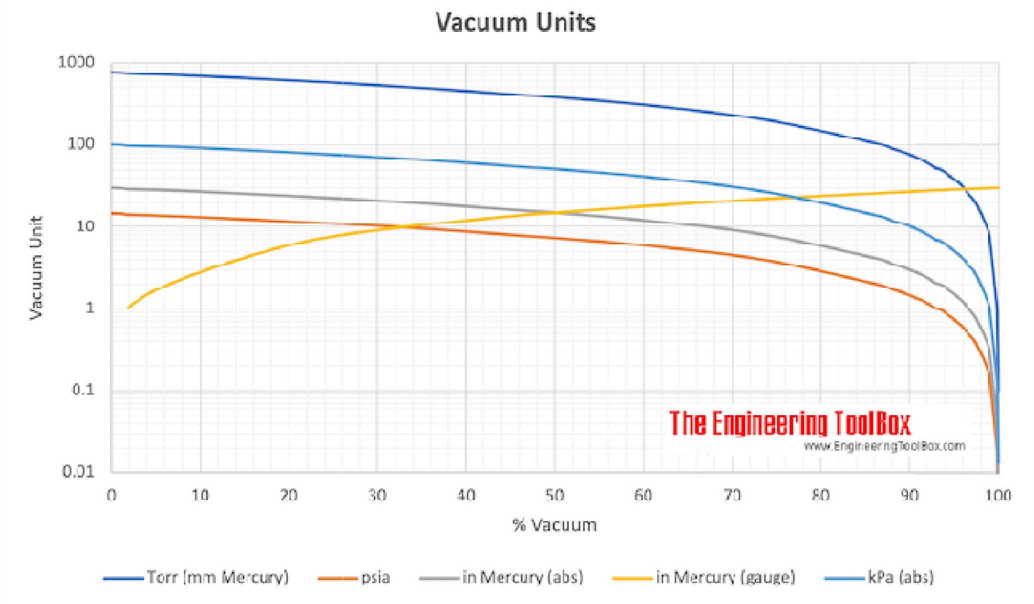
space				

Source: K. Jousten (2016).
The table below can be used to convert between commonly used vacuum units:

Table 4: Convert Between Commonly used Vacuum

% Vacuum	Torr (mm Mercury)	Micron	psia, (lb/in^2 abs)	Inches Mercury Absolute	Inches Mercury Gauge	kPa abs
0.0	760.0	760,000	14.7	29.92	0.00	101.4
1.3	750.0	750,000	14.5	29.5	0.42	99.9
1.9	735.6	735,600	14.2	28.9	1.02	97.7
7.9	700.0	700,000	13.5	27.6	2.32	93.5
21.0	600.0	600,000	11.6	23.6	6.32	79.9
34.0	500.0	500,000	9.7	19.7	10.22	66.7
47.0	400.0	400,000	7.7	15.7	14.22	53.2
50.0	380.0	380,000	7.3	15.0	14.92	50.8
61.0	300.0	300,000	5.8	11.8	18.12	40
74.0	200.0	200,000	3.9	7.85	22.07	26.6
87.0	100.0	100,000	1.93	3.94	25.98	13.3
88.0	90.0	90,000	1.74	3.54	26.38	12
89.5	80.0	80,000	1.55	3.15	26.77	10.7
90.8	70.0	70,000	1.35	2.76	27.16	9.3
92.1	60.0	60,000	1.16	2.36	27.56	8
93.0	51.7	51,700	1.00	2.03	27.89	6.9
93.5	50.0	50,000	0.97	1.97	27.95	6.7
94.8	40.0	40,000	0.77	1.57	28.35	5.3
96.1	30.0	30,000	0.58	1.18	28.74	4
96.6	25.4	25,400	0.49	1.00	28.92	3.4
97.4	20.0	20,000	0.39	0.785	29.14	2.7
98.7	10.0	10,000	0.193	0.394	29.53	1.3
99.0	7.6	7,600	0.147	0.299	29.62	1.0
99.87	1.0	1,000	0.01934	0.03937	29.88	0.13
99.90	0.75	750	0.0145	0.0295	29.89	0.1
99.99	0.10	100	0.00193	0.00394	29.916	0.013
99.999	0.01	10	0.000193	0.000394	29.9196	0.0013
100	0.00	0	0	0	29.92	0

- 1 psi (pound per square inch) = 6,894.8 Pa (N/m^2) = 6.895x10^{-3} N/mm^2 = 6.895x10^{-2} bar **Source: Holkeboer (1966).**



Source: The Engineering Toolbox (2003)

Figure 1: Vacuum units and Ranges

Convert % Vacuum to Pressure Unit

The % of vacuum is a relative figure using normal or standard atmospheric pressure as the base value.

$$Pv\ \% = 100\% - (p_v / p_{atm})\ 100\%$$

where,

$p_v\%$ = vacuum (%)

p_v = absolute pressure (in psia, kPa, bar, and so on).

p_{atm} = absolute pressure under normal or standard conditions (psia, k Pa, bar, etc.)

Example: k Pa pressure and % vacuum

The vacuum may be computed with an absolute pressure of 4 k Pa and a standard pressure of 101.4 k Pa as

$$p_v\% = 100\% - ((4\text{ kPa}) / (101.4\text{ kPa}))\ 100\%$$
$$= 96.1\%$$

Example: k Pa pressure and % vacuum

The vacuum at 0.1 bar absolute pressure and 1 bar standard pressure is computed as

$$pv\% = 100\% - ((0.1\text{ bar}) / (1\text{ bar}))\ 100\%$$

$$= 90\%$$

IV. ADVANTAGES OF VACUUM DRIER

1. Low temperature operation. Vacuum drying actually lowers the boiling point – or vaporization temperature – necessary to remove the liquid. As a result, surface evaporation is more rapid.
2. Drying of the material faster than at normal atmosphere.
3. A vacuum drier is particularly well suited to drying a heat-sensitive material that degrades above a certain temperature and would otherwise necessitate a lengthy drying cycle. Vitamins, medicines, and various fine compounds are examples of such materials.
4. It is done in absence or reduced environment of oxygen which reduces the incidence of chemical discoloration problems caused by the oxidation.
5. The closed-system design necessary to achieve and maintain a low-pressure atmosphere inside the dryer has advantages for processing a hazardous material. Toxic chemicals or solvents, as well as explosive compounds, are examples. The vacuum dryer safely captures and condenses the dangerous vapors from such substances without endangering your workplace or the surrounding environment.
6. The vacuum drying process is a batch operation. Batch drying allows for greater process diversity and adaptability to changing manufacturing practices. By using surge hoppers and other material handling equipment, we can make it a continuous operation.
7. This yields in reduction in mass transfer at the surface.
8. Quality of dried product increases due to low temperature operation.
9. Nutritional value is higher than ordinary drying.
10. Bench life and shelf life is also higher.
11. Shorter drying times and lower temperatures minimize the energy consumption.
12. Raw materials that contain solvent or the solvent to be recovered can be dried.

V. PRINCIPLE OF OPERATION OF VACUUM DRYER

Vacuum drying involves removal of liquid from a solid by evaporation under vacuum. Vacuum drying is used when product degradation dictates low temperature operation. The drying cycle constitutes of

- **Constant Rate Period:** The temperature of the product is equal to the boiling point of water at that pressure in this case.
- **Falling Rate Period:** In this temperature of the product approaches the heating medium temperature.

The amount of energy required to vaporize water at any temperature is determined by the temperature and pressure at that time. Latent heat of vaporization is the energy required to transform water to vapor. The latent heat of sublimation is the energy necessary to convert a solid to a gas. When the vapor pressure of water equals the entire pressure on the water's surface, boiling happens. Water boils at 1,000°C and atmospheric pressure. The boiling point decreases as pressure decreases. As shown in **Table-5**, the heat necessary to vaporize water under any particular set of conditions can be computed.

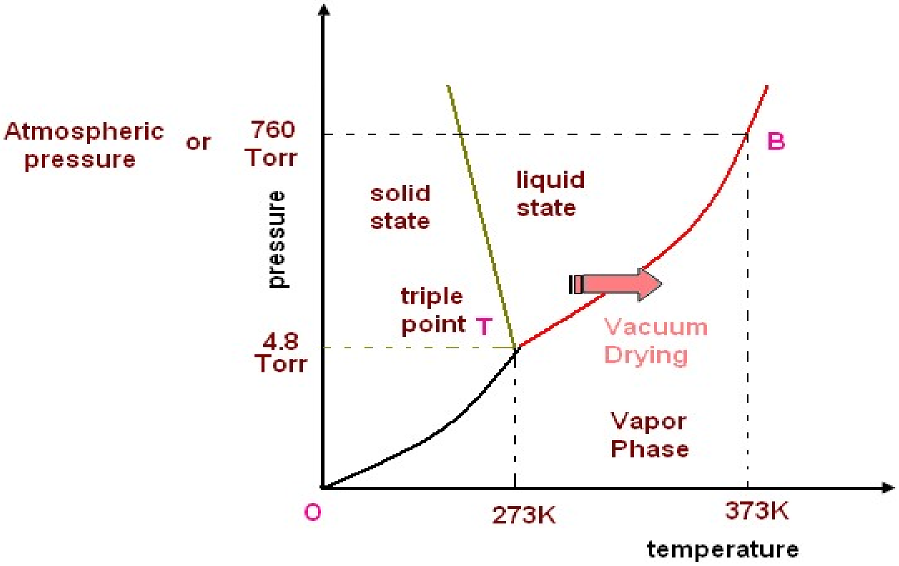


Figure 2: Three phase diagram

Table 5: Vaporization Latent Heat

Absolute pressure (Kpa)	The latent heat of vaporization. (kJ/kg)	Saturation temperature (^{o}C)
1	2485	7
2	2460	18
5	2424	33
10	2393	46
20	2358	60
50	2305	81
100	2258	99.6
101.35(760 Torr)	2257	100
110	2251	102
120	2244	105
200	2202	120
500	2109	152

Source: (Kumar, 2009).

So as the pressure is decreased below atmospheric pressure the temperature at which water starts boiling also decreases. In the above diagram the curve ‘TB’ is shown elaborately in below curve

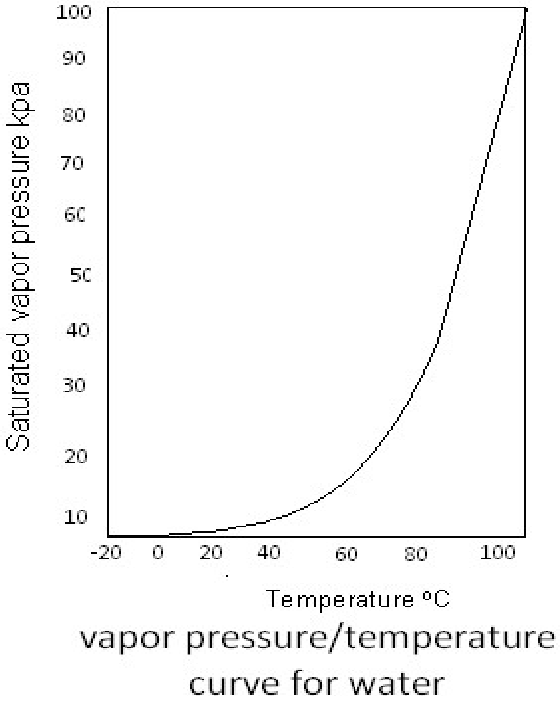


Figure 3: Vapor Pressure /Temperature curve for water

The relation between drying rate and drying time for a solid material dried in a vacuum drier is shown in figure below. With the exception of the curve DE below the drying rate is heat transfer limited. The below drying curve shows a batch operation and the vacuum pump is selected such that its capacity does not affect the evaporation rate. In a batch operation first the drier is loaded and then vacuum is brought online .when the vacuum pump is on pressure gradually decreases in the dryer. The section BC in the curve shows gradual increase in the evaporation rate as the drier wall temperature approaches the temperature of the heating medium and the vacuum pumping system reduces the chamber pressure. the rate at which heat is transferred increases in this period because the driving force for heat transfer increases that is the wall temperature of the drier and the saturation temperature corresponding to the pressure in the drier is increasing section CD of the curve indicates gradual decrease in the drying due to fouling of drier walls by solid and also due to increase in mass transfer resistance, which further increases in curve DE and follows up to very low moisture contents (**Kumar, 2009**).

VI. CLASSIFICATION OF VACUUM PUMPS

Classification of Vacuum Pumps

1. Gas Exhaust	1. Mechanical Pump
	2. Vapour Stream Pump
	3. Cryo Pump, Sorption Pump
2. Gas Storage	4. Chemical Adsorption Pump

1. Mechanical Pump

- **Oil-sealed rotary pump**
  - A thin oil coating exists between the rotor and the stator.
  - Vacuum range 10-4 10-5 torr, restricted only by the vapour pressure of the oil, excellent efficiency
  - Air ballast device: aids in the suppression of water or alcohol liquid development within the pump.

- **Rotary blower pump (also known as a roots pump or a dry pump)**
  - As with a gear pump, there is no lubricant between the rotors, therefore perfect machine fitting (less than 100 m) is required. • Vacuum pressure range: 10-2 -10-4 torr
  - High pumping rate, ranging from 50 to 5000 l/s
  - No oil vapour, not suitable for harsh pumping from ATM, but better suited for booster pump, which may require cooling on occasion.

- **Mechanical molecular pump**
  - **The molecule drag pump**
    - No lubricant between the rotor and the stator, a precise spacing (50) for a big pressure drop, and a very clean design
    - 5000-10000 rpm, a particle of 100 m can harm the pump
    - No need for a vapors traps; nevertheless, be cautious of overheating, which might cause the rotor to become stuck.
    - Higher efficiency is obtained with larger molecular weight molecules (H_2O).
    - Too expansive, replaced by turbo pump
    - Vacuum can reach 10-6 torr (rough pump must reach 10-3 torr)

  - **Turbo-molecular pump**
    - Turbine-like, 15000-60000 rpm.
    - Small pressure drop between discs, which can tolerate a bigger spacing of 1mm, multistage to provide a large pressure drop.
    - Vacuum can be 10-9 10-10 torr (rough pump to 10-3 torr is required), and it can be used in ultra-vacuum range.
    - Higher efficiency, highly clean operation for larger molecular weight molecules (H_2O).

2. Pump for Vapor Stream

- **Diffusor**
  - Entrapping gas molecules by using high-speed molecular flow through a nozzle.
  - For mass spectrometers, use Hg (greater vapor pressure, usually 10-3 torr at ambient temperature) or silicone oil (lower vapor pressure), which is less expensive and safer, and is utilized for high vacuum (10-6 10-9 torr under cooling).
  - Because of vapor, it cannot be used in ultra-high vacuum.

- ➢ Rough pumping to 10-3 torr is required first.
- ➢ Using a cooling baffle (freon) or traps to reduce vapor backflow.

- **Pump for stream ejector**
  - ➢ Vapour stream was ejected perpendicular to the vacuum chamber.
  - ➢ After going through the throat, vapor condenses.

3. Cryo pump and sorption

- **Sorption pump**
  - ➢ Sorption comprises
    - ▪ Absorption (gas dissolved within solid, difficult),
    - ▪ Physical adsorption (using Von der Waals forces on the initial few molecules of a solid surface, as exploited by the sorption pump).
    - ▪ Chemisorption (chemical bond on the surface, classified in the next section)
  - ➢ Physical sorption is reversible: decrease temperature and increase pressure to increase sorption ability. Absorbents are substances that absorb Absorbates
  - ➢ Four crucial factors to consider while choosing an absorbent:
    - ❖ Extensive surface area (porosity)
    - ❖ Chemical inertness
    - ❖ Integrity
    - ❖ Non-hydrolysis
  - ➢ Popular absorbents include activated charcoal (103 m^2 /cm^3) and activated alumina artificial zeolite (600-800 m^2 /g=> containing 100 cm^3 /g at 77K).
  - ➢ Usually paired with a cooling system=>cryogenic sorption pump
  - ➢ Vacuum from 10^{-1} to 10^{-5} (depending on temperature, usually hydrogen or helium remains in system), rough pump needed to aid pump down in the first stage.

- **Cryopumps**
  - ➢ Using coolant to cool and condense gas or vapor and keep it in the pump system. The system is inexpensive and easy, but the consumption is extensive, making it unpopular in the current industry.
  - ➢ A solid has fewer vapors than a liquid, and temperature has a big impact on vapor pressure. For instance, solid N2 has a temperature range of 32K-22K and a vapor pressure range of 10^{-4} -10^{-10} torr.
  - ➢ When liquid N_2 (77K) is used as a coolant, water vapor, CO_2, organic vapor, Xe, Kr, Ar solidify, but H_2, He, Ne, and N_2 remain gases. Cryo pump is barely usable.
  - ➢ Liquid He (4.2K) is a superior coolant, whereas liquid H_2 (10.3K) is less effective and more harmful.

    - ❖ Cryopumps considerations:
      - ▪ big cooling area
      - ▪ thermal isolation
      - ▪ Problems with sealing when there is a lot of thermal expansion happens
  - ➢ Pump starts at 0.1 torr and can go up to 10^{-5} torr. (If the initial pressures are lower, a higher vacuum can be obtained.)

- **Refrigerator Type Cryopumps**
  - ➢ System is cooled using a refrigerator, and the coolant is He.

- ➢ The system can reach 80 °C in the first stage of cooling and 10 °C in the second. H_2 and He can be absorbed by activated charcoal while remaining liquid.
- ➢ This approach is used by the majority of cryopumps.

4. Chemical Adsorption Pumps

- **Gettering Pump**
  - ➢ Getter: chemical process that permanently adsorbs gas. Inert gases are ineffective.
  - ➢ Considerations for getter:
    - ❖ permanently mixed with gas
    - ❖ Reacts with a variety of gases
    - ❖ Does not outgas at normal temperatures and pressures, but does at high temperatures and pressures
    - ❖ Low vapor pressure
    - ❖ High absorption ratio (l/g)
  - ➢ Types:
    - ❖ **Solid Getter:** Tantalum, Niobium, Zirconium, Titanium, Thorium, Tungsten, and Molybdenum. Absorbing gas in different temperatures, from 20-1500 °C. Including bulk getter and coating getter.
    - ❖ **Flash Getter:** active material, Mg, Ca, Cs, Ba and their alloys. Cheaper, and usually used in vacuum tube.
  - ➢ Titanium sublimation pump.

- **Ion Pump**
  - ➢ To ionize inert gases and trap them.
  - ➢ Types:
    - ❖ Gettering ion pump or vapor ion pump: using electrical discharge to ionize inert gases for gettering.
    - ❖ Sputtering-- ion pump

VII. APPLICATIONS OF VACUUM

- **Common Uses**
  - ➢ A vacuum cleaner works by sucking part of the air out of the room. The air and dirt in a room rush into the vacuum that has been left behind, where the dirt is captured by a filter.
  - ➢ A fuel-burning automotive engine employs a vacuum to draw in air, which contains oxygen that allows the fuel to burn.
  - ➢ An incandescent light bulb has a vacuum inside to keep the hot filament from burning up.

- **Industrial uses**
  - ➢ Some industrial machines require vacuuming. To remove air from a vacuum chamber, vacuum pumps are utilized. Although it is not possible to achieve 100% vacuum, some vacuum pumps may achieve 99.9999% vacuum. This is known as a "hard vacuum". Hard vacuum is not required for most industrial applications.
  - ➢ Industrial vacuums are mostly utilized.

- **Food processing**
- **Electronics processing**
- **Packaging**
- **Manipulation**
- **Coating and degassing**

1. Applications of Vacuum Dryer

- Agrochemicals, Polymers, Metal Powders, Herbal Products, Pharmaceuticals, Food Products, Specialty Chemicals. Dehydrated foodstuffs, granule feed, monosodium glutamate, check extraction, organic pigment, synthetic rubber, propylene fibre, fiber-based medicine, medical materials, small wooden products, plastic products, dehydrating or solidifying for electronic elements.
- Elimination of remaining moisture. Evaporation of remainders of organic solvents like isopropanol, for example.
- The vacuum drier is appropriate for drying heat-sensitive raw materials that breakdown, polymerize, and metamorphosis at high temperatures. It is extensively utilised in the pharmaceutical, chemical, food, and electrical industries.

2. **Applications of Vacuum Pumps in Various Industries: Koebel *et al.* (2009)** reported that a vacuum pump is a piece of machinery that operates to create a partial or weak vacuum by operating gas or air molecules out of a sealed chamber. When the pressure inside the chamber is lower than the pressure outside the chamber or in adjoining systems, a vacuum exists. An absolute vacuum is defined as a pressure of 0 Pa and the absence of all gas molecules; this is distinct from that. Ahmedabad vacuum pump manufacturers make a variety of vacuum pumps, and the purpose of each pump is to convert energy into pressure. The sum of power required to run a pump is affected by air pressure. A vacuum pump works more effectively when air pressure increases. Because atmospheric pressure has such a big impact on vacuum pump performance, it changes with temperature, humidity, and altitude and influences vacuum pump operating costs **(Umrath, 1998).**

Vacuum pumps are used effectively throughout a wide range of industries. These are:

- **Ceramics:** Vacuum pumps are used in the ceramic industry to deaerate ceramic materials in extruders. This is a way of removing air to generate a high-quality product. Simultaneous mixing and vacuum deaeration may be utilized on occasion to improve process efficiency. Vacuum pumps significantly reduce the time necessary for deaeration.

- **Fabrication of Metals:** Vacuum pumps are essential in the heavy fabrication industries because they can survive the introduction of contaminated gases that may cause corrosion. Controlling surface reactions is critical for getting the appropriate outcome while treating metal. In addition to eliminating these surface contaminants, vacuum pumps can be used to degas and alter the oxides that are present on a material's surface. These methods include brazing, hardening, annealing, case hardening, sintering, tempering, and diffusion bonding. Pumps are widely used in these operations.

- **Mining, oil and Gas Industries:** Vacuum pumps are particularly useful for recovering carbon dioxide in flue gas compressors operating at temperatures up to 1000 ° F. They fill and clean petroleum barrels with vacuum pumps. They're used for vacuum filtration throughout the dewaxing process, recovering petroleum vapors from storage tanks and vacuum priming pumps. Pumps are used for vacuum filtering of mining products such as alum, coal fines, copper, feldspar, fluorspar, gold, iron ore, lead, uranium, vanadium, and zinc.

- **Manufacturing of Plastics:** Vacuum molding means the process of heating plastic sheets and distributing them over a mold. A vacuum is created, which draws the sheet into the mold. The finished product is then extracted from the mold. Due to the use of vacuum pumps in this process, low forming pressures may be required, enhancing process efficiency. The pumps are used in vacuum deaeration in plastic mixers and extruders.

- **Medical Industries:** A vacuum pump is an essential component of steam sterilizers, which are used in the medical field to cool and dry surgical equipment. They are also used in sterilizers to remove ethylene chloride during the sterilizing process. Because the medical profession is so sensitive because vacuum pumps are utilized with caution at all times.

- **Vacuum Pump Varieties Using Positive Displacement:** Positive displacement pumps expand cavities on a regular basis to increase their volume. During the sealing and draining of a portion of the chamber, gas or fluids are pumped to the desired regions. This is done all the time. Rotary vane pumps are the most common type of pump. Oil contamination is avoided by the design of diaphragm pumps, which are also commonly utilized. The dust resistance of liquid ring pumps is quite strong. Pumps with pistons and blowers are also common.

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