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A Study on CFD Analysis of Sand Erosion in a Pipeline

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ABSTRACT

Elbows are extensively brought in use for gas as well as oil extraction pipelines, power plants, refineries, ammonia gas plant, etc. One of the major challenges which are present further industry of petroleum is the erosion of the pipelines. There are five financial integrity and threats available related to the safety of the pipeline because of the issue of erosion. The pipe system's performance is influenced because of the pipelines erosive issues. This demands rapid arrangements of elbows because of the restrictions of the external spaces as well as there is a shortage among the elbows in respect to their connection length. The erosion characteristics and the flow field of the elbows connection gets influenced because of the interactions among the two elbows. This paper targets for investigating the behavior of the sand erosion six in the pipeline elbow under different fluid mediums such as methane, diesel and water Along with the sand Oklahoma number 1 in a pipe of 76.2-millimeter dia. This investigation is done with the help of computational fluid dynamics. Therefore, the use of CFD analysis with approach of Eulerian-Lagrangian is made for solving continuous phase with the help of "Navier stokes equation" and used "particle force balance" for solving the second phase. For modeling the continuous fluid phase's turbulence behaviour so that it can address the "viscous boundary effects" in the elbow's secondary flow and near wall region and attain more precise outcomes, "low Reynolds number correction" and Reynold stress model is brought in use.

Keywords: Sand erosion; Pipe erosion; Computational fluid dynamics; Navier stokes equation.

I. INTRODUCTION

Corrosion is the slowly occurred process which generally degrades a material because of the chemical or electrochemical actions; also erosion comes under the mechanical wear process (for instance- impact of the solid particles). So, whenever these two processes work together with the joint action of erosion as well as corrosion in the aqueous environment is known as erosion-corrosion. This phenomenon is responsible for the failure of equipments which are used in the engineering applications. Erosion can be found in flow disturbances for instance-valves, fitting and bends. In this work main focus is given on the clear study of the erosion-corrosion phenomena's separately in the real environment where things seem to look clear. In this context many experiments are then performed in the field of flow loop which simulates-disturbances of flow, random contraction of pipe as well as random expansion of pipes. [1]

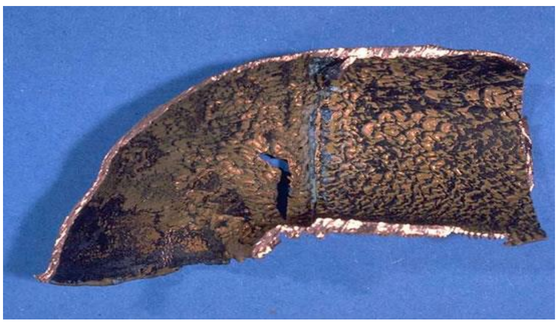

Figure 1: Erosion and Corrosion damage in pipe elbow

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Reasons of Erosion

Upon initiation of the petroleum fluid's extraction from the reservoir, sand also gets extracted as a by-product because of the destabilizing mechanical force. This force is generated during the formation. This occurs because of the collision and physical impaction provided by the sand particles. This process generally regarded as the sand erosion. Erosion can cover up the walls of the particular equipment, which consequently increases the cost of maintenance as well as loss of containment respectively. Since, sand erosion is regarded is the complex process which severely depends on different factors. Since, last decade some of the erosion predictive models also proposed among them 33 parameters which influences erosion process which are obtained from 28 erosion equations containing average of 5 parameters per equation. The obtained parameters contains properties as-fluid, particle and wall material as well as the flow condition. [2]

Particles: The properties of the particles can be determined as sand size which seeks attention of several researchers curious to know about this field. The fact was also well-known that the rate of the particle along with the size contains an exhibit power-law relationship with exponent 'n' that can fluctuate from 0.3 to 2.0. mostly focus was carried out on the studies of particle size in between 100 µm and 700 µm. the contribution of the fined size particle below 100 µm was closer to negligible for the damaging of erosion whose has kinetic energy is comparably low than 100 µm, then also erosion can occur and cause huge threats if the turbidity of the flow condition is high. Some experiments are also shown that the substantial metal loss on a standard elbow with 20 µm sand size. Comparatively the employment of sand management down hole, fine sand of size typically less than 75 µm may still be built up to the surface facilities as well as erode the piping components causing integrity issue. [3]

Pipe Geometry: In this section the geometry of the pipe related to the erosion is elaborated which shows that the dependency of the erosion does not rely on particle property, but fluid which also flows with sand is second important factor to be noticed. Several fluids can also exhibit various behaviours of erosion. Within the flow of gas solid, it seems that particles of sand cross the fluid streamline that is subjected for various variations within the path of flow of the fluid; whereas in the "liquid solid flow state", particles of sand will tend towards flowing very close to the streamline. The particle trajectory as well as the distribution present in fluid generally depends on the connection in between the inertia of particle along with the drag forces of the fluid. The time-to-time updates in researches on the topic on erosion particularly aim at on "standard elbow geometries" as elbow is needed to be the most normal application within the "process industry" as well as in the amenities for production of petroleum. Therefore, elbow along with several flow orientation as well as the angle which is needed in future for the study in order to investigate on the patterns of erosion. [3]

Pipe Material: Many activists have found that damage in the erosion particles which is present on the metallic pipe is generally influenced with the properties of the surface material of the pipe as well as the properties of the impact particles. [4]

II. LITERATURE REVIEW

(Ejeh et al., 2020) [5] Studied that flow dynamics in pipes get hugely impacted because of the available conditions of the flow. Hence, it is a very complex system. The existence of solid particles is correlated with the movement of crude oil through pipelines inside unconsolidated petroleum reservoirs. Through crude oil processing, these particles are often carried as dispersed phases and are therefore harmful to the quality of the pipe surface. This could result in the incidence of corrosion of the crevice due to pipe erosion. This paper aims to examine crude oil dynamics while pipeline flow and to define erosion hotspots for various pipe elbow curvatures in relation to the above study. Approaches which were used in this study are Practical Tracing Modeling (PTM) as well as Reynolds Averaging Navier-Stokes (RANS). Simulation of fluid dynamics as well as tracing of the particles is the main focus of this study. Post-processed findings showed that in the area with the lowest curvature radius, the fluid velocity magnitude was significantly higher. In areas of low-velocity severity, the highest static pressures as well as turbulence dissipation levels were observed. The incidence of erosive wear at the elbow was also significantly higher, and pipe curvature differed with the hotspot.

(Okafor & Ibeneme, 2019) [6] Studied that major issue which is experienced by pipeline engineers is pipe fitting degradation and related issues in gas and oil pipelines. Over time various sand control frameworks have been introduced to restrict sand at its base down the well's pit. These techniques for sand exclusion involve gravel packing at the head of the well and/or using screens to prevent the entry of sand into the pipeline. In addition to enhanced sand observation and control, these sand exclusion systems have been productive in cutting down sand output in the pipeline lines to a great extent and are commonly used as part of oil and gas production wells. The outcomes of this study are made on the basis of simulations made through utilizing a widely validated proprietary CFD model. The rate of erosion is observed to be hiked with both fluid velocity and size of the sand particle and reduced with degree of bending, diameter and radius of the pipe. Outcomes also exhibit that it is probable for

(Xian & Che Sidik, 2019) [7] Analyzed that water as well as ethylene glycol are usually used in the form of coolant in automobile cooling systems. By dispersion of solid particles, the thermal property is enhanced of conventional heat transfer fluid which shows higher thermal conductivity in the nano fluids. Through using nano fluid as a coolant, several previous researchers find enhancement in the rate of transfer of heat in the automotive cooling system. However, very few limitations, such as the tribological effect on components in the automotive cooling system, are documented. Therefore this paper aimed to evaluate the erosion-corrosion effect of the nano fluid on the Perodua Kancil D37 water pump aluminum impeller. With respect to ASTM D2809-09 standard, inlet pressure, rpm of pump as well as coolant temperature are the working parameters. Graphene Nano platelets, corrosive water and ethylene glycol are used for making testing coolants.

(N. H. Saeid, 2018) [8] Studied that 3D CFD simulation has been used for analyzing the amount of sand in choke valve as well as two-phase turbulent flow of crude oil. For the simulation of sand flow, discrete phase mathematical model is being utilized; it is also used in the system for its interaction with the oil flow. For reducing the sand erosion in the given system, the governing parameters are identified by using parametric study. Industrial oil production project is used for taking dimensions as well as valve geometry. Pressure difference between the inlet of the pipe and outlet of the pipe, flow rate of sand and valve opening percentage are the parameters considered in this study. With respect to sand flow rate, valve opening and pressure difference, the erosion rate variation is presented with the simulation results. For both large valve opening as well as small valve opening, it is observed that erosion rate is high. In between 20-30% of valve opening, minimum erosion rate is observed of every case with numerous pressure differences. In the simulations, areas with the highest erosion rate are expected.

(Mathew, 2017) [9] A complex process is to estimate the erosion in multiphase flow. The material loss from the material wall, attributed to the dominance of certain particles, is erosion. A CFD method is used in this to research the impact of sand particle motions by carrier fluids like mixed gasses, methane-oil, methane, and many more. The erosion mechanism is analyzed for both multi and single-phase flow with the help of CFD analysis conducted on ANSYS Fluent 6.0. The most prone areas having the maximum level of degradation of the material were suggested to investigate. By API recommended standards, erosion rate can be calculated which will use CFD for comparing the values numerically. Calculation of the forces striking over the bend section is performed along with the pressure drop.

(Hosseini & Hosseini, 2016) [10] stated the process of erosion among the amin threats to the integrity of assets in hydrocarbon transportation and production industry. Subsea flexible pipes and risers are particularly susceptible to particulate erosion due to the complex geometry of inner metallic carcass. In this work, the sand erosion in a 2” flexible riser carrying a two-phase gas and liquid flow were numerically simulated using a computational fluid dynamic tool and E/CRC model. The erosion rates were estimated for commercial carbon steel, UNS S31600 and UNS S32750 at an angle which yields the minimum bend radius (MBR) in riser. As a reference, the simulation was also conducted on a rigid pipe with a similar geometry. It was found that both maximum and total erosion rates were considerably higher for all three materials in flexible riser.

(Wong et al., 2015) [11] FPSO vessels are commonly using the flexible pipes instead of rigid pipework for transporting gas and oil fluid in subsea pipe network. FPSO stands for Floating Production Storage Offloading. The innermost part of the pipe is in direct communication with the fluids created, which can also carry sand particles over time and cause inner surface erosion. The erosion rate on the surface of a substance is approximately equivalent to the square velocity of the particle impact and particles in gas move at a greater relative speed than fluid flow The use of flexible pipes would also be more prone to sand erosion in gas-dominant fields than in liquid-dominant fields. Various experimental and modeling papers on smooth bore rigid bent pipes were revealed in a study of the literature, but only little knowledge is accessible for rough bore flexible pipes. For proposing new model based on DNV-RP-O501, this paper will contribute to it for analytical prediction of the erosion rate of rough bore flexible pipe. This research provides base which will help in future calibrations, testing and developments that could eventually allow versatile pipe designers, especially in dry gas fields, to improve solid particle erosion estimates.

(Safaei et al., 2014) [12] In 3D erosion prediction is addressed where copper has low volume fraction. From 10nm to 100micron is the range of particle size and from 0.00 to 0.04 is the particle volume fraction. 5m/s to 20m/s is the velocity range in which simulations were performed. By using finite volume method, discretization of differential equation in 3D is performed. The system models are correlated and a strong correlation is identified with the previous research. From the results obtained, it is observed that flow velocity, volume fraction as well as particle size is the factors on which erosion rate is directly dependent. From the results it is also observed that with the particle volume fraction as well as velocity, maximum pressure has direct relation with it. But with particle diameter, it shows reverse relationship. This has also been observed that threshold velocity as well as a particle size threshold is present there, above which major erosion effects step in. The mean friction factor at a defined fluid velocity is independent of volume fraction as well as particle size but it rises with the rise in inlet velocities.

III. PROPOSED METHODOLOGY

Following are the steps of working:

- A pipe elbow is designed by taking dimensions from a reference paper using Catia V5.
- This design file is converted into stp format and now transfer to Ansys fluent workbench for a meshing.
- After meshing had been generated, name selection is assigned.
- With name selection, boundary conditions are applied.
- Different carrier fluids are chosen for the work.
- Setting the proper setup for CFD analysis procedure.
- Evaluating the results after the finish of simulation work.

Case description

The geometry of the case consists of 1000mm vertical length of the pipe and which has 76.2mm of internal diameter which is connected with the horizontal pipe having 1.5D radius and section is 600mm with the curvature of 90degree elbow. This length was chosen to allow full development of turbulence flow field and does not increase the cost of computation. From the inlet, continuous and dispersed phase will flow and it will exit from the outlet. Stainless steel 316 was selected for the wall material. On CATIA V5, the model is designed.

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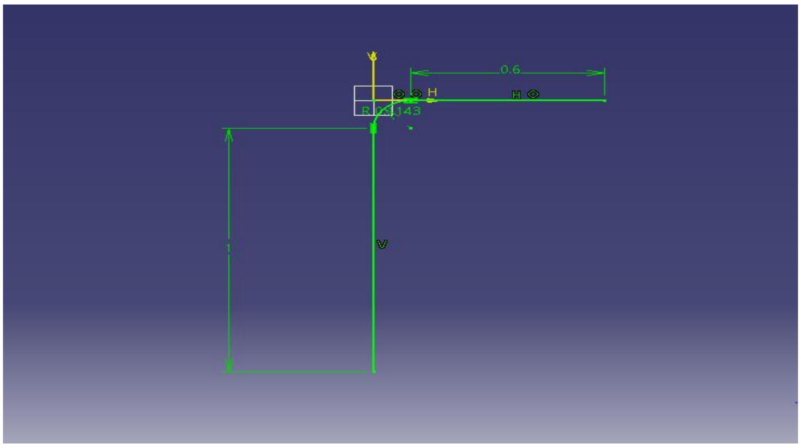

Figure 2: Pipe Sketch

Meshing

In relatively tiny computational cells, flow domain must be used. Computation of flow variables will be permitted by these cells and after that they can be stored up at the cells location. For resolving the viscous boundary layer, 12 inflation layers have been used in this study. Each layer has a thickness of 0.2mm. 0.2mm is the thickness of the mesh adjacent to the wall. And towards the center, the size of the mesh gradually increases. On the basis of mesh type, mesh independence was determined along with the size and medium type. Mesh configuration shown in figure 4.6 is the hexahedral mesh type. For the simulation, 23m/s is considered as the inlet velocity.

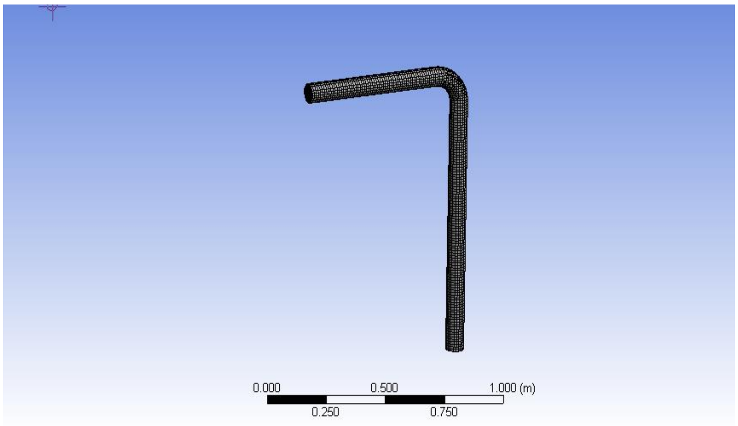

Figure 3: Meshing

Table 1: Nodes and Elements

Nodes	Elements
53590	54352

IV. RESULTS AND DISCUSSION

Validation of Results

For water as fluid medium, the results have been simulated using the liquid solid flow using Oklahoma no. 1 sand particles. Figure shows the erosion profile in the pipe. The erosion can be seen concentrated at the elbow in a small region. This is the region which will be mainly affected by the flow. The maximum erosion rate in this area has been evaluated 3.82e^{-7} DPM. The results have been by comparing the erosion rates with Wee, Siaw Khur et al, 2019 paper.

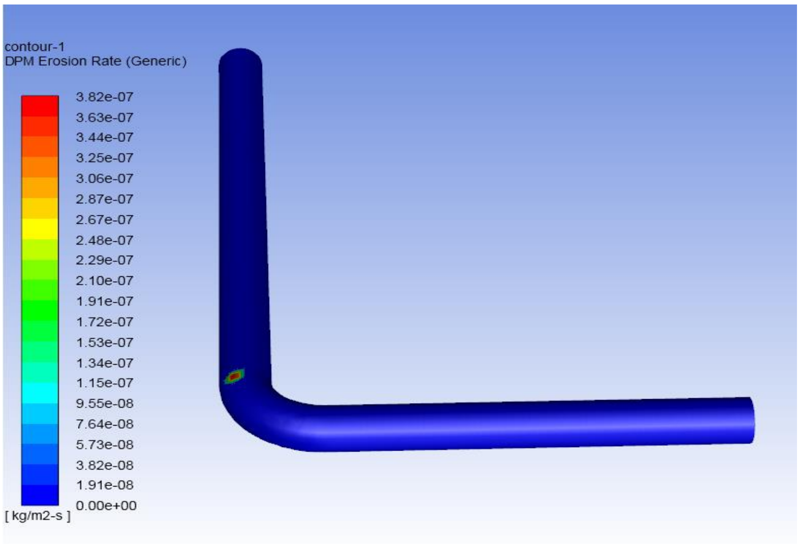

Figure 4: Erosion while water as a fluid medium

Predicting erosion rate by using Diesel

Liquid liquid flow was simulated for predicting the results of erosion rate for the diesel particulates. Since diesel has a lower density than the water, i.e., 730 kg/m^3, and a higher viscosity of 0.0024 kg/ms, it usually gets stick to the walls of the pipe near the inlet itself. The simulation results below show that the maximum erosion in case of diesel occurs at the inlet. However, the rate of erosion is much lower, between 9.38e^{-28} and 1.47e^{-27} DPM, than the solid liquid simulation of the water fluid using sand particles.

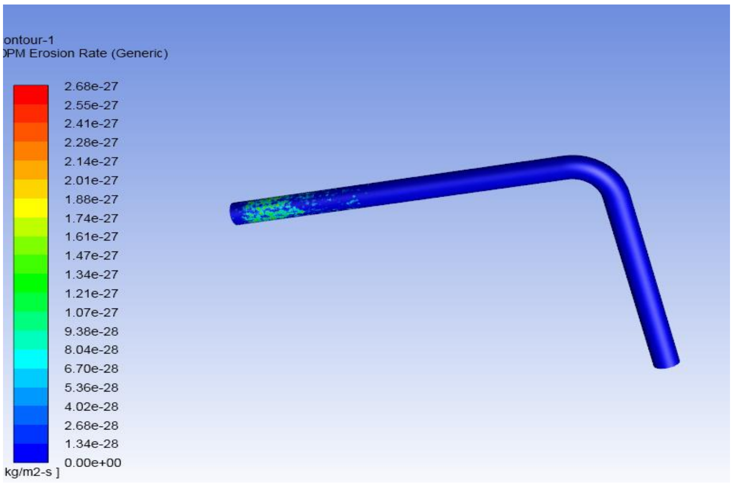

Figure 5: Erosion while diesel as a fluid medium

Predicting erosion rate by using Methane

Gas liquid simulation has been carried out for evaluating the results of the methane gas erosion rate. Methane has a viscosity and a density almost comparable with water, i.e., 1.003x10^{-3} kg/ms and 998.2 kg/m^3 respectively. The erosion rate has been observed to be maximum at the outer radius of the elbow in a vertical flow. The value obtained in this case is higher than both the previous simulations using sand as well as diesel as particulates.

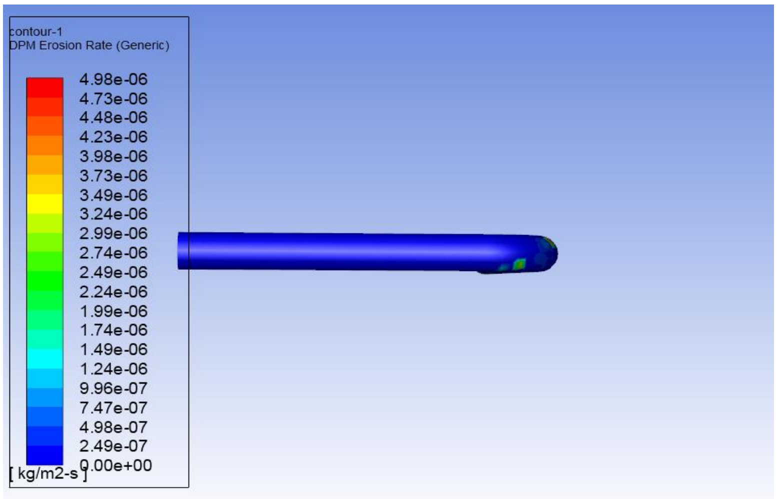

Figure 6: Erosion while methane as a fluid medium

A comparison below shows the huge difference between the erosion rates of the methane as well sand and diesel as particulates. This is owing to the inverse relation between the rate of erosion and the viscosity of the fluid particle. As the viscosity increases, the erosion rate decreases considerably which can be observed in the following graph plotted using the simulation results of the experiment. Among the three fluids diesel has a highest viscosity, which gives best results with minimum erosion rate 2.68e-27 kg/m^2-s as compared to methane and water.

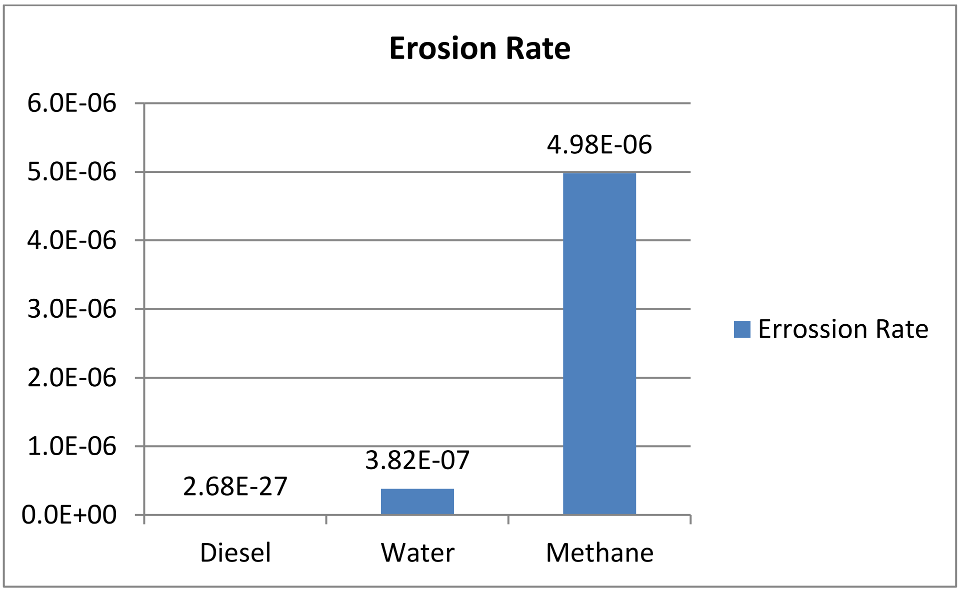

Figure 7: Comparison of erosion rate

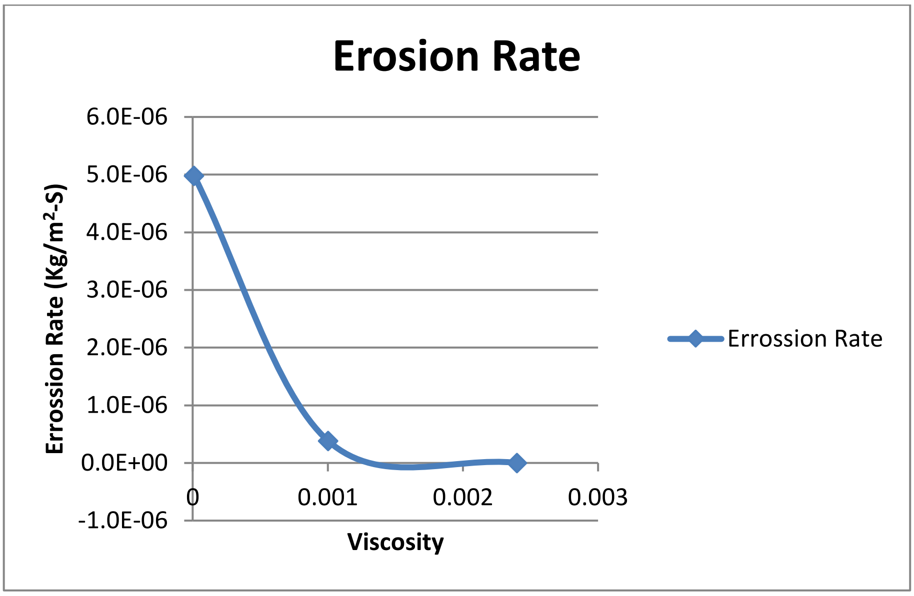

Figure 8: Graph between erosion rates VS Viscosity

V. CONCLUSION

1. Prediction of erosion through "uniform diameter (d)" of pipe elbow. For continuous observation of the elbow's weakest point, precise prediction is needed.

2. Reduction in the percentage error is made by 5 percent for distributing the "Actual sand particle size" which is fitted to the "Rosin-Rammler equation" for modelling the dispersion of the sand size.

3. Water's "liquid solid flow" had erosion that was concentrated on the side of the elbow and had a lower rate of erosion. On the other hand, "methane solid flow" had erosion that was concentrated on the outer radius of the elbow and had a larger rate of erosion.

4. It is seen that, as the viscosity of fluid is increases, the erosion rate is decreased.

5. Among the three fluids diesel has a highest viscosity, which gives best results with minimum erosion rate 2.68e-27 kg/m2-s as compared to methane and water.

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