# Artificial Lift

**Prof.Abdus Samad**

**Department of Ocean Engineering**

**Indian Institute of Technology Madras, Chennai**

## Lecture-55 Hydraulic Engine Pump Fundamentals - Part 1

Good morning, everybody. Today, I will be teaching hydraulic jet pumps. In hydraulic jet pumps, we have one nozzle, a diffuser, a mixing chamber, and we are trying to create low pressure, which will suck the high-pressure fluid from the wellbore. I will first explain how this jet pump works based on the Venturi meter principle. If you have gone through your fluid machinery laboratory, there you may have conducted experiments related to pressure gauges, manometers, and Venturi meters. So, I will try to explain a little bit based on that Venturi meter principle how this jet pump works.

In laboratory experiments, there is normally a system like this one. This is pressure 1, this is 1, this is 2, pressure 1, flow rate q1, velocity v1, area A1. Here, I can say area A2, pressure P2, velocity v2, flow rate q2, maybe ρ 1, maybe ρ 2, mass flow rate maybe m1, and this is m2 dot. Now, fluid will flow, creating a stream like this. Fluid prefers to travel in a straight path. If there is any restriction or obstacle, then fluid will have difficulty passing through that path, leading to losses.

So here, fluid tries to create smooth streamlines in this Venturi meter or restricted system. You can see how this restriction changes the fluid streamlines. Because of these streamline changes, section 2 pressure drops. P1 must be higher than P2, and flow rates q1 and q2 are involved.

What will happen to the flow rate? If it is a liquid, incompressible fluid, we can assume that the flow rate does not change because of mass conservation.

$$\dot{m} = \rho q$$

$$\rho_1 q_1 = \rho_2 q_2$$

In this case, where density is not changing, flow rate also does not change. Flow rate q is not changing. We are pumping hydraulic fluid (water or oil) into our wellbore, and we assume that water or oil is incompressible for this specific application. If it were compressible, the case might be a little different. However, we assume purely liquid for this case, and the flow rate does not change. But what about velocity? Velocity is q divided by A. So flow rate q is not changing; flow rate is not changing, but area is changing. You can see that section A has a larger diameter, while section 2 has a smaller diameter. So, the area is changing, which means q divided by A1 times v1 equals q divided by A2. With the area changing, but the flow rate not changing, velocity changes. So when solving Venturimeter or jet pump problems, where velocity changes but the flow rate does not, we consider this principle.

In this type of problem, we typically assume that there is no energy loss due to heat transfer or frictional pressure drop. If you can include such factors, it would make the problem more complex. However, we are assuming there is no energy transfer, so we apply the rules of mass conservation and energy conservation.

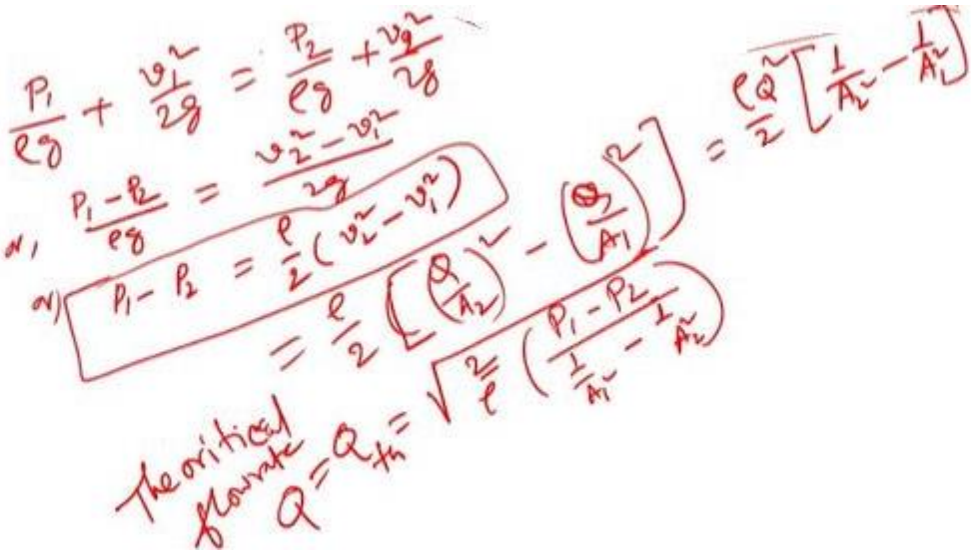
We use Bernoulli's principle in this Venturi meter.

Bernoulli's principle can be remembered as,

$$\frac{p}{\rho g} + \frac{v^2}{2g} + z = C$$

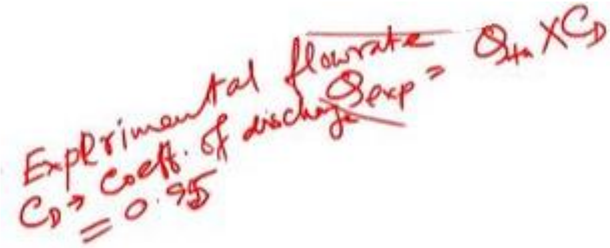
The constant may have additional terms, such as frictional or energy transfer terms, making it a generalized Bernoulli's equation. This is an energy equation, which means it emphasizes energy conservation. The equation states that energy must be conserved, while I previously mentioned mass conservation. As a result, velocity is not conserved due to the changing area.

Now, how does the pressure become different? In section 1, the pressure is p1, and according to the Bernoulli's equation, we can write it as follows:




We have thus obtained a formula that relates pressure and velocity, where velocity is related to the area. When the area changes, velocity changes, and consequently, pressure changes.

Now, let's consider the theoretical flow rate. The theoretical flow rate (q) is given by q equals v2 square minus v1 square. From this, we can write q as q equals the square root of 2 by ρ times p1 minus p2, divided by 1 by a1 square minus 1 by a2 square. This is the theoretical flow rate.




In practice, during experiments, the flow rate will change due to losses, and this is where the coefficient of discharge (Cd) comes into play. The experimental flow rate (q experimental) is related to the theoretical flow rate (qth) by the coefficient of discharge. Cd represents the amount of flow lost due to piping restrictions, pressure drops, frictions, and other factors. A well-designed system would typically have a Cd value around 0.95. However, the Cd value can be higher if the system's restrictions are not designed properly. A higher Cd value indicates more energy loss, resulting in a lower flow rate. For example, consider two Venturi meters: one smoothly designed and the other with a plate that creates more restrictions. The one with more restrictions will have a higher Cd value (Cd2) compared to the smoothly designed one (Cd1).

If you don't design the venturimeter restriction section properly, your pressure drop will be greater, or your flow rate will be lower. However, you are not destroying mass; this is just a practical consideration of how much flow rate you can achieve by creating restrictions in your pipe or tubing.

Let's solve a problem based on this concept. Imagine you have a venturimeter installed with a restriction like this, and there's a manometer here. Manometers are used to measure differential pressure. When the pressure at section 1 is higher than section 2, the manometer column is pushed down further, resulting in a differential pressure. This differential pressure can be determined using a manometer; from that, you can calculate the pressure difference created by this narrow section.

In this case, you have a venturimeter with a 10-centimeter diameter inlet (d1 = 10 cm) and a 5-centimeter throat section (d2 = 5 cm). The pressure difference between the inlet and outlet (P1 - P2) is given as 200 to 2000 Pascal. The fluid flowing through the ventimeter is water, with a density (ρ) of 1000 kg per cubic meter.

To calculate the flow rate of water, you need to calculate the theoretical flow rate because the coefficient of discharge (CD) is not given. So, first, calculate the area (A) since the flow rate (Q) equals A1 * V1, which also equals A2 * V2. The formula to calculate the pressure difference is derived from Bernoulli's equation.

A1 is calculated as π * (0.1 m/2)^2 = 0.00785 m^2, while A2 is calculated similarly and equals 0.00196 m^2. You can find the relationship between V1 and V2, and then calculate the pressure difference (P1 - P2).

The final result is approximately 0.00404 cubic meters per second (m^3/s). If you want the flow rate in cubic meters per hour, you can multiply this by 3600, resulting in 14.54 cubic meters per hour.

So this is the answer. I can change some data; you can modify the problem sometimes. I can give mercury column difference in terms of hg. If I give an hg column difference instead of giving it directly in Pascal, in that case, you have to convert the hg column into Pascal by changing the hg density and the column height, and then you can calculate the differential pressure.

Now, let's discuss the working principle of a jet pump. You can draw a diagram similar to a Venturi meter to understand a jet pump. You have a large pipe that narrows down to create a nozzle. Then, you have different sections in the pump. Section 1 is upstream of the nozzle, and the nozzle leads to a mixing chamber, followed by a throat section, and finally a diffuser. These sections play distinct roles in the jet pump's operation.

In the nozzle section, the pressure increases, and the velocity decreases. The primary and secondary fluids mix in the mixing chamber, and proper mixing is crucial for the jet pump's performance. This section is followed by the throat section, where the pressure decreases, and the velocity increases. The body section is where the secondary fluid enters.

Here's a breakdown of the different parts:

- Section 1: Upstream of the nozzle
- Nozzle: Pressure increases, velocity decreases
- Mixing chamber: Mixing of primary and secondary fluids
- Throat section: Pressure decreases, velocity increases
- Diffuser: Enlarging piping diameter, causing velocity to decrease and pressure to increase
- Section 3: Suction of secondary fluid (entrained or produced fluid)
- Section 4: Randomly named, following no specific rule

In this setup, the primary fluid (also known as motive fluid or power fluid) is responsible for providing the force that drives the system, while the secondary fluid (also called entrained or produced fluid) is the substance you want to move or extract using the jet pump. These fluids interact in different sections of the pump to achieve the desired results.

You can recall that we created a low-diameter section in the Venturi section to decrease velocity and reduce pressure. In the nozzle section, the velocity increases, and the fluid flows through, forming streamlined paths. The secondary fluid joins this flow, creating a mixture in the throat section, also known as the mixing chamber.

Let's understand how the pressure and flow rate change along the nozzle and other sections. The pressure decreases in the nozzle section as fluid flows through the narrowing section. Just after the nozzle, the smallest cross-sectional area is created, known as the vena contracta area, where the pressure is the lowest, resulting in increased suction.

As we move to the entrainment section, power fluid velocity increases, and the velocity remains almost constant. In the diffuser section, power fluid pressure drops. It's important to note that the flow rate does not change at the nozzle; it remains constant. However, when fluid entrainment occurs, increasing the total volume, there is a temporary change in flow rate. After this, the flow rate remains unchanged.

In summary, the nozzle experiences a constant flow rate, while velocity increases and pressure decreases. The entrainment section leads to an increase in velocity and then a constant velocity. Finally, in the diffuser section, fluid velocity decreases, while pressure increases.

Now, let's discuss cavitation, a crucial parameter we have been studying from the beginning of this course.

Cavitation is an integral part of fluid machinery, whether you're designing turbines, pumps, or compressors for working with water or other fluids. In cavitation, fluid passes through a nozzle and then a mixing chamber. When the pressure in the mixing chamber drops below the vaporization pressure of water, it can create bubbles due to the low pressure.

These bubbles will form when the pressure decreases, and as entrained fluid enters, the pressure starts increasing. As the pressure increases, the bubbles collapse in a process called bubble implosion. This implosion generates high-pressure pulses that impact the metal surface, causing continuous alternating stress on the metal. The frequent creation and collapse of bubbles result in pitting of the metal surface, leading to gradual erosion and surface fatigue.

This erosion occurs due to the alternating stress and the implosion of bubbles. The erosion rate increases if sand or other particles are present in the fluid. If corrosive chemicals are also involved, the wear and tear on the equipment become more severe. In the case of a pump or other high-speed machinery, ignoring cavitation can lead to reduced equipment life. For instance, in the case of a jet pump, where no moving parts are involved, the life span can be significantly reduced due to cavitation.

Design engineers need to minimize the system's moving components to extend equipment life. Jet pumps are a good example of systems with no moving parts. Despite their longer life, they have low efficiency because of losses, including those in the nozzle discharge and other components. Typically, jet pumps have reported efficiencies of 10 to 30 percent, and even with research efforts, reaching a maximum of 35 percent efficiency is quite challenging for the entire system.