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Selection of Precise vacuum Pumps for the Systems with Diverse Vacuum Ranges

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Abstract- Basically a vacuum pump is the most essential component of any vacuum system which is accountable to bring into being the required vacuum in the sealed setup, to accomplish a certain process. But for the broad vacuum range, all the vacuums cannot be generated by a single vacuum pump. Consequently, various pumps of distinct types are used to properly generate the vacuum of diverse ranges. Therefore, the selection of suitable vacuum pump or pumps to produce the required vacuum, for a particular vacuum work, is of primary importance. There are many factors that affect the suitable pump selection. In this paper, proper guidelines highlighting key criteria for selecting an appropriate vacuum pump, supportive for proper vacuum production has briefly been discussed that can make the task of pump selection simpler and exact.

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Selection of Precise vacuum Pumps for the Systems with Diverse Vacuum Ranges

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I. Introduction

The vacuum technology is indispensable as well as immeasurably used as a parent one for the rapid progress of many other modern and sophisticated technologies, because it is the most useful tool for a common vacuum pool. From its initial association with research in physics, the range of applications has extended to important sectors of industrial activity, including pharmacy, food industry, metallurgy, mechanical, electrical, electronics, mechatronics, chemical engineering, surface engineering, particle acceleration, medical, etc. making an incalculable contribution to process effecttiveness, efficiency and quality. Therefore, it is almost impossible to list all the areas in which vacuum technology is now used. Generally group wise presentation of some vacuum applications in different fields and ranges is shown in Fig.-1[1].

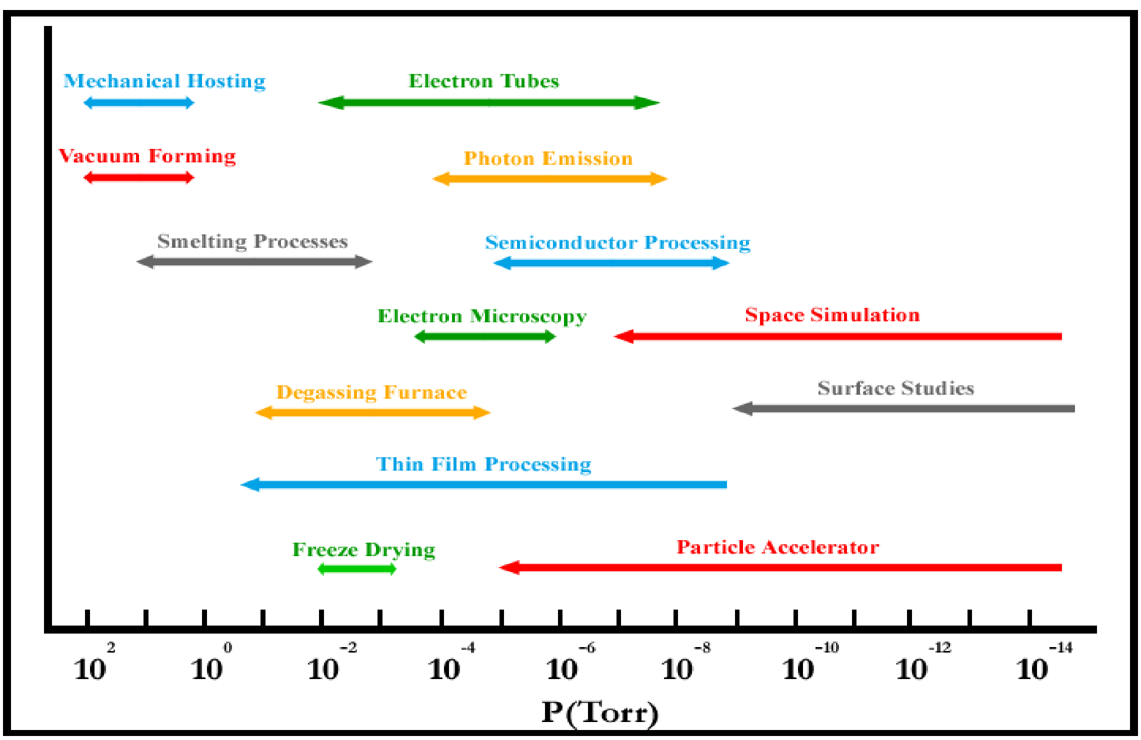

Figure 1 : Vacuum applications in different vacuum ranges [1]

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For all vacuum concern modern and sophisticated technologies, appropriate vacuum generations are as essential as these technologies them selves. So the proper vacuum generation of broad vacuum range is of prime interest and need of the hour. For this purpose, a vacuum pump plays the major role, selection of which is an important and questionable issue. Selecting the right vacuum pump or pumping system for a vacuum process is a complex and challenging task with the realization that no single type of vacuum pump is likely to provide all the characteristics necessary to meet all the process requirements. Vacuum pump selection not only demands a thorough understanding of what you need your vacuum system to do, as important is knowing the impact the selected vacuum pump will have on the overall cost to produce your product, pertaining to cost of ownership and how the selected vacuum pumping system will impact product quality and / or yield [2]. Before the selection of an appropriate vacuum pump for a particular vacuum application, one has to come across a variety of questions which are planned in Fig.-2.

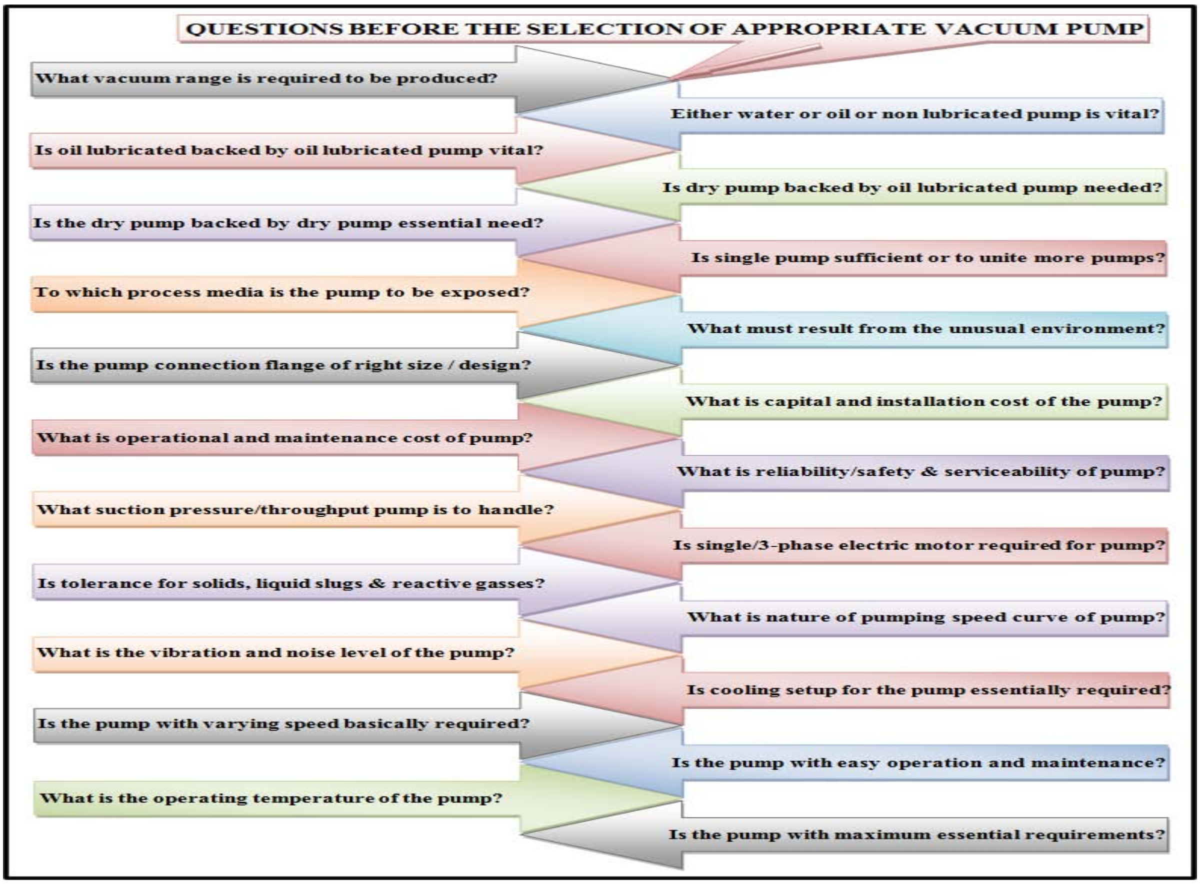

Figure 2 : Questions before the selection of proper vacuum pump

For sealed system the capacity of the vacuum pump is determined by how fast the system of certain volume can be evacuated to a certain vacuum level. This capacity is called the evacuation time of the pump for that volume. For all such considerations, the thorough understanding of vacuum generation technology is essential. Vacuum pumps are used for vacuum generation in the broad vacuum range from atmospheric to Extremely High Vacuum (XHV). Due to some physical reasons, it is not possible to construct a vacuum pump which can generate the vacuums of entire vacuum range. Consequently, a series of vacuum pumps is available, each of which has a characteristic vacuum production range that usually extends over several orders of magnitudes. A variety of pumps have to employ to generate vacuum, depending on its needed range. These pumps normally fall into three different main groups: positive displace pumps, momentum transfer pumps and local entrapment pumps. A graph of molecular density versus vacuum quality, gives up a straight line, consequently defining different vacuum levels: 'Low Vacuum', 'Medium Vacuum', 'High Vacuum', Ultra High Vacuum' & 'Extremely Ultra High Vacuum' and corresponding pump operation regions: 'positive displacement region', 'mentum transfer region' and 'local entrapment region', as shown in Fig.-3 [3]. Due to the diversity of vacuum ranges and pump regions, selection of appropriate pump for a particular region is critical.

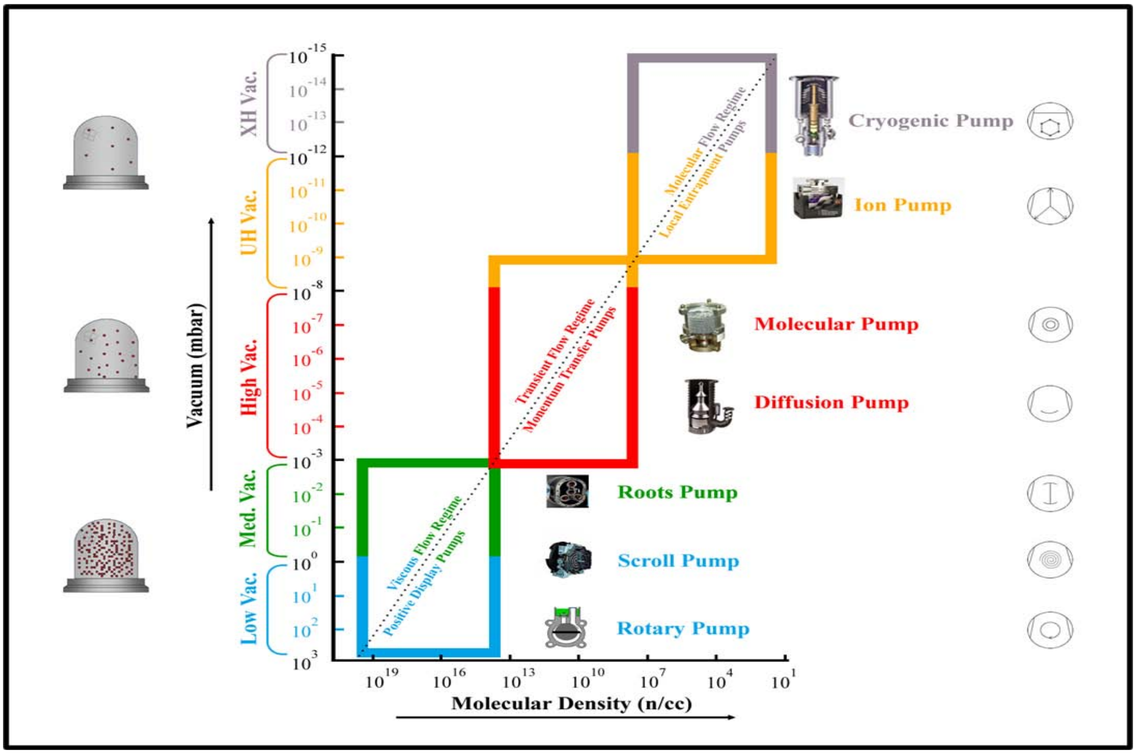

Figure 3 : Pump classification on the basis of degree of vacuum and molecular density [3]

II. Selection of Vacuum Pumps

To meet the requirements of vacuum system entirely, proper pump selection is crucial as vacuum pump has to meet up some well-studied criteria. Several factors affect proper pump selection process and by following it appropriately, the task becomes simpler and more specific. Let us now discuss some of the vacuum pumps widely employed for industrial use as well as R&D and other purposes. Special steps regarding this selection process have briefly been discussed in the manner:

a) Process Vacuum Range

Vacuum pumps can be grouped by the pressure range they measure. Diverse vacuum ranges are shown in Fig.-3. Categorically, a pump has to generate the vacuum of specific range for a particular vacuum system. For this purpose, it is essential to select the pump according to the process range of the system. For all vacuum applications, pumps are selected that are more suitable for these applications. Selection criteria of various pumps for varied vacuum ranges are briefly discussed on basis of the concept given in the graph of Fig.-3 as well as taking into consideration other relevant parameters and requirements of particular vacuum systems.

b) Pumps for Low/Medium Vacuum

The pumps used to generate the low/medium vacuum in viscous flow are usually positive displacement mechanical vacuum pumps. Viscous flow is feasible only when there is a bulk of gas molecules, and if one part of the bulk is removed, the remaining one comes to fill its space. During the evacuation process when the bulk of gas molecules reduces, the pumping speed of the pump decreases simultaneously and ultimoately becomes almost zero at the reduced pressure. To focus the stepwise discussion, we will first concentrate mainly on vacuum pumps capable of producing low vacuum from atmospheric pressure to 1 torr and medium vacuum from a 1 torr to 10^{-3}torr. The mechanical rotary vacuum pumps are positive displacement pumps that move fluids by means of the motion of rotors, cams, pistons, screws, vanes, etc. or mechanical elements in a fixed casing. The mechanical vacuum pump, historically the work horse of the industry is the oil sealed rotary piston vacuum pump. Therefore, the mostly focus is on choosing oil sealed rotary mechanical vacuum pumps [2].

In the early stages of vacuum processing, the rotary vane or piston oil-sealed vacuum pumps provided reliable performance. However, due to the demand of semiconductor, chemical, industrial and other purposes, some vacuum processing problems were soon encountered. The aggressive and hostile gases resulting from these processes demanded radical changes in vacuum pump technology. Initially the responses were the modifications to oil-sealed pumps for increased corrosion resistance, forced lubrication, and the use of expensive inert fluids, filters, traps, etc. Although these improvements did increase the

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compatibility and reliability of oil-sealed pumps, an alternative was still necessary.

Today, the oil-free swept volume vacuum pumps can be considered as an alternative when one or more of the following characteristics are of prime importance: (i) cleanliness, (ii) safety, (iii) corrosion resistance, (iv) cost of operation, and (v) cost of maintenance [4]. An oil-sealed vacuum pump can contaminate a vacuum system by emitting oil vapor (back-streaming and back-migration) and all lubricated vacuum pumps are potential sources of contamination. The only vacuum pumps which will never contaminate a system with oil are the oil-free pumps or dry vacuum pumps. Some oil-free pumps can be considered as safe due to the absence of oil in their design [2]. Good examples of dry pump are scroll vacuum pumps. Now-a-days many vacuum applications are unthinkable without the use of another dry mechanically driven diaphragm pumps for gases. Their particular properties such as oil-free and uncontaminated operation make them suitable for numerous fields of application [5]. Sometime rapid evacuation of the system is essentially required in the medium vacuum range. For this purpose, a roots vacuum pump in series with suitable mechanical vacuum pumps is essential. Another class of positive displacement pumps commonly known as liquid ring vacuum pumps is constantly becoming more important in modern plant production processes. Their design and principle of operation offers many advantages over other types of rotary gas pumps. Liquid Ring Vacuum Pumps can be used on a very large scale for widely divergent applications. The schematics of some of the positive displacement pumpsare shown in Fig.-4[6].

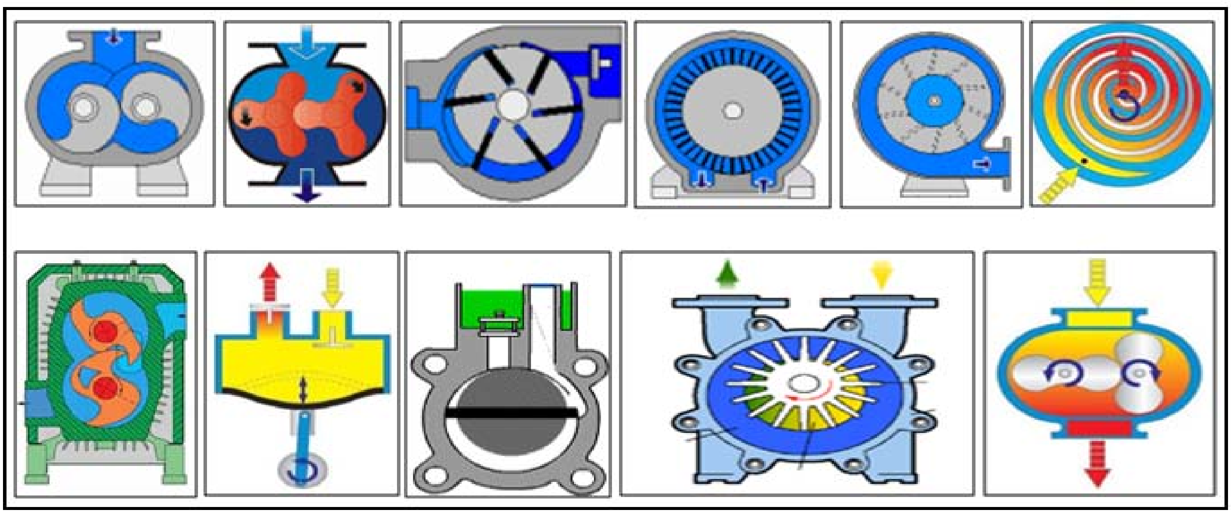

Figure 4 : Schematic of working principle of some positive displacement pumps [6]

Another significant pump of low vacuum range is the ejector vacuum pump, sometimes called a jet pump shown in Fig.-5 It is the simplest and probably most widely used for vacuum production. It works by converting pressure energy of a motive fluid into velocity energy as it flows through a diffuser. The high velocity of the motive fluid through jet nozzle creates the low pressure in the vessel to be evacuated. Ejector offer a range of attractions: Simple design with no moving parts and practically no wear. It can be mounted in any orientation and fabricated of virtually any metal, as well as various types of plastics. It provides largest throughput capacity with lowest capital cost as compared to any vacuum producing device. It does not need any special startup or shutdown procedures and requires simple repair and maintenance.

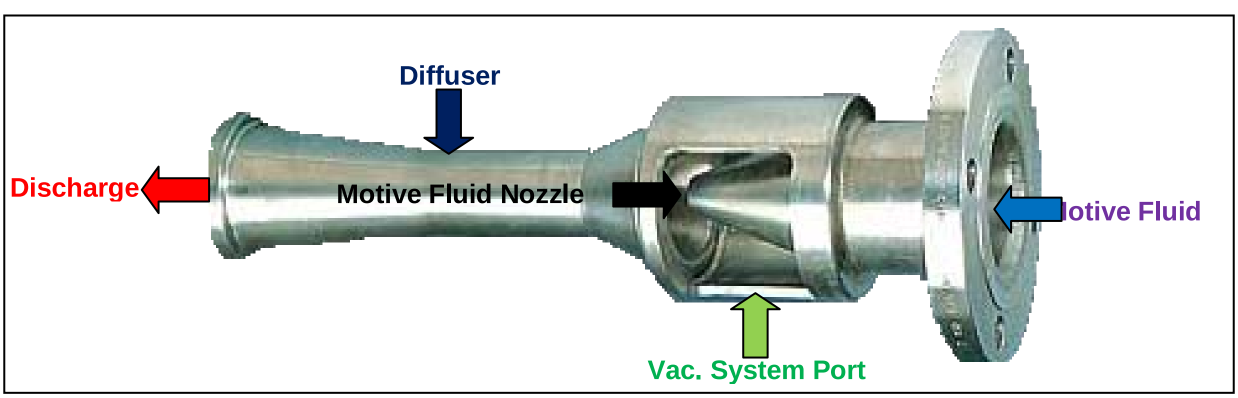

Figure 5 : Schematic of ejector vacuum pump

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c) Pumps for High/ Ultrahigh Vacuum

The transient flow regime is with somewhat lesser molecular density and molecules do not behave like a bulk but act as individual particles that need to be removed individually through the process of momentum transfer. The pumps utilizing this process are called momentum transfer pumps. Two pumps in this low density region are of prime interest and are mostly used. First, the oldest one is the oil diffusion pump (backed by rotary pump), with oil or mercury as working fluid, encountering the main problems of back streaming, back migration and contamination. A good alternative, free from all these problems, with better performance, and producing clean vacuum is turbo-molecular pump (backed by dry scroll pump). The momentum transfer is the governing principle in both diffusion and turbomolecular pumps, used for various purposes in high and ultrahigh vacuum range. The schematic showing working principle of oil diffusion pump and turbomolecular pump is given in Fig.-6 and Fig.-7 respectively.

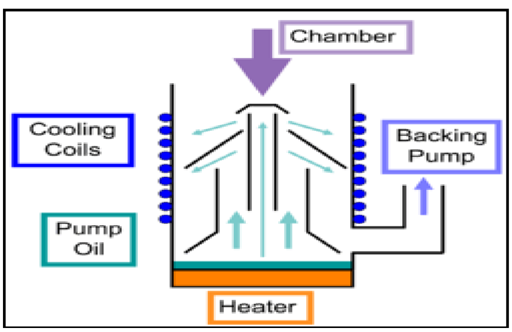

Figure 6 : Schematic of Diffusion Pump working principle

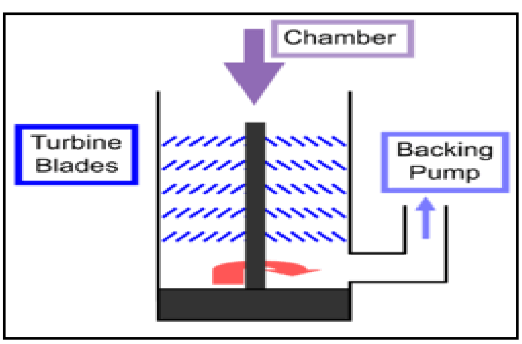

Figure 7 : Schematic of Turbo-molecular Pump working principle

d) Pumps for ultrahigh/extreme high Vacuum

The molecular flow regime is the region of high, ultra high and extreme ultra high vacuum. The principle of entrapment of the residual molecules is used for the evacuation in this region. The pumps operating on this principle are called entrapment pumps. In this least molecular density region, the residual molecules are either wiped out by the process of ionization or condensed cryogenically. Consequently, two types of vacuum pumps namely ion pumps and cryogenic pumps are used for the production of high/ultrahigh vacuum and ultrahigh/ extreme high vacuum respectively. In an ion pump the residual molecules in the working vacuum chamber are vanished through the process of ionization. In a cryogenic pump, gas molecules are condensed on the cold surface by some suitable refrigeration arrangement. As long as the surface remains cold, the gas molecules will remain on the cold surface, creating required vacuum in the rest of the chamber. The schematic showing working principle of oil ion pump and cryogenic pump is given in Fig.-8 and Fig.-9 respectively.

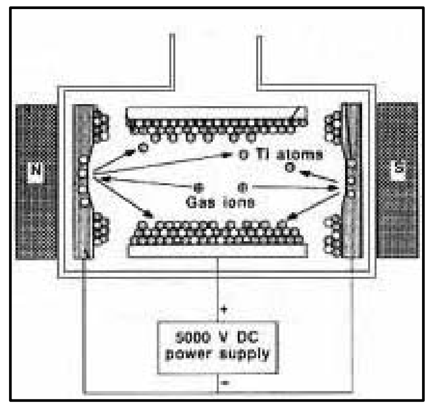

Figure 8 : Schematic oflon Pump working principle

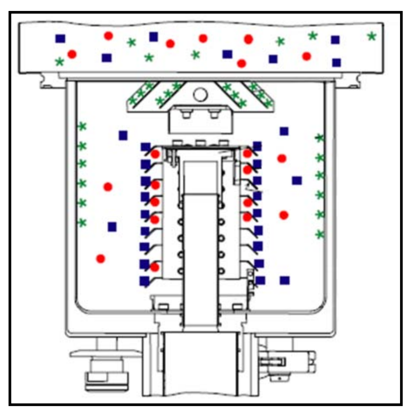

Figure 9 : Schematic of Cryo-genic Pump working principle

e) Pumping Speed

Pumping speed is one of the essential parameters to choose a vacuum pump for particular range. It would have its maximum value at the pressures which are needed for a specific application. Therefore, the knowledge of maximum pumping speed specifications of a vacuum pump is very important. Pumping speed verses pressure curve for any vacuum pump immensely useful because it describes the pump performance throughout its probable application range.

Other important information to be gained from the pumping speed verses pressure curves would make certain whether a given pump could meet and maintain a specified pressure at specified process gas flow adequately. The shape of the curve can easily help to make the decision when specific speeds at specific pressures are important for the process. Pumping speed verses pressure curves can be even more important when high vacuum pumps are considered. These curves for mostly used vacuum pumps with diverse vacuum ranges are given in Fig.-9[7].

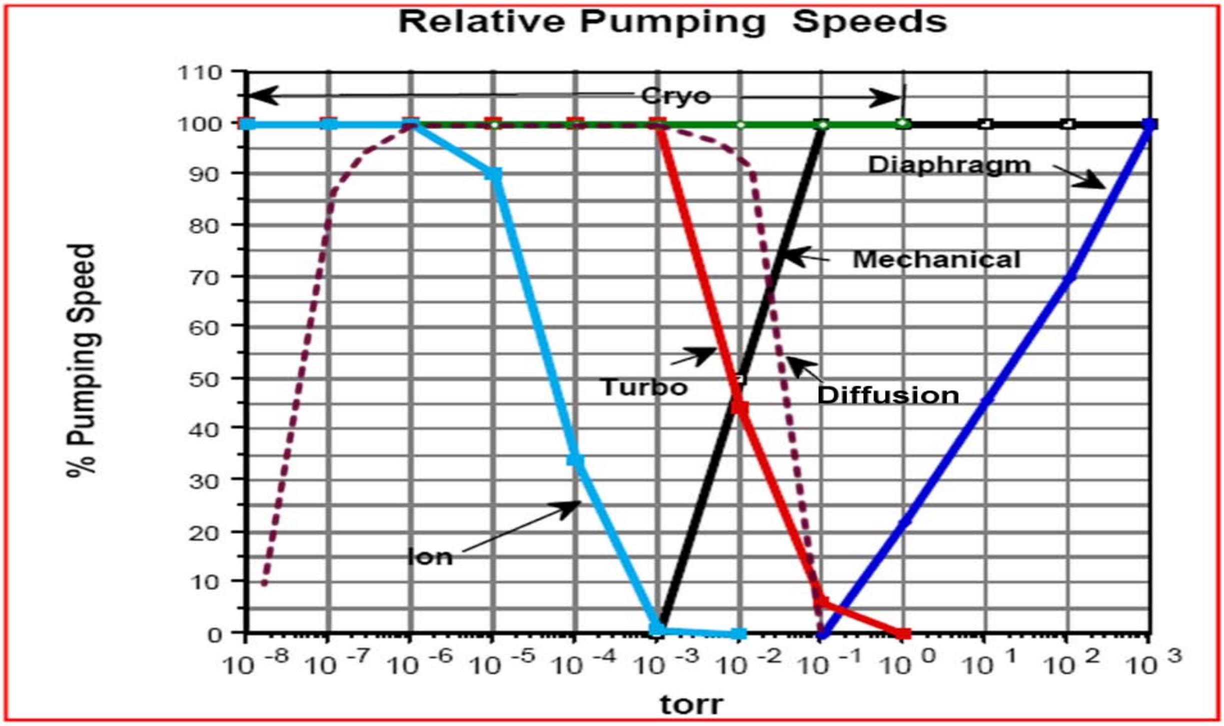

Figure 10 : The change of relative pumping speed with pressure of some common vacuum pumps [7]

f) Environment

The desired vacuum range is not the only factor considered when selecting a suitable vacuum pump. The operating conditions under which the vacuum pump has to work also play a significant role. If the vacuum pump is operated under the conditions with high risk of contamination, vibrations, temperature, pressure, etc, consequently there will be large possibility of damage to pump, worse pump performance and unnecessary maintenance. Other environmental conditions are related to health and safety (emissions and waste generation, noise, general equipment safety).

g) Process Media

While all the factors regarding proper vacuum pump selection are important, consideration for the actual process media for which the pump will be exposed, is vital too. Some gases from the process media may contaminate oil of the rotary pump or diffusion pump, consequently making the pump with poor performance and consequently low ultimate vacuum.

h) Configration

Pump with port size matching with the designed port size of the system to be evacuated should be preferred. Furthermore, pump should be connected to the vacuum system with smallest possible vacuum plumbing. It should be recognized during the design and equipment selection stage that pumping system configuration can be just as important as the pump technology and even small changes in configuration can make significant improvements to vacuum system reliability reducing overall user interference.

III. Conclusion

Vacuum pump is the back bone for any vacuum system which should be selected according to some consistent and well thought criteria to get essential output and effectiveness with required ultimate vacuum. Some basic questions should be considered before deciding which vacuum pump is the best for a particular vacuum application. These include the requirement of degree of vacuum, flow capacity and accordingly the desired horsepower and speed to meet these requirements. Nature of power available, duty cycle either continuous or intermittent, ambient conditions and space limitations should also be considered. Briefly, reducing cost, improving working, expanding applications, gaining production, improving efficiency and saving space and energy are all important engineeing considerations before the selection of suitable vacuum pump.

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