



Technical Evaluation of Pumps in the Bio Energy Sector: Performance, Efficiency and Sustainability Considerations

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International.



ABSTRACT

The bioenergy sector absolutely depends on pumps to manage fluid movement across anaerobic digestion as well as biofuel manufacturing and biomass processing activities. The research examines both efficiencies along with sustainability measures and performance qualities of bioenergy pumps by analysing fundamental operational characteristics involving material endurance and power utilization for managing corrosive and viscous biomaterials. The research explores updated pump technology medicines positive displacement along with centrifugal pumps in order to evaluate their influence on procedure reliability and biological gas production rates and energy utilization. This analysis focuses on the comparison between standard and optimized pump solutions through a study of their whole life value and nature conservation aspects. Optimized selection of pumps combined with operational strategies will help this study make bioenergy systems more sustainable through decreased energy waste and increased process efficiency. The research presents recommendations about enhancing future designs of pumping systems and their implementation methods

INTRODUCTION

Pumps are essential mechanical devices employed to transfer fluids. Their overall function, bundled the category of Hydrodynamic Pumps and Positive Displacement Pumps. While the working principle and design of these pumps are not the same entirely, the one common function has been fluid transfer. The selection of a certain type of pump is based on the velocity of fluid and nature of liquid. Different types of pumps serve different purposes. Dynamic pumps mainly use kinetic energy in the generation of flow while positive displacement type depends on the fixed volume of fluid moved per cycle. This classification is essential for engineers and industries that must choose the right kind of pump based on the properties of the fluid. Dynamic pumps are widely used in applications where a large volume of low-viscosity liquids is needed. An example of it is the centrifugal pump which is used in water supply systems and industrial processes. Rotodynamic pumps convert the kinetic energy provided by a rotating impeller to flow and pressure. They are very efficient for dewatering, irrigation, and sewage activities. With imported pump ranging from 5000 LPH to 7000 LPH; suitable for domestic coke plant, they do requirement and capable coke plants. Yet, positive displacement pumps move a fixed volume with each cycle. As a result, they are perfect for high-viscosity liquids or where the specification for a fixed flow rate is needed. Reciprocating pumps (i.e. piston and diaphragm pumps) and rotary pumps (i.e. gear and screw pumps) are included in this category as they also perform well for oil and fuel. Ezekiel Mills is designed to give constant flow regardless of pressure variation.

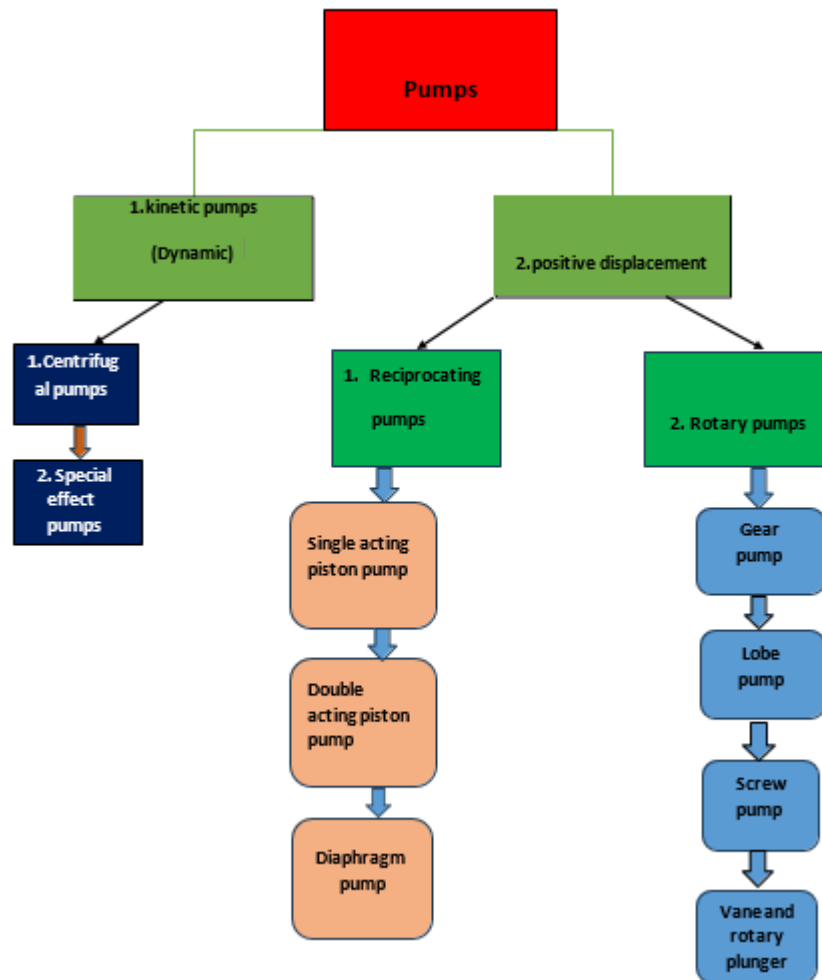
Both in the technological sense and in the perspective of economy, and also in the perspective of ease of use in different working conditions, the contrasts that exist between kinetic and positive displacement pumps are greatly apparent. When talking about manufacturing goods or even talking about ecological protection initiatives geared at self-sustainability, knowing the characteristics that are typical of some of these pumps becomes paramount in ensuring that the job is done in the most efficient way. As the information presented on this topic reveals, there are subtle differences in them that may determine the right pump for their application.

(Figure 1. Pump Types)



LITERATURE RIVIEW

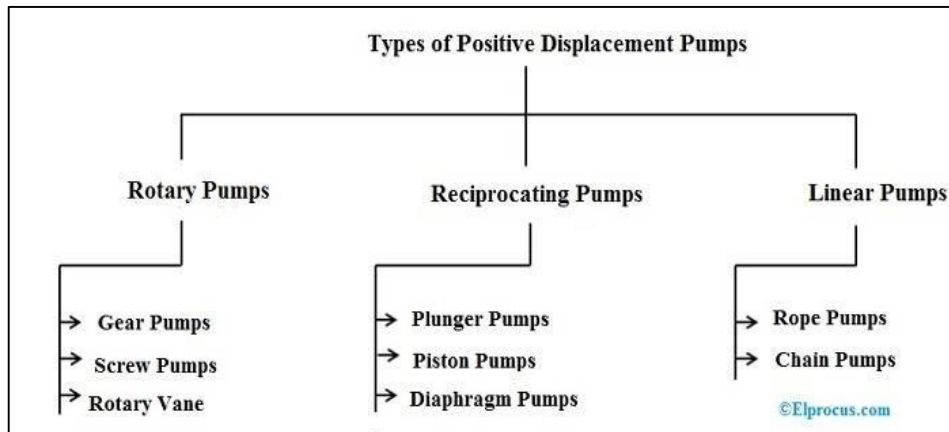
(Diagram 1. Categorization of Pumps)



METHODOLOGY

1. Positive Displacement Pumps

And although the PD pump or positive displacement pump gives it a quasi-constant flow rate according to a certain, constant speed, the changes in the counter force. The working principle of the pump is cyclic which may be operated by screws, pistons, rollers, gears, diaphragms or vanes. The working of positive displacement pump, in this pump, the movement of liquid can be imprisoned in a cavity in order to release the defined volume of liquid. A few very basic parts can be divided in the process of liquid displacement namely piston, diaphragm and plunger.



(Figure 2. Positive Displacement Pumps)

a. Rotary Pumps

A rotary pump is simply one that uses rotatory action to supply liquid, which then migrates from the lake to the discharging pipe. The most common types of pumps include the screw pump, internal gear, flexible impeller, sliding vane, helical twisted roots, and circumferential pump. They are classified in three main types: gear pumps, screw pumps, and rotary vane pumps.

In the case of gear pumps, the fluid can pass between the two rotating gears as they turn. There are Two screw form rotor in screw pumps in which the rotor turns against each other. And one turns the two screws, then it sucks the liquid on the inlet of the pump till the outlet of the pump. Rotary vane pumps are similar to scroll compressors that have cylindrical rotor with vanes over it. It is covered within a cylindrical shaped housing. Once it turns, the vanes on top of the rotor catch the liquid among the rotor & casing, and the liquid discharges through the outlet.

b. Reciprocating Pump

In a reciprocating pump, the segment of the reciprocating hydraulic component allows the liquid to flow forward toward the reservoir. Their reciprocating components are a plunger, piston, or diaphragm, while this class of pumps incorporates several different types of valves, including inlet and outlet valves. In the mode o sucking liquids, the inlet valve opens & the outlet valve remains closed. Thus, if the piston is pulled in a direction so that the cavity of the cavity increases then the liquid will be sucked in. There are classified into three types, namely plunger pumps, piston pumps, and diaphragm pumps. Plunger pumps are chiefly used to move water. The piston pump contains an inner piston, which is the pumping part, used for pumping the liquid. A diaphragm pump acts like a plunger pump, except that it uses a flexible diaphragm to pump the liquid.

c. Linear Pump

Rope pumps and chain pumps are examples of linear pumps. Linear pumps can't be adjusted in operation. These types of pumps can vary in location, but their main limitation is that they are volume-based. These pumps can be very noisy during operation as a result of the removal of the piston in the cavity and, thus, should be installed some distance away from any residence. These pumps

are classified into two types namely rope pump and chain pump. An example of the linear pump is the rope pump, where a loose hanging rope is fitted into a well and hoisted up with the aid of a long pipe with its base immersed in water. Round disks are in a rope, and they will take the water up to the outside. Such kind of pump is used mostly to self-supply as well as to supply water to the community. The pumps can be installed in boreholes or hand-dug wells.

One type of linear pump is the chain pump in which a series of circular discs are mounted on an endless chain. Part of the chain is immersed in / submerged into the water, & the chain passes through a pipe, a little better than the disc diameter. Once the chain is pulled up the pipe then the water ends up being pinched between the discs and is released at the top. Early Middle East, China & Europe These pumps are being used for centuries.

d. Application of Positive Displacement Pumps

These are used to pump high viscosity fluids where precise dosing otherwise high force output is required. Unlike centrifugal pumps, the output of these pumps is not affected by force so they can be used in any condition where supply is unequal. The best positive displacement pump examples are piston, plunger, diaphragm, gear, lobe, screw and vane.

1. Piston and Plunger pumps are used to pump low viscosity fluids, paint spraying, oil production, high force washing.
2. Diaphragm pump for metering, spraying, water treatment, oils, paints
3. Gear pumps for high viscosity fluids in petrochemical, food industries, paints, oils.
4. Lobe pump for food and chemical industries, pharmaceutical, biotechnology, sanitary.
5. Screw pump for fuel transfer, oil production, irrigation.
6. Vane pump for low viscosity liquids, fuel loading, & transmission.

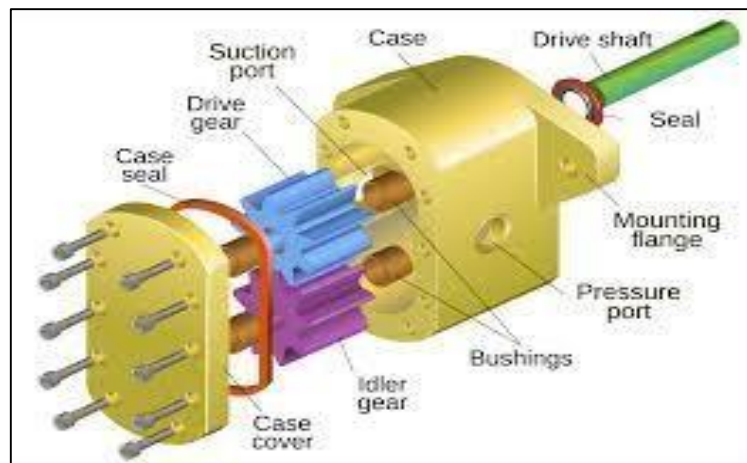
e. Difference Between Positive Displacement Pumps and Non-Positive Displacement Pumps.

The difference between positive displacement and non-positive displacement pump mainly include pressure, efficiency, viscosity, performance.

(Table 1. Difference Between Positive and Non-Positive Displacement Pumps)

| Parameters | Positive Displacement Pumps | Non-Positive Displacement Pump |
|-------------|--|--|
| Pressure | These pumps can handle applications requiring high force, up to 800 bars. | These pumps may have a pressure of 18 to 20 bars and are utilized in low force applications. |
| Efficiency | Increases in pressure will inevitably result in higher efficiency. | At either higher or lower pressure, the efficiency will drop. |
| Viscosity | Because of the frictional losses in the pump, efficiency will rise as viscosity increases. | Because of the frictional losses in the pump, efficiency will drop as viscosity rises. |
| Performance | The flow will alter when the pressure changes. | When the pressure changes then the flow will constant |

f. Gear Pumps



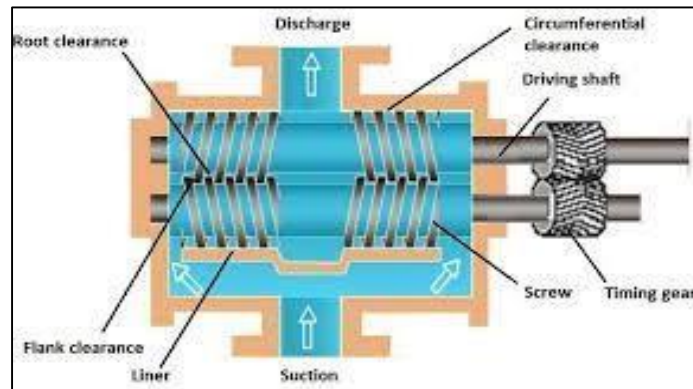
(Figure 3. Gear Pumps)

Totally weird don't you think, but, anyhow, gear pumps are rotary positive displacement pumps, although you can also look at them as two rotational gears that spin in the chamber of the pump. These gears rotate in such a way, one pulling the liquid into the pump and then into the discharge line. The rotating gears catch the water lured inside their teeth and pass it further to the pump in the course of the turning. The liquid that has been trapped between gears gets carried along with the gears' rotation until it is ejected through the other side. In the design of gear pumps, there are of course two categories: the first category is external gear pumps and the second one is internal gear pumps. Pumps with external gears that rotary positive displacement consist of two sprockets, which are fixed on separate drive shafts which could be connected to drive the sprockets (one or both of the shafts may be driven).

The rotating gears are locked, making an identical fluid move between them from the inlet to the outlet, and thereby to the housing. The pump by internal gear works well with the bigger rotor gear (the outer gear) and the smaller inner gear (idler). The idler gear inside the antagonist ring is held by a shaft. In a few designs, both of them are powered, others only the rotor is propelled. Depending on the sense of gear rotation a gear pump may discharge the fluid in one or another direction.

- **Applications:** Universal Gear Pumps or internal and external gear pumps are mostly used in chemical factories, oil refineries, and automotive industries dealing with fuel, lubricants, and polymers.
- **Advantages:** The external gear pump is designed in a simple and compact way and its smooth operation of high viscous fluids is a great benefit.

g. Screw Pumps

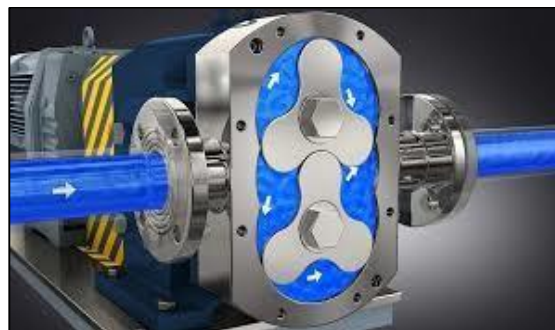


(Figure 4. Screw Pumps)

It utilizes one or several screws (helical rotors) that, when rotated, mate closely with a cylindrical cavity. The screws rotate and create cavities, moving the liquid from the inlet to the exit.

- **Applications:** It is used in applications where smooth, pulsation-free pumping action is useful such as fuel oil transport, hydraulics and in the chemical and food processing industries.
- **Benefits:** Very high flow rates, low noise output, and ability to handle both high and low viscosity liquids.

h. Lobe Pumps

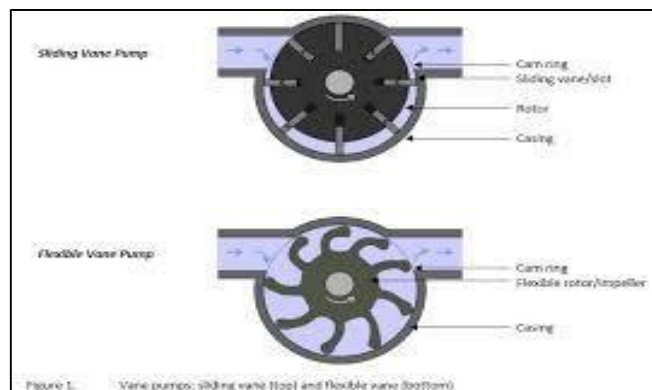


(Figure 5. Lobe Pumps)

Lobe pumps work like gear pumps, but use lobed rotors that rotate against each other with only a small clearance, as opposed to gears. These are non-contacting, so they wear slower than rotary vane pumps. The lobes avoid touch, which reduces damage to pumped fluid and allows gentle handling.

- **Applications:** Owing to their capability to handle larger solids as well as food pastes and pharmaceutical agents, they find use in the pharmaceutical, food and beverage industries.
- **Advantages:** They are able to process solids gently, and are easy to maintain and clean, and can be used in sanitary products.

i. Vane Pumps



(Figure 6. Vane Pumps)

Vane pumps utilize several blades which are encased inside a larger cylindrical cavity. Fluid is transported into enclosed spaces as a result of the rotation of a shaft that houses cylindrical blades. In simpler terms, these blades compress fluid within the enclosed encasements and while this happens, the other area gets filled with fluid, and this process continues as the rotor turns.

- **Applications:** They are used when a steering or brake system automotive or fuel and solvent oiling are required fulfilling mid-pressure applications.
- **Advantages:** They are efficient under varying operating conditions and pressure even though they experience slight slippage or a general overhaul.

j. Core Characteristics and Advantages of Rotary Pumps

1. **Uninterrupted and Constant Flow:** The flow volume remains uniform due to the rotational motion of the movable component thereby eliminating any chances of flow pulsation.
2. **Flexibility:** Permit to pump almost all products with varying viscosity classified as low, medium, or high.
3. **Space Saving Construction:** They are in general more compact and smaller in size than reciprocating pumps, thus ideal for fitment in locations with restricted space.
4. **Experts Split Pumps Into Three Groups:** positive displacement, centrifugal, and other. Centrifugal pumps can move a lot of fluid. In some chemical factories centrifugal pumps make up 90% of all pumps. Positive displacement pumps have their uses too. These machines can handle high-pressure liquids without moving much fluid. They also offer better precision when exact measurements matter.
5. **High Efficiency:** These pumps work very well when pushing fluids at high pressures.
6. **Constant Flow Rate:** The amount of fluid moved stays about the same no matter the pressure. This makes these pumps good for adding exact amounts of substances.
7. **Self-Priming:** These pumps can handle mixtures of air and fluid. This helps in situations where starting the pump might be tricky otherwise.

Reciprocating pumps play a key role in industries that need accuracy high pressure, and dependable performance. Their build makes them useful for many jobs, from moving water to dealing with tricky and dangerous chemicals.

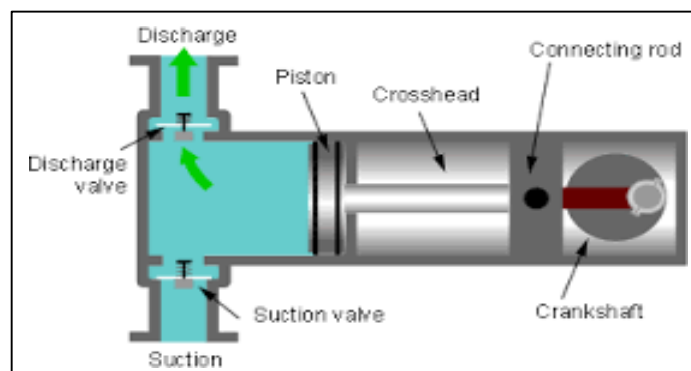
2. Types of Reciprocating Pumps

A positive displacement reciprocating pump works through back-and-forth movements of pistons, plungers (in plunger pumps), or diaphragms. This is called reciprocation. The first stroke creates a vacuum, which opens the outlet valve and shuts the inlet. The reverse stroke puts pressure on the fluid closing the inlet valve and opening the outlet. This lets the fluid leave the chamber. You can find this mechanism in diaphragm piston peristaltic hose helical rotor rotary lobe, gear and rotary pumps.

- **Suction Phase:** In this phase, the piston or plunger pulls back. This makes the cylinder bigger and lowers the pressure of the fluid inside. The result? A partial vacuum forms. Because of this, fluid from the reservoir flows into the cylinder through the pump's inlet valve. What drives this flow? The pressure from the atmosphere or upstream pushing on the fluid.
- **Discharge Phase:** Next, the piston or plunger pushes forward. This shrinks the cylinder and ramps up the pressure. The high pressure then forces the fluid out through the discharge valve and into the delivery pipe.

a. The Main Elements of Reciprocating Pumps:

1. **Pump Cylinder:** This is where you keep the piston or plunger.
2. **Piston/Plunger:** The commutating element which makes the pump move and push the fluid.
3. **Inlet Valve:** Lets fluid come into the cylinder during the suction process.
4. **Outlet Valve:** Lets the fluid exit from the cylinder in the discharge phase.
5. **Crank and Connecting Rod (Some Designs):** Converts motor rotating motion to reciprocating movement of pumping.
6. **Piston Pump**



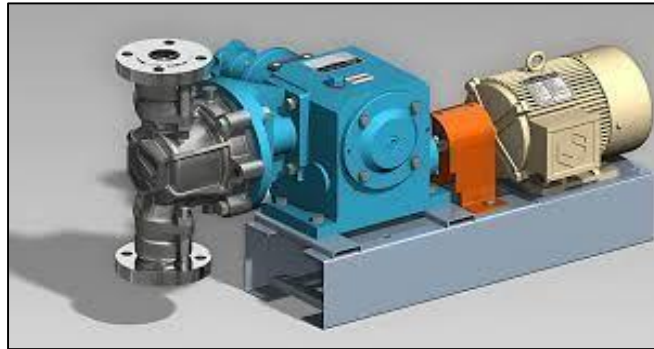
(Figure 7. Piston Pumps)

A piston pump has a mechanical construction with pistons running in cylinders with valves for the inlet and outlet. When sucked up, the piston expands the pump chamber. Pressure will go down as you do this, and the cylinder hose of the piston pump opens up so fluid will flow through your intake. The piston pushes the fluid onto the cylinder and pushes the cylinder up when

the pump is running. Suction valves shut, then the release valve opens, pulling the water out.

- **Application:** The piston pump is the usual one in agriculture (irrigation), water treatment and industrial processes.
- **Advantages:** A piston pump can be used with big volumes and fluid viscosity.

7. Plunger Pump



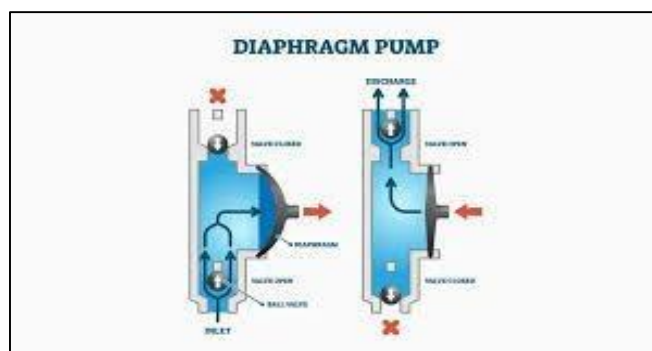
(Figure 8. Plunger Pumps)

A plunger pump is based on the same logic as piston pumps except in different forms. Plunger pumps work at high pressure and maximum flow because the plunger pump seal is very strong. These reciprocating pumps are used for all sorts of essential pumping functions, such as high- pressure water jetting and cleaning.

The Plunger Pump is the Earliest Reciprocating Pump Currently on the Market.

- **Uses:** Great for high pressure oil and gas production, pressure cleaning and dewatering.
- **Advantages:** Pressure-rated, tough and effective without leakage.

8. Diaphragm Pump



(Figure 9. Diaphragm Pumps)

A diaphragm pump also known as membrane pump works on a principle of a flexible diaphragm that contracts and expands in order to change the volume of a chamber. This results in a vacuum that sucks the fluid into the pump through an inlet valve. When the diaphragm expands, it increases the chamber volume and reduces pressure thereby forcing the fluid out through the outlet valve. The

diaphragm's cyclical movement, which is mechanically activated by a crank or motor or pneumatically activated by compressed air, makes sure that the fluid is moved constantly with every stroke. This is because the diaphragm and the pump body of diaphragm pumps can be made of materials that are not easily affected by chemicals hence suitable for handling chemical substances that are dangerous or that can cause corrosion. Furthermore, it is important to note that air operated diaphragm pumps are also capable of handling range a of wide fluid viscosity. Also, these pumps are preferred in applications where the pump environment is to be sealed to avoid mixing of fluids. This is because diaphragm pump is highly suitable in industries such as chemical industry, pharmaceuticals and water treatment.

- **Applications:** Diaphragm pumps are commonly utilized to transfer dangerous and aggressive fluids, thus isolating such fluids from the pumping elements.
- **Advantages:** A Diaphragm pump is a positive displacement pump that offers zero leakage during operation, is capable of handling slurry and chemical fluids and is gentle on mixtures that are prone to separation

9. Industrial Usage of Positive Displacement Pumps

- a. **Oil & Gas:** The positive displacement pumps are used in extracting high pressure oil, which is used for transportation of crude oil and dealing with problems related to viscosity. The accurate control over flow rates is an added advantage in their use especially in the offshore and onshore operations.
- b. **Chemical Processing:** In chemical plants, these pumps control corrosive and dangerous liquids and perform their functions with great caution as in the production of plastics and resins. They ensure that there is a constant flow even when the pressures are not constant.
- c. **Mining:** these pumps significantly improve the efficiency of mineral, ore and resource extraction from mines. Their durability guarantees reliable performance in harsh mining environments.
- d. **Pulp and Paper:** Positive displacement pumps effectively transfer slurries comprising wood pulp, chemicals and water. This capability facilitates efficient paper production by maintaining precise flow rates in pulp mills and processing units. However, the integrity of these systems is crucial to overall productivity.
- e. **Marine:** In shipbuilding and marine operations, these pumps play a vital role in managing bilge water, transferring fuel and supporting lubrication systems. Because of this, vessels can operate smoothly and safely at sea, although challenges may arise in extreme conditions.
- f. **Automotive Manufacturing:** Positive displacement pumps play a crucial role in fluid transfer (such as coolants, lubricants and hydraulic oils) because they ensure precision in automotive assembly lines and component manufacturing.
- g. **Textiles:** These pumps manage the exact movement of dyes, chemicals and wastewater during textile production. However, they ensure accurate

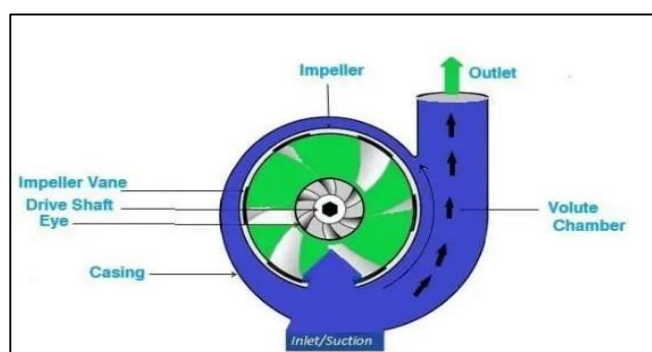
dosing and smooth operation of dyeing and washing machines, although minor fluctuations can occur during the process.

- h. **Pharmaceuticals:** The pharmaceutical sector (industry) depends on these pumps, which are essential for the hygienic and precise transfer of active ingredients, solvents and other fluids that are critical in the production of medicines.
- i. **Wastewater Treatment:** Positive displacement pumps are utilized in wastewater treatment facilities (plants) to transfer sludge, dose treatment chemicals and manage thick or abrasive waste fluids. However, the efficiency of these pumps is paramount, because any failure can lead to significant environmental issues.
- j. **Agriculture:** These pumps are employed for irrigation and spraying applications, thus aiding in the transportation of water and agricultural chemicals across vast farming landscapes (efficiently). Although they are vital, their maintenance is often overlooked.

3. Kinetic Pumps

A dynamic pump (which is often referred to as a kinetic pump) delivers kinetic energy to the working fluid via the action of either axial or centrifugal forces. This process transforms that energy into an increase in pressure or flow rate. Dynamic pumps are particularly notable because they function based on the principles of kinetic energy. However, it is essential to understand that these pumps predominantly utilize centrifugal force to move the fluid. Although dynamic pumps are effective, they are primarily used in applications requiring a continuous flow rate and this makes them quite valuable in various industrial settings.

The difference between a dynamic pump and a positive displacement pump is how they work. In a dynamic pump, use of a rotating impeller to generate the cavity, while a positive displacement pump uses a reciprocating part (plunger or piston) to create the cavity.



(Figure 10. Kinetic Pump)

The number of rotatory parts is lower in dynamic pumps than positive displacement pumps. They weigh less than the PD pumps. Most common examples of dynamic pump are a centrifugal pump and a submersible pump.

Dynamic pump is a category of pump where centrifugal force is used to lift a fluid from a particular area towards another area. The source for this

centrifugal force is a rotating part (e.g. rotor, or impeller). Due to the centrifugal pump impeller, a stream of high-velocity fluid is created. This particular pure fluid then mechanically dilutes the fluids adjacent to the pump or casing while reacting with it. Following this process, when the outlet valve is opened, fluid can flow out to the required area.

a. Axial Flow Pump



(Figure 11. Axial Flow Pump)

An axial flow pump is categorized as a centrifugal pump where the inlet and outlet are in the same line as impeller shaft and this kind of pump does not have a suction that is perpendicular to the impeller. An axial flow pump does not change the direction of the fluid's flow. It is equipped with an Impeller mounted in a cylinder. The impeller has three to four blades attached.

So, the angle of all the blades mounted on the Impeller is like that the water comes out the pump axially along the rotation of the impeller and not out perpendicular to the rotation of the impeller. In many configurations, the flow and head can be varied by varying the pitch of the impeller blades. These are dynamic pumps capable of discharging high quantities of flows, sometimes reaching to the tens or even hundreds of thousands of gallons in the minute's figure. Sometimes it is known as a propeller pump because of the resemblance of the axial impeller to a ship's propeller.

Rather than axial pumps, it is the centrifugal ones that are used mostly in applications requiring low flow rates and high heads, including the nuclear industry. In projects demanding pumping large amounts of water or low-pressure increase, over eight times the number of axial pumps will be employed.

b. Centrifugal Pump

Centrifugal pumps use centrifugal force to move liquids. They are powered by electric motors or engines that provide mechanical energy. In effect, the centrifugal pump uses a centrifugal force to pump fluids, hence its name. There are many centrifugal pumps uses including being the hydraulic device that raises the pressure of liquids, blood, and air. They are widely adopted in many industries and even common pumps in households because they can be operated with low force. Centrifugal pumps, sump pumps, and positive displacement pumps are three common centrifugal pump types. They have centrifugal force and centrifugal direction which allows effective pumping and flow of fluids. In

steamships and submarines, similar pumps were also employed as part of onboard machinery. However, they were purposely built to lift mud.

These pumps have a cost advantage compared to positive displacement pumps. It can transfer low viscous liquids and chemicals efficiently. Besides, it has a brilliant design and works on a simple mechanism making it an easy to operate and maintain pump. And the best part about them is that there is no heat transfer concerns or leakage. These pumps have no power loss.



(Figure 12. Centrifugal Pump)

c. Vertical Centrifugal Pump

A vertical centrifugal pump is also termed as a cantilever pump. These types of pumps possess a distinctive configuration of shaft and bearing currents that enables the volute to pivot within the sump while the bearings are placed above the sump. These pumps use throttle bushing for shaft sealing, therefore stuffing box is not necessary. This pump occupies a very small space for installation. It is the best option if you want to place a pump in an area within small surface. They are suitable for high-pressure and hot fluids.

d. Horizontal Centrifugal Pump

A centrifugal pump having its shaft positioned orthogonal to it is securely placed between bearings or runs overhanging. This kind of unit has easy mounting and servicing due to internal parts being able to easily be reached. Choosing a shaft design which will provide the desired pump pressure is important. The horizontal centrifugal pumps suit well in low suction applications, as high suction needs an inbuilt bearing shaft. Horizontal centrifugal pumps present a spatial challenge in facilities where space is a concern, despite offering lower operating temperatures and pressures compared to vertical pumps.

e. Submersible Pump

A submersible pump is a mechanical device that works by pushing the water toward the surface instead of pulling it. It has a hermetically sealed motor connected to the pump body that helps in pushing the fluid toward the surface. These types of dynamic pumps are most usually used for slurry pumping, general industrial pumping, sewage pumping, septic tank pumping, and drainage.



(Figure 13. Submersible Pump)

f. Hydrant System

A hydrant system is a source of water that feeds into the building through a network of nozzles, pipes, and hydrants with enough pressure to deliver water for firefighting applications. This pump is installed with a series of pipes connected directly to the key water supply, supplying water at each hydrant outlet during emergencies. Each hydrant pump has several discharge valves that you can connect to a fire hose. It is a hydrant system assisting firefighters during the fire suppression process. The hydrant system enhances the ability of firefighters in controlling fires within the construction site it has been placed.



(Figure 14. Hydrant System)

g. Advantages of Kinetic Pumps

1. These pumps have small sizes.
2. They need a short space for installation.
3. They have less cost.
4. The maintenance of a dynamic pump is easy as compared to the positive displacement pump.
5. They can control low to medium-viscosity fluids.
6. They are best for low-head to medium-head applications.
7. They provide a continuous supply of fluid.

8. Disadvantages of Kinetic Pumps

1. These types of pumps have shaft misalignment problems.
2. They have problems concerning the damage of impellers.
3. A ring of this pump damage in a short period they wear.

4. They have problems about seal ring damage.
5. Bearings of these pumps are very quickly damaged due to overshooting.
6. They have issues of priming.
7. They required priming manually.

8. **Application of Dynamic Pumps**

1. These pumps find their wide application for pumping crude oil.
2. Dynamic pumps are used in the chemical industry.
3. They have applications for commercial and household purposes.
4. These pumps are used within the food industry.
5. These pumps have huge applications in fire protection industries.
6. They are used for cellulose, petrochemical production, hydrocarbons, painting, and beverages.

4. **Other type of Pumps**

a. **Vacuum Pump**



(Figure 15. Vacuum Pumps)

The basic principle of the vacuum pump is to take air and other gases out of the sealed area to create a vacuum. They use several modes of operation to include positive displacement, momentum transfer, and entrapment. One common type, the rotary vane pump, uses rotating vanes to create a partial vacuum by drawing in and expelling gas from a chamber. The vacuum created is of low pressure since the gas is being extracted. The applications of vacuum pumps vary from manufacturing, research, and medicine to aerodynamics.

They play a significant role in processes involving semiconductor manufacturing, chemical distillation, and medical equipment sterilization. In research, vacuum pumps enable experiments in material science, chemistry, and physics; in space, they are used to simulate the conditions of outer space. Vacuum pumps are unsung heroes, shaping many industries and enabling various groundbreaking discoveries. Their contribution to maintaining controlled environments and creating vacuum conditions is invaluable in the present context of science and technology. From laboratory to manufacturing plant and into space, vacuum pumps are the quiet powerhouses driving the art of innovation.

b. Jet Pump



(Figure 16. Jet Pump)

Jet pumps are designed based on a principle of fluid entrainment. They consist of a nozzle that forces a high-velocity jet of the fluid into a venturi tube. This high-speed jet creates a low-pressure zone within the venturi that in turn draws in a secondary fluid—usually the one to be pumped. The combined mixture of motive and secondary fluid is discharged next, allowing the secondary fluid to be conveyed to its destination. Jet pumps can be utilized in various industries that range from agriculture, oil and gas, water supply, and wastewater treatment. They serve their purpose especially in lift applications of fluids from deep wells or in the movement of liquids that contain solids or of those having high viscosity. Jet pumps are also used in steam ejectors and aircraft fuel systems.

c. Peristaltic Pumps



(Figure 17: Peristaltic Pumps)

Peristaltic pumps work on a very simple principle indeed. Inside the pump casing, there is a flexible tube, usually made of rubber or silicone. With rollers or shoes compressing and relaxing the tube in sequence, a series of "peristaltic" waves is created, pushing the fluid inside the tube forward. This has the effect of "milking" the fluid through the tube and provides a pulse-free and extremely accurate flow. Peristaltic pumps have quite a wide range of uses, from pharmaceutical to food/beverage to wastewater to laboratory applications, among others. They are especially valued when contamination may be

problematic, as the fluid never actually leaves the confines of the tube and therefore does not come into contact with pump components.

5. Application in Bioenergy Industry

Bioenergy production is therefore heavily reliant on efficient fluid management, especially through the use of various pumping technologies. They play a very important role in the transportation of biomass feedstocks, biogas, and digestate at various stages in the production process, ensuring efficiency and productivity. Positive displacement pumps are very common in the bioenergy field, especially in anaerobic digestion systems. These pumps work by trapping a fixed amount of liquid and forcing it through the discharge pipe. This mechanism has the advantage of dealing with high solid contents normally encountered in most feedstocks in biogas production. Hence, it is quite ideal for mixing and transferring thick slurry without loss of efficiency. Centrifugal pumps are among the common ones applied in the bioenergy industry, especially when handling low-viscosity fluids such as digested slurry or biogas condensate. These pumps utilize a rotating impeller to create a flow of fluid and can therefore be used very effectively to transfer liquids over long distances or high heads. Since it is able to handle variable flow rates, they have wide applications at different bioenergy production stages.

a. Biomass Transport

Pumps play very important roles in transferring feedstocks in most biomass conversion processes. Such as agricultural residues and algae to preprocessing facilities. Liquid-solid extraction methods often require the movement of slurries, where positive displacement pumps excel in conditions where flow rates need to be maintained irrespective of viscosity variation and solids content.

b. Biogas Production

Anaerobic digestion requires reliable pumping solutions for mixing organic materials to provide consistent digestion conditions throughout. As Maja Rosiak, head of Xylem's Biogas Centre of Excellence, says, "High solid content in feedstock does introduce some challenges in fluid management, and therefore ups the ante for efficient mixing and pumping solutions." Besides, pumps are rather important in transferring the biogas, produced by decomposition of organic material, either into storage or for subsequent processing into fuels such as Compressed Natural Gas and Liquefied Natural Gas.

c. Digestate Management

The digestate leftover after anaerobic digestion may be challenging to manage. Due to its high nutritional value and viscosity. Pumps are used to circulate this material for further treatment, application as fertilizers, or conversion to other useful products. Efficient pumping solutions support the optimal recovery of resources from the digestate, hence increasing the general sustainability of the bioenergy system. Smart pumps represent a disruptive movement in pump technology since the incorporation of sensors and IoT allows for real-time monitoring and analytics. These usually smart pumps use sensors that constantly monitor critical parameters such as pressure, temperature, flow rate, and vibration. The information not only optimizes performance but also

yields maintenance that is predictive in nature, whereby operators can stay ahead and avoid failures.

This reduces downtime and operational costs. The possibility of monitoring and operating pumps remotely improves efficiency, especially for the bioenergy industry with complex processes that may also be geographically spread out. With the increasing drive for sustainability, the pump industry is aligning itself with environmental goals in terms of the development of energy-efficient designs. Contemporary pumps are increasingly made with variable speed drives and energy-efficient motors that minimize energy consumption while maximizing output. This focus on energy Efficiency is a key issue in the bioenergy industry, where operational costs and environmental impact need to be minimized. Bioenergy production utilizes a range of specific pump requirements that have necessitated designing equipment to run at suboptimal levels. Such specialized pumps are important in providing performance in the application where standard pump failures could occur easily, being specially designed with strong materials and modern designing principles. The nature of their construction makes them resistant enough to manage the challenges resulting from the peculiarity presented by the bioproducts: different viscosities and corrosive materials. Case studies of advanced biofuel technologies in countries like Germany, Sweden, and Canada reveal considerable advances in developing and scaling up production technologies for advanced and emerging biofuels. These case studies provide insight into not just the successes of successful implementation but also those deficiencies and challenges faced during the commercial development of these technologies. The selected examples chosen were selected based on the expertise of the participating members and the maturity of the technologies with a minimum Technology Readiness Level - TRL 7 (near commercialization).

RESULT AND DISCUSSION

The economic viability of the use of pumps in bioenergy production is evidenced by the increasing investments in processes that mobilize and convert waste into usable energy. Policies of the European Union have been instrumental in driving the percentage of waste-derived biofuels, particularly in Nordic countries, which have enacted even more stringent requirements than those agreed on at the EU level. Despite the progress, only a small fraction of the available waste resources is tapped; hence, there is great potential for further development. Pilot projects on advanced biofuels are being very promising. However, scalability remains a major obstacle to adoption. Scalability in project development is crucial in an effort to make at least an impression on the overall energy market. Public and private investment is also vital towards stirring innovation over financial restrictions to commercialization. One also needs to consider sustainable practices that ensure biofuels production is in line with long-term environmental objectives.

CONCLUSIONS AND RECOMMENDATIONS

Bioenergy facilities require pumps as a fundamental component to achieve both efficient operations and sustainability in their biofuel production and anaerobic digestion systems and biomass processing units. The research examined different pump systems and their performance capabilities while focusing on material types and their energy usage characteristics and their ability to process corrosive viscous biological substances. Bioenergy system availability and rates of biological gas production depend substantially on the selection of pump technology for operation. Effective pump technologies, particularly advanced positive displacement and centrifugal pumps, improve energy efficiency, reduce maintenance costs, and improve process reliability. Applying durable materials and integrating energy-saving technologies further maximize sustainability while reducing operating expenses. Future innovations must prioritize high-efficiency, low-maintenance pumps, smart monitoring, and automatic control to make bioenergy systems improved. Through adopting optimized pump strategies, the industry can improve energy efficiency, reduce waste, and enable worldwide renewable energy targets.

FURTHER STUDY

This research is still delayed, so further research is needed related to the topic of Technical Evaluation of Pumps in the Bio Energy Sector: Performance, Efficiency and Sustainability Considerations in order to improve this research and add insight for readers

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