**Vacuum Science and Its Applications**

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**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**.**

**1.1 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 several ways to use free space (disambiguation). A vacuum is a space that is devoid of all substance, even 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 calibre 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. With only a few hydrogen atoms per cubic meter on average in intergalactic space, the vacuum in space is even better than that found on Earth.

Although vacuum has been a frequent subject of philosophical discussion since the time of the ancient Greeks, it wasn't until the 17th century that it was empirically investigated. Other experimental techniques developed as a result of Evangelista Torricelli's theories of atmospheric pressure, which created 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 contain the mercury **(Maier, 2005)**.

Incandescent light bulbs and vacuum tubes were introduced in the 20th century, turning vacuum into a useful industrial instrument. Since then, a wide range of vacuum technologies has become available. Interest in how vacuum affects life in general and human health in particular has increased as human spaceflight technology has advanced.

Because of its exceptional performance in keeping the quality of dried products, vacuum drying is currently regarded as one of the best drying processes **(Kumar *et al.,* 2023).** Vacuum drying is rapid, more uniform and energy efficient method compared to conventional drying. In recent years, vacuum-drying has been investigated as a potential method for obtaining high quality dried food products, included fruits, vegetable and pharmaceutical. The low temperature and fast mass transfer conferred by vacuum combined with rapid energy transfer by freeze-drying very rapid low temperature drying and thus it has the potential to improve energy efficient and product quality **(Kumar *et al.,* 2022).**

**1.2 Historical understanding**

The very existence of a vacuum has long been disputed. Ancient Greek philosophers argued for the existence of a vacuum, or void, in the context of atomism, which promoted empty and atom as important explanatory components of physics. after Plato, even the abstract concept of a featureless void was met with skepticism 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 cannot be rightly said to exist. According to Aristotle, no void could exist naturally because the denser surrounding material continuum would soon fill any imminent rare that would result in a void.

In his Physics, Book IV, Aristotle made several reasons against the vacuum, including the fact that motion through an open medium may last eternally and that there was no reason why something should come to rest anyplace specific. In the first century AD, Hero of Alexandria attempted but failed to construct an artificial vacuum, but Lucretius said for the existence of vacuum in the first century BC. In the 13th and 14th centuries, European scholars such as Roger Bacon, Blasius of Parma, and Walter Burley paid close attention to the concept of a vacuum. Scholars started departing from the Aristotelian perspective in the 14th century in favour of a supernatural emptiness outside the confines of the cosmos itself, a conclusion that was largely accepted by the 17th century and served to separate natural and theological issues. In this scenario, Stoic physics was ultimately influenced **(Chambers, 1998).**

Almost two thousand years after Plato, René Descartes proposed a geometrically based alternative theory of atomism that avoided the difficult void/atom/nothing contradiction. Although Descartes agreed that a vacuum does not exist in nature, the success of his namesake coordinate system and, more subtly, the spatial-corporeal aspect of his metaphysics would come to define the philosophically modern notion of empty space as a quantified extension of volume. However, magnitude and direction were conceptually distinct in the old paradigm.

According to mediaeval thought experiments on the concept of a vacuum, a vacuum could have existed between two flat plates when they were quickly separated. There was much disagreement about whether the air entered quickly enough as the plates separated or, as Walter Burley proposed, whether a "celestial agent" prevented the vacuum from forming. The phrase "horror vacui" referred to the generally held concept that nature loathed vacuums. The 1277 Paris condemnations of Bishop Étienne Tempier, which insisted that there be no constraints on God's abilities, led to the conclusion that God could create a vacuum if he so wished. There was even some doubt that God could create a vacuum if he so wished. According to Jean Buridan's 14th-century evidence, teams of ten horses were unable to open bellows when the port was sealed. The first attempts to quantify partial vacuum measurements date back to the 17th century. Both Blaise Pascal's investigations and Evangelista Torricelli's mercury barometer from 1643 proved the existence of a partial vacuum.

In 1654, Otto von Guericke invented the first vacuum pump and conducted the well-known Magdeburg hemispheres experiment, which demonstrated 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 improved by Robert Boyle, who also revolutionized vacuum pump technology with the help of Robert Hooke. The pursuit of the partial vacuum fell out of vogue until August Toepler invented the Toepler pump in 1850 and Heinrich Geissler invented the mercury displacement pump in 1855, both of which produced a partial vacuum of roughly 10 Pa (0.1 Torr). A number of electrical features become observable at this vacuum level, rekindling interest in future research.

Later, in 1930, Paul Dirac proposed the Dirac sea theory, which depicted the vacuum as an infinite sea of particles with negative energy. This hypothesis aided in refining the predictions of his earlier-formulated Dirac equation and successfully predicted the presence of the positron, which was proved two years later. Werner Heisenberg's uncertainty principle, developed in 1927, predicted a fundamental limitation to the measurement of instantaneous position and momentum, or energy and time. This has a considerable effect on the "emptiness" of space between particles. The existence of 'virtual particles,' or subatomic particles that arise out of nowhere, was confirmed in the late 20 century **(Boi, 2009).**

**1.3 Measurement of Vacuum**

A high-quality vacuum is one that has very little matter left in it because the amount of matter in a system determines the quality of a vacuum. Vacuum is primarily assessed by its absolute pressure, but additional factors, such as temperature and chemical composition, are needed for a thorough characterization. The mean free path (MFP) of residual gases, which represents the typical distance that molecules would cover before colliding, is one of the most crucial metrics. When the MFP is longer than the chamber, pump, spacecraft, or other items present, the continuum assumptions of fluid mechanics do not hold true as the gas density declines and the MFP increases. High vacuum is the name given to this vacuum state, and particle gas dynamics is the study of fluid movements in this range. At atmospheric pressure, the MFP of air is quite small—70 nm—whereas at 100 mPa (10-3 Torr), the MFP of room-temperature air is approximately 100 mm, on the scale of commonplace items like vacuum tubes. When the MFP is more than the width of the vanes, the Crookes radiometer rotates.

According to the technologies needed to create or measure vacuum quality, it is classified into ranges. The given below Table-2, which compares these ranges according to ISO 3529-1:2019 (100 Pa is equivalent to 0.75 Torr, a non-SI unit):

### Table-1: Vacuum Ranges

|  |  |
| --- | --- |
| **Vacuum Ranges** | **Pressure (Pa)** |
| Low vacuum | 1x105 to 3x103 |
| Medium vacuum | 3x103 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 |

* Outer space 1x10-4 to < 3x10-15 **(**Source: Kumar, 2009)

**Table-2: The reasoning for the definition of the ranges**

|  |  |  |
| --- | --- | --- |
| **Pressure range** | **Definition** | **The reasoning for the definition of the ranges is as follows (typical circumstances):** |
| Prevailing atmospheric pressure (31 kPa to 110 kPa) to 100 Pa | low (rough) vacuum | Pressure can be achieved by simple materials (e.g. regular steel) and positive displacement vacuum pumps; viscous flow regime for gases |
| <100 Pa to 0.1 Pa | medium (fine) vacuum | Pressure can be achieved by elaborate materials (e.g. stainless steel) and positive displacement vacuum pumps; transitional flow regime for gases |
| <0.1 Pa to 1×10−6 Pa | high vacuum (HV) | Pressure can be achieved by elaborate materials (e.g. stainless steel), elastomer sealing and high vacuum pumps; molecular flow regime for gases |
| <1×10−6 Pa to 1×10−9 Pa | ultra-high vacuum (UHV) | Pressure can be achieved by elaborate materials (e.g. low-carbon stainless steel), metal sealing, special surface preparations and cleaning, bake-out and high vacuum pumps; molecular flow regime for gases |
| below 1×10−9 Pa | extreme-high vacuum (XHV) | Pressure can be achieved by sophisticated materials (e.g. vacuum fired low-carbon stainless steel, aluminum, copper-beryllium, titanium), metal sealing, special surface preparations and cleaning, bake-out and additional getter pumps; molecular flow regime for gases |

Source: Hanlon (2003).

1. **Atmospheric pressure** is variable but 101.325 kPa (760 Torr) and 100 kPa (1000 mbar) are common [standard or reference pressures](https://en.wikipedia.org/wiki/Standard_temperature_and_pressure).
2. **Deep space** is far emptier than any manufactured vacuum. Depending on the region of space and astronomical bodies investigated, it may or may not meet the standards of high vacuum above. The MFP of interplanetary space, for example, is smaller than the size of the Solar System but greater than minor planets and moons. As a result, solar winds demonstrate continuum flow on the Solar System scale, but must be considered as a particle bombardment with respect to the Earth and Moon.
3. **Perfect vacuum** is an ideal state without any particles at all. It cannot be accomplished in a laboratory, yet there may be small volumes that contain no particles of matter for a brief period of time. Even if all matter particles were removed, there would still remain photons and gravitons, as well as dark energy, virtual particles, and other characteristics of the quantum vacuum.

**Table-3: Examples**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pressure (Pa or kPa)** | **Pressure (Torr, atm)** | [**Mean free path**](https://en.wikipedia.org/wiki/Mean_free_path) | **Molecules per cm3** |  |
| [Standard atmosphere](https://en.wikipedia.org/wiki/Atmospheric_pressure), for comparison | 101.325 kPa | 760 torrs (1.00 atm) | 66 nm | 2.5×1019[[54]](https://en.wikipedia.org/wiki/Vacuum#cite_note-54) |
| Intense [hurricane](https://en.wikipedia.org/wiki/Hurricane) | approx. 87 to 95 kPa | 650 to 710 |  |  |
| [Vacuum cleaner](https://en.wikipedia.org/wiki/Vacuum_cleaner) | approximately 80 kPa | 600 | 70 nm | 1019 |
| [Steam turbine](https://en.wikipedia.org/wiki/Steam_turbine) exhaust ([Condenser backpressure](https://en.wikipedia.org/wiki/Condenser_(steam_turbine)#Vacuum_system)) | 9 kPa |  |  |  |
| [liquid ring](https://en.wikipedia.org/wiki/Liquid_ring) [vacuum pump](https://en.wikipedia.org/wiki/Vacuum_pump) | approximately 3.2 kPa | 24 torrs (0.032 atm) | 1.75 μm | 1018 |
| [Mars atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Mars) | 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](https://en.wikipedia.org/wiki/Freeze_drying) | 100 to 10 | 1 to 0.1 | 100 μm to 1 mm | 1016 to 1015 |
| [Incandescent light bulb](https://en.wikipedia.org/wiki/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 | 1015 to 1014 |
| [Thermos bottle](https://en.wikipedia.org/wiki/Thermos_bottle) | 1 to 0.01 [[1]](https://en.wikipedia.org/wiki/Vacuum#cite_note-chambers-1) | 1×10−2 to 1×10−4 torrs (1.316×10−5 to 1.3×10−7 atm) | 1 cm to 1 m | 1014 to 1012 |
| Earth [thermosphere](https://en.wikipedia.org/wiki/Thermosphere) | 1 Pa to 1×10−7 | 10−2 to 10−9 | 1 cm to 100 km | 1014 to 107 |
| [Vacuum tube](https://en.wikipedia.org/wiki/Vacuum_tube) | 1×10−5 to 1×10−8 | 10−7 to 10−10 | 1 to 1,000 km | 109 to 106 |
| [Cryopumped](https://en.wikipedia.org/wiki/Cryopump) [MBE](https://en.wikipedia.org/wiki/Molecular_beam_epitaxy) chamber | 1×10−7 to 1×10−9 | 10−9 to 10−11 | 100 to 10,000 km | 107 to 105 |
| Pressure on the [Moon](https://en.wikipedia.org/wiki/Moon) | approximately 1×10−9 | 10−11 | 10,000 km | 4×105[[55]](https://en.wikipedia.org/wiki/Vacuum#cite_note-55) |
| [Interplanetary space](https://en.wikipedia.org/wiki/Interplanetary_space) |  |  |  | 11[[1]](https://en.wikipedia.org/wiki/Vacuum#cite_note-chambers-1) |
| [Interstellar space](https://en.wikipedia.org/wiki/Interstellar_medium) |  |  |  | 1[[56]](https://en.wikipedia.org/wiki/Vacuum#cite_note-56) |
| [Intergalactic space](https://en.wikipedia.org/wiki/Outer_space#Intergalactic_space) |  |  |  | 10−6[[1]](https://en.wikipedia.org/wiki/Vacuum#cite_note-chambers-1) |

Source: K. Jousten (2016).

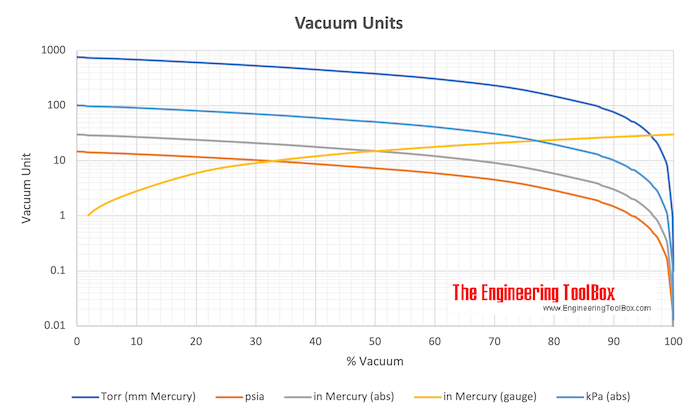
The table below can be used to convert between commonly used vacuum units:

**Table-4: Convert between commonly used vacuum**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **% Vacuum** | **Torr (mm Mercury)** | **Micron** | **psia, (lb/in2 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 (lb/in2) = 6,894.8 Pa (N/m2) = 6.895x10-3 N/mm2 = 6.895x10-2 bar

Source: Holkeboer (1966).



Source: The Engineering Toolbox (2003)

**Fig-1:** **Vacuum units and Ranges**

### Convert from % Vacuum to Unit of Pressure

The % of vacuum is a relative value where pressure at [normal or standard atmosphere](https://www.engineeringtoolbox.com/stp-standard-ntp-normal-air-d_772.html) is the base value.

pv% = 100% - (pv / patm) 100%                                       (1)

where,

pv% = vacuum (%)

pv = absolute pressure (psia, kPa, bar ..)

patm = absolute presure at normal or standard conditions (psia, kPa, bar ..)

#### Example - Pressure in kPa and % Vacuum

The vacuum with absolute pressure 4 kPa and standard pressure 101.4 kPa can be calculated as

pv% = 100% - ((4 kPa) / (101.4 kPa)) 100%

       = 96.1 %

#### Example - Pressure in kPa and % Vacuum

The vacuum with absolute pressure 0.1 bar and standard pressure 1 bar can be calculated as

pv% = 100% - ((0.1 bar) / (1 bar)) 100%

       = 90 %

**1.4 Advantages of vacuum drier**

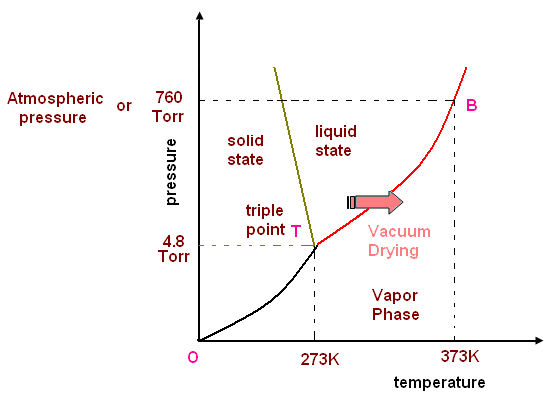
1. Low temperature operation. Vacuum drying simply reduces the boiling point - or vaporization temperature - required for removing the liquid. Resulting in more rapid surface evaporation.
2. Drying of the material faster than at normal atmosphere.
3. Vacuum dryer is especially suited to drying a heat-sensitive material that degrades above a given temperature and would otherwise require a lengthy drying cycle. Examples of such materials are vitamins, antibiotics, and many fine chemicals.
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 required for achieving and maintaining the low-pressure atmosphere inside the dryer also provides advantages for processing a hazardous material. Examples include toxic chemicals or solvents and explosive materials. The vacuum dryer safely contains and condenses the hazardous vapors from such substances without any threat to your workplace environment or outside atmosphere.
6. Vacuum drying process is a batch operation, Batch drying permits greater process versatility and can be more easily adapted to changing manufacturing practices. we can make it a continuous process by adding surge hoppers and other material handling equipment.
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.

**1.5 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

1. **Constant rate period**: In this the temperature of the product is equal to the boiling point of water at that pressure.
2. **Falling rate period**: In this temperature of the product approaches the heating medium temperature.

The energy which must be supplied to vaporize the water at any temperature depends on the temperature and pressure at that point. The energy required to convert water to vapor is *latent heat of vaporization.* Energy required to convert solid to gas is *latent heat of sublimation.*Boiling of water occurs when the vapor pressure of water is equal to total pressure on the water surface. Boiling of water occurs at 1000c at atmospheric pressure. As the pressure decreases boiling point also decreases. The heat required to vaporize water under any given set of conditions can be calculated from the as shown in Table-5.

**

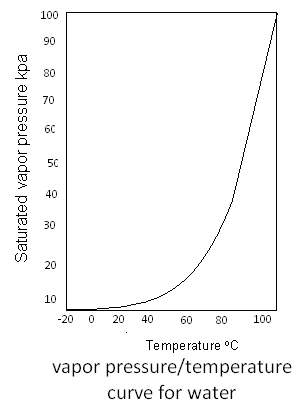
**Fig-2: Three phase diagram**

**Table-5: Latent heat of vaporization**

|  |  |  |
| --- | --- | --- |
| **Absolute pressure (Kpa)** | **Latent heat of vaporization (kJ/kg)** | **Saturation temperature**  **( oC)** |
| 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



**Fig-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**).

**1.6 Classification of Vacuum Pumps**

**Classification of vacuum pumps**

**a. Gas exhaust**

(a) Mechanical pump

(b) Vapor stream pump

**b. Gas storage**

(a) Chemical adsorption pump

(b) Sorption pump

(c) Cryo pump

**1. Mechanical pump**

**a. Rotary oil-sealed pump**

• Thin oil film between rotor and stator

• Vacuum range 10-4 ~10-5 torr, limited by oil’s vapor pressure, high efficiency

• Air ballast device: to help on suppressing water or alcohol liquid formation inside pump

**b. Rotary blower pump (Roots pump, dry pump)**

• Similar to gear pump, no lubricant between rotors, count on precise machine fitting (less than 100 µm) • Vacuum range: 10-2 -10-4 torr

• High pumping rate, from 50-5000 l/s

• No oil vapor, not good for the rough pumping from ATM, but better used for booster pump, however, sometimes need cooling.

**c. Mechanical molecular pump**

(a) Molecule drag pump

• No lubricant between rotor and stator, precise gap (<50) for large pressure drop, very clean

• 5000-10000 rpm, 100 µm particle can damage pump

• No need vapor trap, be careful of overheat which cause rotor stuck.

• Larger molecule weight molecules (H2O) get higher efficiency.

• Vacuum can be to 10-6 torr (need rough pump to 10-3 torr)

• Too expansive, replaced by turbo pump

(b) Turbo-molecular pump

• Similar to turbine, 15000-60000 rpm.

• Small pressure drop between disks, which tolerate larger gap~ 1mm, multi stages to get large pressure drop.

• Vacuum can be 10-9 ~10-10 torr (need rough pump to 10-3 torr), can be applied to ultra-vacuum range.

• Larger molecule weight molecules (H2O) get higher efficiency, very clean operation.

**2. Vapor stream pump**

a. Diffusion pump

• Using molecular flow though nozzle in high speed to entrain gas molecules.

• Using Hg (higher vapor pressure usually 10-3 torr at room temp), for mass spectrometer, or silicone oil (lower vapor pressure) cheaper and safer, used for high vacuum (10-6 ~10-9 torr under cooling).

• Cannot be used for ultra-high vacuum because of vapor.

• Need rough pump to 10-3 torr first

• Using cooling baffle (freon) or traps to reduce vapor back streaming

b. Stream ejector pump

• Ejected vapor stream perpendicular to vacuum chamber.

• Vapor condense after passing through throat

**3. Sorption and Cryo pump**

a. Sorption pump

• Sorption including

a. Absorption (gas dissolved inside solid, not easy),

b. Physical adsorption (using Von der Waals forces on the first several molecules of solid surface, used by sorption pump),

c. Chemisorption’s (chemical bond on surface, classified into the next section)

• Physical sorption has reversibility: to increase sorption ability: decrease temperature and increase pressure. Absorbents absorb Absorbates

• Four important considerations for a good absorbent: a. Large surface area (porosity)

b. Chemical inert

c. Integrity

d. Not hydrolysis

• Popular absorbents: activated charcoal 103 m2 /cm3), activated alumina artificial zeolite (600-800 m2 /g=> contained 100 cm3 /g at 77K)

• Usually combined with cooling system=>cryogenic sorption pump

• Vacuum from 10-1 down to 10-5 (dependents on temp, usually hydrogen or helium still remained in system), need rough pump to help pump down in the first stage.

e. Cryo pump

• Using coolant to cool down and condense gas or vapor and keep them in the pump system. System cheap and simple, but the consumption is expansive, not very popular in the current industry.

• Solid usually has less vapor than liquid, and temperature greatly affect vapor pressure. For example: solid N2: 32K-22K, vapor pressure from 10-4 -10-10 torr.

• If Use liquid N2 (77K) as the coolant, water vapor, CO2, organic vapor, Xe, Kr, Ar, become solid, but H2, He, Ne, N2 are still gas. Barely usable for cryo pump.

• Liquid He (4.2K) is better coolant, but expansive, liquid H2 (10.3K) less effective and more dangerous.

• Considerations for cryo pump:

a. large cooling area

b. thermal isolation

c. Sealing issue when large thermal expansion happens

• Pump start from 0.1 torr, can reach 10-5 torr. (Higher vacuum can be obtained if the original pressures lower)

f. Refrigerator type cryopump

• Using refrigerator to cool down system, the coolant is He.

• System can approach 80K in the first stage of cooling, 10 K for the second stage. H2 and He can be absorbed by activated charcoal while not condense into solid.

• Most of the cryopumps using this method

**4. Chemical adsorption pumps**

a. gettering pump

• Getter: permanently adsorb gas by chemical reaction. Not effective for inert gases.

• Considerations for getter:

a. Permanently combined with gas

b. Can react with various gases

c. Not outgas in normal temperature and low pressure, but at high temp

d. Low vapor pressure

e. Large absorbing ratio (l/g)

• Types:

a. 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.

b. Flash getter: active material, Mg, Ca, Cs, Ba and their alloys. Cheaper, and usually used in vacuum tube.

• Titanium sublimation pump.

b. ion pump

• To ionize inert gases and trap them.

• Types:

a. Gettering ion pump or vapor ion pump: using electrical discharge to ionize inert gases for gettering.

b. Sputtering-- ion pump

**1.7 Applications of Vacuum**

1. **Common uses**

* A [vacuum cleaner](https://simple.wikipedia.org/wiki/Vacuum_cleaner) works by pumping away some of the air. The air and dirt in a room rush into the vacuum left behind, where the dirt is caught by a filter.
* An [automobile engine that burns fuel](https://simple.wikipedia.org/wiki/Internal_combustion_engine) uses a vacuum to pull in air, which contains [oxygen](https://simple.wikipedia.org/wiki/Oxygen) that allows the fuel to burn.
* An incandescent [light bulb](https://simple.wikipedia.org/wiki/Lightbulb) has a vacuum inside so the hot filament doesn't burn up.

1. **Industrial uses**

* Vacuum is needed for some kinds of machines used for industrial production. Vacuum pumps are used to pump air out of a vacuum chamber. It is not possible to create 100% vacuum, but some vacuum pumps are able to create 99.9999% vacuum. This is called "hard vacuum". Most industrial purposes do not need hard vacuum.
* Industrial vacuums are mainly used in:

1. **Food industry**
2. [**Electronics**](https://simple.wikipedia.org/wiki/Electronics)**industry**
3. **Packaging**
4. **Manipulation**
5. **Coating and degasing**

**1.7.1 Applications of vacuum dryer**

1. Dyes and Pigments, Agrochemicals, Polymers, Metal Powders, Herbal Products, Pharmaceuticals, Food Products, Specialty Chemicals. Dehydrated vegetable, granule feed, monosodium glutamate, check extraction, organic pigment, synthetic rubber, propylene fiber, medicine, medical materials, small wooden products, plastic products, aging or solidifying for electronic elements.
2. Removal of residual moisture. Evaporation of residual organic solvents, such as isopropanol etc.
3. The vacuum dryer is suitable for drying heat sensitive raw materials that can decompose and polymerize and metamorphose at high temperature. It is wide used in pharmaceutical, chemical, foodstuff and electronic industries.
   * 1. **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.

**Reference**

**Chambers, A., Fitch, R.K. and Halliday, B.S. (1998).** *Basic Vacuum Technology*, CRC Press; 2nd Edition.

**Boi, L. (2009).** *Creating the Physical World ex nihilo? On the Quantum Vacuum and its Fluctuations.* In The Two Cultures: Shared Problems (pp. 51-97). Milano: Springer Milan.

**Boi, L. (2011).** *The quantum vacuum: A scientific and philosophical concept, from electrodynamics to string theory and the geometry of the microscopic world*. JHU Press.

**Holkeboer, D.H., Jones, D.W., Pagano, F. and Santeler, D.J. (1966).** *Vacuum technology and space simulation* (No. NASA-SP-105).

https://e-publishing.cern.ch/index.php/CYR/article/download/241/183.

O'Hanlon, J.F. (2003). *A User's Guide to Vacuum Technology*, Wiley-Interscience, 3rd Edition.

Jousten, K. (2016). *Handbook of Vacuum Technology*, Wiley-VCH, 2nd Edition.

**Koebel, M. and Manz, H. (2009).** *Development of vacuum glazing with advanced thermal properties*-Final report.

**Kumar, N. (2009). “***Analysis of Vacuum Drier and Vacuum Freeze Drier for Food and Pharmaceutical Application*” (M. Tech. dissertation).

**Kumar, N., Immanuel, G. and Goyal, S.K. (2022).** *"Effect of vacuum freeze drying on physical quality of button mushroom (Agaricus bisporus)."* Emergent Life Sciences Research, 8: 84-91.

**Maier, J.R. (2005).** *Foundations of affordance-based design*. Clemson University.

**Kumar, N., Immanuel, G. and Goyal, S.K. (2023).** *Drying And Dehydration of Mushrooms – A Review*.Strategies for Sustainability in Indian Agriculture and Food Security. Poddar Publication, Varanasi.

**The Engineering Toolbox (2003)**. *Vacuum - Pressure Units Converter*. Available at: https://www.engineeringtoolbox.com/vacuum-converter-d\_460.html.

**Umrath, W. (1998).** *Fundamentals of vacuum technology*.

Howard Twing. *Understanding Vacuum Measurements*

Daniel H. Herring. *Vacuum Heat Treatment*

McAllister Technical Services. *Vacuum History and Technology.*