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by Bayu Triwibowo

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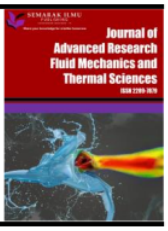

Prediction of Erotion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation

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ABSTRACT

Corrosion is one of the problems cause the material fail, leaks in the equipment and pipe systems in the industry which caused distrub in productivity of production in industry. There are some ways to prediction erosion in pipes, with the conventional or manual and CFD. CFD is to prediction erosion in turbulent air flows with variations in coal particle size and velocity of flowing air. The results of prediction erotion based on CFD is numerical and graphic, by displayed numerical results into visual results. These results include about the velocity, pressure, and temperature distribution in the air flow. So, CFD can be used to prediction pipe because it has wide coverage and effective in display numerical and visual results. Discreate Phase Model is the model of CFD with a variable stream velocity of 10 m/s, 15 m/s, 20 m/s and a solid loading of 5%, 10%, 15%, 20%, 25%. From the results, the maximum erosion rates increased with increasing sizes of particles and stream velocities. However, the location of the maximum erosion rate in the elbows region was independent on those mentioned parameters.

1. Introduction

Research on internal flow was started by a doctor from Germany in 1850, namely Julius Weisbach. He researched related pipes, which was then continued by Henry Darcy a French engineer in 1857. Henry Darcy conducted experiments on pipe flow and he found the theory of the effect of roughness on pipe resistance which is now known as the Darcy Weisbach equation. Then followed by Osborne Reynolds. He conducted experiments through his classic pipe in 1883 and then found a theory related to the importance of the Reynolds number in fluid flow [1].

Corrosion is one of the most common damages to piping systems due to the relative movement of corrosive materials with metal surfaces, relatively high flow rates and particles that will cause corrosion, and relatively slow flow rates will corrode [2]. The reason why corrosion must be predicted is that corrosion itself is one of the problems causing material failure, leaks in equipment and piping systems that exist in the industrial world which later if not addressed and left alone can disrupt productivity [3]. Most of the experimental studies that have been done previously are focused on

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using water and air as working fluid. Recently, some of the researchers have started to utilise air as working fluid in pipe system [4]. Disturbance that can occur due to the content of sand in an air flow to a structure is erosion. Therefore, prediction of erosion is very important, especially in estimating the age of the tool in the piping system. Benefits in predicting accurate erosion especially at elbows can be used to improve pipe work design, inspection area, operating limits, and others. Corrosion that causes leaks in equipment will result in a lack of production to the cost of dealing with it. Therefore, a study of corrosion is very important, especially in estimating the age of equipment in a piping system. So far, in predicting the corrosion problem, we usually use manual calculation methods such as calculating flow velocity in pipes, reducers, valves, and elbows. However, this manual calculation tends to be more complicated, less accurate, and there is no modeling so that it is only a numerical calculation. In addition to manual calculations, CFD modeling can also be used. Computational Fluid Dynamics has overcome this difficulty as well as revolutionized the field of engineering. In CFD a problem is simulated in software and the transport equations associated with the problem is mathematically solved with computer assistance. Thus, we would be able to predict the results of a problem before experimentation [5]. The results of the CFD program can be in the form of numerical results, as well as graphical results, by displaying numerical results into visual results. The results are in the form of visual images of the physical geometry of the air flow with a choice of table forms from the processing results and other forms. This research was conducted to predict corrosion spots on pipe geometry, first of all the model must be able to accurately predict the corrosion distribution in a relatively simple geometry such as an elbow by using CFD to predict pipe corrosion with two elbows. Elbow is designed based on the characteristic's method and the CFD method for various performance parameters analysis [6].

On the other hand, there is still no other publication found related to CFD studies with variation two elbows. So, there is a need to study the effects corrosion with two elbows using CFD method. It is often reported that CFD results supplements the experimental findings by showing results that is difficult to be measured and shown experimentally [7]. It must be admitted that often an engineer is only interested in the location and rate of erosion at the maximum point, which will always occur at the elbow wall in direct contact with the particles. However, many more complex situations occur where erosion occurs, such as an elbow, valve or fitting [8]. In that case the importance of this research is to predict the erosion spot in the pipe geometry, first of all the model must be able to accurately predict the erosion distribution in a relatively simple geometry such as an elbow by using CFD to predict pipe erosion with two elbows for the case. Multiphase both numerically and visually so that it can be a solution to productivity problems in the industry due to erosion.

2. Methodology

Process simulation software is software that functions to improve the performance and optimization of chemical processes. CFD is a numerical solution program (Finite Element Method) based on its visual simulation. In CFD, there is a Discrete Phase Model (DPM). Discrete Phase Model is applied to express the interaction between particles and turbulence. This model assumes that the particles pass through the turbulent flow structure present in the flow.

2.1 Research Design

This study uses a pipe with two elbows with the phase flowing in it is air and the existing particles are coal, for the design used as the object of erosion simulation as follows as in Figure 1.

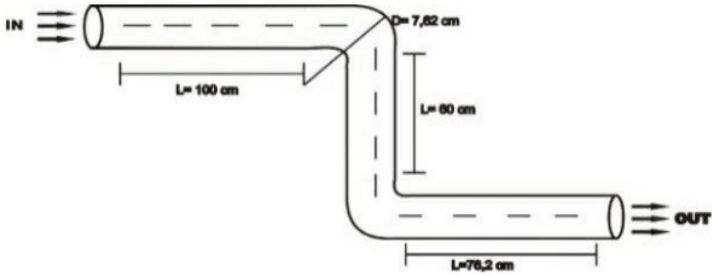

Fig. 1. Pipe with two elbows

Stream velocity affects the erosion rate and the maximum erosion rate occurred at the centre area of the elbow section due to the multiple impingements of one particle effects. Further results by them also shows that maximum erosion rate occurred almost at the centre area of the elbow section when they varied the solid loading [9]. The solid loading is the number of suspended solids in a substance. Increase in stream velocity results in higher particles momentum produced and lead to the higher erosion rate [10,11]. This occurs since the impinging particles must pass through a larger stagnation region and thus allowing extra time for the particles to decelerate [12]. Bigger solid loading results in larger erosion and different fluid types may cause in different erosion effects. Despite a lot of research reported on the erosion prediction for the elbow's component in pipeline, however, there is still lack of information on the prediction based on the stream velocity in two elbows.

In this research, CFD was applied to numerically predict erosion rate in elbows for a broad range of liquid/solid particles flow conditions. The elbows were tested under three different flow conditions named as stream velocity (10-20 m/s) and solid loading (5%-25%). Each flow conditions consist of five different sets of values and the results are presented in the form of maximum erosion rate graphs and visual illustration of erosion rate surface contours.

2.2 Material and Particle Specifications

The materials used in this research are low quality coal and air as an oxidizer as shown in Table 1.

Table 1
Air and Coal Properties

Air and Coal	
Air Density	1.225 kg/m^3
Coal Density	1.200 kg/m^3
Type	Sub-bituminous

Subbituminous coal, also called black lignite, generally dark brown to black coal, intermediate in rank between lignite and bituminous coal according to the coal classification used in the United States and Canada. Between lignite and bituminous coal according to the coal classification used in the United States and Canada. In many countries subbituminous coal is considered to be a brown coal. Subbituminous coal contains 42 to 52 percent carbon (on a dry, ash-free basis) and has calorific values ranging from about 19 to 26 megajoules per kilogram (about 8,200 to 11,200 British thermal units per pound) [13]. Subbituminous coal is characterized by greater compaction than lignites as well as greater brightness and lustre. The woody structure characteristic of most lignite is absent from subbituminous coal, which often exhibits alternating dull and bright maceral bands composed of vitrinite in patterns similar to those found in bituminous coals. Some subbituminous coal is macroscopically indistinguishable from bituminous coal. Subbituminous coal contains less water (typically 10 to 25 percent) and is harder than lignite, making it easier to transport, store, and use [13,14]. So, that the reasons why in this research use subbituminous coal.

3. Results and Discussion

Two parameters were changed to demonstrate their influence on erosion rate of the elbows component. The two parameters were variable stream velocity of 10 m/s, 15 m/s, 20 m/s and a solid loading of 5%, 10%, 15%, 20%, 25%. The Reynolds number was range from 5,11x107 to 1,08x108. Reynolds number determines the pattern of fluid flow in different situations, investigated both numerically and experimentally the elbows section's performance affected by Reynolds number [15]. During the simulation, other parameters were kept constant for each tested flow conditions. The effects of flow conditions stream velocity and elbows diameter on erosion rate of the elbows component are presented in the form of maximum erosion rate graphs and visual illustration of erosion rate surface contours.

3.1 Effects of Flow Conditions Stream Velocity 10 m/s with Reynold Number 5,11x10^{7}

Erotion rate surface contours for the particles diameter 100 µm. Solid loading of 5%, 10%, 15%, 20%, 25% show maximum erosion rate occurred in two locations of maximum erosion rate observed and it is located of the section first elbow are depicted in Figure 2 and second elbow are depicted in Figure 3. In addition, particle with solid loading 25% indicates clear impingement at the inlet section of elbows compared to other solid loading. This might be due to the smaller size of particles which is lightweight and easier to deviate from streamline at the entrance region of the elbow. After multiple impingements at the entrance region of the elbow, the deviated particles then follow the streamline again and strikes the turn region of the elbow.

Figure 4 shows the maximum erosion rate that occurs at the first and second elbow with this flow conditions. The maximum erosion rate is influenced by the increase in stream velocity and solid loading. Solid loading is the mass flow rate of particles in percent. The relationship about solid loading and maximum erotion rate in Figure 4, shows that the higher of the solid loading, the higher the maximum erotion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow wall. The larger or deeper the indentation in the elbow, the greater the amount of material flowing or the higher the maximum erosion rate [16]. In this condition, 25% of solid loading produces the highest maximum erotion rate compared to the other.

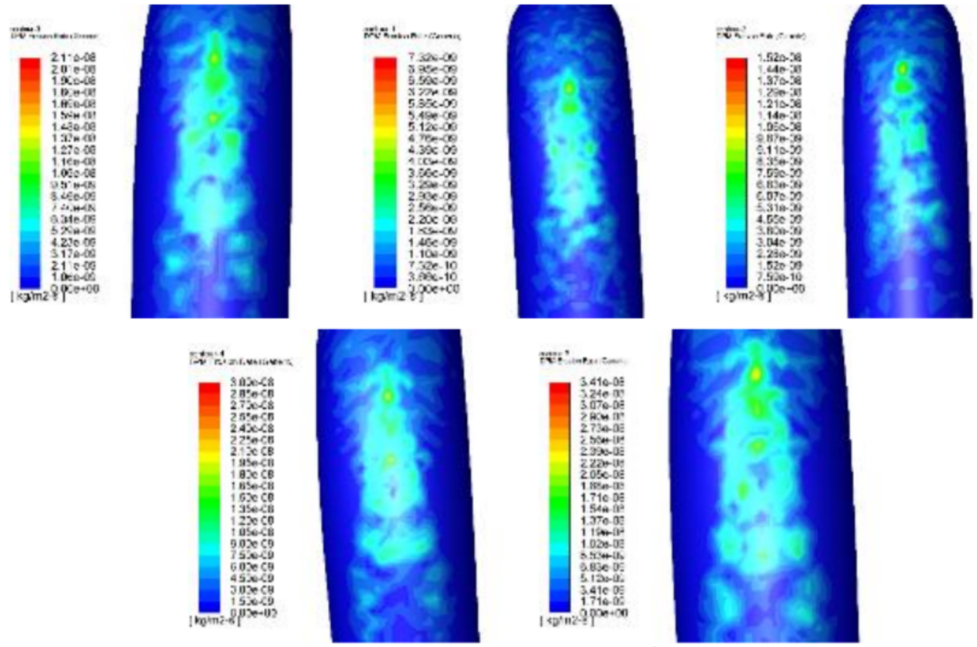

Fig. 2. Erosion rate surface contour in first elbow (kg/m^2.s) for 10 m/s stream velocity

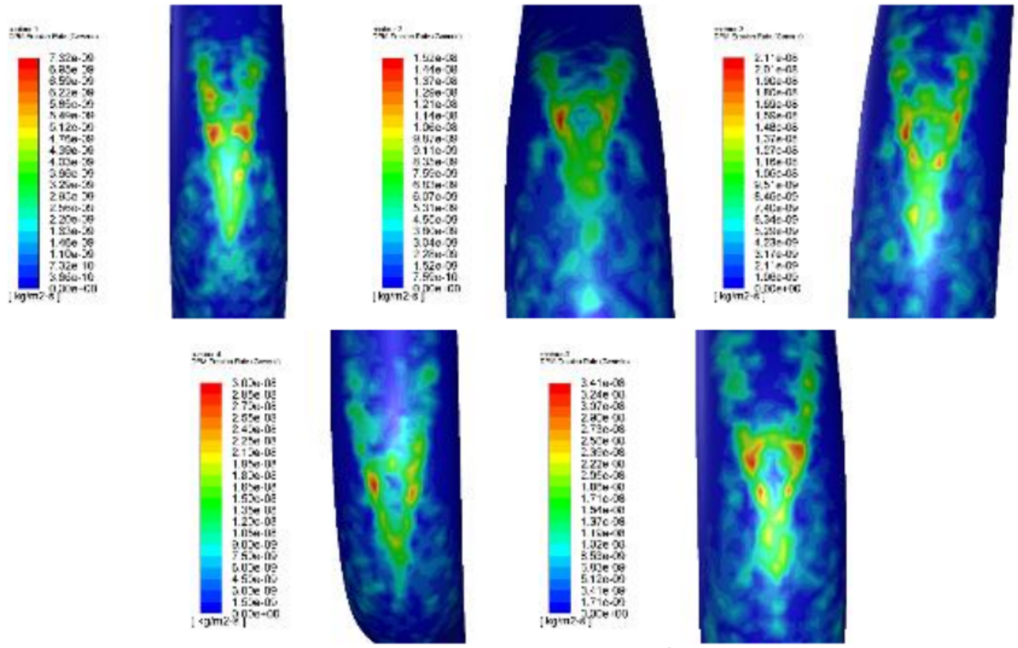

Fig. 3. Erosion rate surface contour in second elbow (kg/m^2.s) for 10 m/s stream velocity

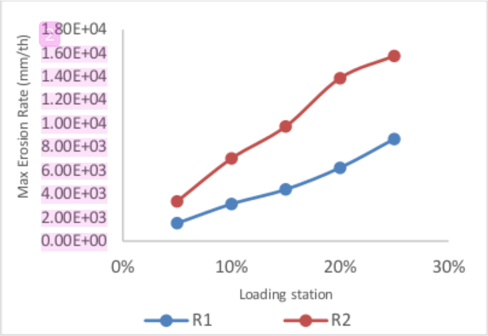

Fig. 4. Maximum erosion rate (kg/m^2.s) for various loading station (%)

3.2 Effects of Flow Conditions Stream Velocity 15 m/s with Reynold Number 7,67x10^7

Erotion rate surface contours for the particles diameter 100 µm in conditions stream velocity 15 m/s. Solid loading of 5%, 10%, 15%, 20%, 25% show maximum erosion rate occurred in two locations of maximum erosion rate observed and it is located of the section first elbow are depicted in Figure 5 and second elbow are depicted in Figure 6. In addition, particle with solid loading 25% indicates clear impingement at the inlet section of elbows compared to other solid loading.

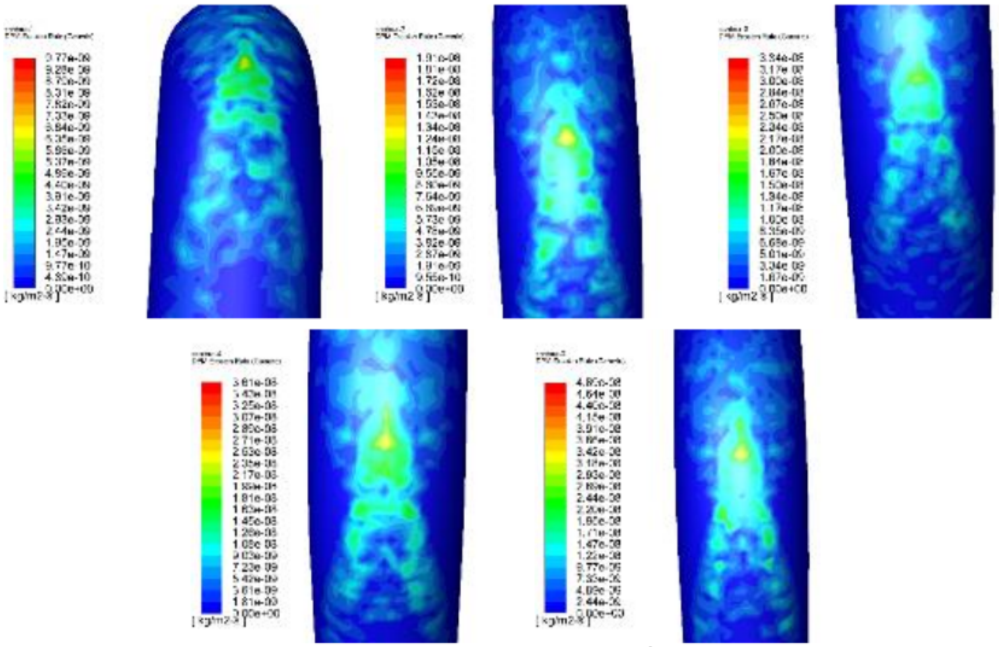

Fig. 5. Erosion rate surface contour in first elbow (kg/m^2.s) for 15 m/s stream velocity

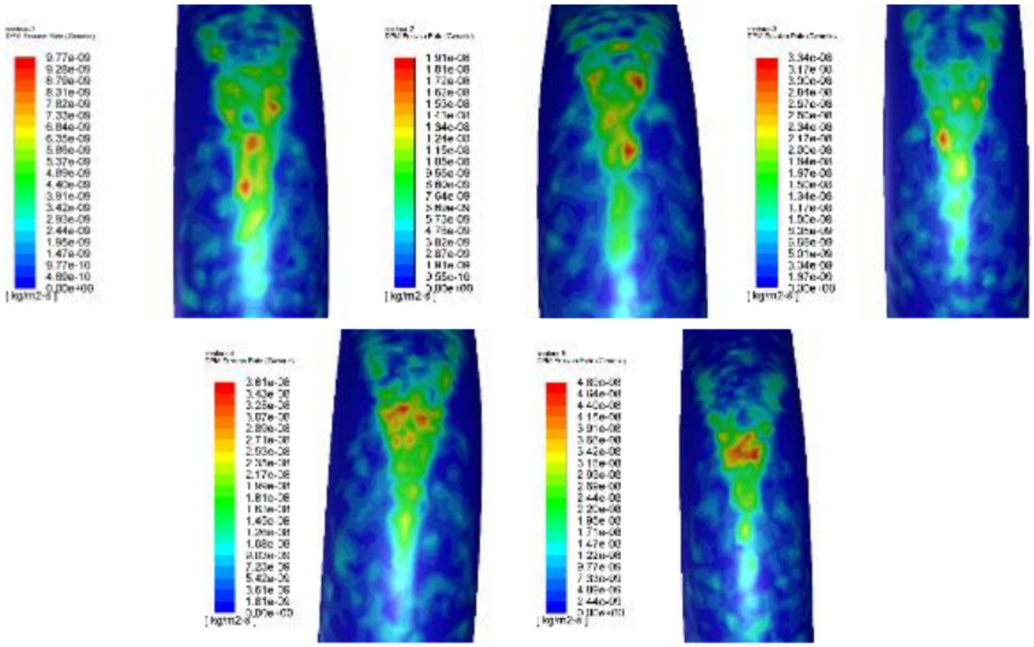

Fig. 6. Erosion rate surface contour in second elbow (kg/m^2.s) for 15 m/s stream velocity

The relationship about solid loading and maximum erotion rate in Figure 7, shows that the higher of the solid loading, the higher the maximum erotion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow wall. The larger or deeper the indentation in the elbow, the greater the amount of material flowing or the higher the maximum erosion rate [16]. In the stream velocity of 15 m/s as shown in Figure 7 produce surface contours is deeper with maximum erosion rates compared to stream velocity of 10 m/s.

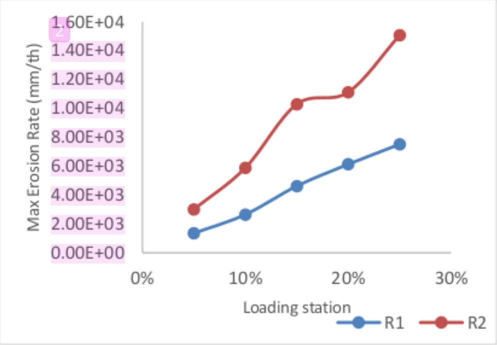

Fig. 7. Maximum erosion rate (kg/m^2.s) for various loading station (%)

3.3 Effects of Flow Conditions Stream Velocity 20 m/s with Reynold Number 1,08x10^8

Erotion rate surface contours for the particles diameter 100 µm in conditions stream velocity 20 m/s. Solid loading of 5%, 10%, 15%, 20%, 25% show maximum erosion rate occurred in two locations of maximum erosion rate observed and it is located of the section first elbow are depicted in Figure 8 and second elbow are depicted in Figure 9. In addition, particle with solid loading 25% indicates clear impingement at the inlet section of elbows compared to other solid loading.

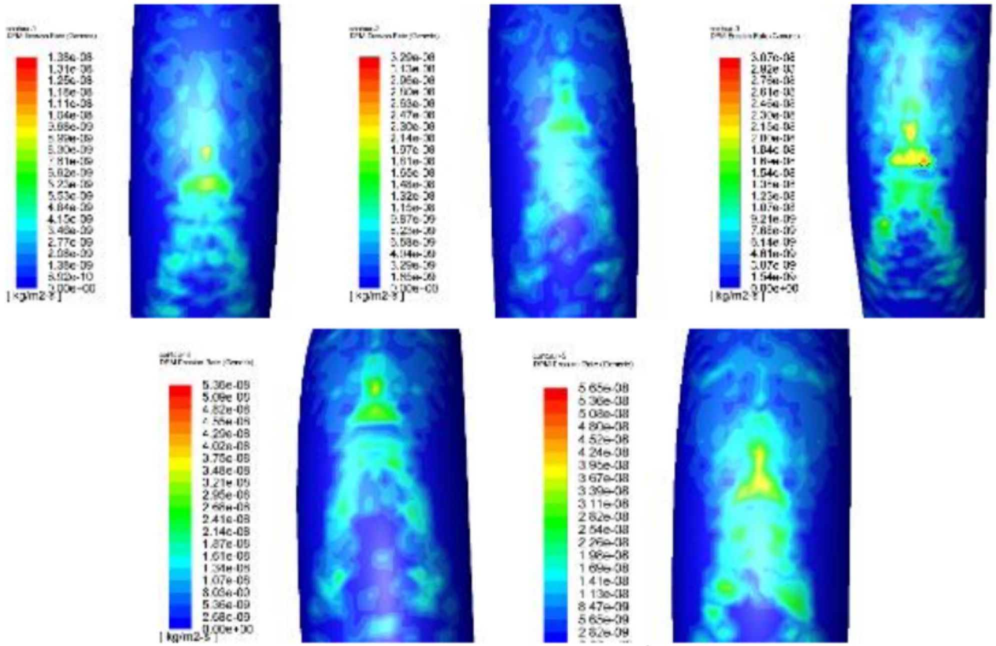

Fig. 8. Erosion rate surface contour in first elbow (kg/m^2.s) for 20 m/s stream velocity

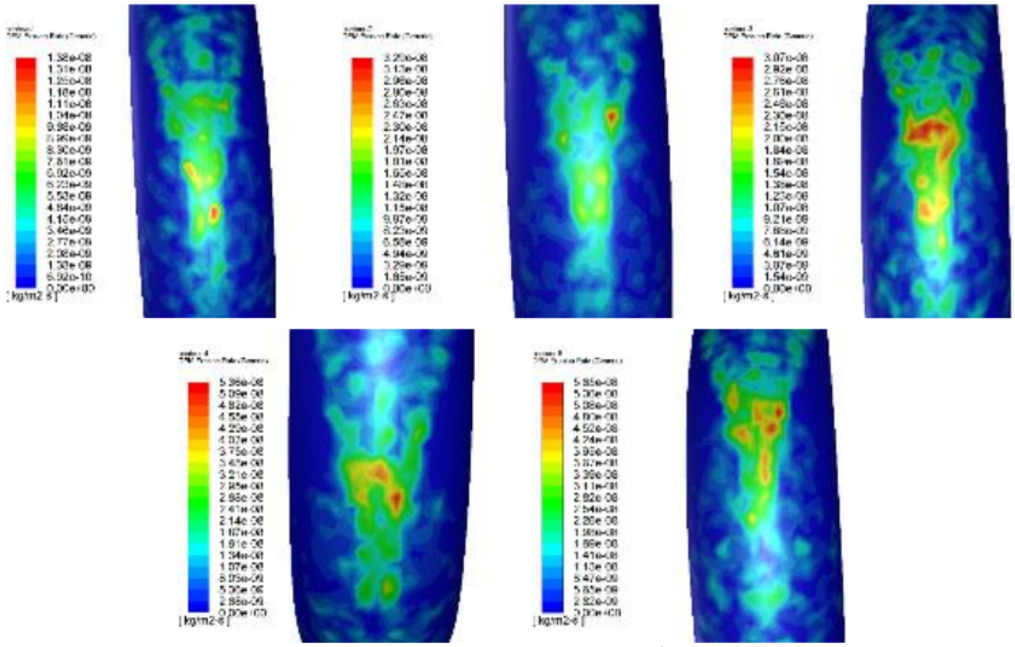

Fig. 9. Erosion rate surface contour in second elbow (kg/m^2.s) for 20 m/s stream velocity

The relationship about solid loading and maximum erotion rate in Figure 10, shows that the higher of the solid loading, the higher the maximum erotion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow wall. The larger or deeper the indentation in the elbow, the greater the amount of material flowing or the higher the maximum erosion rate [16]. In the stream velocity of 20 m/s as shown in Figure 7 produce surface contours is deepest with maximum erosion rates compared to stream velocity of 10 m/s and 15 m/s.

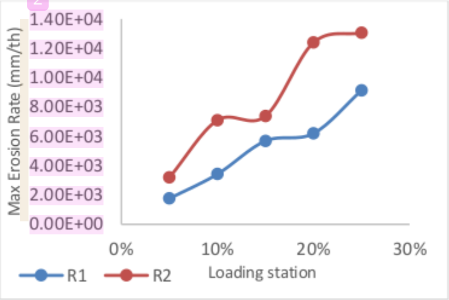

Fig. 10. Maximum erosion rate (kg/m^2.s) for various loading station (%)

3.4 Effects of Stream Velocity Vs Maximum Erotion Rate

All of stream velocity show similarity in terms of the location of the maximum erotion rate that occurs in the exit area of elbow. This is due to the effect of gravity when the flow moves towards the elbow bend. The increasing of stream velocity causes increase of the maximum erosion rate [16]. At high stream velocity, the inertial momentum of the particles and fluid will be increase and the impact between the particles with the elbow wall will be increase. Therefore, a flow velocity of 20 m/s as shown in Figure 9 to generate in a surface contour of a severe maximum erosion rate compared to other stream velocity. This result is in accordance with theory that the maximum erotion rate is directly proportional to stream velocity. In this condition, the increase of the flow rate an increase in the fluid stream velocity which in increases the stream velocity of the particles impact the elbow wall [17]. This situation is in accordance with research that the increase in flow stream velocity causes the particle transport capacity by the air to increase and increases the kinetic energy of the particles so that the touch pressure is greater on the inner wall of the pipe [18]. From the Figure 11 the effect of stream velocity of fluid on the maximum erotion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erotion rate. This indicates that the application of the erotion model in a simulation is dependent on the stream velocity is used.

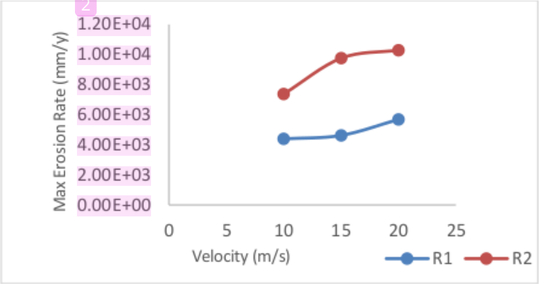

Fig. 11. Stream velocity (m/s) for maximum erosion rate (mm/y)

4. Conclusions

Based on the CFD method used in this study, erosion in elbow is predicted using numerical simulation. The 2 elbows are used with air as fluid system and coal as particles system. The model of CFD with a variable stream velocity of 10 m/s, 15 m/s, 20 m/s and a solid loading of 5%, 10%, 15%, 20%, 25%. From these results, the following conclusions can be drawn, that the location of maximum erotion rate in the elbow is weakly influenced by flow parameters including stream velocity and solid loading. Solid loading and stream velocity are directly proportional to the maximum erotion rate. Higher velocity results in rapid collision between particles and the wall of the elbows and bigger solid loading will cause in deeper indentations on the wall of elbows. As a consequence, higher maximum erotion rate will be produced.

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