

**BUKTI KOREPONDENSI ARTIKEL PADA JURNAL  
INTERNASIONAL BEREPUTASI**



**PENGUSUL**

Bayu Triwibowo, S.T., M.T. / NIDN 0022118801

**UNIVERSITAS NEGERI SEMARANG**

Yth. Penilai

Pada Usulan Kenaikan Jabatan ke Lektor Kepala

Bersama dengan surat ini, saya bermaksud menyertakan bukti-bukti korespondensi proses artikel pada Jurnal Internasional dengan judul "Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation", yang dimuat pada *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, edisi Vol. 97 No. 2, 11 Juli 2022, ISSN: 2289-7879, hal. 115-125.

Adapun susunan kronologi bukti korepondensi terdiri dari beberapa poin, pada tabel di bawah ini:

No.	Tanggal	Aktivitas
1.	10 Oktober 2021	Mendapatkan Username ( <i>btriwibowo</i> ) dan Notifikasi Submisi Jurnal
2.	10 Oktober 2021	Pembuatan Password untuk Username ( <i>btriwibowo</i> )
3.	23 Oktober 2021	Editor decision: Revisi
4.	25 Oktober 2021	Mengirimkan revisi artikel sesuai komentar reviewer
5.	28 Oktober 2021	Mendapatkan Notifikasi dari Editor Jurnal: Submisi telah Diterima
6.	23 Desember 2021	Permintaan File Artikel dalam Bentuk Ms. Word
7.	23 Agustus 2022	Mendapatkan Notifikasi Email : Produksi Jurnal Tahap Akhir
8.	21 Agustus 2022	Mendapatkan Notifikasi Email: Pembuatan Artikel Versi Copyediting
9.	18 September 2022	Artikel Jurnal telah Terpublikasi dan Terindeks Scopus

Demikian, agar dapat menjadi periksa.

Terimakasih

Semarang, 20 Agustus 2024

Hormat saya



Bayu Triwibowo, S.T., M.T.

## KRONOLOGI KORESPONDENSI PUBLIKASI ARTIKEL PADA JURNAL INTERNASIONAL BEREPUTASI DAN BERFAKTOR DAMPAK

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

Jurnal : *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*

Volume : 97

Nomor : 2

Tanggal publikasi : 11 Juli 2022

ISSN : 2289-7879

Hal : 115-125

Penerbit : Semarak Ilmu Publishing

SJR jurnal : **0,28 (2022)**

Quartile : Q3 (Scopus)

SNIP : 0,556

Cite Score : 2,2

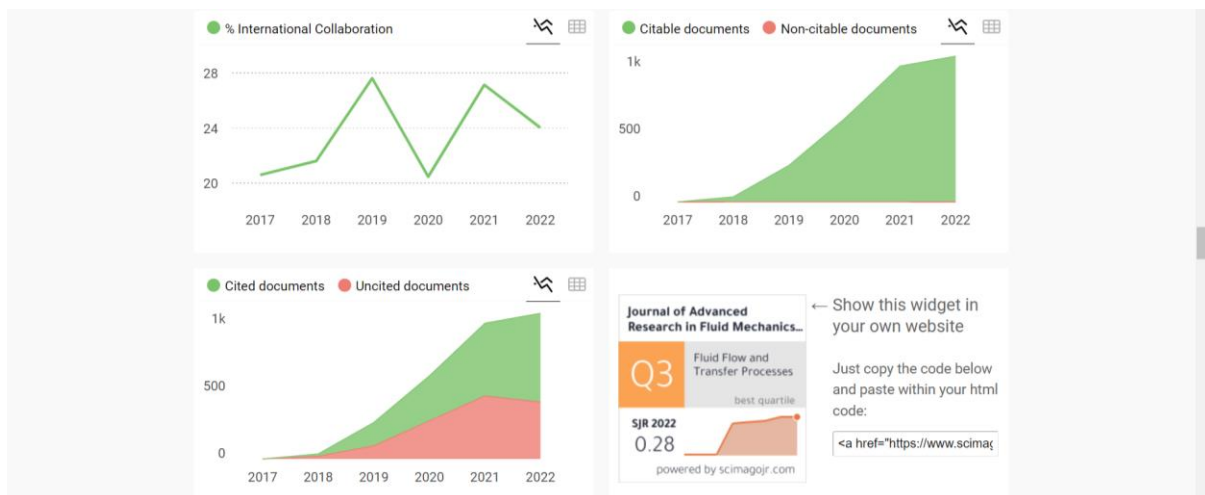
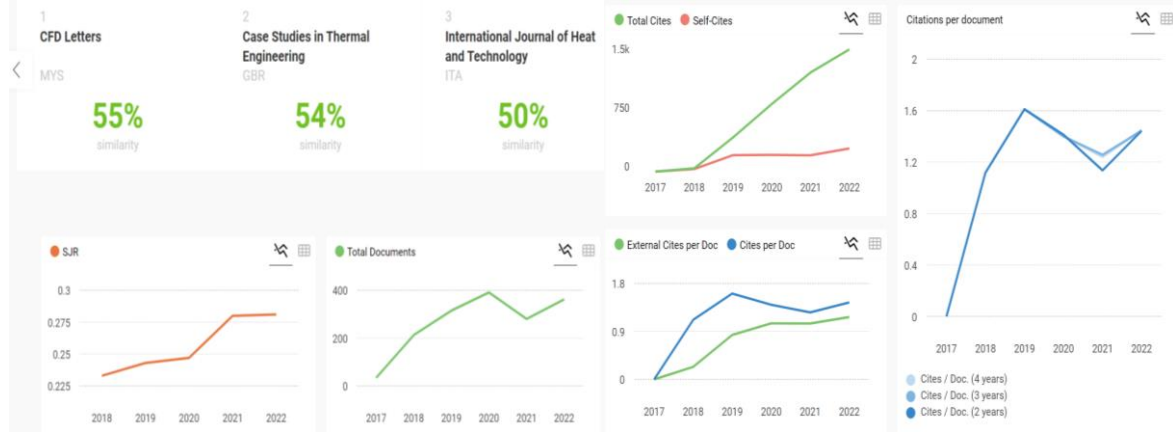
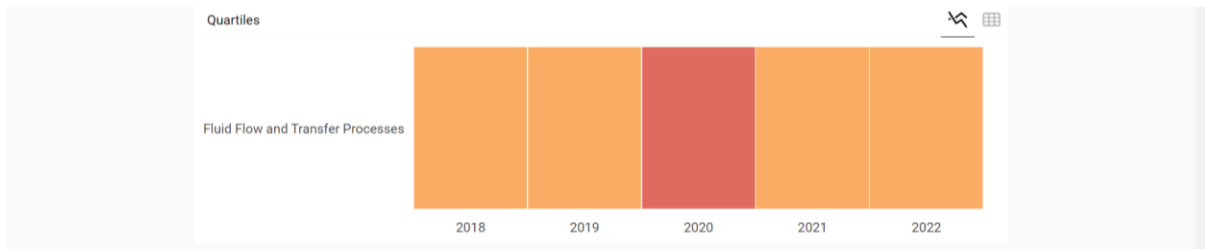
Penulis : Bayu Triwibowo, Heni Wahyu Widayanti, Miftakhul Indra Rukmanasari

### Bukti indexing jurnal:

#### ▪ Scimago

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COUNTRY	SUBJECT AREA AND CATEGORY	PUBLISHER
Malaysia Universities and research institutions in Malaysia Media Ranking in Malaysia	Chemical Engineering └ Fluid Flow and Transfer Processes	Penerbit Akademia Baru
H-INDEX <b>21</b> COVERAGE 2017-2022	PUBLICATION TYPE Journals	ISSN 22897879



## Scopus

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### Source details

**Journal of Advanced Research in Fluid Mechanics and Thermal Sciences**

Scopus coverage years: from 2017 to Present

Publisher: Penerbit Akademia Baru

ISSN: 2289-7879

Subject area: Chemical Engineering: Fluid Flow and Transfer Processes

Source type: Journal

View all documents > Set document alert Save to source list Source Homepage

CiteScore CiteScore rank & trend Scopus content coverage

CiteScore 2021  
**2.2**

SJR 2021  
**0.280**

SNIP 2021  
**0.556**



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$$2.2 = \frac{2,644 \text{ Citations 2018 - 2021}}{1,194 \text{ Documents 2018 - 2021}}$$

Calculated on 05 May, 2022

CiteScoreTracker 2022

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Last updated on 05 April, 2023 - Updated monthly

CiteScore rank 2021

Category	Rank	Percentile
Chemical Engineering		
Fluid Flow and Transfer Processes	#49/87	44th

## Sci journal

scjournal.org/impact-factor-of-j-of-advanced-research-in-fluid-mechanics-thermal-scis.shtml



SCI JOURNAL



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# Journal of Advanced Research in Fluid Mechanics and Thermal Sciences Impact Factor & Key Scientometrics

## NEW Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences Overview

Impact Factor



Web of Science Group

H Index



Google Scholar

Impact Factor



Scopus

### I. Basic Journal Info

Country



Malaysia

Journal ISSN: 22897879

Publisher: Penerbit Akademia Baru

History: 2017-2021

Journal Homepage: [Link](#)

How to Get Published:

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## Research Categories

Chemical Engineering

**NEW** Journal of Advanced Research in Fluid Mechanics and Thermal Sciences  
SJR, SJR Impact Factor and H Index

H Index

17

Google  
Scholar

SJR

Scopus<sup>®</sup>

Scopus Impact Factor

1.123

Scopus<sup>®</sup>

**NEW** Journal of Advanced Research in Fluid Mechanics and Thermal Sciences  
SJR Impact Factor 2-year, 3-year, 4-year

2-year  
Impact Factor

1.123

3-year  
Impact Factor

1.233

4-year  
Impact Factor

1.123

**RINCIAN KRONOLOGI KORESPONDENSI  
PUBLIKASI ARTIKEL PADA JURNAL INTERNASIONAL  
BEREPUTASI**

# KRONOLOGI KORESPONDENSI PUBLIKASI ARTIKEL DI EMAIL

## Mendapatkan Username (*btriwibowo*) dan Notifikasi Submisi Jurnal (10 Oktober 2021)

The screenshot shows a Gmail interface with a search bar containing "norazwadi". The email subject is "[J. Adv. Res. Fluid Mech. Therm. Sc.] Submission Acknowledgement". The sender is "Dr. Nor Azwadi Che Sidik <azwadi@semarakilmu.com.my>". The email body contains the following text:

B Triwibowo:

Thank you for submitting the manuscript, "EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation" to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: [https://semarakilmu.com.my/journals/index.php/fluid\\_mechanics\\_thermal\\_sciences/authorDashboard/submission/18](https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/authorDashboard/submission/18)  
Username: btriwibowo

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Dr. Nor Azwadi Che Sidik

[Journal of Advanced Research in Fluid Mechanics and Thermal Sciences](#)

## Pembuatan Password untuk Username (*btriwibowo*) (10 Oktober 2021)

The screenshot shows a Gmail interface with a search bar containing "NORAZWADI". The email subject is "[J. Adv. Res. Fluid Mech. Therm. Sc.] Password Reset". The sender is "Dr. Nor Azwadi Che Sidik <azwadi@semarakilmu.com.my>". The email body contains the following text:

Your password has been successfully reset for use with the web site. Please retain this username and password, as it is necessary for all work with the journal.

Your username: btriwibowo  
Password: 2cCC4Q

Dr. Nor Azwadi Che Sidik

[Journal of Advanced Research in Fluid Mechanics and Thermal Sciences](#)

## Editor decision : Revisi (23 Oktober 2021)

The screenshot shows a Gmail interface with a search bar containing "norazwadi". The email subject is "[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision". The sender is "Nor Azwadi <azwadi@semarakilmu.com.my>". The email body contains the following text:

B Triwibowo:

We have reached a decision regarding your submission to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, "EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation".

**Our decision is: Revisions Required**

Please submit the revised article by 30 Oct 2021

**Editorial Comments:**

Please cite few articles from

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<http://www.akademiabaru.com/submit/index.php/cfdi>  
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<http://www.akademiabaru.com/submit/index.php/arefmht>  
<http://www.akademiabaru.com/submit/index.php/aram>

Reviewer A:

Grammar and Spelling:

No language mistakes. Good sentence and paragraph structure and transitions. However, the full stop symbol should be changed to a comma in the first paragraph on page 5 and page 6.

Abstract:

Abstract section is excellently written. The abstract has all the required elements (as stated below) that are connected properly.

1. Introduction
2. Aims/objective
3. Methodology
4. Results
5. Discussion

Quality of Tables and Figures:

Tables and figures have excellent clarity and numbered. All tables and figures are mentioned in text and properly discussed except for Figure 1 and Table 1.

Conclusion:

Conclusion related to objective. However, please add introduction sentence in conclusion.

References:

Need more than 15 recent references (within 5 years of study).

Recommendation: Revisions Required

## Mengirimkan Revisi Artikel Sesuai Komentar Reviewer (25 Oktober 2021)

Gmail interface showing an email from Bayu Triwibowo to heniwahyu42. The email contains a scanned document attachment named D010.docx. The sender's contact information is: Bayu Triwibowo, +62 857 45980952, Chemical Engineering Department, Fakultas Teknik Universitas Negeri Semarang 50229.

## Mendapatkan Notifikasi dari Editor Jurnal : Submisi telah Diterima (28 Oktober 2021)

Gmail interface showing a notification email from Nor Azwadi to the user. The subject is "[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision". The email content states: "We have reached a decision regarding your submission to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 'EIC- Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation ". Our decision is to: Accept Submission. Thank you. Truly. Editor-in-chief, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences".

## Permintaan File Artikel dalam Bentuk Ms. Word (23 Desember 2021)

The screenshot shows a Gmail interface with a search for "prediction". The selected email is from "Fluid Mechanics Thermal Sciences" (journal2017arfmts@gmail.com) dated Thu, Dec 23, 2021, 12:40 PM. The subject is "[18] Manuscript required-Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation". The email body reads: "Dear author, Kindly provide your revised manuscript in word format in order for copy editing purposes. Thank you". An attachment is shown as a scanned PDF document titled "NEW+REVISION+...".

## Mendapatkan Notifikasi Email : Pembuatan Artikel Versi Copyediting (21 Agustus 2022)

The screenshot shows a Gmail interface with a search for "norazwadi". The selected email is from "Ahmad 'Ulwan" (ulwan@akademiabaru.com) dated Sun, Aug 21, 2022, 11:02 PM. The subject is "[J. Adv. Res. Fluid Mech. Therm. Sc.] New notification from Journal of Advanced Research in Fluid Mechanics and Thermal Sciences". The email body reads: "You have a new notification from Journal of Advanced Research in Fluid Mechanics and Thermal Sciences: You have been added to a discussion titled 'Copyediting Initiated' regarding the submission 'EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation'." A link is provided: [https://semarakilmu.com.my/journals/index.php/fluid\\_mechanics\\_thermal\\_sciences/authorDashboard/submission/18](https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/authorDashboard/submission/18). The sender is identified as "Dr. Nor Azwadi Che Sidik" and the journal name "Journal of Advanced Research in Fluid Mechanics and Thermal Sciences" is mentioned at the bottom.

## Mendapatkan Notifikasi Email : Produksi Jurnal Tahap Akhir (23 Agustus 2022)

The screenshot shows a Gmail interface with a search bar containing "editor de". The email is titled "[18] Editor Decision" and is from "Fluid Mechanics Thermal Sciences" (journal2017arfmts@gmail.com), dated August 23, 2022, at 10:18 PM. The email content reads: "Dear author, The editing of your submission, 'EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation,' is complete. We are now sending it to production. Please find the copy-edited manuscript for your perusal. In addition, kindly provide the email addresses of all authors in order for us to complete the system database prior to publication. Thank you". Below the text, there is a section for "One attachment" which has been scanned by Gmail, showing a thumbnail of a document titled "18 NEW 2-NEW R...".

## Artikel Jurnal telah Terpublikasi dan Terindeks Scopus (18 September 2022)

The screenshot shows a Gmail interface with a search bar containing "norazwadi". The email is titled "Congratulations, your paper is now available in SCOPUS!" and is from "Nor Azwadi" (azwadi@akademiabaru.com), dated September 18, 2022, at 9:23 AM. The email content reads: "Congratulations, your paper is now available in SCOPUS! Dear Bayu Triwibowo, Heni Wahyu Widayanti, Miftakul Indra Rukmanasari, Your published work in the Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, volume 97, no. 2, is now available in SCOPUS database. ([Click here](#)). Bayu Triwibowo, Heni Wahyu Widayanti, & Miftakul Indra Rukmanasari. (2022). Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 97(2), 115–125. <https://doi.org/10.37934/arfmts.97.2.115125> Promote your works to boost your citation count. You may consider the following techniques: • Use social media. Provide links to your papers on social media (e.g., Facebook, Twitter, Academia.edu, ResearchGate, Mendeley) and your university profile page. • Talk to other researchers about your paper, and email copies of your paper to researchers who may be interested. Create a blog or a website dedicated to your research and share it. • Cite your own past papers as appropriate to increase visibility of your published papers. Thank you again for publishing with us. We wish you the best success with your research. Kind regards". Below the text, there is a diagram of a pipe with two elbows, labeled "Fig. 1. Pipe with two elbows".

**Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation** is now available in SCOPUS database. ([Click here](#)).

Bayu Triwibowo, Heni Wahyu Widayanti, & Miftakul Indra Rukmanasari. (2022). Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 97(2), 115–125. <https://doi.org/10.37934/arfmts.97.2.115125>

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Thank you again for publishing with us. We wish you the best success with your research.

Kind regards

# KRONOLOGI KORESPONDENSI PUBLIKASI ARTIKEL DI SISTEM JARFMTS

## Mengisi Identitas Jurnal

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

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18 / Bayu Triwibowo et al. / Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulati Library

Workflow Publication

Status: Published

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Title  
Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulati

Subtitle

Abstract

**B** *I*  $\times^2$   $\times_2$

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. Discrete Phase Model is the model of CFD with a variable stream velocity of 10 m/s.

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## Proses Pengisian Data Penulis

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List of Contributors

Name	E-mail	Role	Primary Contact	In Browse Lists
Bayu Triwibowo	bayu.triwibowo@mail.unnes.ac.id	Author	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Heni Wahyu Widayanti	heniwahyu42@gmail.com	Author	<input type="checkbox"/>	<input checked="" type="checkbox"/>
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Maximum erosion rate ✕ coal ✕ Discrete Phase Model ✕ Computational Fluid Dynamics ✕

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Workflow **Publication**

Submission **Review** Copyediting Production

Round 1

**Round 1 Status**  
Submission accepted.


**Notifications**

<a href="#">[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision</a>	2021-10-23 08:05 AM
<a href="#">[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision</a>	2021-10-28 02:03 PM
<a href="#">[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision</a>	2022-08-23 03:16 PM

**Reviewer's Attachments** Q Search

No Files

**Revisions** Q Search Upload File

 116	NEW REVISION Prediction of erosion rate (Autosaved)-converted-compressed.pdf	October 28, 2021	Article Text
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Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

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Workflow **Publication**

Submission **Review** **Copyediting** Production

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**Copyedited** Q Search

 3942	18 NEW 2-NEW REVISION+Prediction+of+erosion+rate+(Autosaved).docx	August 23, 2022	Article Text
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Bayu Triwibowo &lt;bayu.triwibowo@mail.unnes.ac.id&gt;

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**[J. Adv. Res. Fluid Mech. Therm. Sc.] Submission Acknowledgement**

1 message

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**Dr. Nor Azwadi Che Sidik** <azwadi@semarakilmu.com.my>  
To: B Triwibowo <bayu.triwibowo@mail.unnes.ac.id>

Sun, Oct 10, 2021 at 7:23 PM

B Triwibowo:

Thank you for submitting the manuscript, "EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation " to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: [https://semarakilmu.com.my/journals/index.php/fluid\\_mechanics\\_thermal\\_sciences/authorDashboard/submission/18](https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/authorDashboard/submission/18)

Username: btriwibowo

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Dr. Nor Azwadi Che Sidik

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[Journal of Advanced Research in Fluid Mechanics and Thermal Sciences](#)

# Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation

B Triwibowo<sup>1</sup>, H W Widayanti<sup>1</sup> and M I Rukmanasari<sup>1</sup>

<sup>1</sup>Departement of Chemical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Semarang, Indonesia, 50299  
[bayu.triwibowo@mail.unnes.ac.id](mailto:bayu.triwibowo@mail.unnes.ac.id)

**Abstract.** Corrosion is one of the problems cause the material fail, leaks in the equipment and pipe systems in the industry which caused disturb in productivity of production in industry. There are some ways to prediction erosion in pipes, with the conventional or manual and CFD. CFD on the ANSYS Student application to prediction erosion in turbulent air flows with variations in coal particle size and velocity of flowing air. The results of prediction erosion based on CFD is numerical and graphic, by displayed numerical results into visual results. This 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. Discrete 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 damage 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]. 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. 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 in the ANSYS Student application to predict pipe corrosion with two elbows.

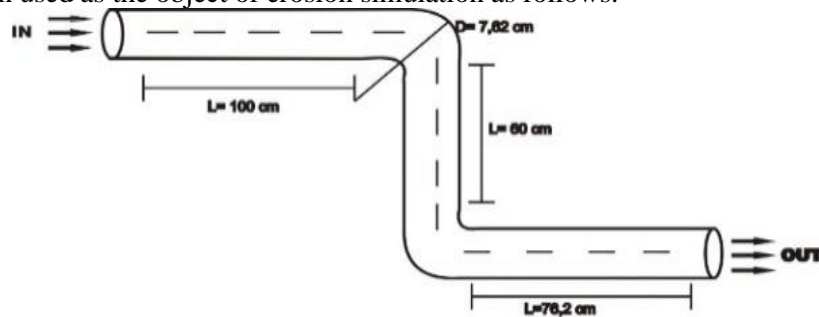
It must be admitted that often an engineer is only interested in the location and rate of erosion at the maximum point, which will always occur at the elbow wall in direct contact with the particles. However, many more complex situations occur where erosion occurs, such as an elbow, valve or fitting [4]. 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 in the ANSYS application Student 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. Examples of process simulation software may include Ansys, Aspen Plus, Aspen Hysys, PRO II, and SuperPro. In this study, Ansys 18.1 software was used. Ansys is a numerical solution program (Finite Element Method) based on its visual simulation. In Ansys Fluent, 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:



**Figure 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 [5]. The solid loading is the amount of suspended solids in a substance. Increase in stream velocity results in higher particles momentum produced and lead to the higher erosion rate [6][7][8]. This occurs since the impinging particles must pass through a larger stagnation region and thus allowing extra time for the particles to decelerate [9]. 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 elbows component in pipeline, however, there is still lack of information on the prediction based on the stream velocity in two elbow.

In this research, CFD with commercially available FLUENT code (ANSYS 18.0) 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.

Table 1. Air and Coal Properties

Air and Coal	
Air Density	1.225 kg/m <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
Type	Sub-bituminous

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 5,11x10<sup>7</sup> to 1,08x10<sup>8</sup>. During the simulation, another 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<sup>7</sup>

Eroton 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.

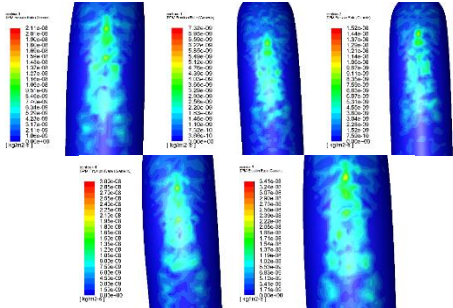
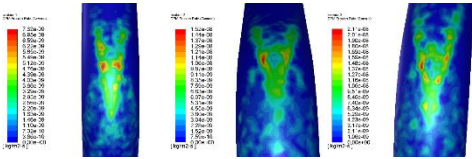
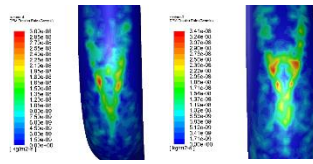
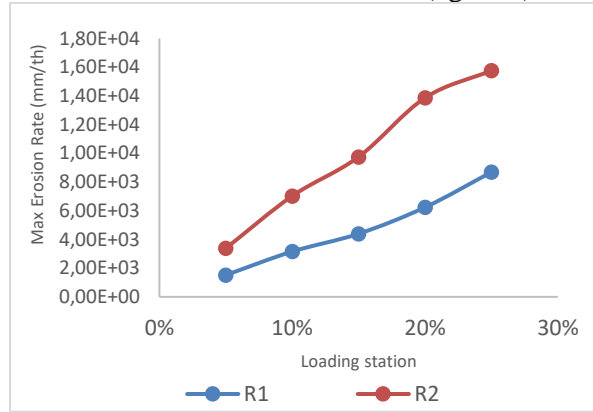


Figure 2. Erosion rate surface contour in first elbow (kg/m<sup>2</sup>.s) for 10 m/s stream velocity





**Figure 3.** Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity

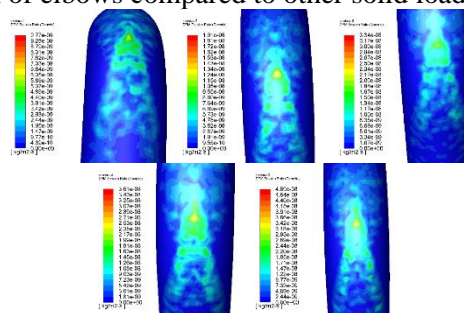


**Figure 4.** Maximum erosion rate ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

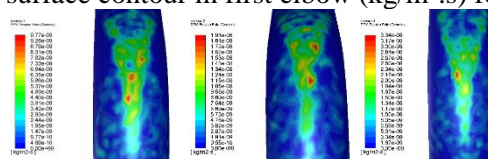
Figure 4 shows the maximum erosion rate that occurs at the first and second elbow with this flow conditions. The maximum erosion rate is influenced by the increase in stream velocity and solid loading. Solid loading is the mass flow rate of particles in percent. The relationship about solid loading and maximum erosion rate in the figure 4, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [10]. In this condition, 25% of solid loading produces the highest maximum erosion rate compared to the other.

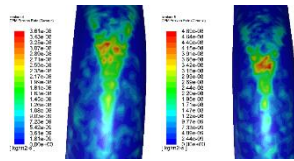
### 3.2. Effects of flow conditions stream velocity 15 m/s with reynold number $7,67 \times 10^7$

Eroton rate surface contours for the particles diameter 100  $\mu\text{m}$  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.

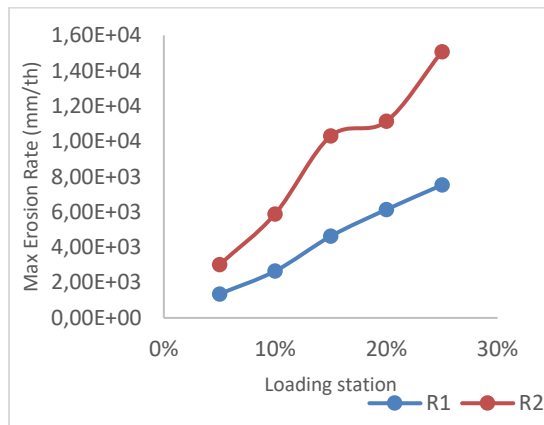


**Figure 5.** Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 15 m/s stream velocity





**Figure 6.** Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 15 m/s stream velocity

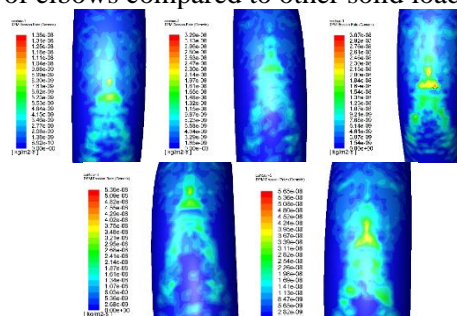


**Figure 7.** Maximum erosion rate ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

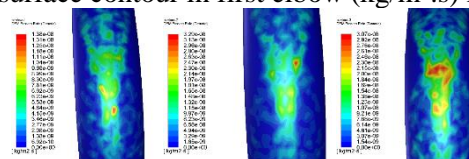
The relationship about solid loading and maximum erosion rate in the figure 7, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced larger or deeper indentations in the 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 [10]. 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.

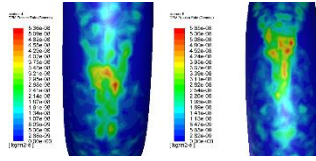
### 3.3. Effects of flow conditions stream velocity 20 m/s with reynold number $1,08 \times 10^8$

Erosion rate surface contours for the particles diameter 100  $\mu\text{m}$  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.

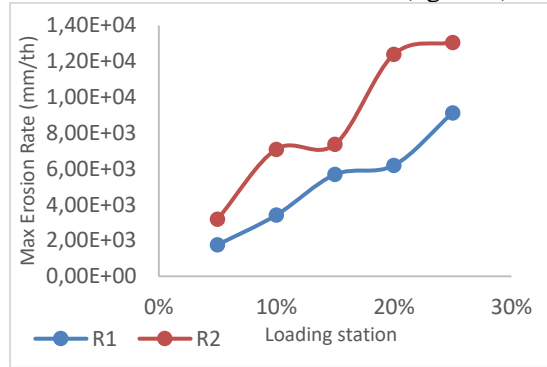


**Figure 8.** Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 20 m/s stream velocity





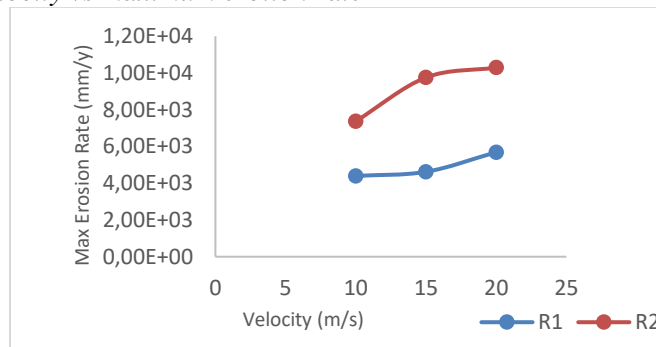
**Figure 9.** Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2\cdot\text{s}$ ) for 20 m/s stream velocity



**Figure 10.** Maximum erosion rate ( $\text{kg}/\text{m}^2\cdot\text{s}$ ) for various loading station (%)

The relationship about solid loading and maximum erosion rate in the figure 10. shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [10]. 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.

### 3.4. Effects of stream velocity vs maximum erosion rate



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

All of stream velocity show similarity in terms of the location of the maximum erosion 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 [10]. 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 erosion 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 [11]. 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 [12]. From the Figure 11 the effect of stream velocity of fluid on the

maximum erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion model in a simulation is dependent on the stream velocity is used.

#### 4. Conclusion

Based on this research, it can be concluded that the location of maximum erosion 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 erosion 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 erosion rate will be produced.

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**[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision**

2 messages

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**Nor Azwadi** <azwadi@semarakilmu.com.my>  
To: B Triwibowo <bayu.triwibowo@mail.unnes.ac.id>

Sat, Oct 23, 2021 at 3:05 PM

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**Our decision is: Revisions Required**

Please submit the revised article by 30 Oct 2021

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Reviewer A:

Grammar and Spelling:

No language mistakes. Good sentence and paragraph structure and transitions. However, the full stop symbol should be changed to a comma in the first paragraph on page 5 and page 6.

Abstract:

Abstract section is excellently written. The abstract has all the required elements (as stated below) that are connected properly.

1. Introduction
2. Aims/objective
3. Methodology
4. Results
5. Discussion

Quality of Tables and Figures:

Tables and figures have excellent clarity and numbered. All tables and figures are mentioned in text and properly discussed except for Figure 1 and Table 1.

Conclusion:

Conclusion related to objective. However, please add introduction sentence in conclusion.

References:



Need more than 15 recent references (within 5 years of study).

Recommendation: Revisions Required

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[Journal of Advanced Research in Fluid Mechanics and Thermal Sciences](#)

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Mon, Oct 25, 2021 at 9:00 AM

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# Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation

B Triwibowo<sup>1</sup>, H W Widayanti<sup>1</sup> and M I Rukmanasari<sup>1</sup>

<sup>1</sup>Departement of Chemical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Semarang, Indonesia, 50299  
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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 disturb in productivity of production in industry. There are some ways to prediction erosion in pipes, with the conventional or manual and CFD. CFD on the ANSYS Student application to prediction erosion in turbulent air flows with variations in coal particle size and velocity of flowing air. The results of prediction erosion based on CFD is numerical and graphic, by displayed numerical results into visual results. This 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. Discrete 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 damage 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]. 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. 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 in the ANSYS Student application to predict pipe corrosion with two elbows.

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 [4]. 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 in the ANSYS application Student 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. Examples of process simulation software may include Ansys, Aspen Plus, Aspen Hysys, PRO II, and SuperPro. In this study, Ansys 18.1 software was used. Ansys is a numerical solution program (Finite Element Method) based on its visual simulation. In Ansys Fluent, 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:

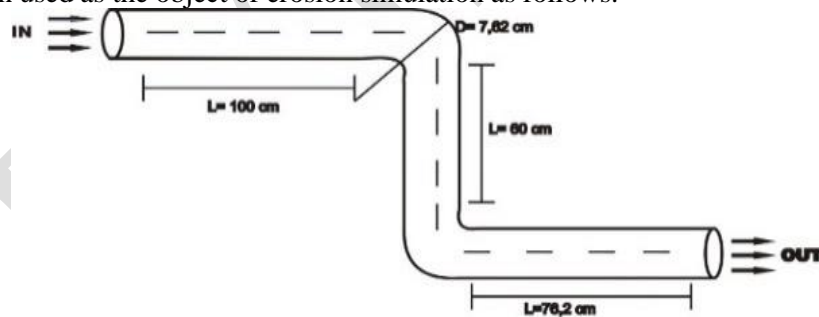


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The elbows were tested under three different flow conditions named as stream velocity (10-20 m/s) and solid loading (5%-25%). Each flow conditions consist of five different sets of values and the results are presented in the form of maximum erosion rate graphs and visual illustration of erosion rate surface contours.

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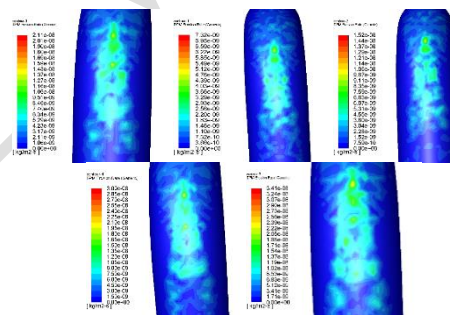
Air and Coal	
Air Density	1.225 kg/m <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
Type	Sub-bituminous

### 3. Results and discussion

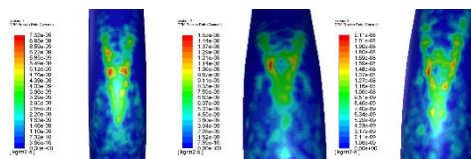
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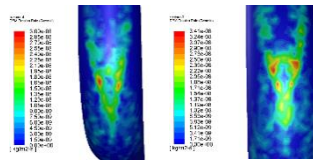
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Erosion rate surface contours for the particles diameter 100  $\mu\text{m}$ . Solid loading of 5%, 10%, 15%, 20%, 25% show maximum erosion rate occurred in two locations of maximum erosion rate observed and it is located of the section first elbow 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.

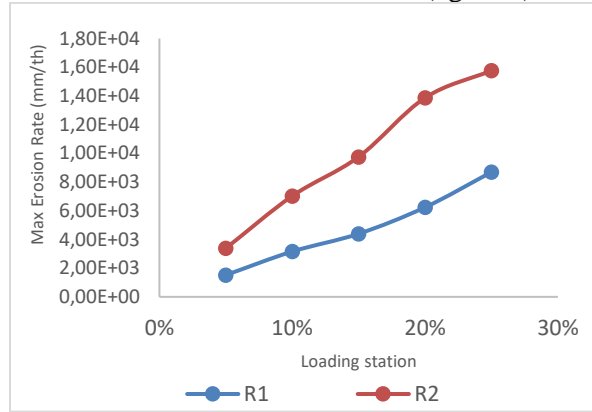


**Figure 2.** Erosion rate surface contour in first elbow ( $\text{kg/m}^2 \cdot \text{s}$ ) for 10 m/s stream velocity





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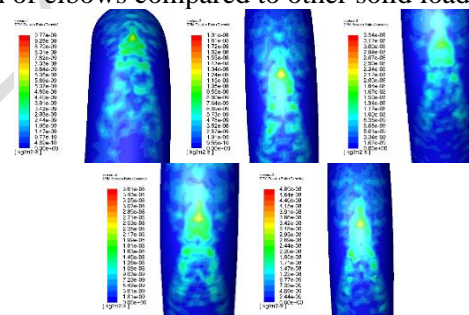


**Figure 4.** Maximum erosion rate ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

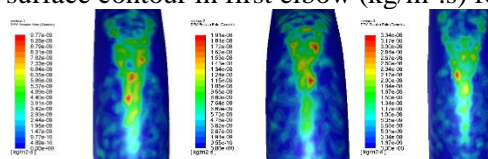
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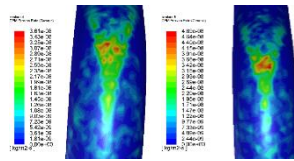
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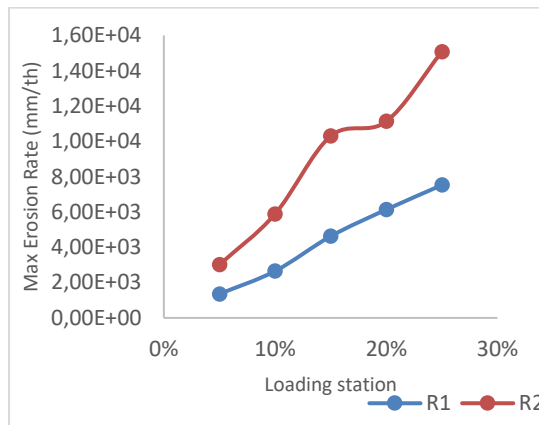


**Figure 5.** Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 15 m/s stream velocity





**Figure 6.** Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 15 m/s stream velocity

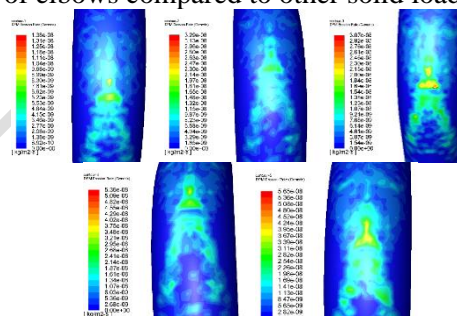


**Figure 7.** Maximum erosion rate ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

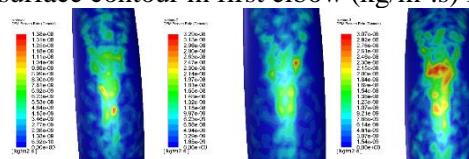
The relationship about solid loading and maximum erosion rate in the figure 7, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced larger or deeper indentations in the 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 [10]. 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.

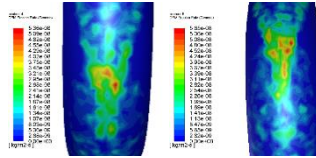
### 3.3. Effects of flow conditions stream velocity 20 m/s with reynold number $1,08 \times 10^8$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$  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.

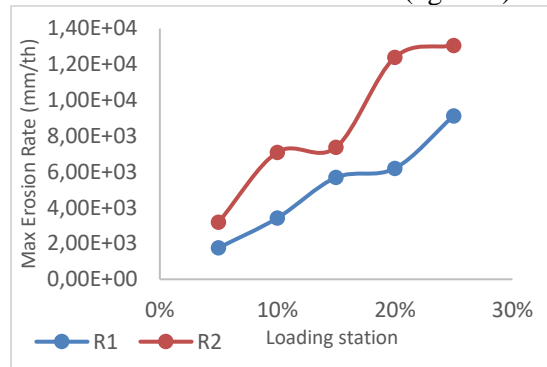


**Figure 8.** Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 20 m/s stream velocity





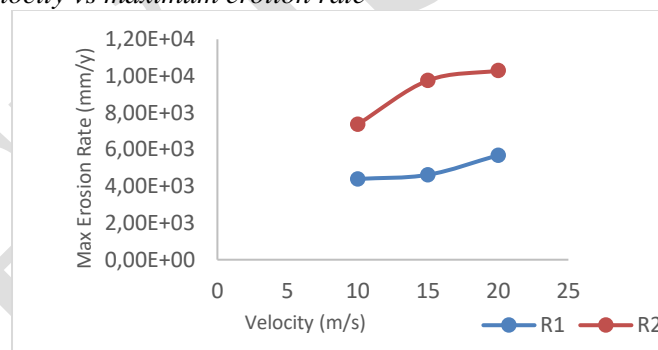
**Figure 9.** Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2\cdot\text{s}$ ) for 20 m/s stream velocity



**Figure 10.** Maximum erosion rate ( $\text{kg}/\text{m}^2\cdot\text{s}$ ) for various loading station (%)

The relationship about solid loading and maximum erosion rate in the figure 10. shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [10]. 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.

### 3.4. Effects of stream velocity vs maximum erosion rate



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

All of stream velocity show similarity in terms of the location of the maximum erosion 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 [10]. 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 erosion 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 [11]. 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 [12]. From the Figure 11 the effect of stream velocity of fluid on the

maximum erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion model in a simulation is dependent on the stream velocity is used.

#### 4. Conclusion

Based on this research, it can be concluded that the location of maximum erosion 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 erosion 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 erosion rate will be produced.

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**[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision**

1 message

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**Nor Azwadi** <azwadi@semarakilmu.com.my>  
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Thu, Oct 28, 2021 at 9:03 PM

B Triwibowo:

We have reached a decision regarding your submission to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, "EIC-Prediction of erosion rate in two elbows for coal-air flow based on computational fluid dynamics simulation".

Our decision is to: Accept Submission

Thank you

Truly

Editor-in-chief, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

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Bayu Triwibowo &lt;bayu.triwibowo@mail.unnes.ac.id&gt;

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**[18] Manuscript required-Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation**

2 messages

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Kindly provide your revised manuscript in word format in order for copy editing purposes.

Thank you

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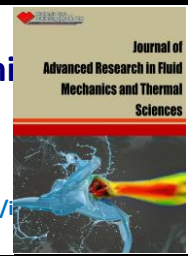
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## Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation

Bayu Triwibowo<sup>1,1\*</sup>, Heni Wahyu Widayanti<sup>1</sup>, Miftakhul Indra Rukmanasari<sup>1</sup>

<sup>1</sup> Department of Chemical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Semarang, Indonesia, 50229

<p><b>Article history:</b> Received 29 October XXXX Received in revised form 1 December XXXX Accepted 9 December XXXX Available online 10 December XXXX</p> <p><b>Keywords:</b> Maximum erosion rate; Coal; Discrete Phase Model; Computational Fluid Dynamics</p>	<p>Corrosion is one of the problems cause the material fail, leaks in the equipment and pi the industry which caused disturub in productivity of production in industry. There are son to prediction erosion in pipes, with the conventional or manual and CFD. CFD is to pri erosion in turbulent air flows with variations in coal particle size and velocity of flowing results of prediction erotion based on CFD is numerical and graphic, by displayed nu results into visual results. This results include about the velocity, pressure, and temp distribution in the air flow. So, CFD can be used to prediction pipe because it has wide c and effective in display numerical and visual results. Discreate Phase Model is the mode with a variable stream velocity of 10 m/s, 15 m/s, 20 m/s and a solid loading of 5%, 10 20%, 25%. From the results, the maximum erosion rates increased with increasing particles and stream velocities. However, the location of the maximum erosion rate in the region was independent on those mentioned par</p>
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### 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 damage 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 using water and air as working fluid. Recently, some of the researchers have started to utilise air as

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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:

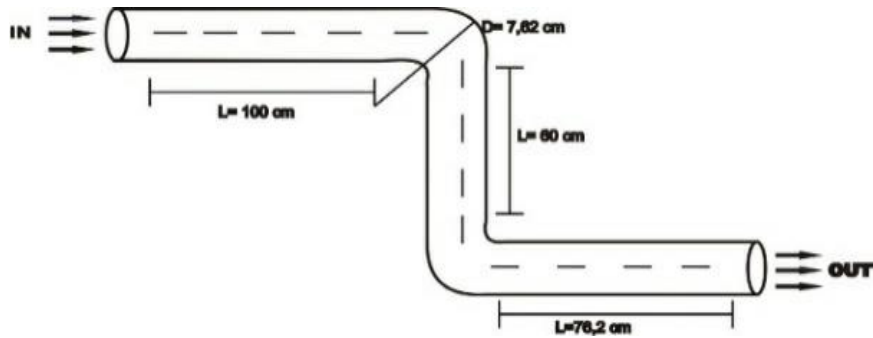


Fig. 1. Pipe with two elbows

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 amount 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][12]. This occurs since the impinging particles must pass through a larger stagnation region and thus allowing extra time for the particles to decelerate [13]. 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 elbows component in pipeline, however, there is still lack of information on the prediction based on the stream velocity in two elbow.

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 <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
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) [14]. 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 [15][16]. 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  $5,11 \times 10^7$  to  $1,08 \times 10^8$ . 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 [17]. During the simulation, another 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 $5,11 \times 10^7$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$ . 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.

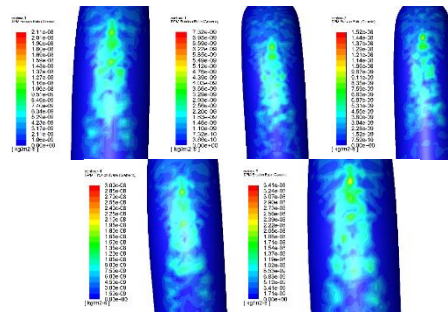


Fig. 2. Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2 \cdot \text{s}$ ) for 10 m/s stream velocity

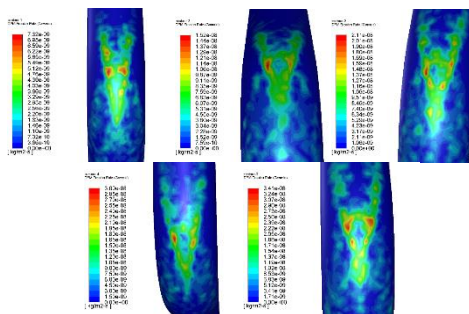


Fig. 3. Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2 \cdot \text{s}$ ) for 10 m/s stream velocity

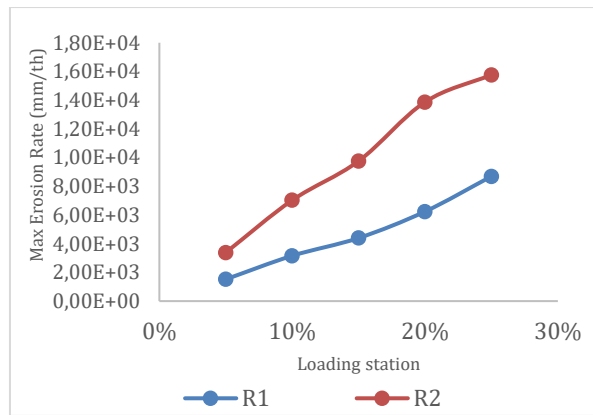


Fig. 4. Maximum erosion rate (kg/m<sup>2</sup>.s) for various loading station (%)

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 erosion rate in the figure 4, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [18]. In this condition, 25% of solid loading produces the highest maximum erosion rate compared to the other.

### 3.2 Effects of flow conditions stream velocity 15 m/s with reynold number 7,67x10<sup>7</sup>

Erosion 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.

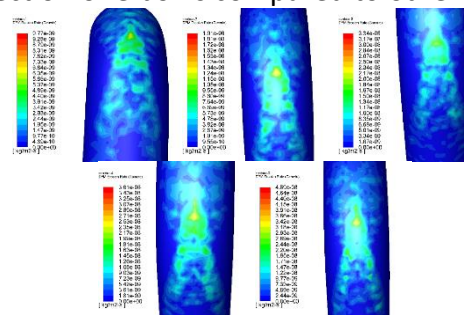


Fig. 5. Erosion rate surface contour in first elbow (kg/m<sup>2</sup>.s) for 15 m/s stream velocity

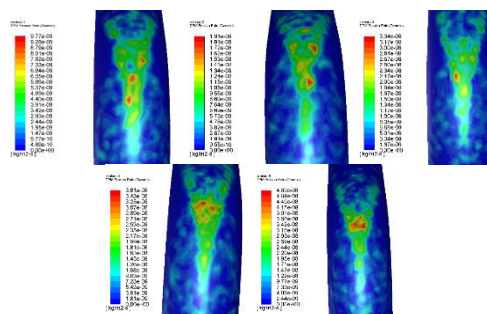


Fig. 6. Erosion rate surface contour in second elbow (kg/m<sup>2</sup>.s) for 15 m/s stream velocity

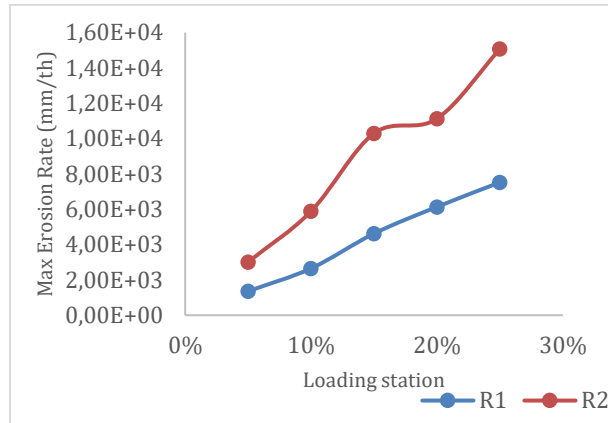


Fig. 7. Maximum erosion rate (kg/m<sup>2</sup>.s) for various loading station (%)

The relationship about solid loading and maximum erosion rate in the figure 7, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [18]. 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.

### 3.3 Effects of flow conditions stream velocity 20 m/s with reynold number 1,08x10<sup>8</sup>

Erosion 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.

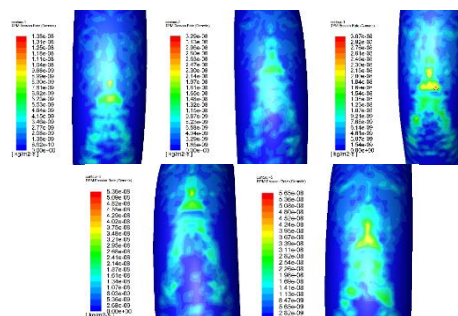


Fig. 8. Erosion rate surface contour in first elbow (kg/m<sup>2</sup>.s) for 20 m/s stream velocity

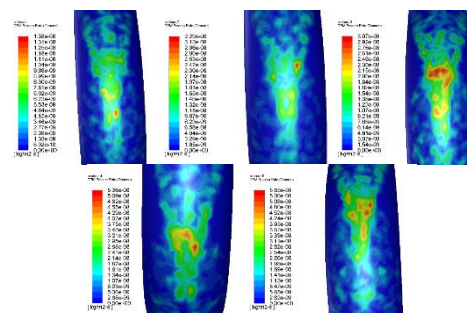
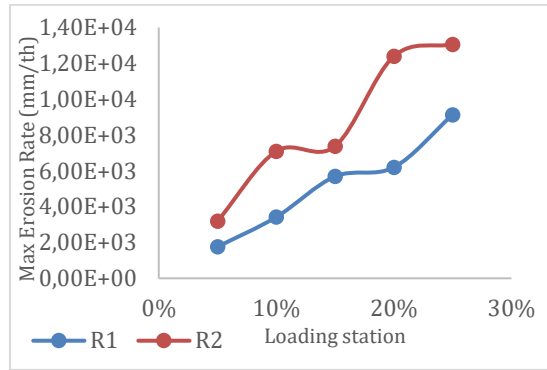


Fig. 9. Erosion rate surface contour in second elbow (kg/m<sup>2</sup>.s) for 20 m/s stream velocity

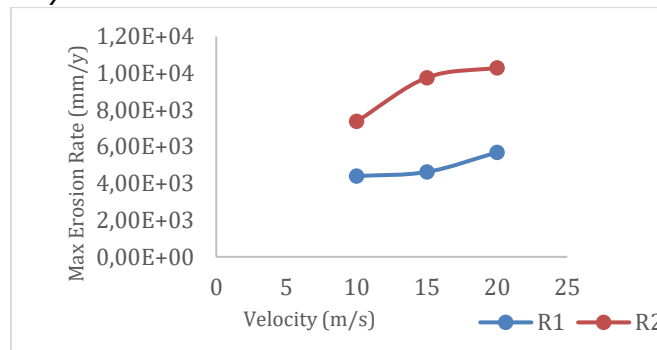




**Fig. 10.** Maximum erosion rate (kg/m<sup>2</sup>.s) for various loading station (%)

The relationship about solid loading and maximum erosion rate in the figure 10, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produced 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 [18]. 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.

### 3.4 Effects of stream velocity vs maximum erosion rate



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

All of stream velocity show similarity in terms of the location of the maximum erosion 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 [18]. 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 erosion 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 [19]. 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 [20]. From the Figure 11 the effect of stream velocity of fluid on the maximum erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion model in a simulation is dependent on the stream velocity is used.

## 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 erosion 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 erosion 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 erosion rate will be produced.

## Acknowledgement

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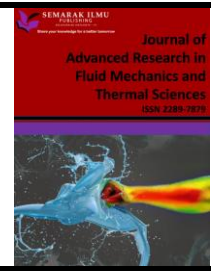
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## Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation

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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 disturb 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 erosion 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. Discrete 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.

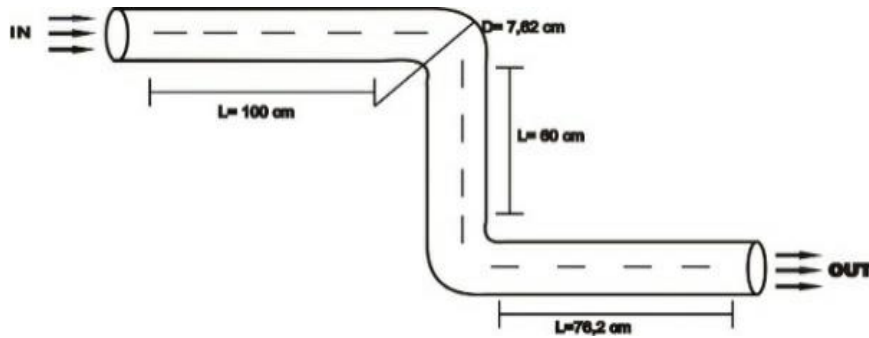


Fig. 1. Pipe with two elbows

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 <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
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  $5,11 \times 10^7$  to  $1,08 \times 10^8$ . 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 $5,11 \times 10^7$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$ . 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 erosion rate in Figure 4, shows that the higher of the solid loading, the higher the maximum erosion 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 erosion rate compared to the other.



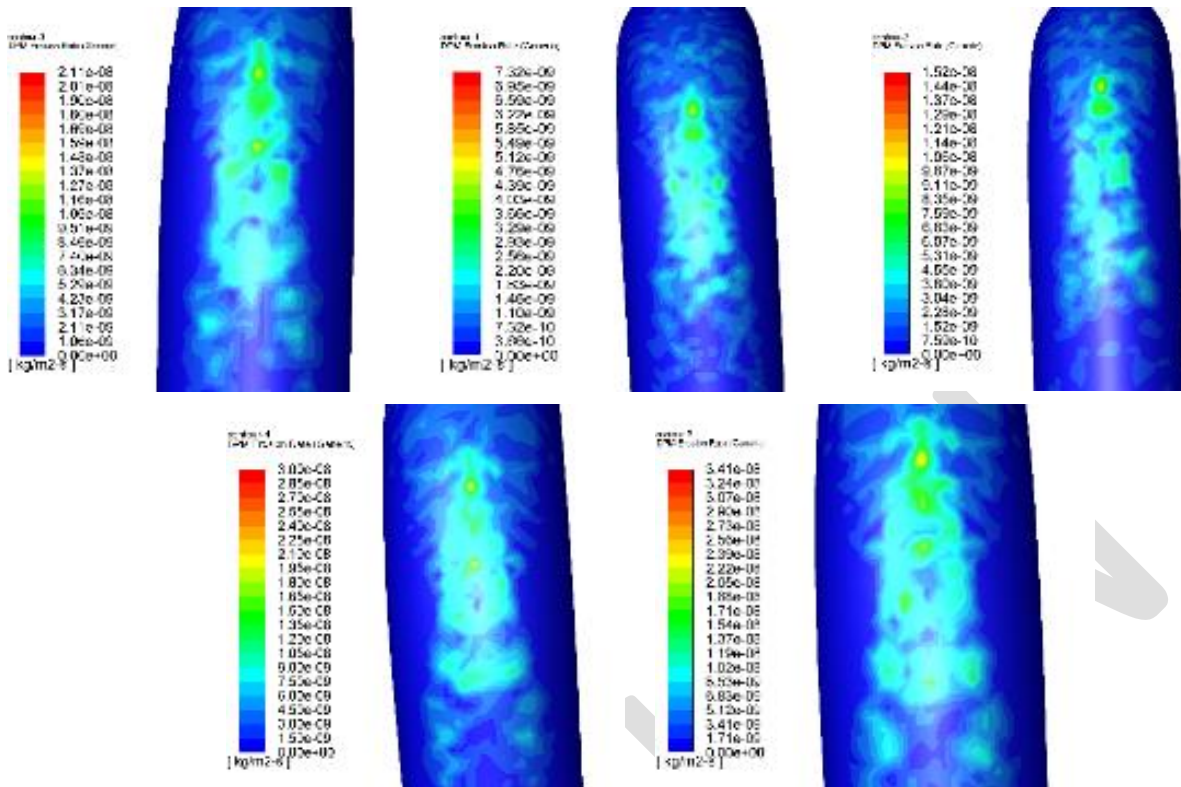


Fig. 2. Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity

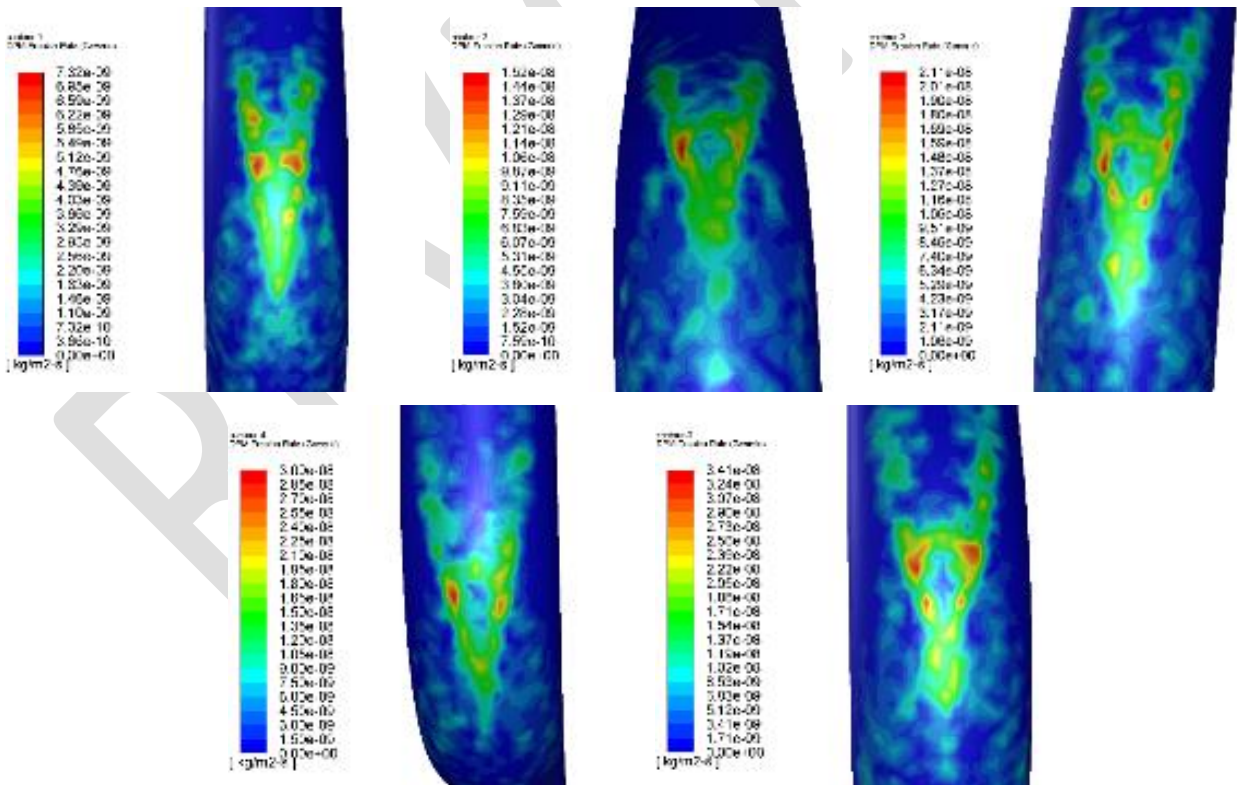
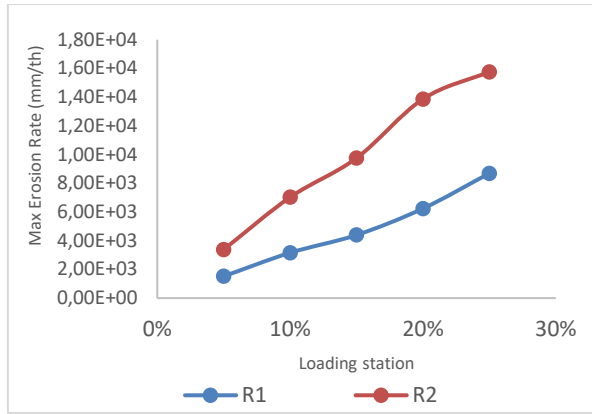


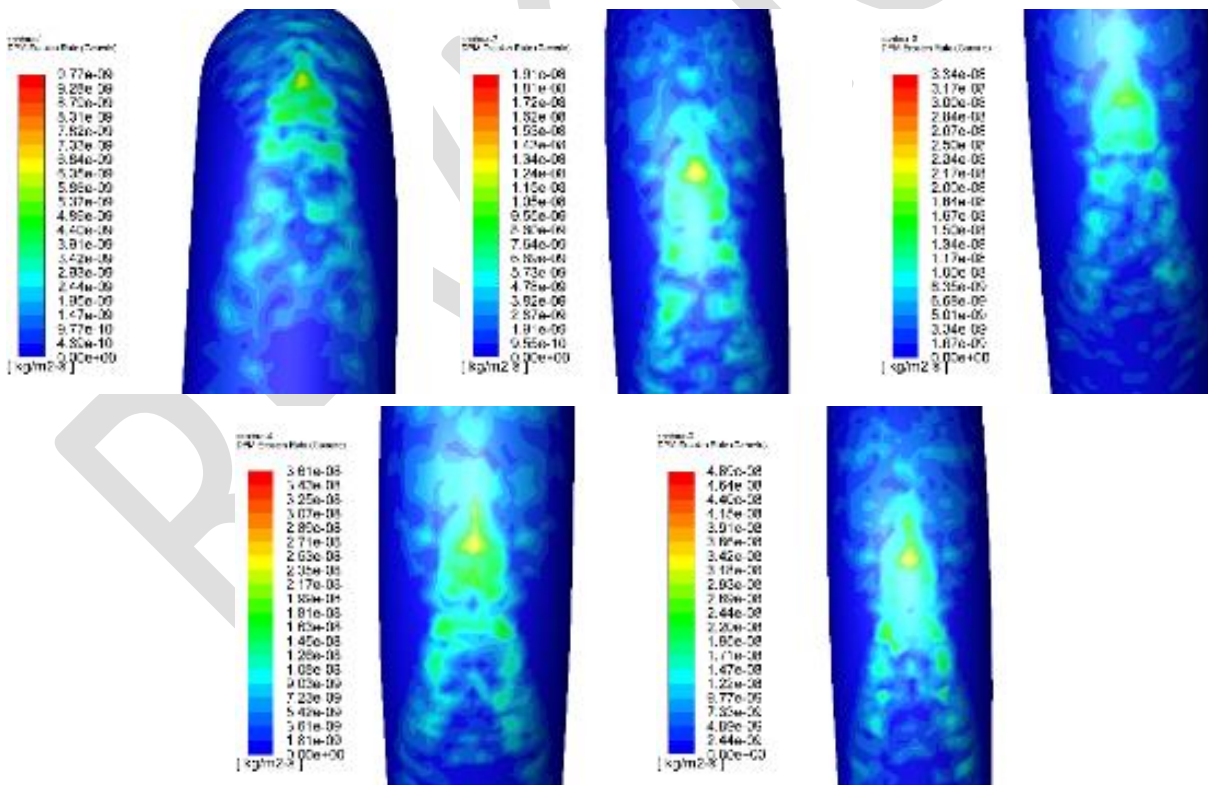
Fig. 3. Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity



**Fig. 4.** Maximum erosion rate (kg/m<sup>2</sup>.s) for various loading station (%)

### 3.2 Effects of Flow Conditions Stream Velocity 15 m/s with Reynold Number 7,67x10<sup>7</sup>

Erosion 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<sup>2</sup>.s) for 15 m/s stream velocity

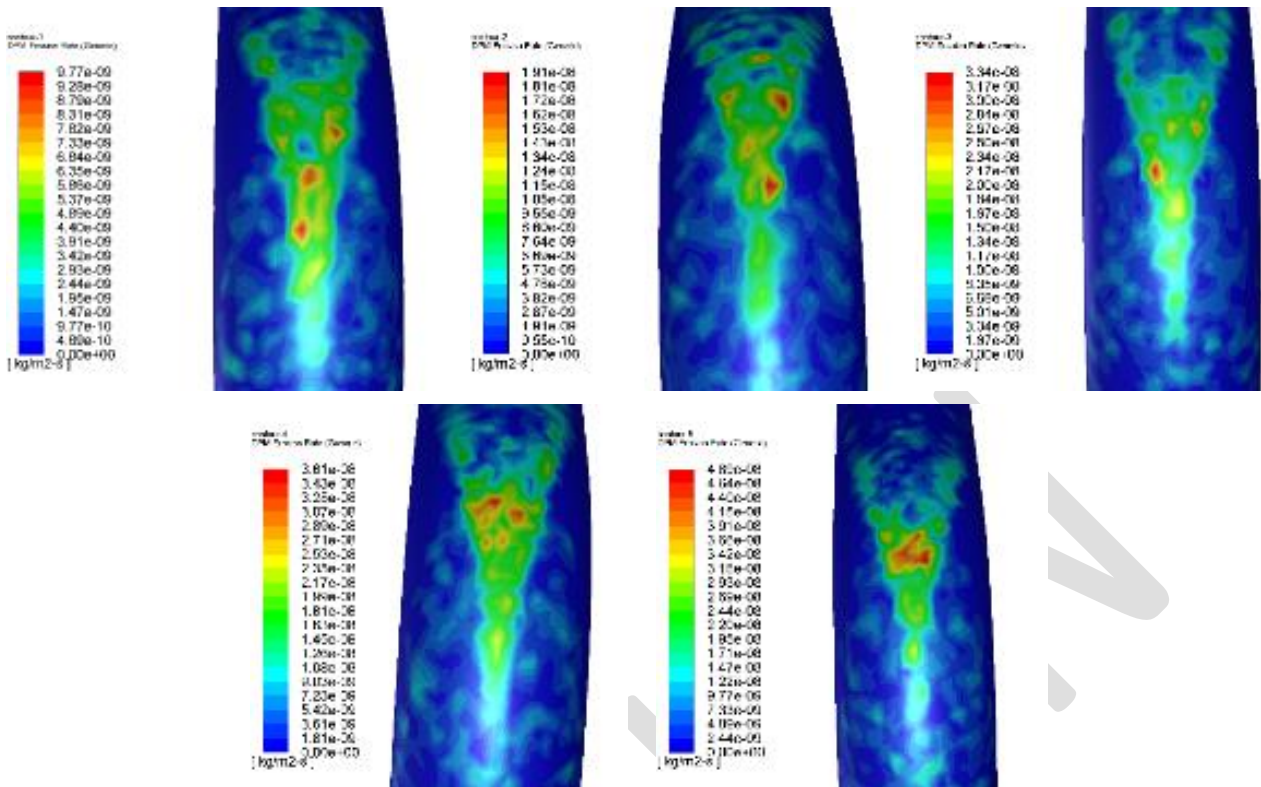


Fig. 6. Erosion rate surface contour in second elbow ( $\text{kg/m}^2.\text{s}$ ) for 15 m/s stream velocity

The relationship about solid loading and maximum erosion rate in Figure 7, shows that the higher of the solid loading, the higher the maximum erosion 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.

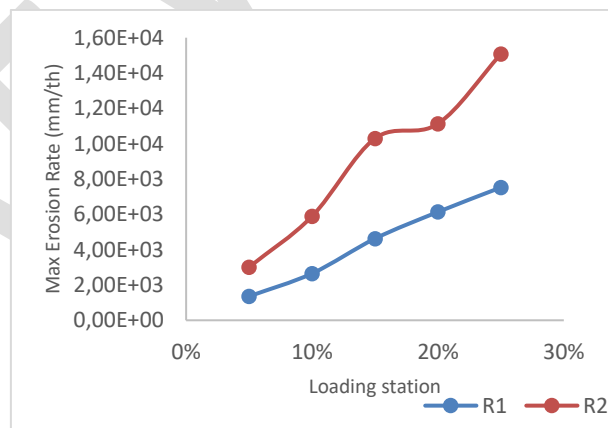


Fig. 7. Maximum erosion rate ( $\text{kg/m}^2.\text{s}$ ) for various loading station (%)

### 3.3 Effects of Flow Conditions Stream Velocity 20 m/s with Reynold Number $1,08 \times 10^8$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$  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.

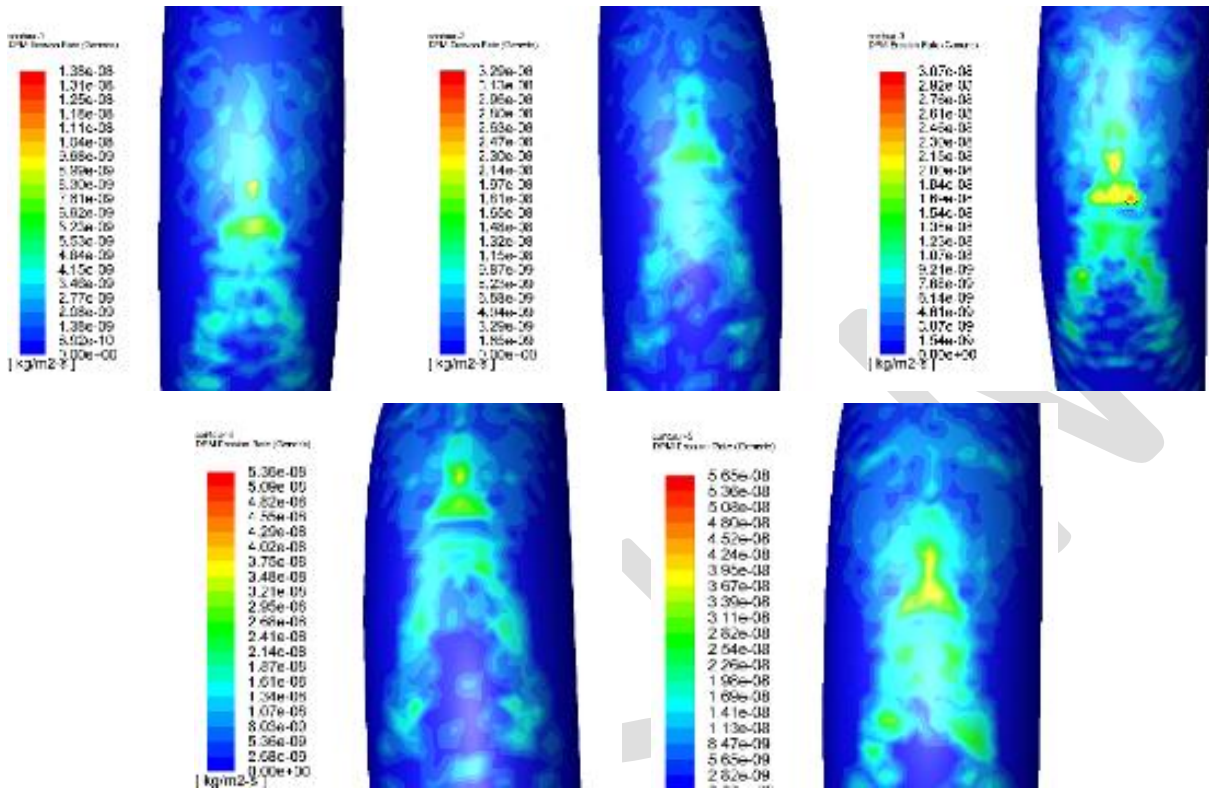


Fig. 8. Erosion rate surface contour in first elbow ( $\text{kg/m}^2.\text{s}$ ) for 20 m/s stream velocity

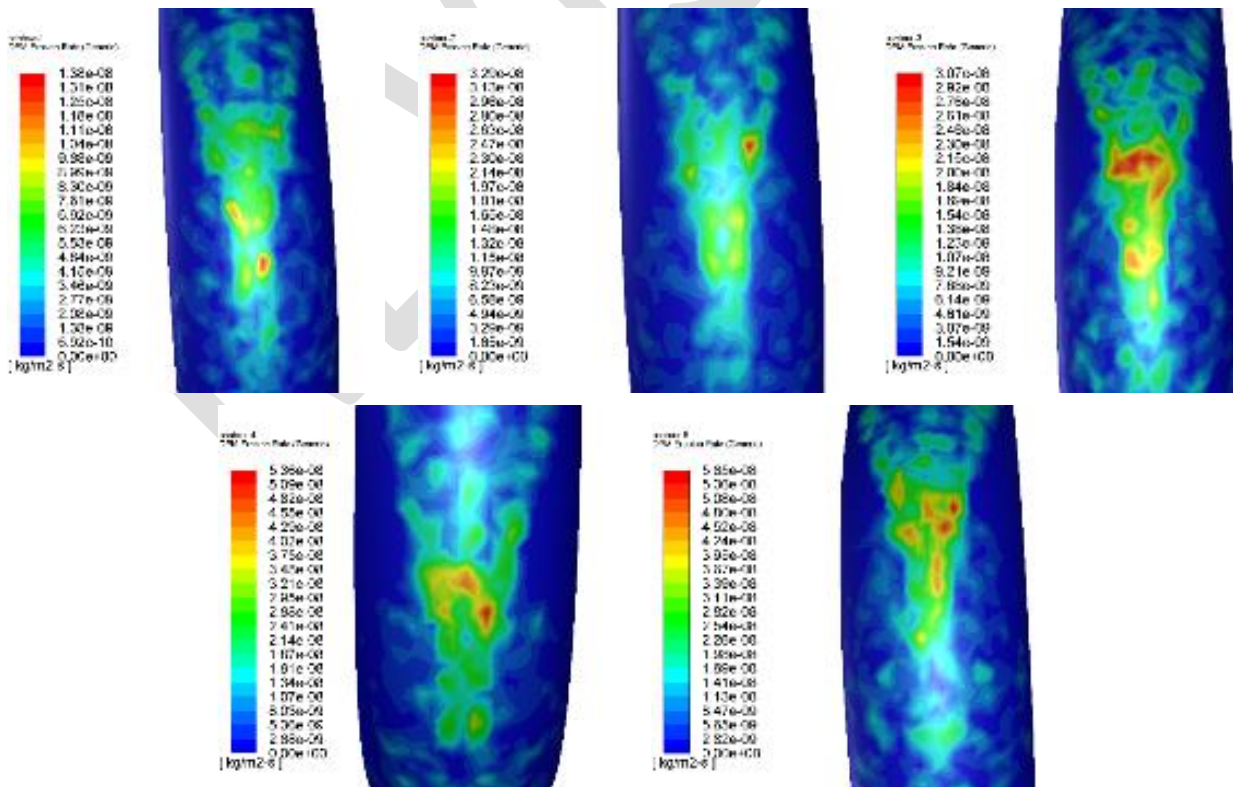
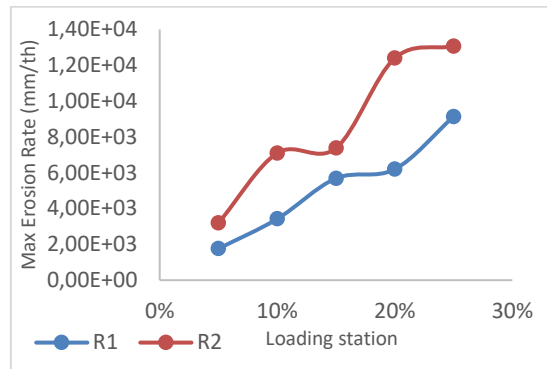


Fig. 9. Erosion rate surface contour in second elbow ( $\text{kg/m}^2.\text{s}$ ) for 20 m/s stream velocity

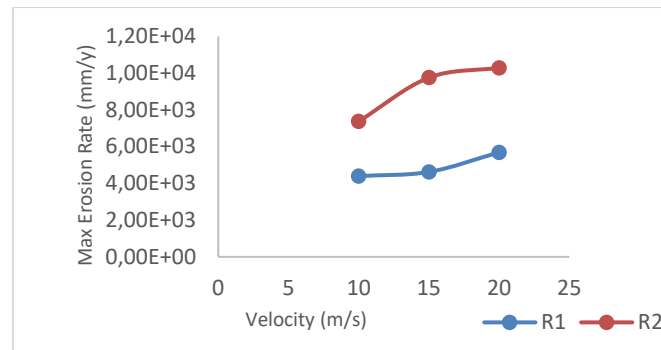
The relationship about solid loading and maximum erosion rate in Figure 10, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow 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 ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

### 3.4 Effects of Stream Velocity Vs Maximum Erosion Rate

All of stream velocity show similarity in terms of the location of the maximum erosion 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 erosion 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 erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion 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 erosion 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 erosion 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 erosion rate will be produced.

#### Acknowledgement

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## [18] Editor Decision

1 message

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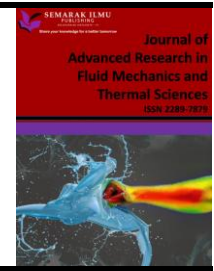
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## Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation

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### ABSTRACT

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Corrosion is one of the problems cause the material fail, leaks in the equipment and pipe systems in the industry which caused disturb 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 erosion 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. Discrete 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.

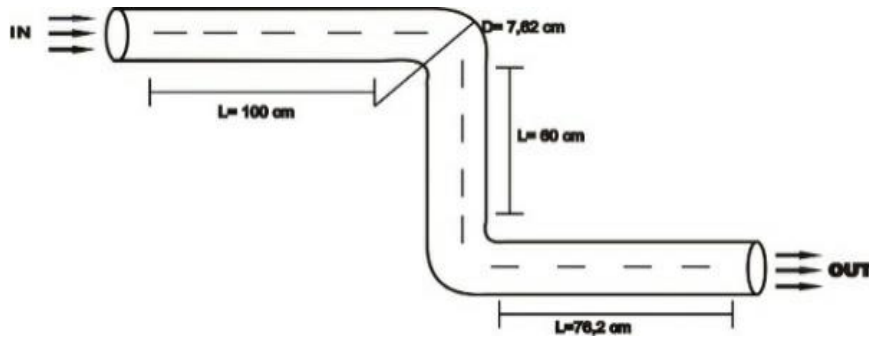


Fig. 1. Pipe with two elbows

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 <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
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  $5,11 \times 10^7$  to  $1,08 \times 10^8$ . 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 $5,11 \times 10^7$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$ . 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 erosion rate in Figure 4, shows that the higher of the solid loading, the higher the maximum erosion 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 erosion rate compared to the other.

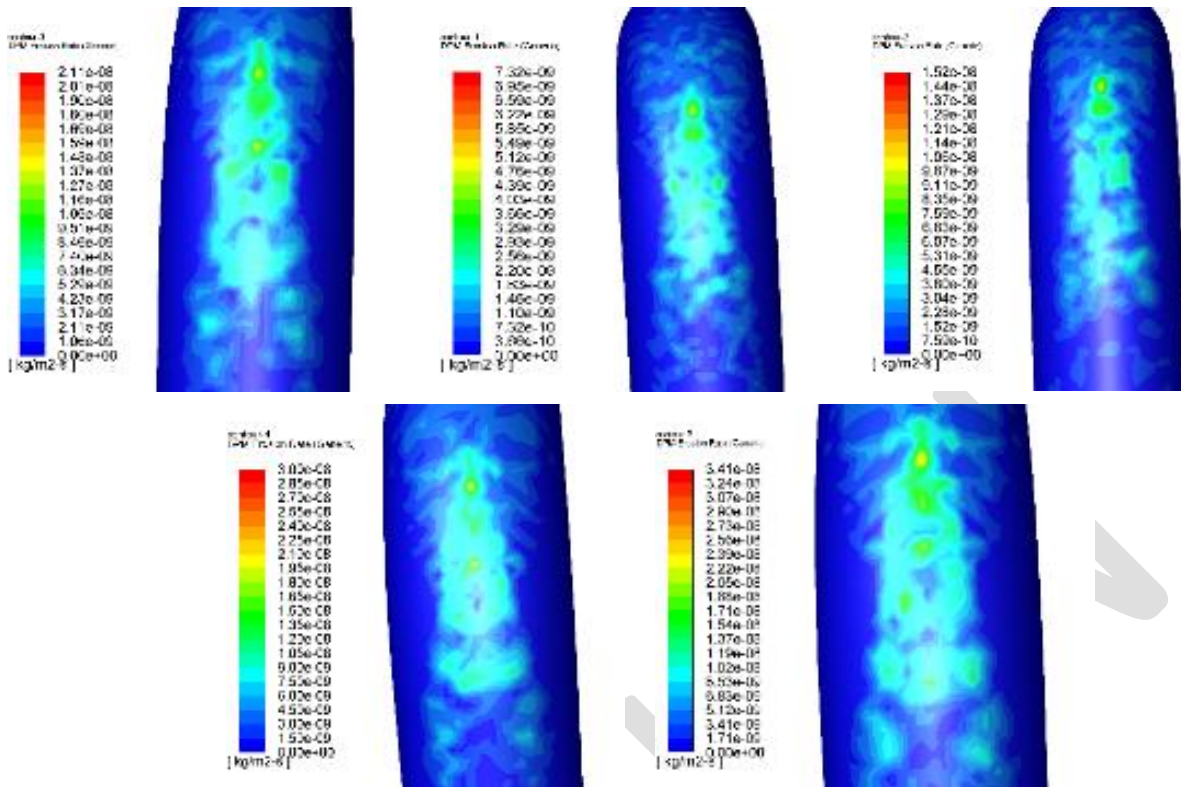


Fig. 2. Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity

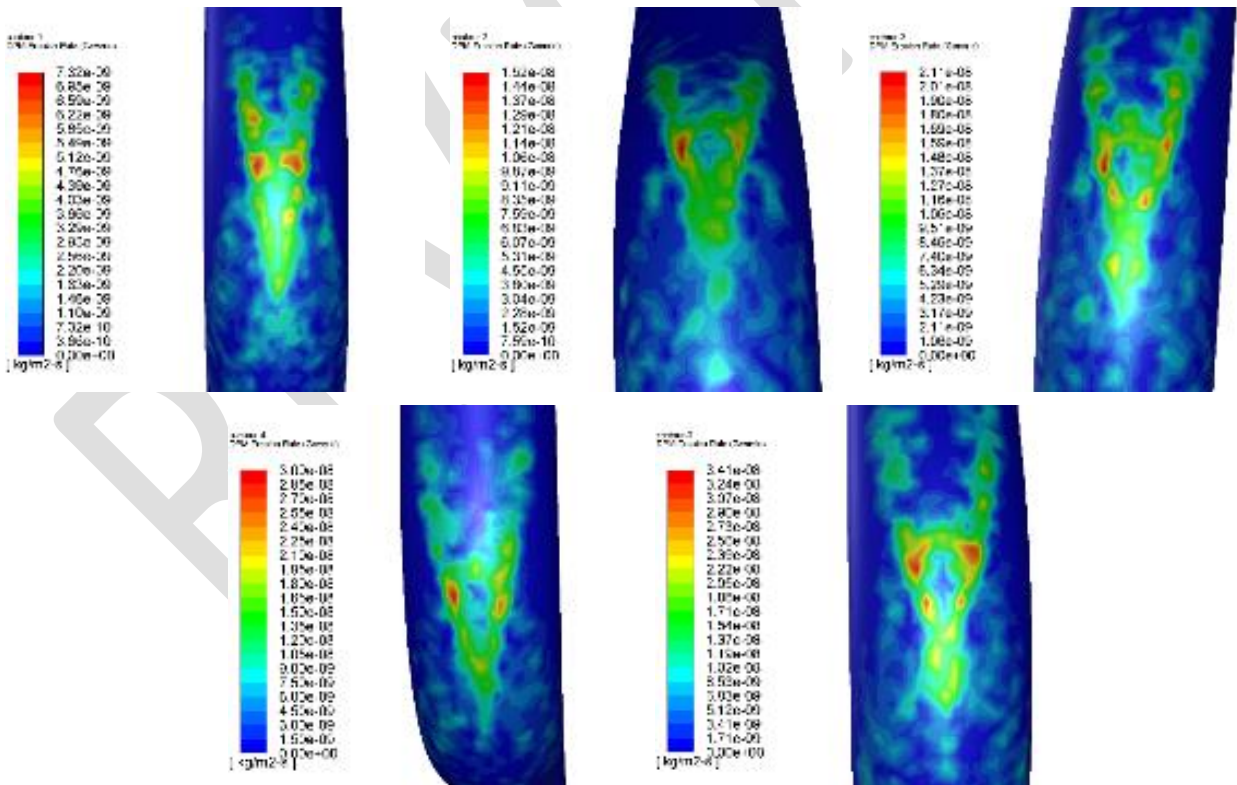
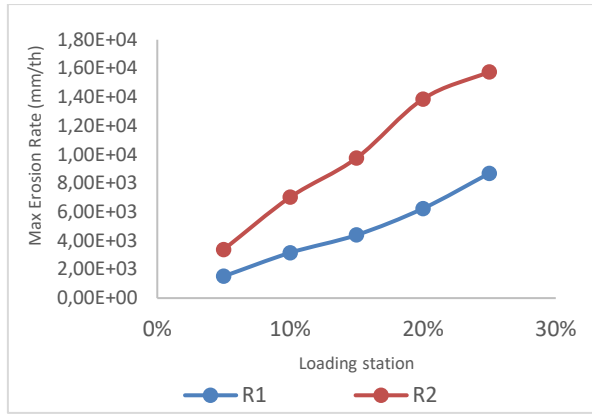


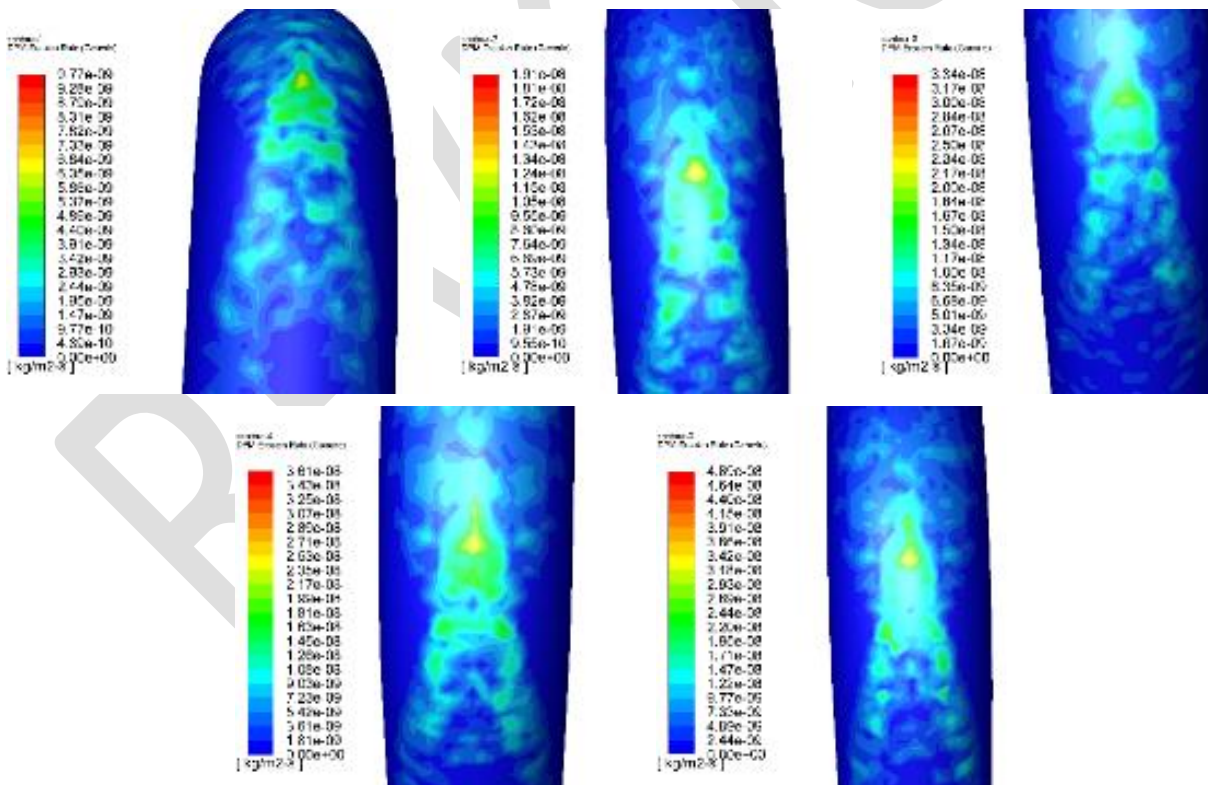
Fig. 3. Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity



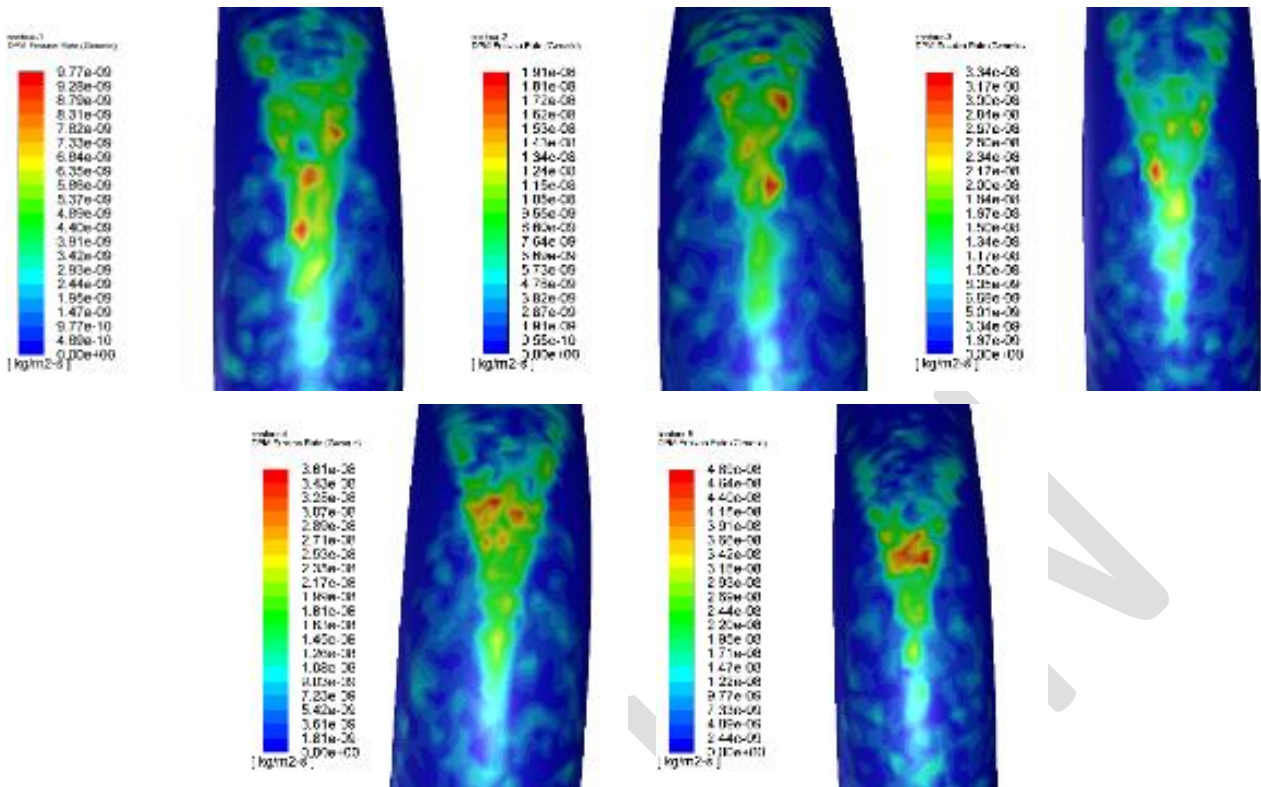
**Fig. 4.** Maximum erosion rate (kg/m<sup>2</sup>.s) for various loading station (%)

### 3.2 Effects of Flow Conditions Stream Velocity 15 m/s with Reynold Number 7,67x10<sup>7</sup>

Erosion 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.

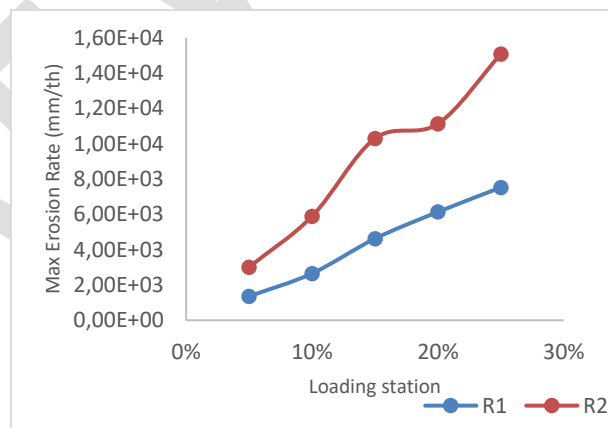


**Fig. 5.** Erosion rate surface contour in first elbow (kg/m<sup>2</sup>.s) for 15 m/s stream velocity



**Fig. 6.** Erosion rate surface contour in second elbow ( $\text{kg/m}^2.\text{s}$ ) for 15 m/s stream velocity

The relationship about solid loading and maximum erosion rate in Figure 7, shows that the higher of the solid loading, the higher the maximum erosion 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 ( $\text{kg/m}^2.\text{s}$ ) for various loading station (%)

### 3.3 Effects of Flow Conditions Stream Velocity 20 m/s with Reynold Number $1,08 \times 10^8$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$  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.

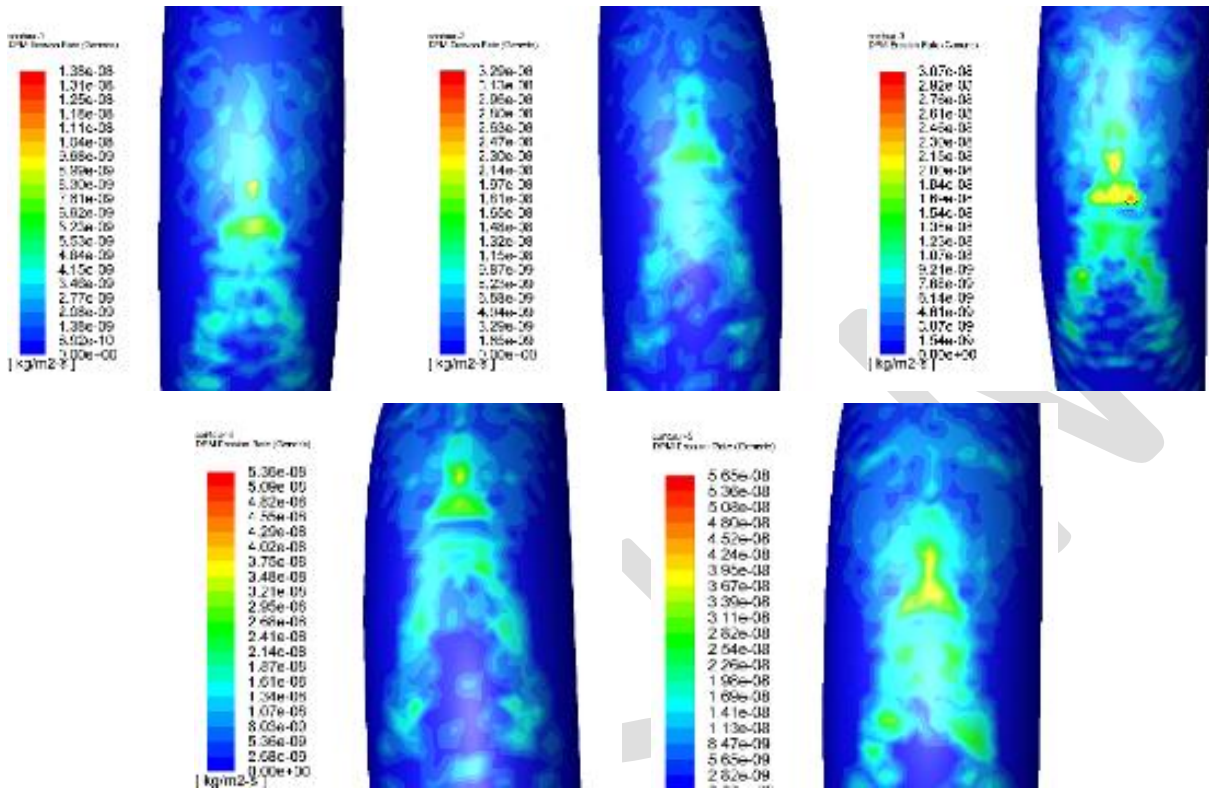


Fig. 8. Erosion rate surface contour in first elbow ( $\text{kg/m}^2.\text{s}$ ) for 20 m/s stream velocity

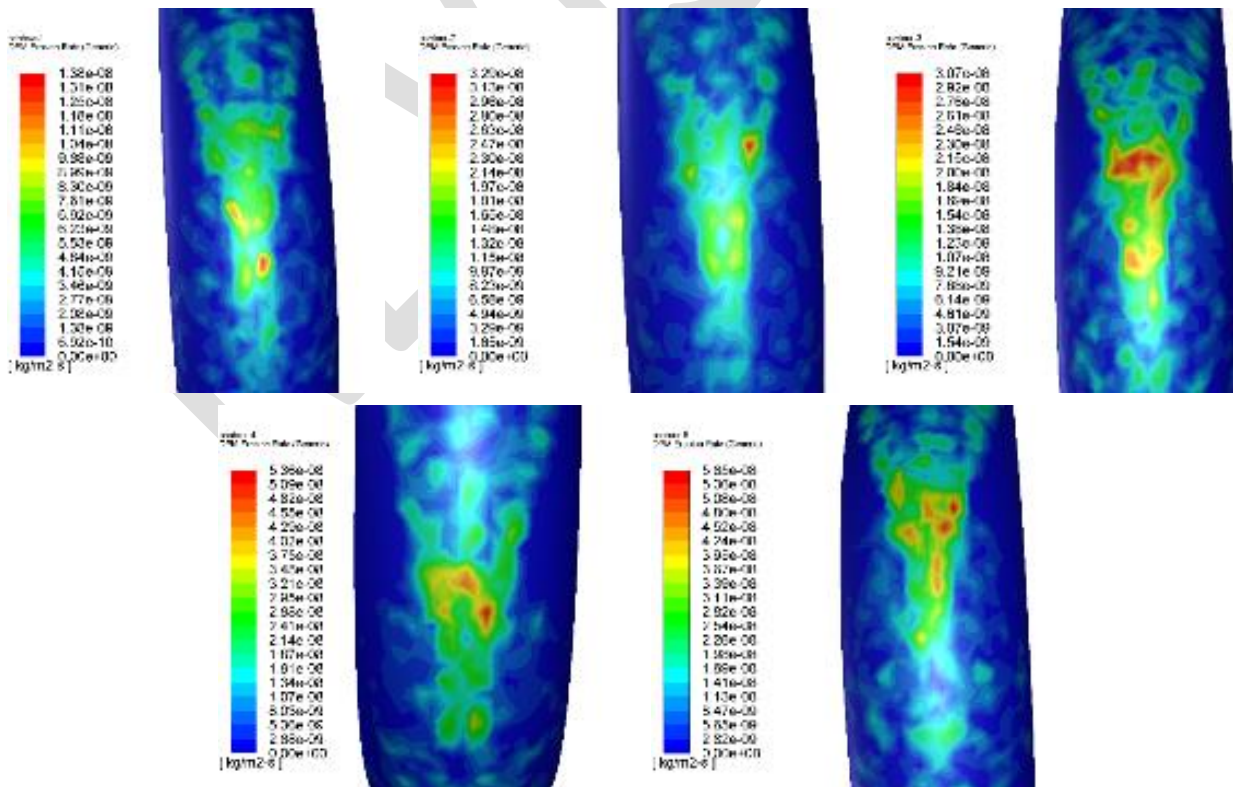
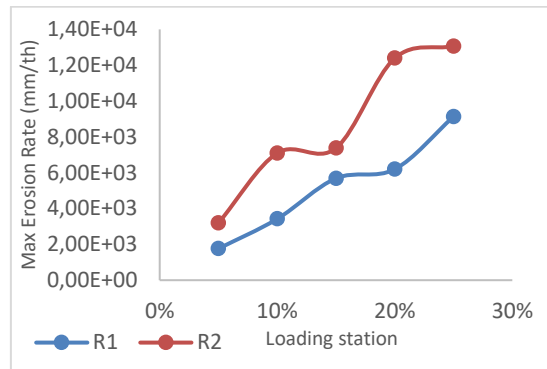


Fig. 9. Erosion rate surface contour in second elbow ( $\text{kg/m}^2.\text{s}$ ) for 20 m/s stream velocity



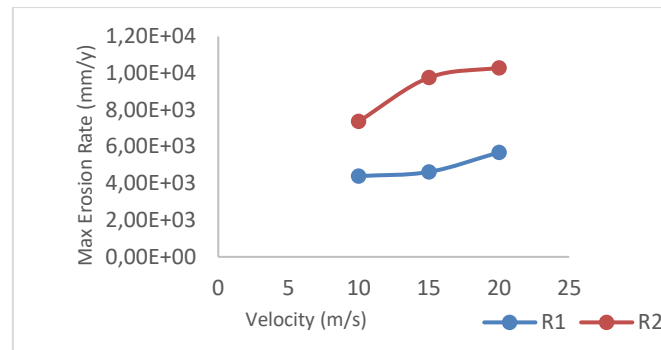
The relationship about solid loading and maximum erosion rate in Figure 10, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow 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 ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

### 3.4 Effects of Stream Velocity Vs Maximum Erosion Rate

All of stream velocity show similarity in terms of the location of the maximum erosion 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 erosion 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 erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion 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 erosion 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 erosion 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 erosion rate will be produced.

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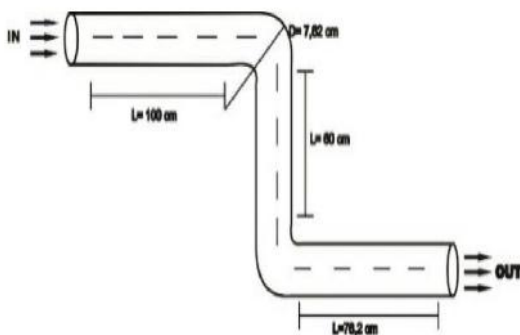


Fig. 1. Pipe with two elbows

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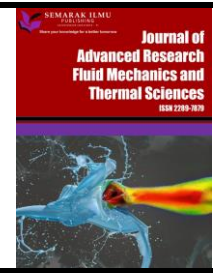
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# Prediction of Erosion Rate in Two Elbows for Coal-Air Flow Based on Computational Fluid Dynamics Simulation

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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 disturb 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.

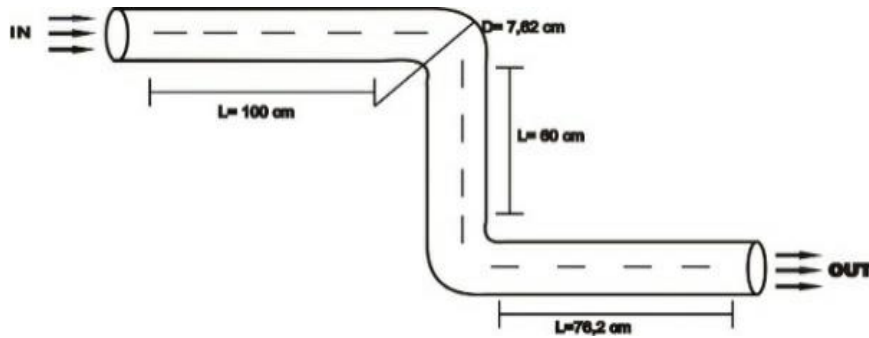


Fig. 1. Pipe with two elbows

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 <sup>3</sup>
Coal Density	1.200 kg/m <sup>3</sup>
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  $5,11 \times 10^7$  to  $1,08 \times 10^8$ . 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 $5,11 \times 10^7$*

Erosion rate surface contours for the particles diameter 100  $\mu\text{m}$ . 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 erosion rate in Figure 4, shows that the higher of the solid loading, the higher the maximum erosion 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 erosion rate compared to the other.



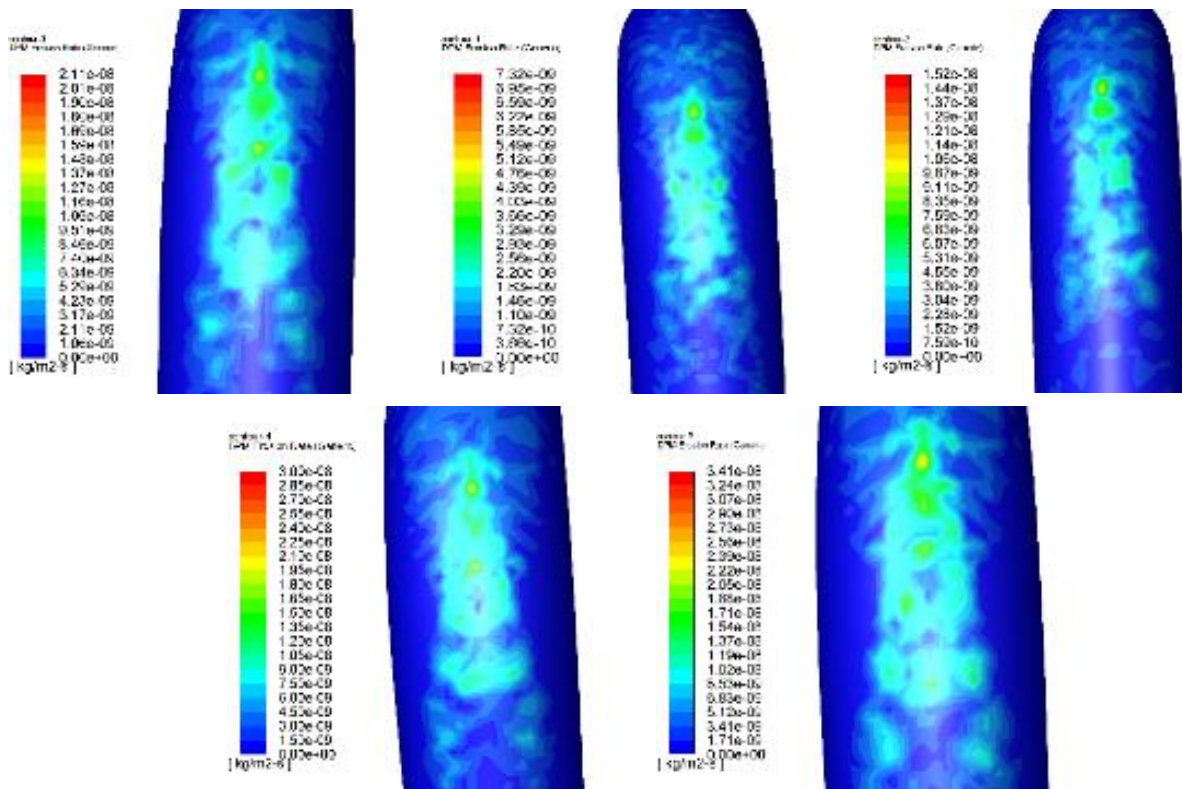


Fig. 2. Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity

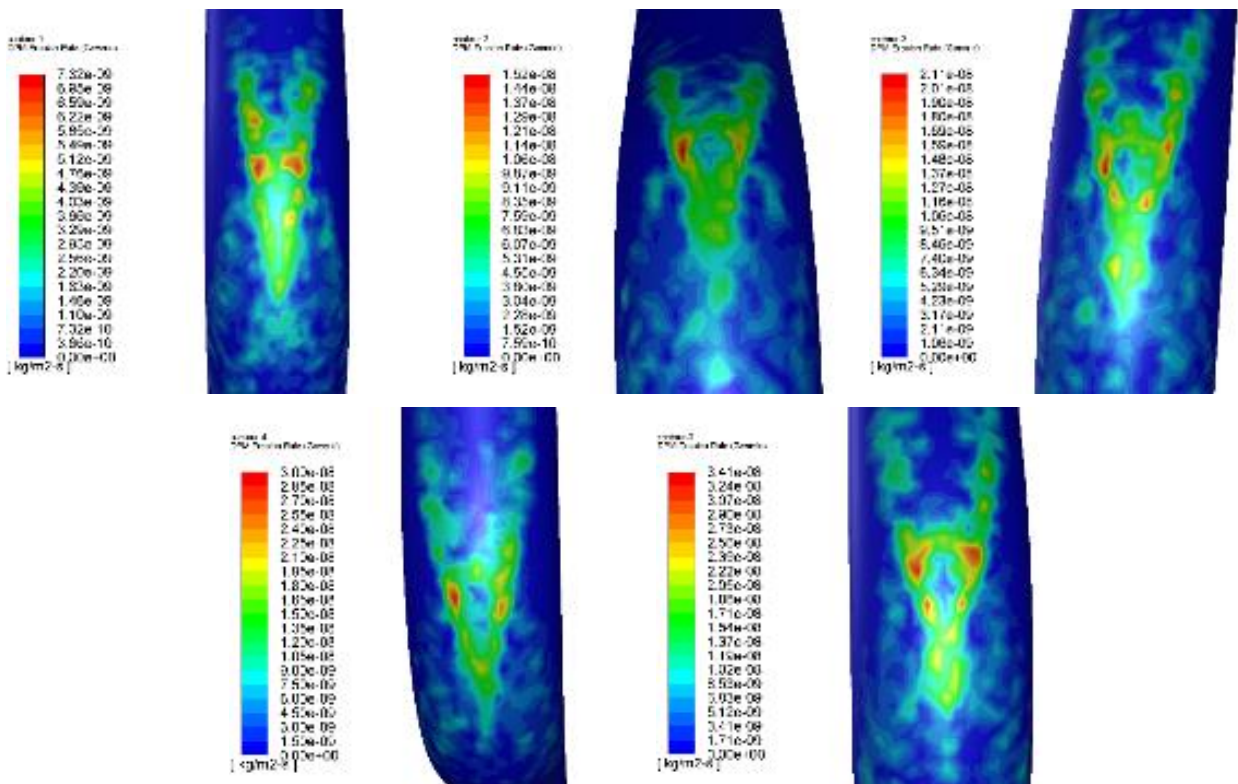
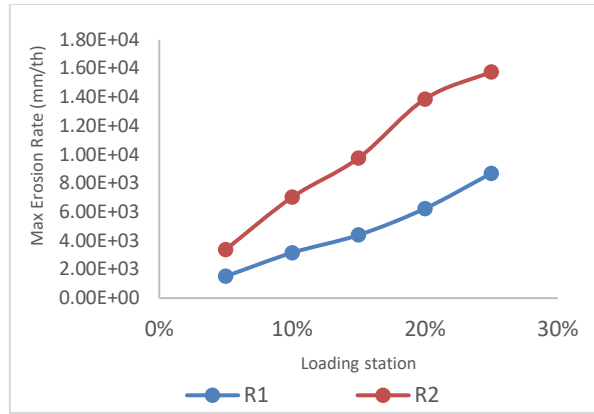


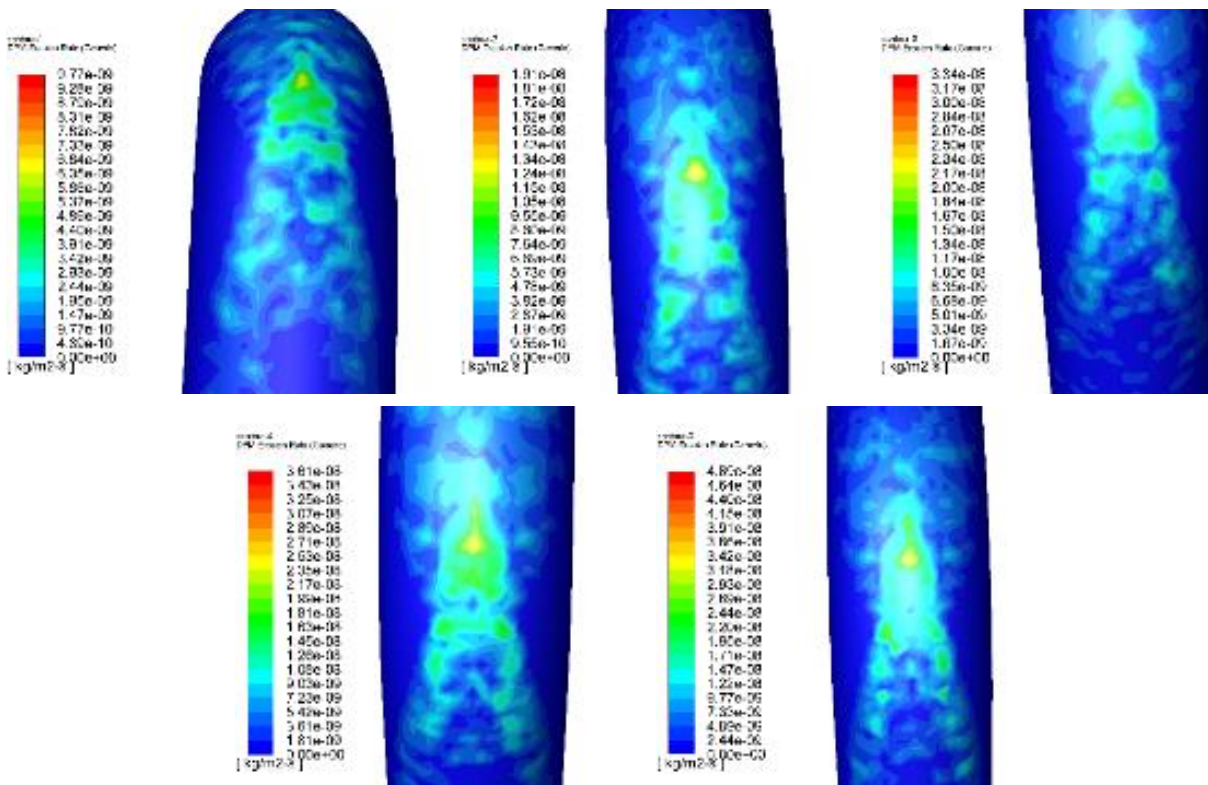
Fig. 3. Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 10 m/s stream velocity



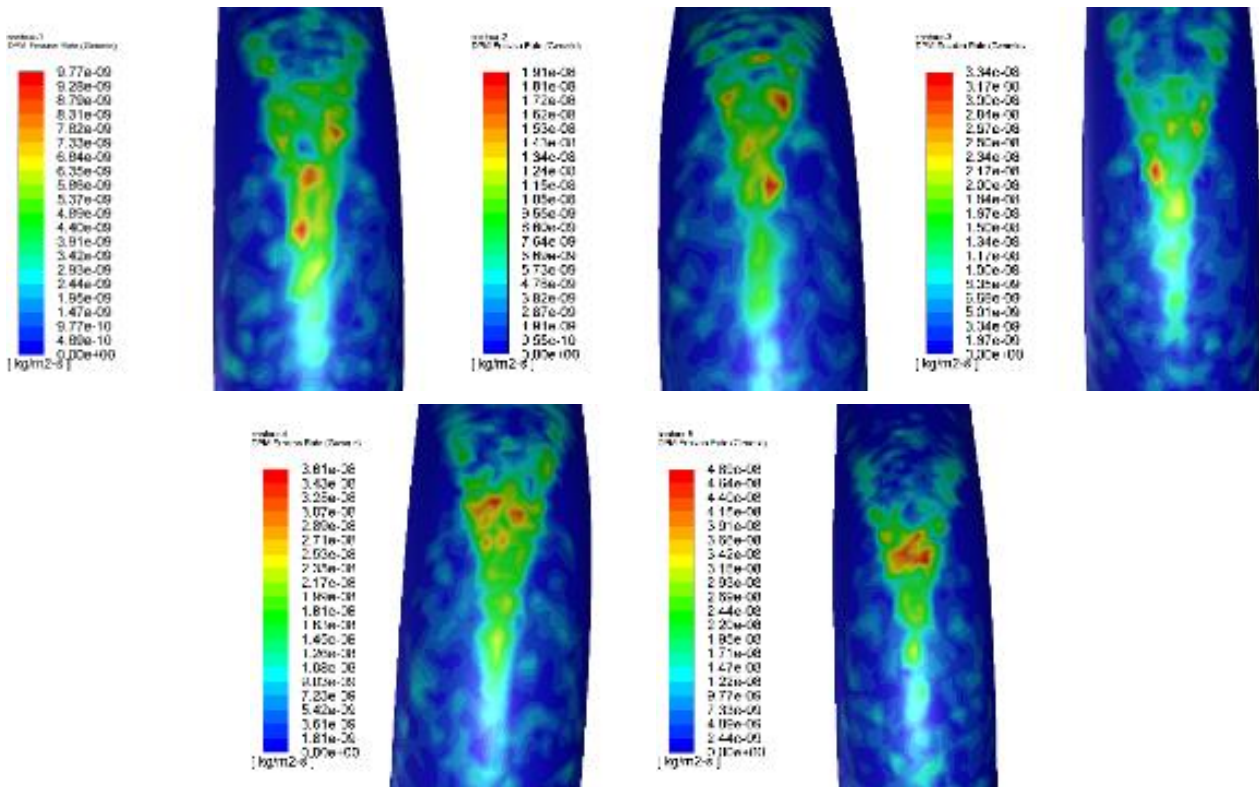
**Fig. 4.** Maximum erosion rate ( $\text{kg/m}^2.\text{s}$ ) for various loading station (%)

### 3.2 Effects of Flow Conditions Stream Velocity 15 m/s with Reynold Number $7,67 \times 10^7$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$  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.

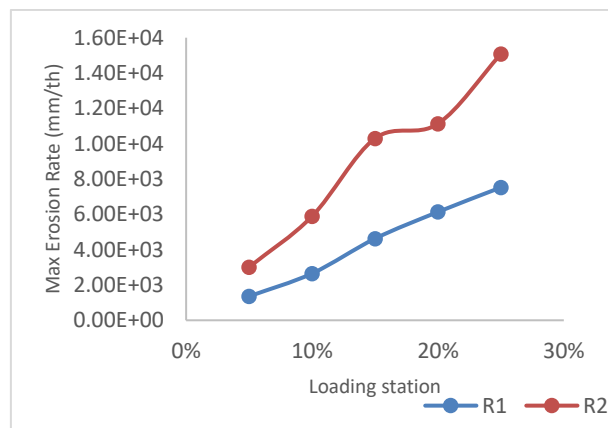


**Fig. 5.** Erosion rate surface contour in first elbow ( $\text{kg/m}^2.\text{s}$ ) for 15 m/s stream velocity



**Fig. 6.** Erosion rate surface contour in second elbow ( $\text{kg/m}^2.\text{s}$ ) for 15 m/s stream velocity

The relationship about solid loading and maximum erosion rate in Figure 7, shows that the higher of the solid loading, the higher the maximum erosion 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 ( $\text{kg/m}^2.\text{s}$ ) for various loading station (%)

### 3.3 Effects of Flow Conditions Stream Velocity 20 m/s with Reynold Number $1,08 \times 10^8$

Erosion rate surface contours for the particles diameter  $100 \mu\text{m}$  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.

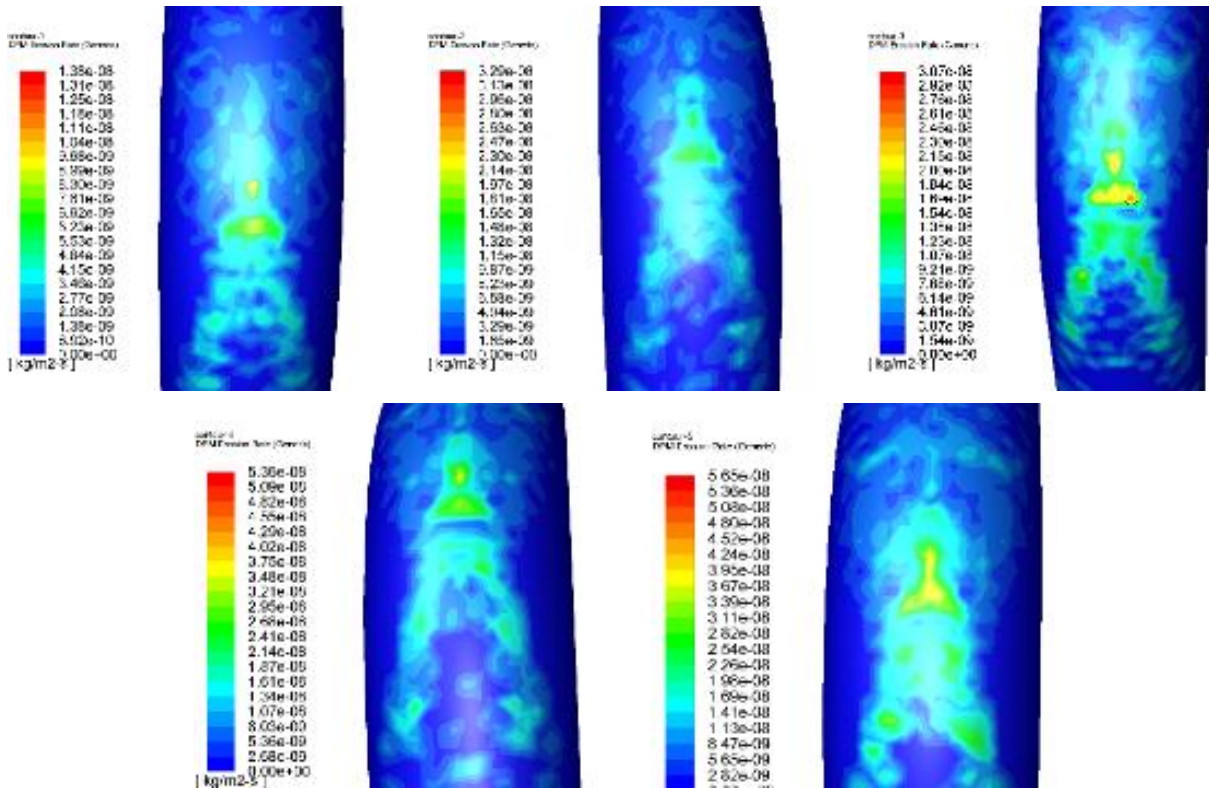


Fig. 8. Erosion rate surface contour in first elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 20 m/s stream velocity

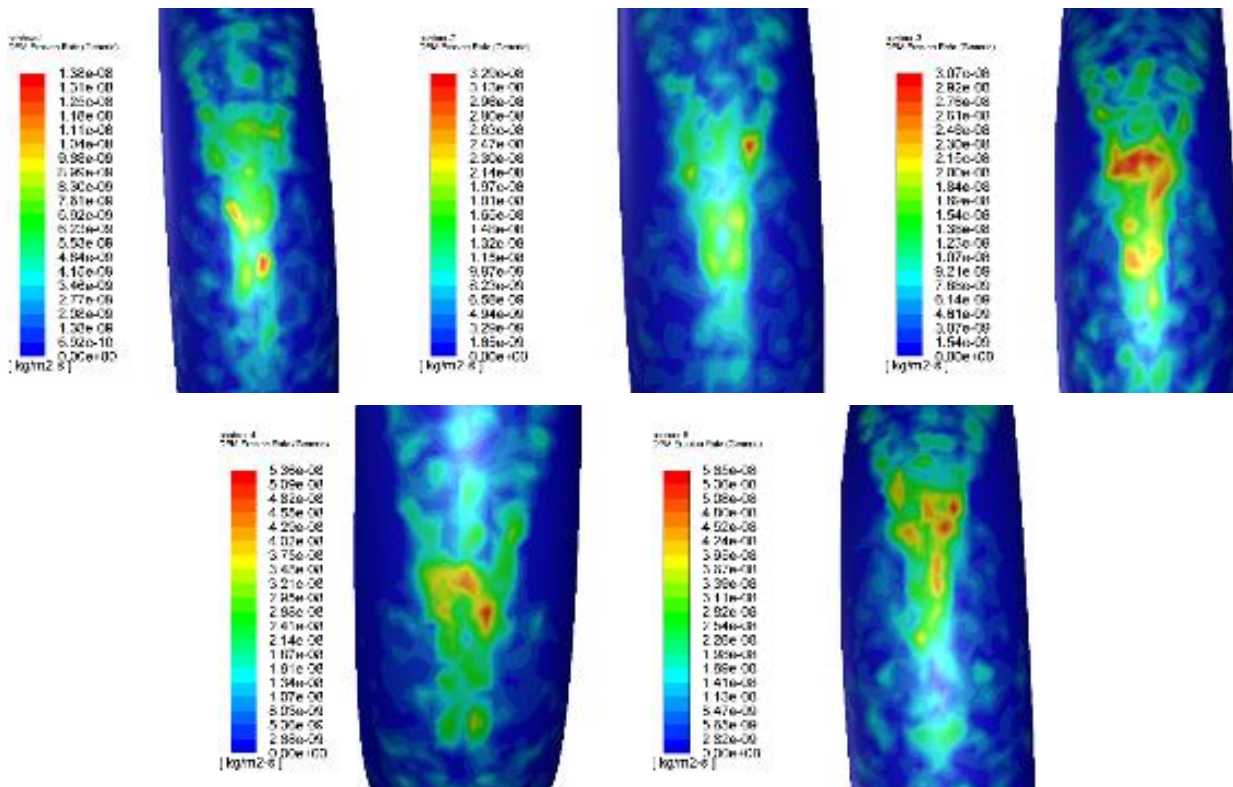
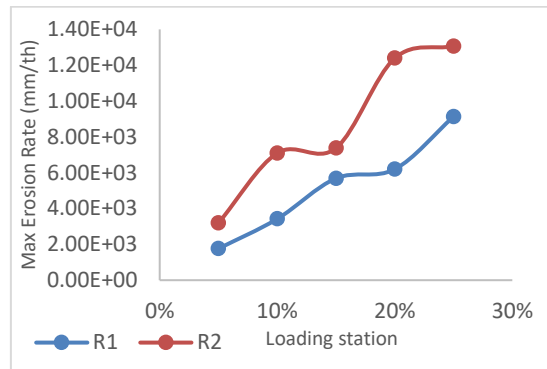


Fig. 9. Erosion rate surface contour in second elbow ( $\text{kg}/\text{m}^2.\text{s}$ ) for 20 m/s stream velocity

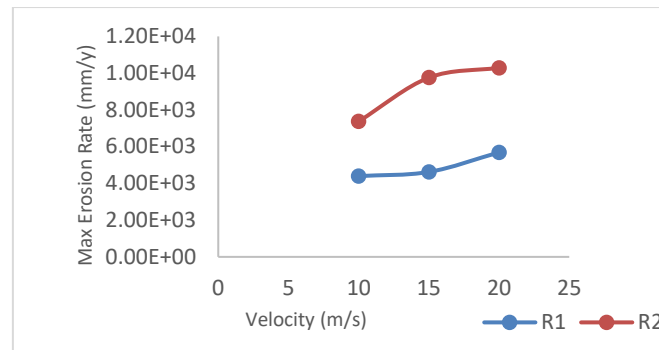
The relationship about solid loading and maximum erosion rate in Figure 10, shows that the higher of the solid loading, the higher the maximum erosion rate. This is because, the larger of solid loading leads to higher kinetic energy therefore, so it will produce larger or deeper indentations in the elbow 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 ( $\text{kg}/\text{m}^2.\text{s}$ ) for various loading station (%)

### 3.4 Effects of Stream Velocity Vs Maximum Erosion Rate

All of stream velocity show similarity in terms of the location of the maximum erosion 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 erosion 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 erosion rate, it can be seen that the higher the stream velocity, the greater the difference in the maximum erosion rate. This indicates that the application of the erosion 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 erosion 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 erosion 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 erosion rate will be produced.

#### Acknowledgement

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