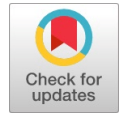


# Experimental Design and Numerical Modelling of Suspending the Sediments Inside the Pipeline Along with the Pipe



Sivakumar Karthikeyan, Krishnakumar. S Mithunn Balaji. S

**Abstract:** In this paper, we present a novel approach to addressing existing sewage pipeline system challenges by designing a new blending instrument that operates using the force exerted by sediment within the pipelines. The instrument incorporates an impeller that suspends particles along the pipeline flow, effectively preventing blockages. This innovation enhances the efficiency of the pipeline system and mitigates issues inherent in the current pipeline infrastructure. The impeller blade is designed for installation inside the pipeline, requiring minimal maintenance while capable of withstanding the corrosive environment of sewage systems. This is particularly critical given the highly acidic conditions, as evidenced by a maximum recorded pH value of 4.5 in the sewage.

**Keywords:** ANSYS CFX, Impeller, Rack and Pinion, Ratchet and Pawl.

## Abbreviations:

NGLs: Natural Gas Liquids  
CFX: Command Field Exercise  
ANSYS: Analysis System  
CFD: Computational Fluid Dynamics  
pH: Potential of Hydrogen  
mg/L: Milligram per liter  
MPa: Mega Pascal  
GPa: Gega Pascal  
PSI: Pounds per Square Inch  
PSAs: Pressure Sensitive Adhesives  
HVAC: Heating, Ventilation, and Air Conditioning  
EKG: Electrocardiogram  
CAD: Computer-Aided Design

## I. INTRODUCTION

Pipeline transport refers to the movement of goods or materials through a pipe; according to the latest data from 2024, there are slightly fewer than 2,175,000 miles (3,500,000 km) of pipelines in 120 countries worldwide. The United States accounts for 65% of this total, Russia for 8%, and Canada for 3%, meaning that 75% of all pipelines are concentrated in these three countries.

The Pipeline and Gas Journal's worldwide survey indicates that 118,623 miles (190,905 km) of the pipelines are currently planned or under construction; of these, 88,976 miles (143,193 km) are in the planning and design phase, while 29,647 miles (47,712 km) are in various stages of construction [1]. Pipelines transport liquids, gases and any chemically stable substance that can be sent through them. They are commonly used to transport crude and refined petroleum, fuels such as oil, natural gas, biofuels, and other fluids, including sewage, slurry, water, and beer. The pipelines are particularly useful for transporting water for drinking or irrigation over long distances, especially in areas where canals or channels are unsuitable due to evaporation, pollution, or environmental impact. Additionally, pneumatic tubes using compressed air can transport solid capsules.

Oil pipelines are typically made from steel or plastic tubes and are usually underground. The oil is moved through these pipelines using pump stations located along the route. Natural gas and similar gaseous fuels are lightly pressurized into liquids known as Natural Gas Liquids (NGLs). The natural gas pipelines are constructed from carbon steel [2]. Although highly toxic ammonia is theoretically the most dangerous substance transported through long-distance pipelines, accidents have been rare. Hydrogen pipeline transport involves the movement of hydrogen through pipes. District heating or district heating systems use networks of insulated pipes to deliver heated water, pressurised hot water, or steam to customers.

Pipelines carrying flammable or explosive materials, such as natural gas or oil, raise significant safety concerns, and there have been various accidents over the years. Also, the pipelines can be targets of vandalism, sabotage, or even terrorist attacks [3]. At times of war, pipelines are often strategic targets for military operations.

## II. TYPES OF PIPELINES

The pipeline system is divided into two types:

- The gravity flow pipelines.
- The pump-driven pipelines.

### A. The Gravity Flow-Driven Pipelines

In a Gravity feed, Fig. 1 uses Earth's gravity to move substances, typically liquids, from one place to another. This is a simple and effective method for transporting liquids without the need for a pump. A typical example is the fuel supply to an internal combustion engine, where the fuel tank is positioned above the engine. A non-liquid application of this principle is the carton flow. Shelving system [4]. Ancient Roman aqueducts relied on gravity feed, as do many water

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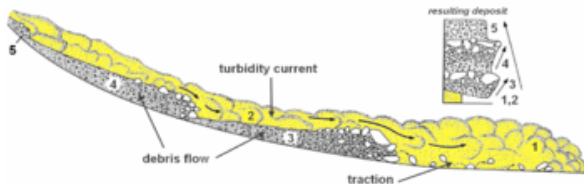
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supply systems in remote villages of developing countries today. In such a system, water flows from the source to the town due to the hydraulic head, the vertical distance between the water intake at the source and the outflow in the village [5]. Gravity drives this flow, while it is resisted by friction within the pipe. The amount of friction depends primarily on the pipe's length, diameter, age, and the material from which it is made.

### B. The Pump-Driven Pipelines

A sump pump was used to remove water that accumulates in a water-collecting sump basin, which is commonly found in the basements of homes.



[Fig.1: Gravity-Driven Flows [1]]



[Fig.2: Pump Used for Forced Pipeline Flow [1]]

Water may enter the basin through the perimeter drains of a basement waterproofing system or result from rainwater or natural groundwater, especially if the basement is below the water table level. The sump pumps are employed where basement flooding occurs regularly and address dampness caused by a water table above a home's foundation. These pumps direct water away from the house to a location where it no longer poses a problem, such as a municipal storm drain or a dry well. In older installations, the sump pumps may discharge water into the sanitary sewer. While this was once considered acceptable, it is now often prohibited by plumbing codes or municipal bylaws because it can overwhelm municipal sewage treatment systems [6]. The municipalities encourage homeowners to disconnect and reroute sump pump discharge away from sanitary sewers, and fines may be imposed for noncompliance. Many homeowners are unaware that their inherited sump pump systems discharge into the municipal sewer system. There are two primary types of sump pumps available: pedestal and submersible. The motor is mounted above the sump in a pedestal pump, making it easier to service but more visible to the eye.

The pump impeller was driven by a long vertical extension shaft and housed in a scroll casing at the pump's base. In this case, a submersible pump was mounted inside the sump and

specially sealed to prevent short electrical circuits. Sump pump systems are also used in industrial and commercial settings to manage water table-related issues in the upper soil layers. For instance, an artesian aquifer or a periodically high-water table can saturate the ground, leading to instability. As long as the pump operates effectively, the surface soil remains stable. The industrial sumps are typically ten feet deep and lined with corrugated metal pipes with perforations or drain holes. These may include electronic control systems with visual and audible alarms, usually covered to prevent debris and animals from falling in.

### III. THE SEWAGE PIPELINE SYSTEMS IN INDIA

According to the Metro Water Supply and Sewage Control Board Fig. 3, sewage transportation is primarily carried out through forced pumping at various pumping stations located at specific points across the city. Those stations are designed to transport sewage sludge and wastewater. However, the current pumping capacity is insufficient to handle the increasing volume of sewage and solid particles, due to their higher densities, as well as the growing volume of wastewater resulting from population growth.

To address this issue, the government plans to install additional pumping stations, supported by other agencies, to transport sewage to the treatment facilities. This initiative requires significant capital investment and a substantial power supply to succeed.

This paper presents a novel design for the existing sewage pipeline system: a blending instrument that operates using the force exerted by sediment within the pipeline. The instrument features an impeller that suspends particles along the pipeline flow, effectively preventing blockages. This innovation enhances the efficiency of the pipeline system and helps address the challenges posed by the current infrastructure.

This impeller blade is designed to be installed inside the pipeline, requiring minimal maintenance while being capable of withstanding the corrosive environment of the sewage system [7].



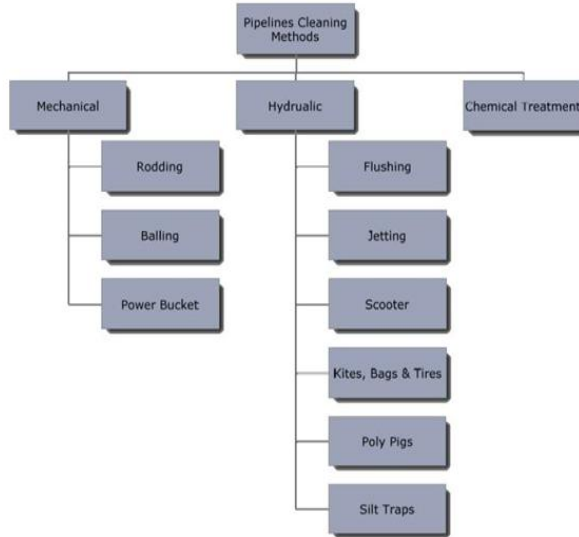
[Fig.3: The Indian Sewage Pipelines [1]]

This was particularly important, as the maximum recorded pH value of the sewage was 4.5, indicating a highly acidic environment. By combining experimental and numerical approaches, this study provides a comprehensive understanding of the flow dynamics and mechanical interactions within pipelines, offering a practical solution to

improve pipeline maintenance and performance.

#### IV. THE BLOCKAGES OR SEDIMENTS CAUSED IN SEWAGE PIPELINES

A. The plastic bottles or other plastic objects in drainage systems: These materials often enter drainage systems through improper waste disposal, leading to blockages and hindering wastewater flow. Over time, they accumulate and cause significant disruptions in the sewage network.



[Fig.4: Pipe Cleaning Methods [2]]

- B. Prolonged transportation of heavy suspended particles along the flow: Heavy particles, such as sand, grit, and debris, can settle in pipelines over time, reducing flow efficiency and increasing the risk of blockages. This issue is exacerbated in systems with inadequate flow velocity.
- C. Improper pipeline maintenance systems: Lack of regular cleaning, inspection, and maintenance of pipelines can lead to the buildup of sediments, grease, and other materials, resulting in reduced efficiency and frequent blockages.
- D. Insufficient pipeline diameter to handle large volumes of sewage and sludge: Many existing pipelines were designed for smaller capacities and cannot accommodate the increasing wastewater volumes associated with growing populations. This leads to overflows, backups, and system failures.
- E. Inadequate slope or gradient in pipeline design: Pipelines with improper slopes can stagnate water and sludge, leading to sediment buildup and blockages over time.
- F. Corrosion and wear of pipeline materials: Over time, pipelines can corrode or degrade due to exposure to acidic or chemically aggressive sewage, leading to leaks, cracks, and reduced structural integrity.
- G. Tree root intrusion into pipelines: Roots from nearby trees can infiltrate pipelines through cracks or joints, resulting in blockages and damage to the pipeline structure.
- H. Improper disposal of grease and oil: Grease, oil, and fat from households and industries can solidify inside pipelines, narrowing the flow path and causing blockages.
- I. Inadequate stormwater management: During heavy rainfall, stormwater can overwhelm sewage systems,

leading to overflows and mixing of stormwater with sewage, which strains the system.

- J. Lack of public awareness and improper waste disposal practices: Many blockages and pipeline issues arise from the inappropriate disposal of non-biodegradable materials, such as wipes, sanitary products, and plastics, into the sewage system.

#### V. EXISTING METHODS OF PIPELINE CLEANING

We focus on modifying the mechanical aspects of Fig. 4, specifically the methods used in pipeline maintenance. Our approach combines the rodding and balling techniques, which have been experimentally and numerically validated through flow analysis [8]. The study aims to enhance the efficiency of pipeline systems by addressing common issues, including blockages, sediment buildup, and flow restrictions. Key aspects of our methodology include:

- **Integration of Rodding and Balling Techniques:** By combining these two methods, we aim to enhance the removal of blockages and sediments from pipelines, ensuring smoother flow and reducing the frequency of maintenance.
- **Experimental Validation:** Laboratory tests were conducted to assess the effectiveness of the combined technique under controlled conditions, simulating real-world pipeline scenarios. Numerical flow analysis: Computational fluid dynamics (CFD) simulations were performed to analyze flow patterns, pressure drops, and the impact of the modified mechanical methods on pipeline performance [9].
- **Optimisation of Mechanical Tools:** The design of the rodding and balling tools was refined to minimise wear and tear, enhance durability, and improve compatibility with various pipeline diameters and materials.
- **Field Application and Testing:** The modified techniques were tested in real-world pipeline systems to evaluate their practicality, efficiency, and cost-effectiveness.
- **Environmental and Economic Benefits:** The proposed method reduces the need for chemical treatments and minimizes energy consumption, contributing to more sustainable pipeline maintenance practices.

#### VI. EXPERIMENTAL TECHNIQUE

##### A. Physical Aspects of Pipe Flow

Pipe flow is a branch of hydraulics and fluid mechanics that deals with the movement of liquids within a closed conduit, where a conduit refers to a means of containment. Another type of flow within a conduit is open-channel flow. While these two types of flow share many similarities, they differ in one critical aspect: pipe flow does not have a free surface, which is a defining characteristic of open-channel flow.

Flow [10]. In pipe flow, the liquid



It is entirely confined within the closed conduit and exerts hydraulic pressure rather than direct atmospheric pressure on the conduit walls. However, not all flow within a closed conduit is classified as pipe flow. For example, storm sewers are closed conduits but typically maintain a free surface, making them examples of open-channel flow. The exception occurs when a storm sewer operates at full capacity, at which point it can transition to pipe flow. The energy in pipe flow is expressed in terms of head and is defined by the Bernoulli equation. Diagrams illustrating pipe flow often include a hydraulic grade line to visualize the head along the flow path within the pipe. Additionally, pipe flow is subject to frictional losses, which are quantified using the Darcy-Weisbach equation.

**B. States of Flow**

The behavior of pipe flow is primarily governed by the effects of viscosity and gravity relative to the inertial forces of the flow. Depending on the balance between viscosity and inertia, as represented by the Reynolds number, the flow can be either laminar or turbulent. When the Reynolds number is below the critical value of approximately 2040, the flow will ultimately be laminar. Conversely, turbulent flow can persist when the Reynolds number exceeds this critical value. Additionally, the transition between laminar and turbulent flow is often sensitive to disturbance levels and imperfections in the system [11].

**C. Types of Flow Through Pipes**

- 1. Laminar Flow
- 2. Turbulent Flow

Laminar flow is a smooth, orderly fluid motion where the fluid moves in parallel layers with minimal mixing between them. It occurs at low velocities or when the fluid's viscosity dominates over inertial forces, typically at low Reynolds numbers (below approximately 2040 for pipe flow). In laminar flow, the fluid particles follow well-defined paths, called streamlines, and the flow is predictable and stable [12].

**D. Standard Fluid-Dynamics Notation**

In standard fluid-dynamics symbols:

Pressure reduction ( $\Delta P$ ) =  $8MLQ / \pi r^4$  OR

$\Delta P = 128\mu LQ / \pi d^4$  or  $\Delta P = 32\mu Lv / d^2$

Where:

$\Delta P$  - pressure reduction

$L$  - Length of pipe

$\mu$  - Dynamic viscosity

$Q$  - volumetric flow rate

$r$  - Pipe radius

$d$  - Pipe diameter

$v$  - Average velocity

Volumetric flow rate ( $\Phi$ ) =  $\pi R^4 \Delta P / 8 \eta L$

We're in compatible units

$\Phi$  - Volumetric flow rate (denoted as  $Q$  above),

$V(t)$  - Volume of the liquid transferred as a function of time,  $t$ ,

$v$  - Mean fluid velocity along the length of the tube,

$x$  - Distance in direction of flow,

$R$  - Internal radius of the tube,

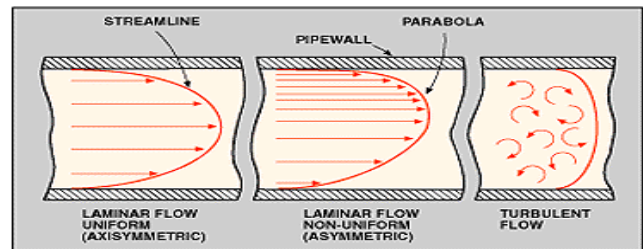
$\Delta P$  - pressure difference between the two ends,

$\eta$  - Dynamic fluid viscosity,

$L$  - Length of the tube.

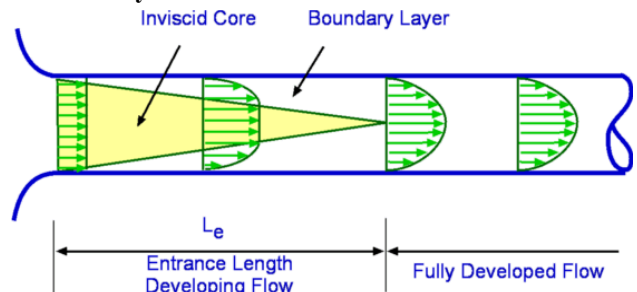
**E. Turbulent Flow**

Turbulent flow is a fluid (gas or liquid) flow Fig. 5 in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow, the fluid's speed at a point continuously changes in magnitude and direction. The flow of wind and rivers is generally turbulent in this sense, even if the currents are gentle [13]. The air or water swirls and eddies while its bulk moves in a specific direction. Most kinds of fluid flow are turbulent, except for laminar flow at the leading edge of solids moving relative to fluids or extremely close to solid surfaces, such as the inside wall of a pipe, or in cases of fluids of high viscosity (relatively significant sluggishness) flowing slowly through small channels. Common examples of turbulent flow are blood flow in arteries, oil transport in pipelines, lava flow, atmosphere, ocean currents, the flow through pumps and turbines, and the flow in boat wakes and around aircraft wing tips Fig. 6.



[Fig.5: Turbulent Flow Characteristics [6]]

**F. Boundary Condition**



[Fig.6: Physical Flows Through Pipes [6]]

**VII. CALCULATION FOR MINIMUM HEIGHT OF THE EQUIPMENT**

**A. Boundary Layer Thickness**

$$\delta = \frac{5.0 \cdot X}{\sqrt{Re}}$$

**B. Friction Factor Calculation**

$$f = \frac{8\tau_w}{\int v^2_{avg}} \text{ (friction)}$$

$$\text{pressure loss } \Delta PL = \frac{fL \delta v^2_{avg}}{D \cdot 2}$$

$f$  = friction factor

$$f = \frac{64\mu}{\delta D V_{avg}} = \frac{64}{Re}$$

Horizontal pipe =  $V_{avg} =$

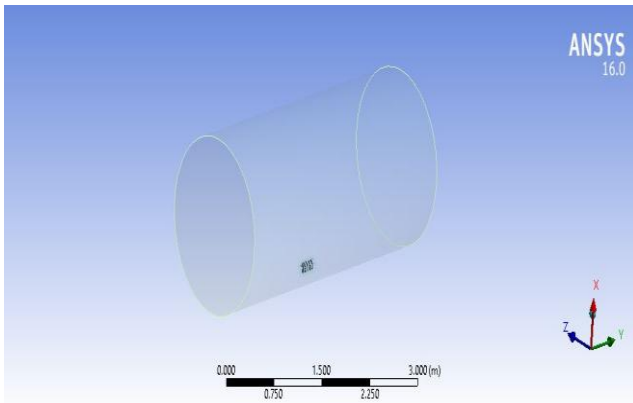
$$\frac{(P_1 - P_2) R^2}{8\mu L}$$



$$= \frac{\Delta P D^2}{32 \mu L} \text{ (Poiseuille's law)}$$

$$F = \frac{64.00}{Re}$$

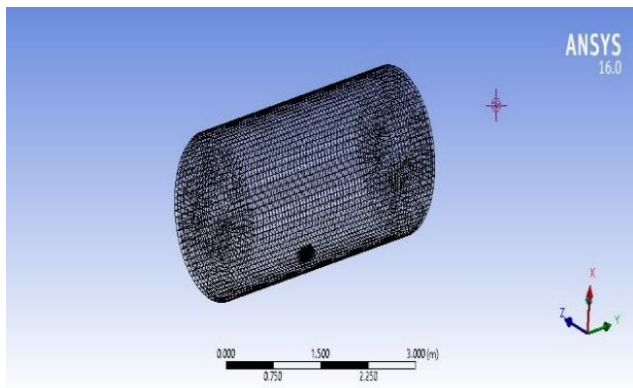
**C. Boundary Conditions for the Project**



[Fig.7: Actual Project View]

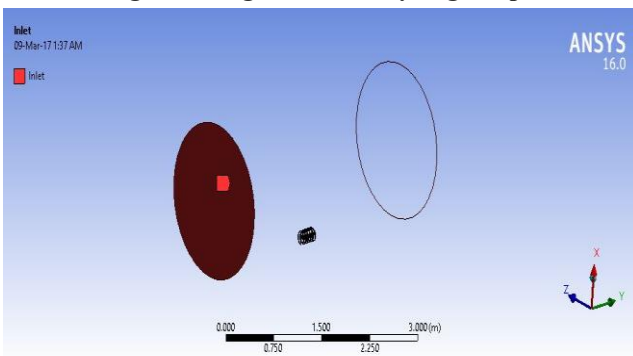
A boundary condition is a requirement that must be satisfied at all or part of the boundary of a region where a set of differential equations is to be solved. In ANSYS Workbench, the impeller model is imported and placed within the fluid domain, along with the appropriate mesh details.

The generated domain represents the pipe, whose walls are considered solid. The impeller is treated as an immersed solid positioned inside the drainage pipe through which the flow occurs. The inlet and outlet conditions are specified accordingly, with relevant fluid flow parameters applied to the main pipe.

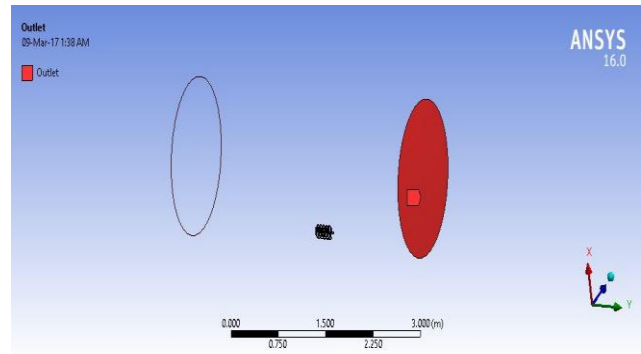


[Fig.8: Fine Meshes]

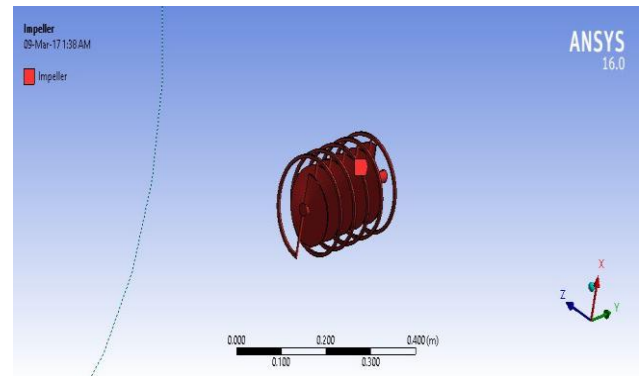
**D. Flow Regions Assigned for Analyzing Purposes**



[Fig.9: Inlet Region of Continuous Flow]



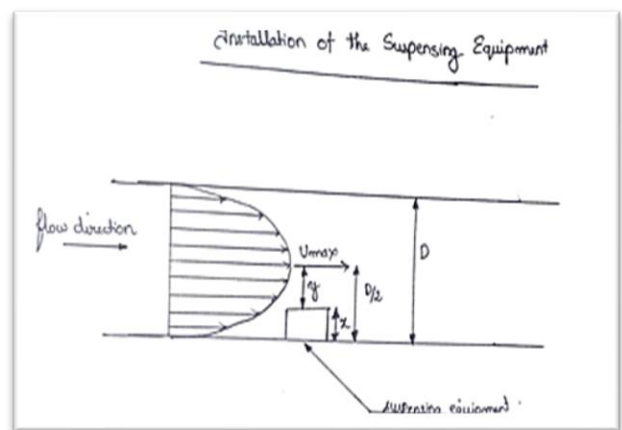
[Fig.10: Outlet Region of Continuous Flow]



[Fig.11: The Immersed Solid Condition of Impeller Blades]

**E. Suspension of Sediments Through the Equipment**

Practically, the flow rate is maximum along [Fig.13] at the centre of the pipe, i.e., at  $D/2$ , the diameter of the pipe being  $D$ . Therefore, the height of the equipment should be less than  $D/2$ , which is specified by the boundary condition formula. At this height, sediments can most disturb the flow through the pipe. The upper surface was not considered for the flow analysis, as sediments cannot stick to the top layer.



[Fig.12: The Practical Application of the Project Concept]

The notations are as follows.

- X = height of the equipment
- Y = maximum allowable sedimentation.
- $U_{max}$  = maximum flow velocity region
- D = diameter of the pipe.

The sedimenting sludge imparts Pressure on the pipeline causes the particles to be suspended in the flowing water, which is

carried away along with the flow. The impeller is connected with a weight-acting surface, which, when acted upon by the sediments, converts into the rotational motion of the impeller [14]. The impeller is designed so that the outer helical ring suspends the detailed particle, and the inner spiral blade pushes the water along with the suspended particles through the stream of water.

- The screw agitator turning on its axis produces a lifting action as it spirals the material in an upward flow
- At the same time the screw orbits the tank, the screw removes material away from the wall and deflects it into the center of the tank setting up a spiral current through the batch
- The material lifted by the screw gravitates downwards thoroughly intermixing with material being spiralled upward.
- This results in the most intimate intermingling of all ingredients

Ribbon mixers are a basic industrial mixing tool. They consist, basically, of a trough-shaped casing (usually 2 to 3 times longer than it is wide) with a semi-circular bottom, fitted with a horizontal longitudinal shaft on which are mounted arms supporting a combination of ribbon blades, paddles or helical screws set at a reasonably close clearance to the semi-circular mixer body so that no layer of material remains on the bottom of the mixer [15]. The most effective design of ribbon layout is the double spiral, in which the outer ribbon moves the product in one direction and the inner ribbon moves it in the opposite direction. This creates axial flow and prevents the build-up of material moved by the blades as they rotate, which is relatively small, allowing for longer mixing times. The capacity of the mixer should not be exceeded, otherwise the ribbon and/or blades are not effective and the surface layers of the powder do not get adequately mixed [16]. Ribbon mixers are normally operated at room temperature. Still, they may be jacketed for steam heating (at atmospheric pressure) or water cooling, as needed. Although ribbon mixers are relatively standard in design, there are many modifications and commercial design options available depending on:

- Materials Characteristics
- Production requirements, particularly batch size, and working conditions
- Machine characteristics, such as loading and unloading facilities, typically dictate that one does not fill this type of mixer to more than 50% of the available volume. Usually, the capacity of this type of mixer is restricted to an upper limit of 15 m.

Sometimes, to improve the dispersion of ingredients in ribbon mixers, the ribbon blades are designed to be close to the cylindrical wall, allowing for high shearing. Sometimes the ribbons are also fitted with rubber wipers to ensure complete intermingling of the ingredients by lifting any packed material near the wall into the middle of the ribbon ensemble [17]. It is challenging to predict the scale-up performance when attempting to increase mixing capacity by switching to a larger mixer of the same type.

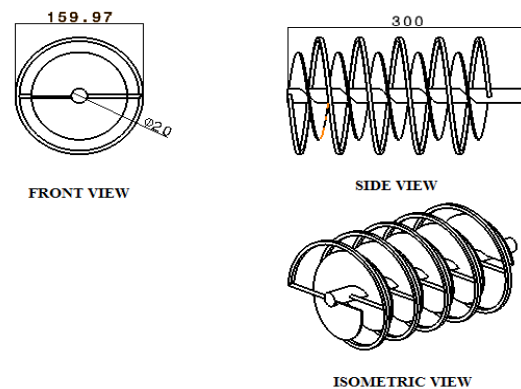
**F. Some of the Important Factors to be Considered Before the Selection of the Impeller Blade**

- i. *Critical Speed for Mixing:* The minimum speed required to rotate the impeller blade to generate mixing of the sediments.
- ii. *Just Lift off Distance:* the minimum distance from the pipe wall so that the sediments can be suspended in the flowing water.
- iii. *Critical Length:* the minimum length along which the sediments can be dragged along the water flow to have continuity in the 0pipe.
- iv. *Thickness:* The minimum thickness of the blade so that it can withstand the pressure generated during sludge flow.
- v. *No. Of Turns for the Blade:* The minimum no. of turns should be assigned to the blade to mix the sediments thoroughly and adequately.
- vi. *Blade Angle:* The blade angle varies with various applications.

**VIII. THE DESIGN SPECIFICATION OF THE IMPELLER BLADE**

- Type = The screw with helical ribbon impeller.
- Length = 300mm
- Diameter for screw=100mm
- Diameter for helical ribbon = 150mm
- Off bottom clearance for impeller=20mm
- Pitch for screw= 50mm
- Pitch for helical ribbon= 50mm
- Width of the helical ribbon= 2.5x 2.5
- Number of turns = 5
- The diameter of impeller = 30% of tank diameter
- Helical ribbon design parameters
- Clearance wall
- Pitch size ratio
- Blade width
- Effect of geometrical variables on ribbon impellers

**IX. THE MECHANISM AND OUTER DESIGN CONFIGURATION OF EQUIPMENT**



[Fig.13: CAD Drafted the Design of Impeller Blades]

**A. Effect of Impeller Pitch**

Effect of the blade: The flow circulation increases as the blade widens. However, too



many wide blades will decrease the flow rates, reducing the mixing.

Effect of number of blades: The greater the number of blades, the greater the efficiency.

Mixing time and impeller geometry region: In the laminar flow region.

**B. The Calculation for Rack and Pinion**

- Rack = no of teeth =9
- Pinion = no of teeth =21
- Outer diameter (D) =75 mm
- Pressure angle (∅) =20°
- Number of teeth on pinion (n) =21
- Module (m) =  $\frac{D}{n} = \frac{75}{21} = 3.57 \text{ mm}$
- Diametric pitch (PD) =  $\frac{n}{D} = 0.28 \text{ mm}$
- Circular pitch (pc) =  $\frac{\pi D}{n} = 11.21 \text{ mm}$
- Tooth space or root circle diameter = pitch circle diameter \* cos ∅
- =  $11.21 * \cos 20^\circ = 10.53 \text{ mm}$
- Dedendum circle radius = Pitch circle diameter – root circle diameter =  $11.21 - 10.53 = 0.68 \text{ mm}$
- Addendum = working depth – dedendum =  $14.8 - 0.68 = 14.12 \text{ mm}$
- The pitch circle radius of the rack
 
$$R = m * \frac{N}{2}$$
 N = number of teeth on the rack  
 =  $3.75 * \frac{9}{12}$   
 =  $16.065 \text{ mm}$
- The pitch circle radius of the pinion
 
$$R = m * \frac{n}{2}$$
 =  $3.57 * \frac{21}{2} = 36.855 \text{ mm}$
- The radius of the addendum circle on the pinion
 
$$Ra_1 = r + \text{addendum} = 36.855 + 14.12 = 50.975 \text{ mm}$$
- The radius of the addendum circle on the rack
 
$$Ra_2 = R + \text{addendum} = 16.05 + 14.12 = 30.17 \text{ mm}$$

- The length of the path of approach
 
$$K_p = (Ra_2 - R_2 \cos 2\emptyset)^{0.5} - R \sin \emptyset$$
 =  $(30.17 - 16.05 \cos 40)^{0.5} - 16.05 \sin 20$   
 =  $1.26 \text{ mm}$

Contact ratio or number of pairs of teeth in contact = length of arc of contact / circular pitch  
 =  $\frac{1.26}{0.28} = 4.5 \text{ mm}$

The length of the path of rows = LP  
 =  $ra_2 - (ra_2 * (\cos 20 * \cos 20))^{0.5} - r \sin 20$   
 =  $50.975 - (36.85 (2 \cos 20)^{0.5} - 36.85) = 5.695 \text{ mm}$

$$\text{Contact ratio} = \left( \frac{LP}{\cos 20} + \frac{LP}{\cos 20} \right) / 23.56$$

$$= \left( \frac{5.695 + 4.5}{\cos 20} \right) / 23.56 = 1.90 \text{ mm}$$

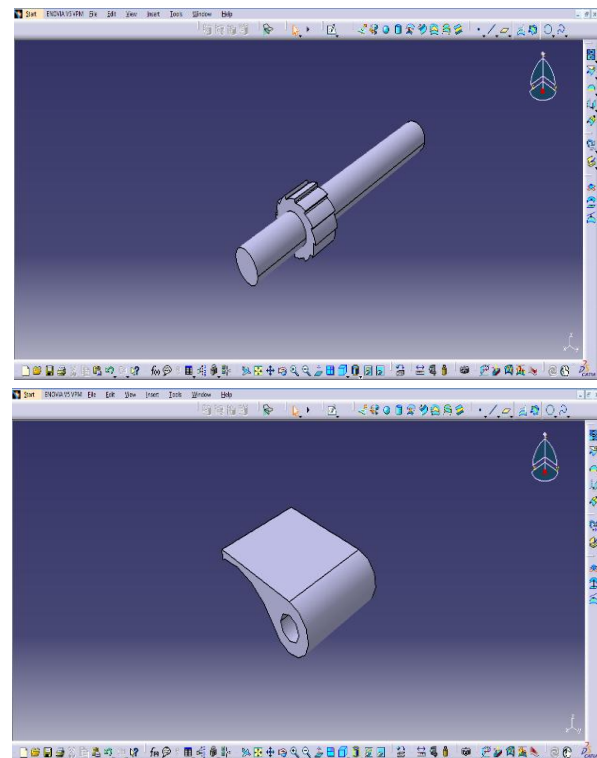
**C. The Design for the Ratchet and Pawl Mechanism**

From the standard dimension formula table for ratchet and pawl design, the following dimension parameters are drawn

out according to the gear and rack's geometrical parameters to stop the impeller blade's reverse motion due to transverse motion.

**D. The Ratchet Specification**

- D = 33.3 mm
- Face width E = 6 mm
- Depth of teeth H = 2 mm
- Centre distance I = 33.84 mm
- Total length G = 6 mm
- No of teeth = 36 P = 6mm
- Pitch = 2.09
- Teeth angle = 60°
- Material s45c
- Mounting dist. J = 15.67 mm
- Torque N.m = 3.07
- Weight kg = 0.035
- Angular spacing = 10



[Fig.14: Ratchet and Pawl CAD Model]

**E. Design for Suspension Mechanism**

The rotation of the impeller blades is achieved through a rack and pinion mechanism, where a forward rotating pinion gear is used. The force acting on the weighing surface is transferred to the rack, generating linear motion. This motion causes the pinion to rotate, which is connected axially to the shaft. The linear motion is then converted into an axial twisting moment on the shaft, which rotates only clockwise. Ball bearings further facilitate the rotation of the gear. A ratchet and pawl mechanism is used to ensure the impeller blade rotates in one direction. Under high-density flow conditions, excessive shear and stress may be applied to the impeller blade, potentially generating unwanted turbulence that could adversely affect the pipeline flow. The weight-acting surface of the mechanism is made of



polymer rubber, allowing it to create equivalent pressure even with the relatively low pressure generated by the sediments.

**F. The Pawl Specification**

- Weight = 0.020
- N = 10.77
- M = 30 mm
- L = 8 mm
- K = 5 mm

**G. Design of the Helical Spring steel - Design Calculations From PSG Design Data Book (Page No. 8.11)**

- $\delta = \frac{8NaD^3P}{Gd^4}$
- $K_{\frac{P}{\delta}} = \frac{Gd^4}{8NaD^3} = 3.3448 \text{ N/mm} \tau_o = \frac{8DP}{\pi d^3} = 9.167$
- $\tau_o = \frac{Gd\delta}{\pi NaD^2}$
- $T = \chi T_o$
- $d = \sqrt[3]{\frac{8DP}{\pi \tau_o}} = 5.00 \text{ mm}$
- $Na = \frac{Gd^4}{8D^3k} = 20$
- $U = \frac{p\delta}{2} = \frac{k\delta^2}{2} = \frac{3.3448 * 3^2}{2} = 15.003$
- $\delta = \frac{8 * 20 * 45 * 10}{78 * 10^3 * 5^4} = 2.99 \text{ mm}$
- D = 45 mm
- Δ = 3mm
- P = 10N
- N = 21
- d = 5 mm
- Na = 20
- Pitch = 7.5 mm

**H. The Material Selection for the Equipment under Pipeline Flowing Conditions.**

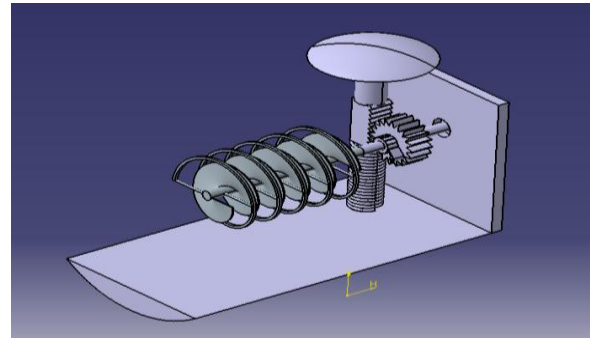
Wastewater plays a significant role in influencing pump lifetime, as different types of wastewaters require other materials to optimise durability. Factors such as chloride content, pH value, temperature, oxygen content, and abrasives all affect the selection of materials and the level of protection needed for the pump. Untreated wastewater typically lacks dissolved oxygen, as microorganisms consume it to break down organic material. However, if oxygen is present—even in low quantities—it can cause severe corrosion, particularly when materials like grey iron and carbon steel are used. The chloride content in wastewater can vary between 10 and 500 mg/L, but it can be higher in some cases, particularly with seawater infiltration. For context, the chloride level in the Atlantic Ocean is approximately 19,500 mg/L. In most wastewater, the pH value typically hovers around 7; however, untreated sewage often contains abrasive particles, which increases the risk of wear on hydraulic parts.

Corrosion and wear are common issues in wastewater pumps, resulting in unplanned breakdowns and a reduced lifespan. Wear refers to material loss from a surface and can occur due to multiple mechanisms, though one typically dominates.

Abrasive wear is typical in wastewater due to the presence of particulate matter. High velocity in the pump volute accelerates water erosion, particularly in pump components such as impellers, propellers, suction covers, and volutes that come into direct contact with the pumped media. Wear is not

directly proportional to the velocity of the pumped media. For metallic materials, wear is generally proportional to more than the square of the velocity. Tests indicate an exponent of 2.4 is appropriate, meaning if the velocity increases by 50%, wear will increase by 2.6 times. There is a strong linear relationship between wear resistance and the hardness of the material. Hard iron, for example, demonstrates extremely high wear resistance due to embedded hard chromium carbides. These tests, conducted at the Xylem material laboratory, used a specially designed apparatus that simulated actual conditions inside the pump.

**I. Final Assembled Model of the Equipment**



[Fig.15: Assembled Mechanism]

**J. Types of Corrosion in Sewage Pipeline Systems**

Several types of corrosion can occur inside a sewage pipeline:

- General Corrosion
- Galvanic Corrosion
- Erosion-Corrosion

The selection of pump materials is crucial for ensuring a long pump lifetime, and the material choice primarily depends on the specific application [18]. The material used in the impeller is significant, as it is heavily affected by wear and erosion-corrosion due to its high velocity relative to the liquid.

Grey iron is known for its excellent casting properties, ability to be easily hardened, and good machining characteristics. It is the most commonly used impeller material in municipal wastewater applications, especially when there are no special corrosion protection or wear resistance requirements. Grey iron is suitable for wastewater with a pH range of 5.5 to 14, as long as the chloride content does not exceed 200 mg/L. If the chloride content exceeds the recommended value, the use of zinc anodes and a special epoxy coating is recommended for added protection [19].

- Brinell Hardness 160 to 300.
- Compressive (Crushing) Strength 570 to 1290 MPa (83 to 190 x 10<sup>3</sup> psi)
- Density 7.2 g/cm<sup>3</sup> (450 lb/ft<sup>3</sup>)
- Elastic (Young's, Tensile) Modulus 82 to 140 GPa (12 to 20 x 10<sup>6</sup> psi)
- Elongation at Break 0.51 %
- Fatigue Strength (Endurance Limit) 69 to 170 MPa (10 to 25 x 10<sup>3</sup> psi)

## X. WORKING OF THE EQUIPMENT, PLACEMENT INSIDE THE PIPELINE

### A. Working on the Equipment

When the weight-acting cone is subjected to the pressure exerted by the sediments or the flowing water, it generates a linear motion in the rack. This linear motion is then converted into rotational motion by the meshed pinion. A ratchet and pawl mechanism is attached to the surface of the gear, on which the impeller blade is mounted. The ratchet and pawl restrict the impeller blade's reverse rotation, which the rack's to-and-fro motion could cause. The rotation of the impeller blade must be maintained in one direction for effective sediment blending. This ensures increased blade life while preventing excessive deformation or stress that may arise due to the high-density flow. The impeller's rotation facilitates the mixing of sediments along the water flow. The outer ribbon blade suspends the settled sediments just off the bottom region, while the screw-type ribbon blade pushes the sediments along with the water in the flow direction. The impeller blade is positioned opposite to the flow direction, which aids in the mixing process and helps reduce pressure after the sediments are suspended in the flow.

In future designs, the impeller blade will be modified for use inside square ducts and adapted for pipelines transporting crude oil and other high-viscosity materials, where the flow velocity is lower due to the fluid's low density and high kinematic viscosity.

### B. Efficiency of the Equipment or Boundary Conditions Calculations Regarding the Placements of the Equipment

#### (i) The Boundary Condition: Reynolds Number Calculation

$$\begin{aligned} Re &= V_{avg} \times D / \mu / \rho \\ &= 5 \times 1.8 / 0.00000001 \\ &= 9 \times 10^{-8} \end{aligned}$$

#### (ii) Boundary Layer Height

$$\begin{aligned} \Delta &= 5.0 \times X / Re^{0.5} \\ 0.320 &= 5.0 \times X / (9.8 \times 10^{-8})^{0.5} \\ X &= 1920 \text{ m or } 1.92 \text{ km} \end{aligned}$$

The above calculations indicate that, based on the initial conditions of the slurry flow at a speed of 5 m/s, the equipment should be placed every 1.92 km along the pipeline length.

This spacing ensures an effective composition of the slurry inside the pipeline and helps maintain optimal flow conditions.

### C. Working under Different Conditions

The equipment is to be used under the following conditions,

- High acidic medium
- High-density flow
- High-pressure flow
- Low-pressure flow
- High velocities
- Low velocities
- High turbulent flow
- Backflow condition

### D. Placement of the Equipment Inside the Pipeline

The equipment is designed to be placed inside the pipe, featuring a circular base that allows for easy attachment to the

pipe's inner surface. Using traditional methods, such as rivets or welding, for attachment is not feasible, as these methods could lead to crevices. These crevices may disrupt the flow, causing localised turbulence in that region. Increased turbulence from such cracks can result in improper pressure generation inside the pipeline, leading to excess stress on the pipe walls and potentially causing deformation or even pipe bursts. To address these issues, the equipment is attached to the inner surface of the pipe using an adhesive layer that creates a vacuum between the pipe surface and the equipment, ensuring a smooth and uninterrupted flow of fluid.

### E. The Pressure-Sensitive

Pressure-sensitive adhesives (PSAs) form a bond by applying light pressure, which allows the adhesive to adhere to the surface. They were designed to balance flow and resistance to flow. The bond is created because the adhesive is soft enough to flow (or "wet") onto the adhered surface and hard enough to resist flow when stress is applied to the bond. Once the adhesive and the adhered surface are nearby, molecular interactions, such as van der Waals forces, contribute significantly to the ultimate strength of the bond.

The PSAs are engineered for permanent or removable applications. Permanent PSAs

They are used in power equipment safety labels, HVAC ductwork foil tape, automotive interior trim assembly, and sound/vibration-damping films. Some high-performance permanent PSAs exhibit strong adhesion and support kilograms of weight per square centimetre of contact area, even at elevated temperatures. These adhesives may initially be removable (for example, to recover mislabeled goods), gradually building a permanent bond over several hours or days.

Conversely, removable PSAs form a temporary bond and can ideally be removed after months or years, leaving no residue. These adhesives are used in various applications, including surface protection films, masking tapes, bookmarks, barcode labels, price marking labels, promotional graphics, and skin-contact applications such as wound care dressings, EKG electrodes, athletic tape, analgesic and transdermal drug patches. Some removable adhesives are designed to adhere and detach repeatedly, although they generally have low adhesion and cannot support significant weight. An example of a removable pressure-sensitive adhesive (PSA) is the adhesive used in Post-it Notes.

PSAs can be manufactured with either a liquid carrier or in 100% solid form. Liquid PSAs are made by coating the adhesive and drying off the solvent or water carrier. They may be further heated to initiate a cross-linking reaction, which increases their molecular weight. In contrast, 100% solid PSAs can be low-viscosity polymers that are coated and then irradiated to increase molecular weight, or they may be high-viscosity materials that are heated to reduce viscosity, allowing for coating before cooling to their final form. The primary raw material for PSAs is acrylate-based polymers.

**F. Epoxy**

Epoxy refers to both the basic components and the cured end products of epoxy resins and is also a common term for the epoxide functional group. Epoxy resins, known as polyoxides, are a class of reactive prepolymers and polymers containing epoxide groups. Those resins can cross-link through catalytic photopolymerization or by reacting with various co-reactants, including polyfunctional amines, acids (and acid anhydrides), phenols, alcohols, and thiols.

**XI. INTERPRETATIONS AND OUTCOMES BY FLOW ANALYSIS**

The k-epsilon model solves for two key variables: k, the turbulent kinetic energy, and epsilon, the rate of kinetic energy dissipation.

This model employs wall functions, meaning the flow in the buffer region is not directly simulated [20]. Due to its reasonable convergence rate and relatively low memory requirements, the k-epsilon model is widely used in industrial applications. However, it has limitations in accurately computing flow fields with adverse pressure gradients, strong curvature, or jet flow. Despite these limitations, it performs well in external flow problems around complex geometries.

For instance, it is effective in solving the airflow around a bluff body. In this study, the flow analysis was conducted using Ansys CFX software under both slurry and normal water conditions.

**A. The CFD Specification for Flow Analysis**

Data from Metro Water Boards, Chennai)

- Pipe diameter=1800mm
- Pipe length= 44 x D
- Size of the particle= 3-7mm
- Particle volume fraction = 0.10-0.45
- Sp. Gravity of particle = 2.65
- Sp. Gravity of water = 1.00
- Velocity of flow = 5m/s
- Elurian- elurian model
- K-Elipson turbulence model.
- To study the effect of velocity and pressure on particle and normal water flow

**B. The Boundary Conditions**

*i. Inlet*

- Medium: Air
- Velocity: 5m/s<sup>2</sup>

*ii. Impeller*

- Domain: Immersed Solid
- Rotational Velocity: 100rev / Min

*iii. Material Details - Slurry*

- Density: 2000 Kg/M3
- Viscosity: 44 M/S
- Specific Conductivity: 3.16

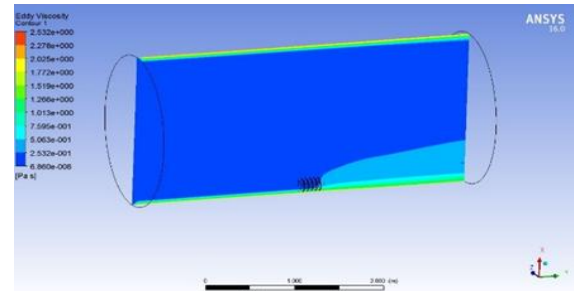
**C. Results Interpretation**

The CF contours for various parameters are shown below.

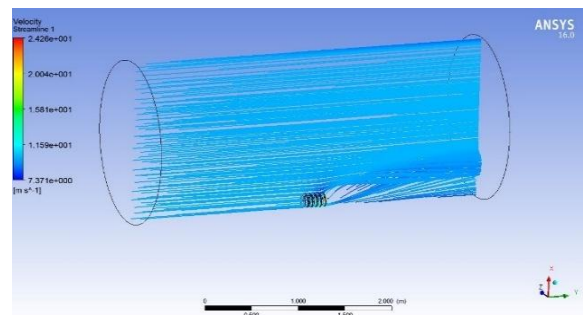
**Table-I: Flow Outcomes on the Rotation of the Impeller Blade**

Fluid Passed	Pressure (Pa)		Velocity (m/s)	
	Max	Min	Max	Min
Water	$1.24 \times 10^5$	$5.1 \times 10^4$	24.26	0
Slurry	$1.54 \times 10^3$	$2.08 \times 10^3$	24.34	0

**D. The CFD Analysis in Normal Water Conditions**

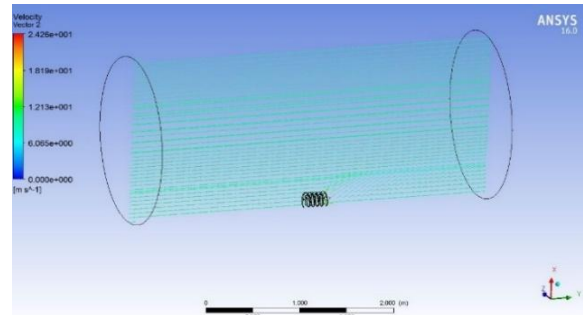


**[Fig.16: The Eddy Flow Due to Normal Water]**



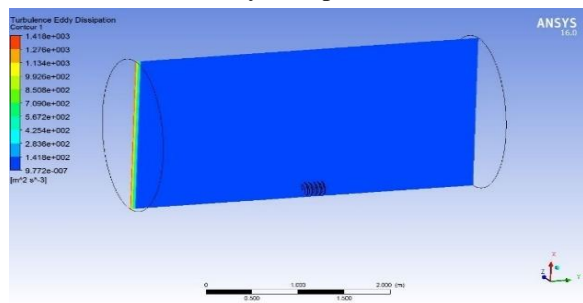
**[Fig.17: The Velocity Streamlines Flow Due to Normal Water]**

**E. Velocity Vector Flow Analysis**

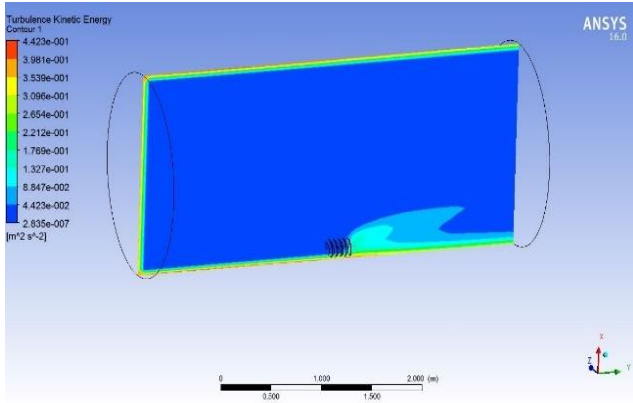


**[Fig.18: The Velocity Vector Flow Due to Normal Water]**

**F. The Turbulence Eddy Dissipation**

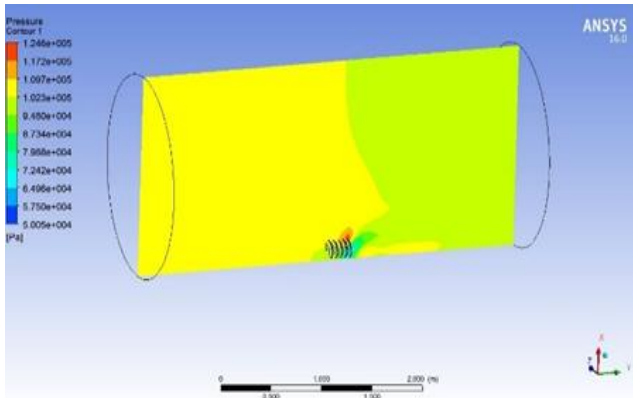


**[Fig.19: The Turbulence Eddy Dissipation Flow Due to Normal Water]**

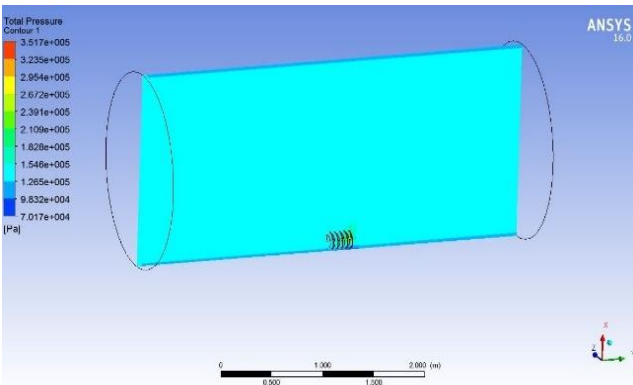


[Fig.20: The Turbulence Kinetic Energy Flow Due to Normal Water]

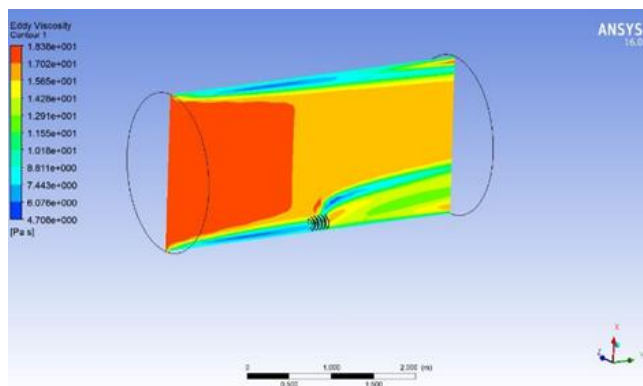
G. The Pressure Flow Analysis



[Fig.21: Pressure Contour Flow Due to Normal Water]

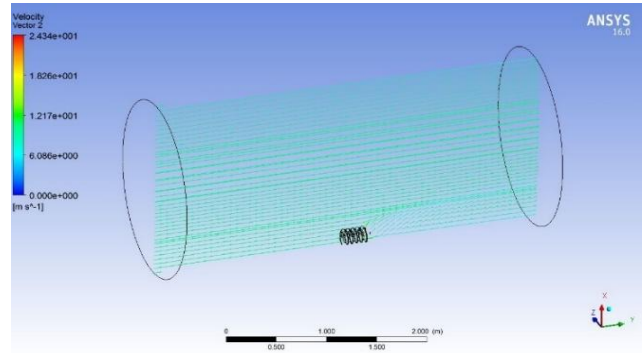


[Fig.22: Pressure Contour Flow Due to Sludge Water]

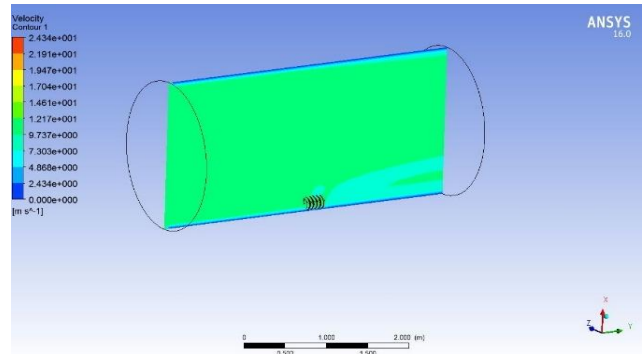


[Fig. 23: Eddy Velocity Contour Flow Due to Sludge Water]

H. The Velocity Vector Flow Analysis

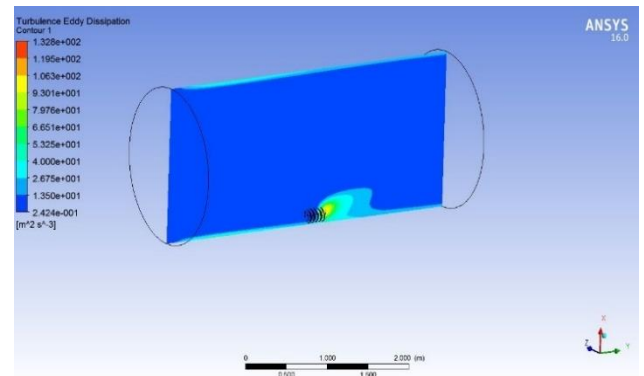


[Fig.24: Velocity Vector Flow Due to Sludge Water]

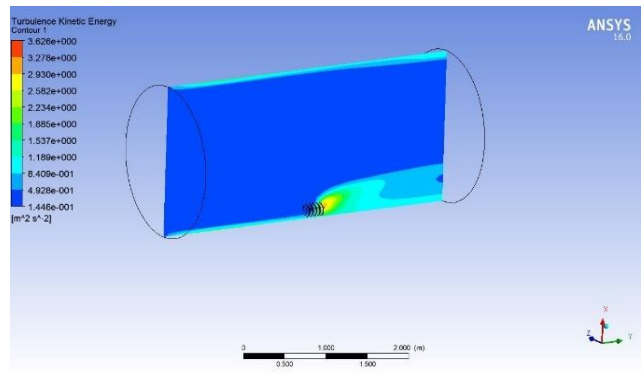


[Fig.25: Velocity Contour Flow Due to Sludge Water]

I. The Turbulence Eddy Dissipation

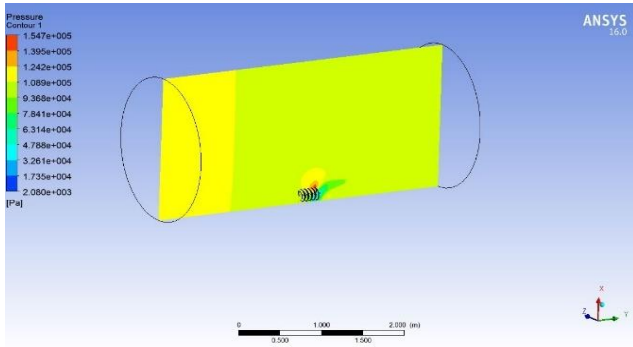


[Fig. 26: The Turbulence Eddy Dissipation Flow Due to Sludge Water]

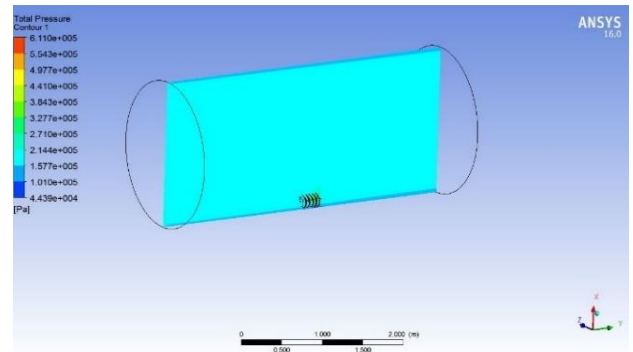


[Fig.27: The Turbulence Kinetic Energy Flow Due to Sludge Water]

**J. Pressure Contour Flow Analysis**



[Fig.28: Pressure Contour Flow Due to Sludge Water]



[Fig.29: Pressure Contour Flow Due to Sludge Water]

**K. The Final Result Interpretations Under CFD Analysis**

- A significant increase in turbulence was observed at the end of the impeller blade.
- The generated drag force is sufficient to push the sediments forward.
- The pressure difference indicates drag force generation, facilitating sediment flow along with the water.
- Flow viscosity decreases with impeller rotation near the pipe section's bottom wall.
- A comprehensive pipeline evaluation was conducted instead of a sectional analysis, ensuring the feasibility of the impeller.
- The justified distance between each piece of equipment validates the boundary layer calculation.
- Pressure decreases after the fluid exits the impeller, leading to an increase in velocity.
- The impeller exhibited different results under normal and slurry water conditions due to variations in fluid density.
- In slurry water conditions, turbulence, velocity, and pressure differences are higher than standard water conditions, demonstrating the impeller blade's effectiveness.
- Under normal water conditions, the impeller rotation has minimal impact, whereas in slurry water conditions, the pressure generated by sediments influences the flow.
- The eddy viscosity changes are more prominent in slurry flow due to increased particle movement, leading to higher turbulence and eddy losses.
- The streamlined flow results for normal and slurry water conditions reveal variations before and after turbulence generated by the impeller blade.

- The streamlined analysis illustrates how sediments are distributed along the water flow and the resulting flow characteristics after suspension.
- The water density changes significantly after sediment suspension, while the drag viscosity along the bottom walls decreases due to sediment removal.
- Sediment suspension increases the outlet head, which, in turn, enhances the flow velocity.
- As the pipe diameter increases, pressure decreases, allowing smoother flow.

**XII. CONCLUSIONS**

The experimental design and numerical modelling of suspending sediments inside the pipeline, combined with the pipe operating efficiently without requiring an external power supply, make it a cost-effective and energy-saving solution. It significantly reduces the need for frequent sediment cleaning, ensuring continuous flow without substantial head loss. Additionally, the system helps lower labour costs by minimising manual intervention and simplifying maintenance requirements. The installation process was straightforward, and minimal upkeep made it a practical choice for long-term operation. The system enhances overall pipeline efficiency by reducing reliance on costly cleaning equipment and addressing challenges related to section cleaning. Furthermore, it enhances the effectiveness of long-distance pipeline transportation while reducing the need for excessive pumping, resulting in energy conservation and operational cost savings.

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**DECLARATION STATEMENT**

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it was conducted without any external influence.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.



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## AUTHOR'S PROFILE



**Dr. Sivakumar Karthikeyan**, obtained his degree in Bachelor of Engineering with a Specialization in Mechanical Engineering from Madras University in 1997. He earned an M.E. in Design and Production of Thermal Power Equipment at the National Institute of Technology, Trichy, in 2003. He received his Ph.D. in Heat Transfer and Computational Fluid Dynamics from Anna University, Chennai, in 2015. He has over 20 years of experience in teaching and research and is currently an Associate Professor in the Department of Mechanical Engineering at SRM Valliammai Engineering College, Kattankulatur, Chennai – 603203. His area of research includes Energy, Heat transfer, and CFD, in which he has published over 40 International and 8 National Journal Articles, written six textbooks, and authored one book chapter. He has registered and published seven patents, four of which have been granted in his name, and presented papers at 18 International and National Conferences. He was a reviewer for Heat and Mass Transfer, Thermal Science, the Journal of Thermal Engineering, the Australian Journal of Mechanical Engineering, Materials Today: Proceedings, Archive in Mechanical Engineering, the International Journal of Heat and Mass Transfer Research, and the Journal of Applied Engineering Science. He is a life member of various societies, like the India Society of Technical Education, the International Association of Engineers, and the Society of Automotive Engineers.





**Krishnakumar. S** is an Undergraduate student in the Department of Mechanical Engineering. He is developing knowledge of fluid mechanics and CFD Fluent software for analysing flow, identifying various forces acting on obstacles, gaining a deeper understanding of machine element design, and referencing PSG design data books.

In classrooms, they absorb principles of thermodynamics and fluid mechanics, eager to apply them in real-world scenarios. With grease-stained hands and a mind ablaze with innovation, they succeed in workshops, crafting prototypes and refining designs. Beyond what they learn in the classroom, they are enthusiastic problem solvers who are compelled to make a difference in the world via their engineering. Their future is shaped with each project, representing the untiring spirit of innovation that characterises mechanical engineering.



**Mithunn Balaji. S** is a lower-college student at Amador Valley High School, California, USA. He was introduced to various coding languages, including HTML, Java, Python, C++, C, and others. Nevertheless, he fell in love with two coding languages: Java and Python. He started building projects to learn them more deeply, exploring smaller but

interesting nodes of the language. He still vividly remembers when he transformed my small treasure hunt project into a graphical format with the help of a graphical user interface (GUI). The treasure he gained from this project was not just its completion, but also the learning experiences, his struggles to build it, and the skills he developed, such as resilience, determination, and perseverance. He contributes to my local community by teaching coding. After improving my skills in several programming languages through ACE Coding, I began mentoring middle school students on a weekly basis at my local school. This experience has been incredibly fulfilling, allowing me to interact with bright and aspiring young minds while sharing my knowledge and expertise.

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