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Vacuum Applications in Phenol Derivatives Extraction and Vacuum System Selection

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Abstract - *Phenol is a major pollutant because of the presence in the products of major processing and refining plants. It has a significant short-term and long-term impact on many materials used in manufacturing equipment for chemical plants. Phenol and its derivatives are mutagens, teratogens, and carcinogens that have negative physiological consequences and are classified as environmental hazards. Various methods are used for the extraction of phenol and its derivatives from columns and other systems in an industry, such as adsorption and various biological and non-biological methods. In the present study, an attempt is done to analyze the survey of the research on phenol removal by using Dry screw Vacuum pump. It is one of the ways that has been reported to be effective in removing phenol from industries and extending the life of the equipment.*

Key Words: Phenol, Everest vacuum system, Dry screw vacuum pump, Superscrew, Supervac.

1.INTRODUCTION

For the past few decades, rapid industrialization and urbanization have had a negative impact on the worldwide environment, as well as the quality and quantity of environmental resources. Pollution caused by improper industrial waste management is one of India's most serious environmental issues.

As a result, the poisoning of these metals and alloys has resulted in a true catastrophe. The need of the hour is to develop green and sustainable technology for effluent treatment. In this period of industrial and social development, developing effective phenol vapors removal technology is a critical study topic. Many researchers have worked in this field. Phenol and its derivatives are one of the major effluents found.

Everest Vacuum offers dry vacuum pumping systems developed with a variety of designs and cross linkages to meet the needs of different processes and operate as import alternatives. Everest offers a wide range of vacuum systems, from simple compact devices to large purpose-built systems with integrated instrumentation and control panels that may be operated locally or remotely. These systems are delivered as skid-mounted, plug-and-play units. Everest Vacuum Pumping Systems are noted for their dependability and unique design, as well as their unmatched quality, value and performance. They are also simple to use and maintain.

Phenol's and its derivatives are manufacturing /producing in large scale of chemical and pharmaceutical industries, including petrochemical plants, petroleum refineries, coal gasification plants, liquefaction plants, resin manufacturing plants, dye synthesis plants, pulp and paper mills, and pharmaceutical plants. So it is necessary to remove phenol vapors and their derivatives from these industries.

One of the key goals is to correctly extract these phenol vapors, as these vapors have numerous acute and long-term negative effects on humans. It's a caustic and nerve-poisoning chemical. Side effects of phenol include a sour taste in the mouth, diarrhea, blurred eyesight, and black urine discharge. It is also poisonous to aquatic life. Human toxicity values typically vary from 10 to 24 mg/L, while fish toxicity levels typically range from 9 to 25 mg/l.The lethal concentration of phenol in the blood is roughly 150 mg/100 ml.

1.1. Dry screw Vacuum Pumps:

For many medium and high vacuum applications, dry pumps are becoming more popular as an alternative to oil-filled rotary vane pumps (e.g., in low-pressure vacuum carburizing where fine granular soot is carried from the process into the pump). Vacuum furnace designers and users must have a thorough understanding of how claw and screw pumps work. The principles of operation, pump design, sealing, operational characteristics, features, purging, and ancillary devices are all covered in this section.

When a high vacuum is not required and a slower draw down is acceptable, a dry screw pump (Fig. 1) is used alone, or in conjunction with a Roots blower (aka booster) when higher performance is necessary. With the primary pump, which offers the quickest pumping speed and highest ultimate vacuum, both a Roots booster pump and a secondary high-vacuum (e.g., diffusion) pump are used for the best system performance. When used in series with either a booster pump, or with both a booster and secondary high-vacuum pump, the primary pump is referred to as a “backing” pump.[1]

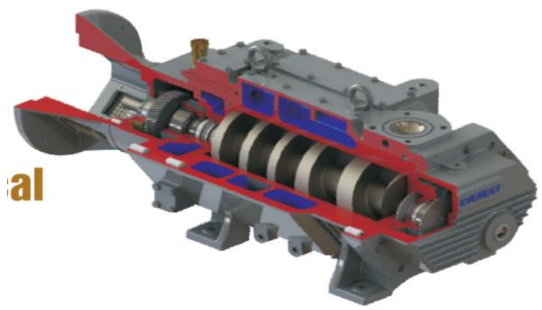

Fig -1: Typical dry screw vacuum pump (Superscrew)

Fig -2: Typical dry screw vacuum pump (Supervac)

1.2. Operating Principles:

Of the various vacuum pump technologies, screw pumps are considered dry, positive displacement pumps. Dry, because the gas being transferred is not exposed to oil or water used in the pump, whereas wet pumps use oil or water as a lubricant and help provide a seal. Positive displacement refers to the fact that the pump works by mechanically trapping a volume of gas and moving it through the pump, creating low pressure on the inlet side.

Two screw-shaped rotors in Everest ESPH vacuum rotate in opposite directions in a screw vacuum pumps.Process gases are sucked in, trapped between the c ylinder and screw chambers, compressed, and carried to the gas discharge.The screw rotors do not make touch with each other or the cylinder during the compression operation. This operating principle is enabled by precise manufacturing and minimum clearances between the moving elements, as well as a low ultimate pressure of up to 0.01 millibar (absolute).[3]

1.3. Operating Characteristics

Dry screw pumps are capable of handling gases with high levels of moisture or other vapors, as well as dust and other impurities. Furthermore, unlike oil-sealed rotary vane pumps, the pushed gas is not exposed to oil (the alternate wet pump technology). As a result, oil pollution of the pumped gas is prevented, as are oil replacement maintenance expenses.The design is low friction and requires less energy than the rotary vane pump since the revolving surfaces do not come into contact.

There is no oil or water in the pumped gas stream to remove heat created by the compression of the gas because the screw pump operates dry. This has the benefit of reducing the condensation of pumped vapors, which would normally condense at lower temperatures. The pump is thus protected from contamination by condensate residue. The high operating temperature also aids water vapor pumping by preventing water condensation in the pump. When flammable gases are treated, screw pumps can self-ignite due to their high working temperature. Polymerization of process vapors can build up on the surfaces of the screws and the interior of the stator because they run hot leading maintenance concerns and potential pump failure.

The greater operating temperature has the disadvantage of necessitating continual purging of the pump bearings to avoid heat-related early failure. The gearbox is sealed from the outside with shaft seals and O-rings, and the compressor chamber is sealed with piston rings in a purged seal. There is an atmospherically ventilated region between the two that is purged with air or a specific sealing gas. Purging is also utilized to keep particles and harsh process gases out of the seals and bearings.

Because of the close rotor/stator clearances, any rotor thermal increase influences the clearances and thus the back flow (gas leakage). As a result, the pump's performance is temperature dependent. The pump is cooled by water flowing through internal passageways in the stator to avoid/control the pump temperature and prevent overheating. In the cooling water, a thermostatic control valve regulates the temperature by altering the water flow rate automatically. A thermostatic control is also included with the screw pump. If the pump temperature reaches a predefined level, it switches off the pump to prevent damage.

The screw rotors are frequently coated with spray-on Electroless nickel plating (which is actually a nickel-phosphorus alloy (2-10% P)) and Poly-ether ether ketone

(PEEK) type material to increase the pump's ultimate pressure and efficiency. The thin covering allows for narrower clearances between the screws and between the screws and the stator. The coating also aids in the prevention of corrosion. The coating will wear down over time and will need to be renewed to avoid affecting pump performance.[3]

SUPERSCREW DRY SCREW VACUUM PUMP

SPECIFICATIONS

Model	Nominal Displacement (50/60 Hz) m³/hr	Nominal Displacement (50/60 Hz) CFM	Ultimate Vacuum Torr	Ultimate Vacuum Pa	Power (KW) 50 Hz	Power (KW) 60 Hz	Rotation (RPM) 50 Hz	Rotation (RPM) 60 Hz	Cooling Water Flow Lts./Min	Gear Oil (Mineral) Lts.	Approx Weight (Bare Shaft) Kgs.
ESPH 150	120/150	70/90	0.75	100	3.7	3.7	2900	3480	5~10	1.2	200
ESPH 300	250/300	150/180	0.075	10	7.5	7.5	2900	3480	10~15	1.8	300
ESPH 400	330/400	195/235	0.075	10	7.5	11	2900	3480	10~15	2.2	380
ESPH 800	660/800	390/470	0.05	6.66	11	15	2900	3480	15~20	3	500
ESPH 1500	1250/1500	735/885	0.05	6.66	30	37	1470	1750	30~40	8	1200
ESPH 3000	2250/2700	1325/1590	0.05	6.66	45	55	1470	1750	40~50	10	1500

Chart -1: Vacuum solutions offered By Everest Vacuum

2. Vacuum system Protection

The vacuum pump may be subjected to certain hazards depending on the process gas. As a result, it's critical that the process gases be well-understood in order to reduce these dangers. In order to transmit the process gas without damaging the vacuum pump, several components that can be mounted on the intake or pressure side are frequently necessary. This is referred to as a vacuum system, which can also include multiple vacuum pumps.

Thus, It is essential to protect the vacuum system from corrosion and deposits induced by crystallization or polymerization, as well as to strengthen the material resistance, in order to ensure safe operation.[7]

2.1. Vacuum pump/system leak-tightness

In a chemical environment, vacuum pumps and vacuum systems must be so tight that no or only a small amount of ambient air can enter, potentially creating an explosive atmosphere, or hazardous or explosive gases can leave.

Polymer o-rings are commonly used to prevent leakage between two stationary pieces. The resistance is determined by the polymer chosen. As a result, the seal material must be suited to any process gases that may be present.[7]

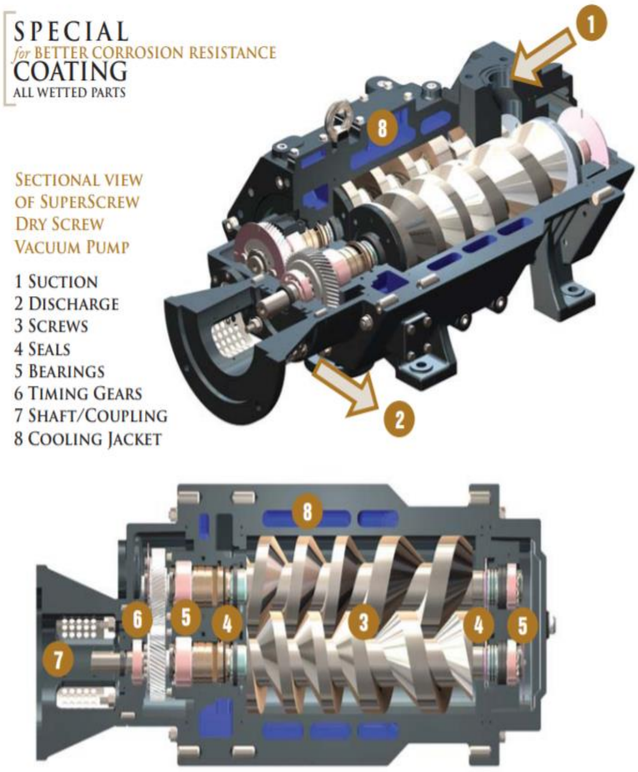

Fig -3: Special Coating for Corrosion Resistance

2.2. Protection against corrosion

Several methods can be used to preserve the vacuum system or individual vacuum pumps against corrosion:

The first solution is to keep corrosive chemicals out of the vacuum pump’s interiors.Upstream condensers or gas scrubbers can be used to accomplish this.

The second alternative for preventing corrosion is to retain the process stream in a gaseous state. This can be done with a screw vacuum pump by setting a specific operating temperature.In addition, a provided ballast gas can be used to dilute the process gas, lowering the partial pressure of the condensable gases. As a result, the following simple reasoning applies: suction in gaseous form and ejection in gaseous form. As a result, the minimum temperature must be set high enough to prevent gases from condensing out.The maximum temperature must be chosen to avoid damaging the vacuum pump or to ensure that the maximum permitted temperature is not exceeded.

A third option is to make the vacuum pump out of appropriate materials.as example we can apply special coating like paint to metals and alloys to prevent from corrosive chemicals.[7]

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MOC	BODY	C.I FG 260 with PEEK coating	Alloy Cast Iron with ENP+PEEK coating	C.I FG 260 with ENP
	SCREW	Ductile Iron with PEEK coating	Alloy Ductile Iron with ENP+PEEK coating	Ductile Iron with ENP
	CP PLATE	C.I FG 260 with PEEK coating	Alloy Cast Iron with ENP+PEEK coating	C.I FG 260
	GP PLATE	C.I FG 260 with PEEK coating	Alloy Cast Iron with ENP+PEEK coating	C.I FG 260

Chart -2: Materials Of construction

2.3. Protection from particles entering

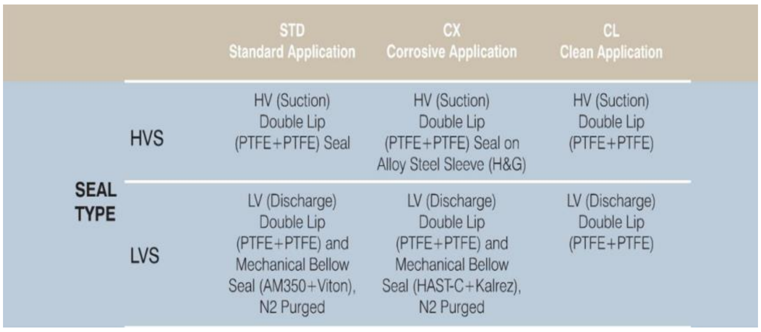
Only one way flow of particles should be allowed.An inlet screen or filter should be used with screw vacuum pumps at all times. This is done to keep particles out of the vacuum pump's interior. Screw vacuum pumps are sensitive to entrained particles due to their precision manufacturing and accompanying narrow clearances and tolerances.

Particulate dryers usually require dry screw vacuum pumps, especially in the pharmaceutical business. A small number of these particles can readily travel through the vacuum pump with the process gas or be flushed out at the end.

However, it is recommended to take the necessary precautions to avoid particles being sucked in on a frequent basis.[7]

2.4. Pump Seal

Between the meshing rotors and the rotors and the housing, the dry screw pump is constructed with a very narrow clearance. The screws rotate at high speeds, causing thread velocity to reach up to 100 m/s at the outer edge. Due to the rapid speed, tight clearances, and viscosity of the gas, resistance to gas back flow is created by dragging the gas along with the rotor threads, creating a non-contact, dry seal. Back flow of gas across these dry sealing surfaces limits the maximum vacuum possible. Because of the tight clearances and highly manufactured nature of the screw rotors, they must be replaced in matched sets if the screws need to be replaced due to wear. Unlike some other dry pump designs, where only one rotor can be replaced, this one cannot.[7]



		STD Standard Application	CX Corrosive Application	CL Clean Application
SEAL TYPE	HVS	HV (Suction) Double Lip (PTFE+PTFE) Seal	HV (Suction) Double Lip (PTFE+PTFE) Seal on Alloy Steel Sleeve (H&G)	HV (Suction) Double Lip (PTFE+PTFE)
	LVS	LV (Discharge) Double Lip (PTFE+PTFE) and Mechanical Bellow Seal (AM350+Viton), N2 Purged	LV (Discharge) Double Lip (PTFE+PTFE) and Mechanical Bellow Seal (HAST-C+Kalrez), N2 Purged	LV (Discharge) Double Lip (PTFE+PTFE)

Chart -3: types of seats used

3. Properties of Phenol and its derivatives:

Phenol appears as a colorless liquid when pure otherwise turns pink or red on slow oxidation with air. Generally, Phenol's have higher boiling points than other corresponding hydrocarbons due to the formation of hydrogen bonding with a flashpoint 175°F. Phenol is manufactured both chemically and also found naturally. Phenol vapors are heavier than air.

Phenol and their derivatives are corrosive to the skin but because of anesthetic qualities will result in numb rather than burn. Upon direct skin, contact may turn white. May be lethal by skin absorption. It does not react with water and remains stable in normal transportation. Reactive with various chemicals on normal conditions and may be corrosive to lead, aluminum and its alloys, certain plastics, and rubber. The freezing point is about 105°F. Density 8.9 lb. /gal. Phenols are used to make plastics, adhesives, and other chemicals .[6]

3.1. Phenol typical properties

Physical State @20℃	**Solid**
Appearance	**White to amber**
Odour	**Phenolic**
pH	**4-6**
Melting Point	**40℃**
Boiling Point	**182℃**
Flash point	**78℃**
Flammable Properties	**Combustible liquid**
Flammability Limits in Air	
upper	**8.6%**

lower	**1.7%**
Vapor Pressure	**0.35mmHg @25▯**
Vapor Density	**3.24**
Specific Gravity	**1.05**
Water solubility	**80g/L@25▯**
Partition coefficient	**1.46**
Auto-ignition temperature	**715▯**
Viscosity,dynamics	**3cp@50▯**
Molecular weight	**94.11**

3.2. Need for Solvent Vapour Extraction in Reactors

Solvent extraction is a frequent and useful process for separating and purifying a variety of components. Solvent extraction has always proven to be an effective recovery method for a variety of components. This method is used to separate compounds based on their solubility, as if they were two different immiscible liquids.

Solvent charge, removal, and storage are all required when using solvents in any manufacturing process. In addition to the solvent vapors produced when the solvents are physically utilized in the manufacturing process, each stage produces its own. Recovery of these solvent vapors is crucial for process efficiency, cost savings, operator health and safety, and compliance with environmental regulations. Solvent processing is used in a wide range of industrial applications. Distillation, drying, evaporation/crystallization, solvent/vapour recovery, and filtration are examples of such applications, with reactors, mixers, and dryers as equipment.

Solvents used in reactors are often displaced through a vent system to a solvent recovery system in the pharmaceutical industry, and numerous reactor systems are frequently displaced to a common solvent recovery unit in bigger plants. Few of the vent systems are "one-pass" systems, in which the vapors are discharged from the reactor, passed through the recovery unit, cooled, and then released into the atmosphere (where applicable). A “closed-loop” system is a more efficient and cost-effective way of solvent recovery in reactors, mixing, coating, and drying/granulating activities. A closed-loop system is best for batch processing, but it can also be used in a continuous feed system. The advantage of a closed-loop system is that there are no emissions during operation, resulting in a 100 percent solvent recovery. This is quite appealing from a business standpoint for the manufacturing plant, and it is significantly safer for the operators.

A vacuum pump is used to handle solvents in the most popular closed-loop arrangement. Vacuum pumps come in a variety of shapes and sizes, including Liquid Ring, Dry Pumps, Rotary Lobe, Claw, and Screw pumps. Internal lubrication is usually not required in these systems, allowing solvent vapors to be drawn through the pumps without jeopardizing the lubrication. Oil-sealed pumps, such as rotary vane or piston, that require internal lubrication, on the other hand, frequently fail in such applications.

External bearings are isolated from the process fluid in both Liquid Ring and Dry Pumps. The Dry Pump also has oil- lubricated timing gears to keep the two parallel shafts rotating in the correct phase and avoid collision. Given the range of options available, the user must be aware of the potential drawbacks of each.

Screw pumps, for example, have a high wear rate because they must operate with very close radial clearances. Galling occurs when stainless steel rotating parts come into touch with stainless steel stationary parts, resulting in excessive heat generation and premature pump failure.

Some pump manufacturers use ductile cast iron components in their pumps to help avoid potential galling contact concerns. Unfortunately, this creates a new set of problems because condensation, as seen in solvent recovery applications, is devastating for pumps made of corrosive materials. Additionally, because many pumps are horizontally oriented, this condensation is unable to escape. As a result of the high corrosion attach of ductile iron material, radial clearances are lost, and the pump fails prematurely. [8]

A self-draining dry pump made of non-galling materials installed in a vertical configuration is the best approach whenever possible. This prevents product media from becoming stagnant and condensation from forming between counter-rotating components.

It's crucial to recover the solvent vapors as:

- Process efficiency
- Plant cost savings
- Operator health & Safety
- Safety Legislation compliance.

Thus Everest vacuum pumps are manufactured using cast iron and Ductile Iron as base material whereas Stainless steel SS304 and SS316 are used in Piping and Valves. Based on use, Equipment's are coated with ENP

(Electroless Nickel plating) and PEEK (Poly-ether ether ketone) materials to avoid corrosion. Polymer O-rings are commonly used to prevent leakage between two stationary pieces. These O -Rings and seals are manufactured by using polymers like Viton, Nitrile, EPDM (ethylene propylene diene monomer rubber), KALREZ and Teflon. [9]

3.3. Screw Pump Design

Two inter-meshing helical rotors are placed in parallel in a dry screw pump and rotate at high rotational speeds in opposite directions without touching. Each screw rotor is attached to its own shaft and rotates in unison thanks to a precision gear drive system. The rotors can have a fixed pitch (number of threads per unit length) or a tapered pitch that compresses the gas as it moves. The process gas flows axially along the screws from inlet to output in a straight line. The process gas is drawn in as the screws counter spin, creating gaps of increasing volume in front of the rotor chamber. The gas is contained in compartments between the rotors and the housing and transferred to the discharge with each turn of the thread acting as a pump stage. The discharge end of the screw threads is tapered, lowering the confined volume and compressing the gas. The trapped gas is released against air pressure by compression at the discharge port.

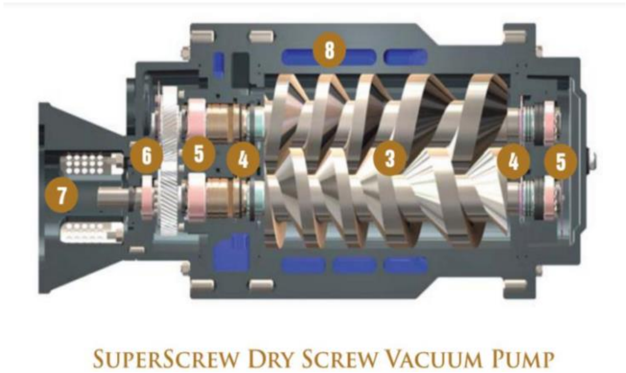


Fig -4: Superscrew Dry Screw Vacuum pump Design

The trapped gas is continuously compressed from inlet to discharge with the maximum energy efficiency and the lowest discharge gas temperature in a continuous variable pitch rotor design.

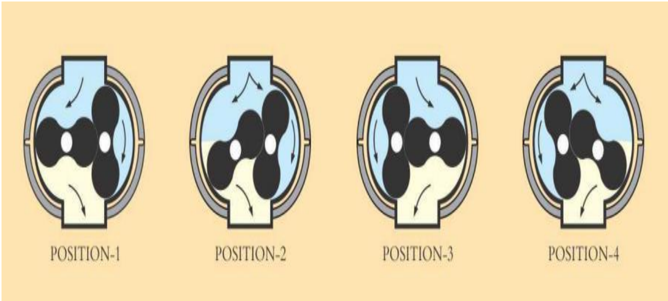


Fig -5: Rotary Lobe Vacuum pump

The pumping capacity of Everest Twin Lobe Rotary Compressors/Blowers is determined by their size, working speed, and pressure conditions. It uses two Twin Lobe impellers installed on parallel shafts that rotate in opposing directions inside a casing with side plates at the ends. Air is sucked into one side of the casing and driven out of the opposing side when the impellers rotate, against the existing pressures. As a result, the differential pressure created is determined by the resistance of the coupled system. Because positive displacement blowers do not generate pressure within the casing, the discharge pressure is determined by the system resistance / back pressure. The use of a very narrow operational clearance effectively seals the compressor inlet area from the discharge area, reducing the requirement for any internal lobe lubrication. During rotation, a pair of precisely machined alloy steel, hardened and ground timing gears maintain clearances between the impellers. The air that is so provided is OIL-FREE. The pumping capacity of a lobe compressor running at constant speed is generally unaffected by fluctuations in inlet and discharge pressures. These Blowers are constant volume machines that deliver a fixed discharge against the back pressure of the system. As a result, it's critical to enforce minimum pipeline constraints at both the input and discharge. Minimum line losses are achieved with adequate pipe and big radius bends, resulting in improved efficiency and lower power consumption. A sudden shift in the cross section of the pipeline should also be avoided. To adjust capacity, either change the speed (to save energy) or vent some of the air into the atmosphere (not energy saving). [2]

Recycling air from the discharge to the suction is not a good idea because it can cause overheating. Using throttle valves in the intake or discharge pipes to manage the compressor's capacity is never a good idea. This raises the motor's power load, which could cause catastrophic damage to the compressor. The temperature of the discharge air rises due to the heat of compression. As a matter of thumb, every 0.1 Kg/cm2 of P over the inlet temperature raises the discharge air temperature by 100C.

The operation of the screw pump can be separated into 5 phases (Fig. 6), as follows:

- Phase 1: Gas enters inlet cavity. Screw rotors rotate at high speed and create inlet cavities between the rotors and the stator.
- Phase 2: Gas is sealed from inlet. As the screws continue to rotate, the cavity becomes a sealed cavity separated from the pump inlet.
- Phase 3: Gas is displaced along the pump axis. Relative motion of the screws causes the trapped gas pocket to be transferred from the inlet toward the outlet.
- Phase 4: Back leakage. As the gas is transferred, some back leakage (back flow) occurs, whereby a small amount of gas leaks between the surfaces the rotors and the stator against the direction of gas transfer.
- Phase 5: Gas exits the pump. The trapped gas is transferred to the pump outlet at atmospheric pressure, creating the pumping action.

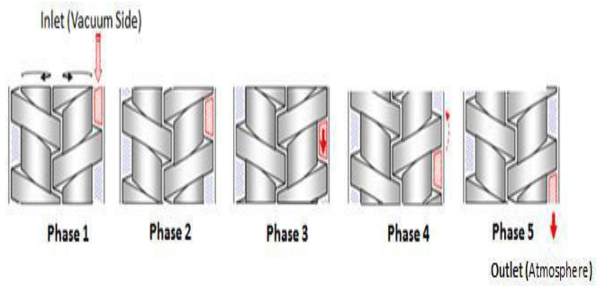


Fig -6: Phases of dry pump operation

Screw pumps can be single-ended or double-ended with the gas entering in the middle and exiting both ends.

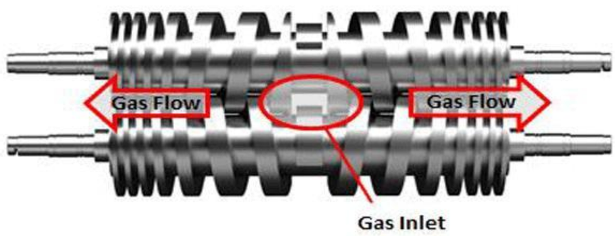


Fig -7: High-capacity double-ended variable-pitch screw

4. CONCLUSIONS

Based on the vacuum pressure requirement for a particular process, the suitable vacuum pump must be chosen from the various range of vacuum systems offered to decrease the energy loss and for making profit in long run.

Few of the listed things should be done to maintain the efficiency of pump over a long run:

- The vacuum pump should be warmed up for a particular amount of time before being used in most applications. It is now possible to set the desired temperature.
- Before turning off the vacuum pump, it is recommended to purge it with non-condensable inert gas to thoroughly remove the process gas. This flushing procedure is usually done with nitrogen.
- If there is a possibility of deposits building inside the vacuum pump during cooling, flushing it with a cleaning solvent at the end of the procedure is also possible and advised.

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