SIMULATION OF SAND PARTICLE FLOW THROUGH SAND SCREEN IN OIL WELL

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Dissertation submitted in partial fulfilment of the

Requirement of the

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(Mechanical)

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CERTIFICATION OF APPROVAL

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Approved by,

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JANUARY 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the reference and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified source or person.

aldrin

(Muhammad Aldrin Syafrizal Bin Zamani)

Abstract

Sand production is a process occurs in oil and gas wells during the process of drilling recovery hole. The sandstone being drilled is left unsupported next to the cavity and dislodged sand grains can enter the oil recovery system. Sand production can cause several problems such as clogging up of the well or damage the wall equipment. Thus, the study of sand production is very important for safe and economical oil and gas production. Most of numerical models to predict the behaviour of sand in the well that have been used until now are continuum-based, but this approach cannot easily capture the important properties or features of the sand production problem and it is a difficult task due to the large number of interactions and non-linearities intrinsic to the problem. To counter this problem, discrete element-based approaches allow a simpler formulation of the problem and a better understanding of the sand production features. Discrete Element Method or DEM describes the problems more naturally of the disaggregation and erosion of sand particles and fluid-solid interaction. The main objective of this research is to gain the knowledge and understand on how long the sand takes to clog up the oil pipe on a Computational Fluid Dynamics (CFD - DEM coupling model. CFD - DEM is frequently used for process and chemical engineering problems (Zhu, Zhou, Yang, & Yu, 2007). To simulate the interaction of particles with fluid, CFD-DEM coupling is essential as DEM can only simulate particles while CFD can simulate. Thus, by coupling both CFD and DEM, one can simulate both in one simulation process.

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Chapter 1: Introduction

1.1. Background of Study

Oil and gas industry or also known as petroleum industry is an industry that explores, extracts, refining, transporting, and marketing of petroleum products. Oil and gas industry are divided into two sectors, namely upstream and downstream. Upstream is the is connected to exploration and exploration process, which involves searching for underwater or underground natural gas or crude oil fields and also the process of drilling the wells. Meanwhile, downstream refers to the filtering of raw materials obtained during the upstream phase and refining and purifying them. The crude oil and natural gas from the upstream are refined and purified into natural gas, diesel oil, petrol, gasoline, lubricants, kerosene, and many more which is then distributed to the end users.

This project will be focused on the upstream sectors, specifically the pipe that pull the crude oil from the fields. The pipe is designed to only pull the crude oil up, but it also has some flaws. One of the flaws is it also pull some sand up causing it to stick in pipe, this phenomenon is called sand production. Sand production is the cause of many problems in the oil industry and it affects the completion adversely. These problems include plugging the perforations or production liner, wellbore instability, failure of sand control completions (Willson, Moschovidis, & Cameron, 2002), collapse of some sections of a horizontal well in unconsolidated formations, environmental effects, additional cost of remedial and clean-up operations, and pipelines and surface facilities erosion, in case the sand gets out of the well. The mechanical prevention of sanding is costly and leads to low productivity/injectivity. Therefore, there is always a cost benefit if sand management and modelling is implemented early before well completions.

Sand production can occur if the material the cavity is disaggregated and additionally, the operation of the well generated sufficient seepage force (the viscous of drag water which flow through the interconnected pore spaces) to remove the sand grains. Sand production is a very complex phenomenon and it depends on various parameters such as stress distribution around the wellbore, the properties of the rock and fluids in the reservoir, and also the completion type of the reservoir. The causes of sand production can occur naturally as a result of unconsolidated nature of the formation or by the activities on the well imposed by humans. When this happens, it will cause agitation of the formation loose fines to disintegrate from the rock grains which leads to sand production along with hydrocarbon fluid, As stated by Anderson, Coates, Denoo, Edward, & Risnes (1986), that mechanical rock failure can be caused by any or more inherent rock strength, naturally existing earth stresses and additional stress cause by drilling or production. In totally unconsolidated formations, sand production may be triggered during the first flow of the formation fluid due to drag from the fluid or gas turbulence which detaches sand grains and carries them to the perforation. In the case of the unconsolidated formation, sanding can start due to changes in production rate, water breakthrough, change in gas/liquid ratio etc.

Therefore, these causes can lead to several problems during the lifetime of the wells drilled in a reservoir which a major problem. These can lead to many complications, such as formation damage or collapse by the flowing sand grains, wellbore instability, impairment or failure of down hole and surface equipment, and many more (Sylvester & Ikporo, 2015). Thus, researching the behaviour of sand particles in oil wells become much more important to counter these problems.

1.2. Problem Statement

As stated in the introduction, sand production in oil well is a major problem in the industry as it can cause damage to the system, environmental problem, erosion, flow lines blockage, and malfunction. It is obvious that a solution is badly needed to prevent sand production from happening. Although sand production is one of the major problems in oil and gas industry, there is still only a few researches covering the simulation of sand retention test. Thus, there is not enough data gathered on how the sand can behave in the pipelines. Secondly, the reason why sand production in oil wells are still happening is because there is no efficient method. There are a few methods to prevent the phenomenon from happening such as resin injection and installing screen with gravel pack, but these two methods have a big disadvantage such as they are very difficult to evenly applied, constricted to a certain level of temperature, as well as limited longevity. Thus, it can be said that there is still no efficient method to prevent the sand production from occurring.

1.3. Objectives

The main aim of this research is to gain knowledge and to understand on how long sand takes to clog up the oil pipe using CFD-DEM coupling model. CFD -DEM is frequently used for process and chemical engineering problems (Zhu, Zhou, Yang, & Yu, 2007). To simulate the interaction of particles with fluid, CFD-DEM coupling is essential as DEM can only simulate particles while CFD can simulate. Thus, by coupling both CFD and DEM, one can simulate both in one simulation process.

The objectives of the research reported in this thesis are:

1. To review the current available fluid-solid coupling techniques used in DEM in order to develop an appropriate model to study the sand production process.
2. To test the CFD-DEM model and to identify its limitations.
3. To develop and calibrate a DEM parallel-bond model for performing sand production simulations.

1.4. Scope of Study

The main focus of this project is to investigate the behaviour of the sand particles as it were trapped by the sand screen in the downhole. For this project to be successful, two simulation software will be used which is Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM). Combinations of CFD and DEM have been used to describe the behaviour of particles moving and colliding inside a flowing fluid. In sand retention test (SRT), the CFD-DEM coupled approaches are of interest as they promise to optimize screen design. CFD-DEM simulation will be developed to evaluate sand screen performance. The result of the simulation is then studied to find out the behaviour of sand particles in the SRT. For this project, the simulation will be affected by gravity only, no fluid flow will be simulate in this project.

Chapter 2: Literature Review

A significant proportion of the world oil and gas reserves is contained in weakly consolidated sandstone reservoirs and hence is prone to sand production (Rahmati, et al., 2012)**.** Sand production in oil and gas wells may occur if the fluid flow inside the pipelines exceed a certain threshold that is governed by a few factors. The factors include consistency of the reservoir rock (properties of reservoir such as porosity, permeability, and sealing mechanism), stress state, and the type of completion used around the well (open-hole or cased hole). The amount of solids can be less than a few grams per cubic meter of reservoir fluid, which poses only minor problem, or a substantial amount over a short period of time, resulting in erosion and in some cases filling and blocking of the wellbore (Rahmati, et al., 2012). Operations such as drilling, cyclic effects of shut in and start up, operational conditions, and reservoir pressure depletion can slowly lead to sandstone degradation around perforations and boreholes. Moreover, fluid flow is responsible for the transport and production of cohesionless sand particles or detached sand clumps to the wellbore.

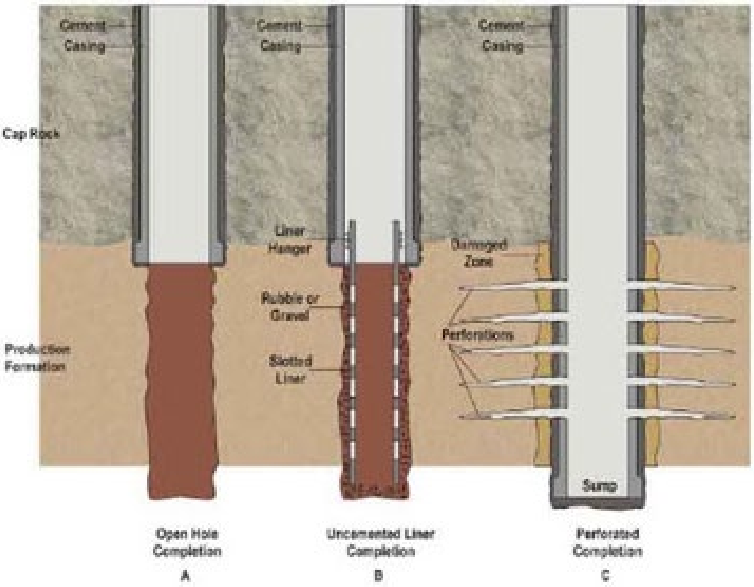


Figure 2.1 Basic types of completion

Sand production is the cause of many problems in the oil industry and it affects the completion adversely. These problems include plugging the perforations or production liner, wellbore instability, failure of sand control completions (Willson, Moschovidis, & Cameron, 2002), collapse of some sections of a horizontal well in unconsolidated formations, environmental effects, additional cost of remedial and clean-up operations, and pipelines and surface facilities erosion, in case the sand gets out of the well. The mechanical prevention of sanding is costly and leads to low productivity/injectivity. Therefore, there is always a cost benefit if sand management and modelling is implemented early before well completions. Sand production can occur if the material the cavity is disaggregated and additionally, the operation of the well generated sufficient seepage force (the viscous of drag water which flow through the interconnected pore spaces) to remove the sand grains. Sand production is a very complex phenomenon and it depends on various parameters such as stress distribution around the wellbore, the properties of the rock and fluids in the reservoir, and also the completion type of the reservoir. Due to the importance of the sand production prediction in oil and gas industry, many considerable efforts have been made in developing robust numerical methods for sand production prediction.

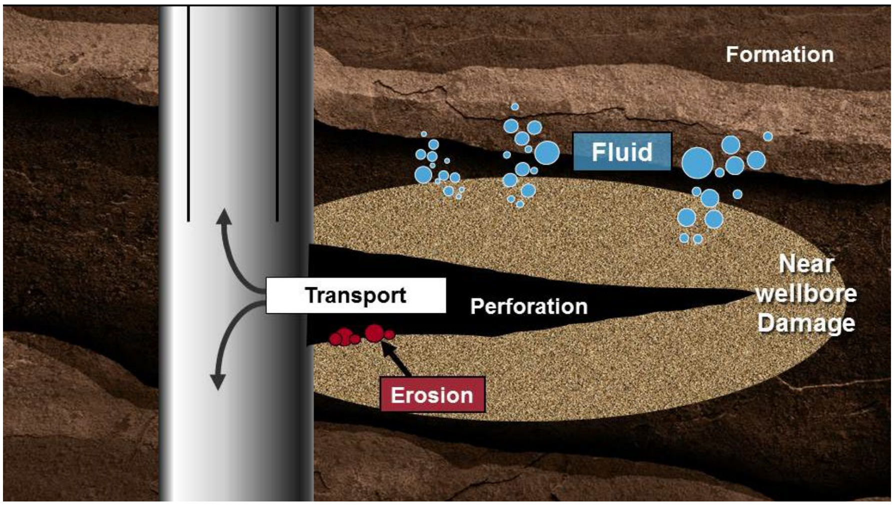
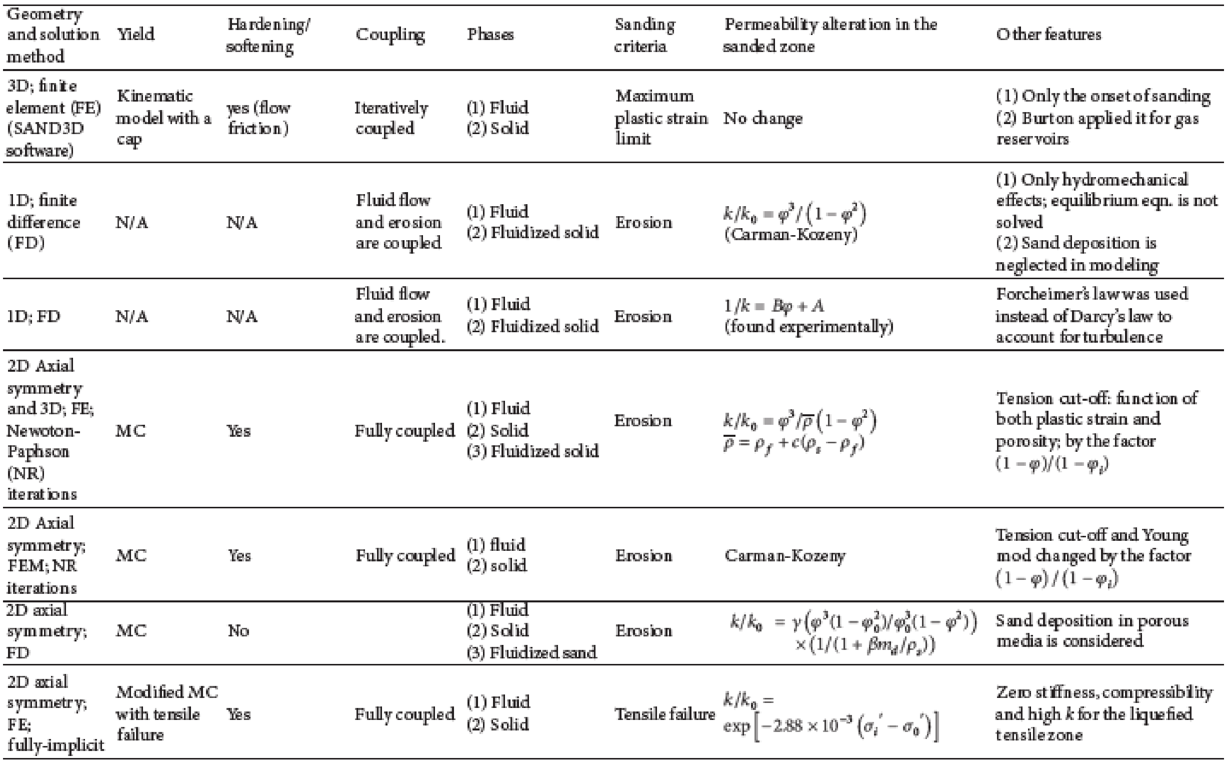
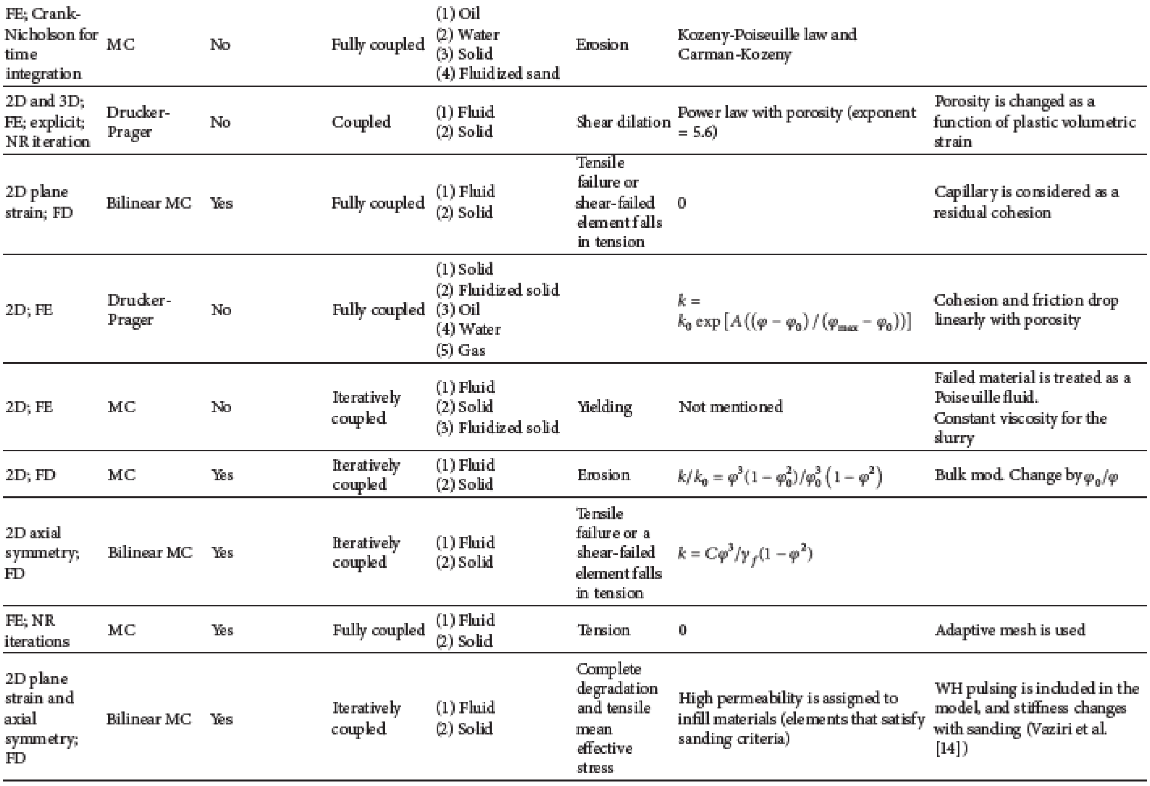


Figure 2.2 Process for sanding

According to Rahmati et. al (Rahmati, et al., 2012), the common techniques used in san management decisions are Numerical Models Based on Continuum Approach, Numerical Models Based on Discontinuum Approach, and Hybrid Approaches. The developments of continuum models in Numerical Models Based on Continuum Approach are based on various assumptions, constitutive laws, sanding criteria, and numerical procedures with different levels of complexity to capture the physical behaviour of the material. Figure 2.3 shows the majority of continuum- based sanding models. Sulem et. al (Sulem, Vardoulakis, Papamichos, Oulahna, & Tronvoll, 1999), in his article, said that rock failure or degradation is commonly accepted as prerequisite for sanding. Failure of geomaterials is usually associated with formation of shear bands which are narrow zones of concentrated plastic deformation. This phenomenon, known as "deformation localization ", is one of the key parameters in sanding prediction models.



Geometry and solution method	Yield	Hardening/ softening	Coupling	Phases	Sanding criteria	Permeability alteration in the sanded zone	Other features
3D; finite element (FE) (SAND3D software)	Kinematic model with a cap	yes (flow friction)	Iteratively coupled	(1) Fluid (2) Solid	Maximum plastic strain limit	No change	(1) Only the onset of sanding (2) Burton applied it for gas reservoirs
1D; finite difference (FD)	N/A	N/A	Fluid flow and erosion are coupled	(1) Fluid (2) Fluidized solid	Erosion	$k/k_0 = \varphi^3/\left(1-\varphi^2\right)$ (Carman-Kozeny)	(1) Only hydromechanical effects; equilibrium eqn. is not solved (2) Sand deposition is neglected in modeling
1D; FD	N/A	N/A	Fluid flow and erosion are coupled.	(1) Fluid (2) Fluidized solid	Erosion	$1/k = B\varphi + A$ (found experimentally)	Forcheimer's law was used instead of Darcy's law to account for turbulence
2D Axial symmetry and 3D; FE; Newoton-Paphson (NR) iterations	MC	Yes	Fully coupled	(1) Fluid (2) Solid (3) Fluidized solid	Erosion	$k/k_0 = \varphi^3/\overline{\rho}\left(1-\varphi^2\right)$ $\overline{\rho} = \rho_f + c(\rho_s - \rho_f)$	Tension cut-off: function of both plastic strain and porosity; by the factor $(1-\varphi)/(1-\varphi_i)$
2D Axial symmetry; FEM; NR iterations	MC	Yes	Fully coupled	(1) fluid (2) solid	Erosion	Carman-Kozeny	Tension cut-off and Young mod changed by the factor $(1-\varphi)/(1-\varphi_i)$
2D axial symmetry; FD	MC	No		(1) Fluid (2) Solid (3) Fluidized sand	Erosion	$k/k_0 = \gamma\left(\varphi^3(1-\varphi_0^2)/\varphi_0^3(1-\varphi^2)\right) \times (1/(1+\beta m_d/\rho_s))$	Sand deposition in porous media is considered
2D axial symmetry; FE; fully-implicit	Modified MC with tensile failure	Yes	Fully coupled	(1) Fluid (2) Solid	Tensile failure	$k/k_0 = \exp\left[-2.88\times10^{-3}\left(\sigma_i' - \sigma_0'\right)\right]$	Zero stiffness, compressibility and high k for the liquefied tensile zone



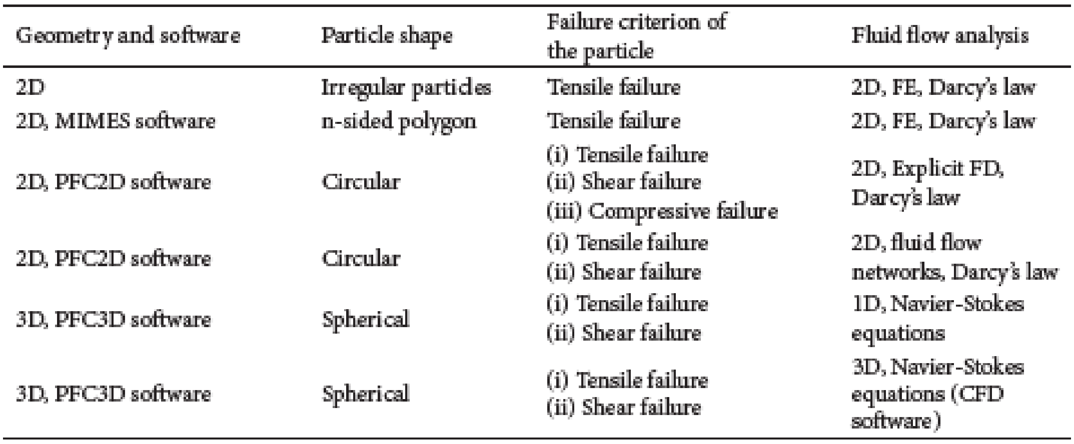
FE; Crank-Nicholson for time integration	MC	No	Fully coupled	(1) Oil (2) Water (3) Solid (4) Fluidized sand	Erosion	Kozeny-Poiseuille law and Carman-Kozeny	
2D and 3D; FE; explicit; NR iteration	Drucker-Prager	No	Coupled	(1) Fluid (2) Solid	Shear dilation	Power law with porosity (exponent = 5.6)	Porosity is changed as a function of plastic volumetric strain
2D plane strain; FD	Bilinear MC	Yes	Fully coupled	(1) Fluid (2) Solid	Tensile failure or shear-failed element falls in tension	0	Capillary is considered as a residual cohesion
2D; FE	Drucker-Prager	No	Fully coupled	(1) Solid (2) Fluidized solid (3) Oil (4) Water (5) Gas		$k = k_0 \exp\left[A\left((\varphi - \varphi_0)/(\varphi_{\max} - \varphi_0)\right)\right]$	Cohesion and friction drop linearly with porosity
2D; FE	MC	No	Iteratively coupled	(1) Fluid (2) Solid (3) Fluidized solid	Yielding	Not mentioned	Failed material is treated as a Poiseuille fluid. Constant viscosity for the slurry
2D; FD	MC	Yes	Iteratively coupled	(1) Fluid (2) Solid	Erosion	$k/k_0 = \varphi^3(1-\varphi_0^2)/\varphi_0^3\left(1-\varphi^2\right)$	Bulk mod. Change by φ_0/φ
2D axial symmetry; FD	Bilinear MC	Yes	Iteratively coupled	(1) Fluid (2) Solid	Tensile failure or a shear-failed element falls in tension	$k = C\varphi^3/\gamma_f(1-\varphi^2)$	
FE; NR iterations	MC	Yes	Fully coupled	(1) Fluid (2) Solid	Tension	0	Adaptive mesh is used
2D plane strain and axial symmetry; FD	Bilinear MC	Yes	Iteratively coupled	(1) Fluid (2) Solid	Complete degradation and tensile mean effective stress	High permeability is assigned to infill materials (elements that satisfy sanding criteria)	WH pulsing is included in the model, and stiffness changes with sanding (Vaziri et al. [14])

Figure 2.3 Summary of the numerical works on sand production (continuum approach)

In continuum approach, several mechanisms are recognized as responsible for sand production which is mainly based on shear and tensile failure, critical pressure gradient, critical drawdown pressure, critical plastic strain, and erosion criteria. When the effective minimum principal stress is equal to the tensile strength of the formation rock, tensile failure may occur. This mode of failure is responsible for rock degradation. It can occur as a standalone degradation mechanism or in combination with shear failure (Crook, Willson, Yu, & Owen, 2003). Tensile mode is also believed to be responsible mechanism for particle removal after degradation during production.

On the other hand, sand production is a continuous and dynamic process that occurs at microscopic scale and the rock become discontinuum in nature and continuum approaches cannot capture local discontinuous phenomena. Thus, discontinuum approach is a promising approach to simulate the phenomena. Cundall (Cundall P. A., A computer model for simulating progressive large scale movement in blocky rock systems, 1971) first introduced the Discrete

Element Method (DEM). The method can be used to simulate the disintegration of granular media subjected to loading. Each particle of the granular media is considered as an individual entity with a geometric representation of its surface topology and a description of its physical state. Particle bonds are modelled with a spring-dashpot in the normal direction and a spring-dashpot-frictional slider in the tangential direction. In DEM, the interaction of the particles is treated as a dynamic process and a state of equilibrium is reached whenever the internal forces are equal to the external forces. The contact forces and displacements of a stressed assembly of particles are found by tracing the movements of the individual particles (Cundall & Potyondy, 2004). Some of the discontinuum-based sanding models are summarized in Figure 2.4.



Geometry and software	Particle shape	Failure criterion of the particle	Fluid flow analysis
2D	Irregular particles	Tensile failure	2D, FE, Darcy's law
2D, MIMES software	n-sided polygon	Tensile failure	2D, FE, Darcy's law
2D, PFC2D software	Circular	(i) Tensile failure (ii) Shear failure (iii) Compressive failure	2D, Explicit FD, Darcy's law
2D, PFC2D software	Circular	(i) Tensile failure (ii) Shear failure	2D, fluid flow networks, Darcy's law
3D, PFC3D software	Spherical	(i) Tensile failure (ii) Shear failure	1D, Navier-Stokes equations
3D, PFC3D software	Spherical	(i) Tensile failure (ii) Shear failure	3D, Navier-Stokes equations (CFD software)

Figure 2.4 Summary of the numerical works on sand production (Discontinuum approach)

Lastly comes the hybrid approaches. Continuum and discontinuum approaches have their own advantages and disadvantages and by considering them a hybrid model combining both approaches can be practical and efficient in sand production modelling. Continuum-based approaches can be used where the deformation is small while discontinuum approaches can be used to described large deformation or discontinuity near the wellbore or the perforations (Rahmati, et al., 2012). Using the hybrid approach, accurate and descriptive simulation of field scale problems becomes possible.

Cundall & Strack (1979) originaly proposed to present macroscopic behaviour of behaviour particulate matter through the interactions between discrete individual particles that usually have simple geometries such as spheres or discs. These particles which are ideal are rigid but small overlaps are allowed at contact points when soft contact model is applied and if the overlap between these particles no longer exist, the particles are allowed to lose contact. DEM can provide micromechaniocal quantities and parameters that cannot be easily obtained from experimental tests and it can capture the particle-scale interactions underlying the observed macro-scale behaviour of soils anf other geomaterials (O'Sullivan, 2011). DEM simulation can provide a lot of dynamic information as example, trajectories and transient force, which are very difficult to obtain by traditional physical experimentation.

There are two types of DEMs related to contact forces, which are soft-particle and hard-particle approaches (Zhu, Zhou, Yang, & Yu, 2007). Hard particle models interaction forces are assumed to be impulsive and hence the particles only exchange momentum by means of collision (Hoomans, Kuipers, Briels, & van Swaaij, 1996). This method is most useful in rapid granular flows. Meanwhile, soft-sphere method originally developed by Cundall & Strack (1979) was the first granular dynamics simulation technique published in open literature. In this approach, the particles are permitted to suffer minute deformations, and these deformations are used to calculate elasticm frictional, and plastic forces between the particles. This approach is most commonly used in linear frictional model and Hertz-Mindlin model.

In DEM simulations, displacement and force boundary conditions are commonly used and they can be achieved by fixing or specifying the coordinated of selected particles by applying displacements to selected particles or by applying a specified force to selected particles. However, these force boundary conditions cannot easily be directly used with systems that include thousands of particles as the system deforms. Consequently, algorithms to select boundary particles are needed. There are different kind of boundary conditions that can be applied in DEM, as periodic walls or membrane boundaries. In this thesis rigid walls are systematically used to apply boundary conditions. The most used boundary type is rigid wall, which are analytically described surfaces that can be planar or curved. The rigid wall can be used to simulate inclusions or machinery interacting with granular material. For example, Butlanska, Arroyo, & Gens (2009) and Climent, Butlanska, Arroyo, & Gens (2011) used rigid wall boundaries to represent cone penetration testing (Figure 2.5)

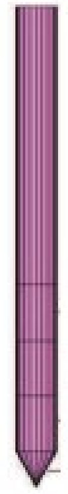


Figure 2.5 DEM Boundaries in a cone penetration test (Butlanska et al., 2009)

The variables obtained using DEM are discrete variables as forces, particle displacements, particle radii, stresses on particles or particles velocities. Rocky DEM is used in this thesis to simulate sand flow in a pipe and the result from the simulation can also be shown using the Rocky DEM software.

On the other hand, CFD are a method to obtain numerical solutions discretizing and approximating differential equation described by fluid flow by a system of algebraic equations (Ferziger & Peric, 1999). Fluid dynamics describes the behaviour of fluid, focusing them on macroscopic level, where fluid is treated as continuum medium. The fluid particle is not actually a single molecule, but consists of a large number of molecules in a small region with respect to the scale of the considered domain, but still sufficiently large in order to be able to define a meaningful and non-ambiguous average of the velocities and other properties of the individual molecules and atoms occupying the volume and the approximation are applied and given at discrete locations in space and time (Ferziger & Peric, 1999). ANSYS software is used to simulate flow and results such as contours, iso-surfaces, vector fields, streamlines, arrows, cones, and spheres from scalars and vectors from the simulation can be shown.

CFD-DEM coupling is derived from classical treatment of fluidized dense suspensions (Anderson & Jackson, 1967). In the coupling, a pore-scale locally averaged version pf Navier-Stokes equations are used to represent fluid motion and solved numerically using CFD techniques. In CFD-DEM, the particle velocity adds drag force to the fluid momentum balance equations and the porosity affects directly the flow through the fluid governing equations. Each particle has their own properties while the fluid velocity is the same for entire cell.

Sand production process has been studied by several researchers using different particle-fluid coupling methods with DEM (e.g., Dorfmann et al., 1997; O'Connor et al., 1997; Cook et al., 2004). Most of them are 2D-DEM-based models and the fluid flow assumed Darcy's law, therefore implicitly disregarding fluid flows with a high Reynolds number. Thus, using simulation to describe the behaviour of sand in SRT is the best approach. For this research, ANSYS Fluent and Rocky DEM will be used so that the results can be as accurate as possible.

Chapter 3: Methodology

3.1. Project Details

3.1.1. Identify the alternatives to conduct the project

From the researches carried, there are a few simulation software alternatives that can be used such as ANSYS, Rocky, SimScale, and Autodesk. From all these alternatives, the best software to used is ANSYS and Rocky as Universiti Teknologi PETRONAS (UTP) already has the license to the software and Rocky DEM can be easily integrated with ANSYS.

ANSYS is a Computational Fluid Dynamics (CFD) simulation software. CFD is the application of algorithm and numerical techniques to solve fluid problem and in CFD, the fluid body is divided into small fluid elements called cells. Algebraic variables are attributed to each flow characteristic of each cell such as mass, pressure, and velocity. The interfaces of fluid body are used as boundary conditions. Unfortunately, CFD can only be used to simulate fluid and not solid particles like sand. In order to simulate sand and fluid together, Rocky DEM must be used.

Discrete Element Method (DEM) is a numerical technique to simulate behaviour of population of independent particles. In DEM, each particle is represented numerically and is identified with its specific properties such as shape, size, and material properties. The interior shape of a domain containing the particle is used as the domain of the simulation and is separated into grids to identify the particle’s position. Particles are then subjected to a small motion over a small-time interval. The motion will cause the particles to make contacts with other particles or the domain boundaries or walls. The contacts are monitored and produces discrete reaction forces on each particle. The magnitude of the contacting forces is determined by a contact model. The summation of the total force on each particle is then computed and forces created by external factors can be added. Newton’s laws of motion are then used to determine the motion parameters of each particle over small time interval. The new position of particles is then computed, and the process of contact detection can restart for the next iteration. After computation of every time step, the particles’ behaviour can be known and hence the bulk behaviour of the particles is known. The combinations of CFD and DEM are going to be used to describe the behaviour of particles moving and colliding inside a flowing fluid.

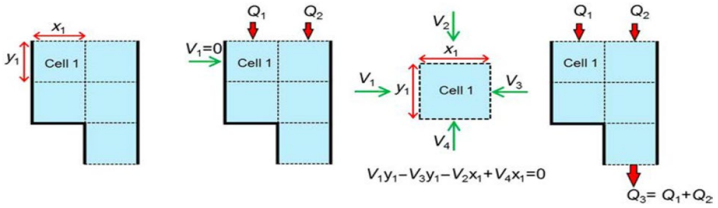


Figure 3.1 simplified application of CFD technique

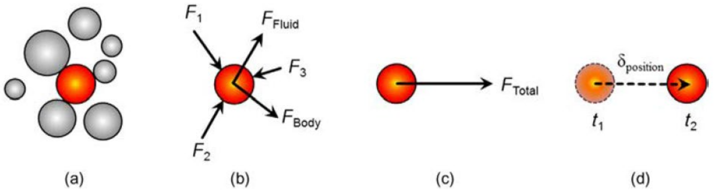


Figure 3.2 Process of DEM

3.1.2. Understanding the software to be used

After deciding which simulator to use, the next step is to learn and understand how to use them. Both ANSYS and Rocky DEM have the same components which are pre-processing, solver, and lastly, post-processing. Pre-processing is a process that must be performed before doing the actual simulation. During this process, the user needs to develop a geometry, generate mesh, and define the boundary conditions. The second component is the solver. Solver is where the software (ANSYS and Rocky DEM) will perform discretisation and solve relevant equations according to the boundary condition. The last component of the software is post-processor. Post-processing process is a stage where the output of numerical simulation is visualized using external or built-in visualisation programs. In these programs, the domain geometry and the grid can be displayed.

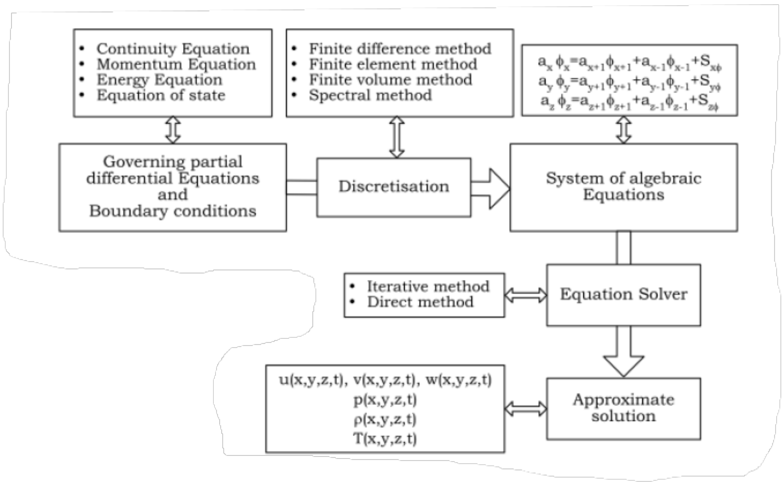


Figure 3.3 CFD solver component working principle

3.1.3. Developing the simulation

3.1.3.1. Creating 3-Dimensional pipe

To create a 3D object, a pipe with a sand mesh in this case, the software used in ANSYS. For this research three different pipe with three different kind of sand screen is created to investigate which sand screen will clogged up faster while the dimension of the pipe and the flow rate is kept constant. Figure 3.6 shows an example of the 3D pipe with a sand retention.

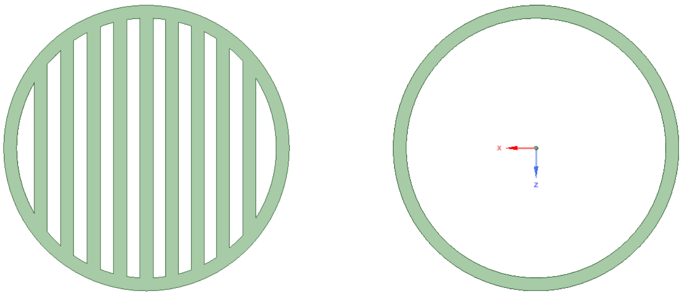


Figure 3.4 Pipe with a straight sand screen

Using the data received from PETRONAS Research Sdn Bhd (PRSB) as example, a pipe geometry with a sand screen at the centre can be developed. The geometry of the project is shown in Figure 3.7. From the geometry, mesh size can be generated. The accuracy of the result is dependent on the mesh size. The smaller the mesh size the longer the time it takes to simulate but the result will be more accurate as the smaller mesh will cover more areas to be calculated. Defining boundary conditions is one of the most important steps in developing the simulation. If wrong boundary condition is defined, the result will be wrong, thus it is very crucial to define the correct boundary condition. In the case of this project, there are only two boundary condition, which are velocity inlet, where the oil and sand particles will flow, and the outlet. For this research, a few of geometries of the sand screen will be tested, the other variables such as the flow rate of the sand, size of sand, and duration of sand inlet will be constant.

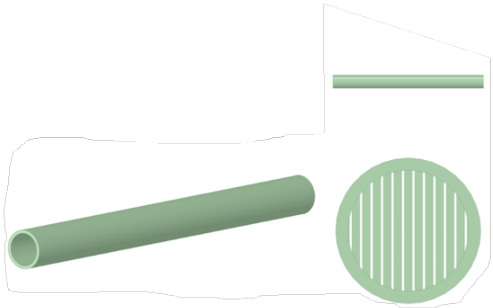


Figure 3.5 Geometry of pipe with sand screen

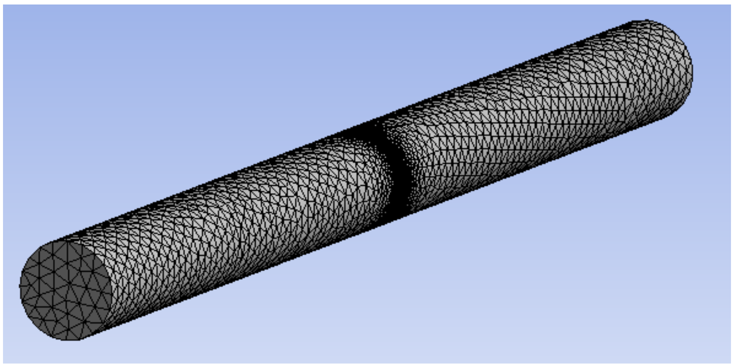


Figure 3.6 Defining mesh size and boundary condition

After getting the results using the first mesh size, the next step is to find the mesh independency. Mesh independency solution is a solution that does not vary significantly even the mesh size is refined even further. The purpose of finding mesh independency is to find the optimum mesh size that will give the best result

3.1.3.2. Simulating the object with particles

For this part, Rocky DEM software is used to create a simulation where sand is flowing through the pipe. In this part, the flow rate is constant, but if the pipe is not clog, the flow rate will be increased until the pipe is clog. Figure 3.9 shows an example of the simulation. For this project, the simulation is purely affected by gravity and no fluid low.

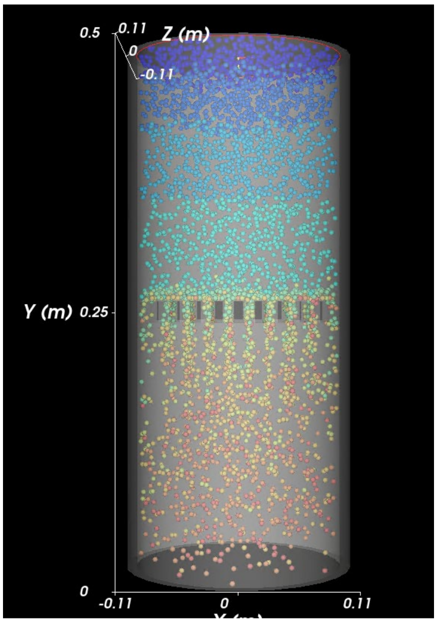
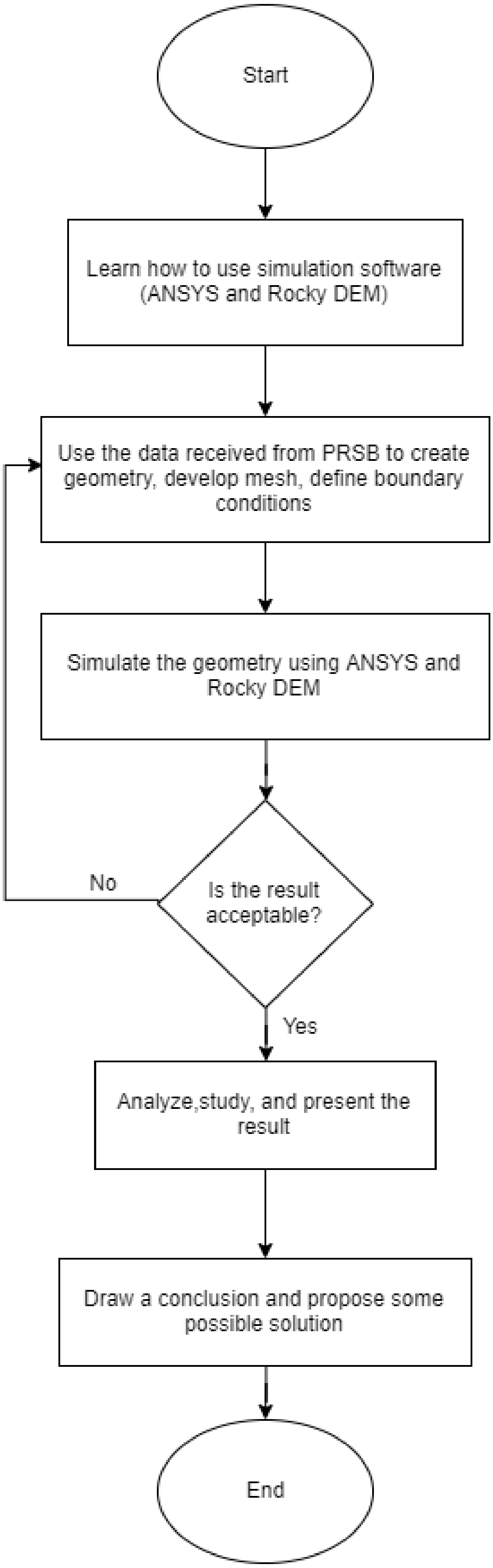


Figure 3.9 Simulation of sand retention test using Rocky DEM

3.1.4. Study the result of the simulation

The last step of this project is to study intensively the behaviour of the sand in the pipe with sand screen. Based on the result, conclusion will be drawn and some possible solution to prevent sand production will be given.

3.2. Project Flow Chart



3.3. Gantt Chart and Key Milestone

Table 3.1 FYP 1 Gantt Chart and Key Milestone

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of project title	🟩													
Identification of problem		🟩												
Extensive literature review		🟩	🟩	🟩										
Proposal for the project					🟩	🟩	🟩	⬛						
Selecting methodology							🟩	🟩	⬛					
Familiarization with ANSYS and Rocky DEM			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Table 3.2 FYP 2 Gantt Chart and Key Milestone

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Setting up the software based on data	🟩	🟩	🟩											
Set the boundary conditions of the simulation			🟩	⬛										
Run the simulation				🟩	🟩	🟩	⬛							
Results analysis of the simulation							🟩	⬛						
Report and documentation of the project							🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬛

Legends:

🟩 Project Progress

⬛ Key Milestone

Chapter 4: Results and Discussions

4.1. Simulation of the First Sand Screen Geometry

4.1.1. 3-Dimensional drawing of pipe

For the first simulation, the geometry of the sand screen is 9 straight cylindrical shape in the middle of the pipe as shown in Figure 4.1. The drawing is done in ANSYS software and saved in stereolithography format.

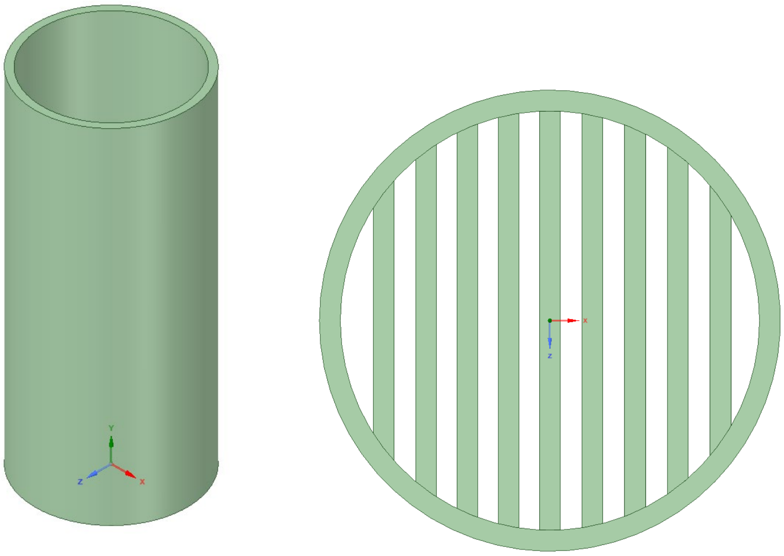


Figure 4.1 3D drawing of pipe with the first sand screen geometry

Properties of the drawing are as below:

Table 4.1 Properties of the first 3D drawing

Inner Diameter	200mm
Outer Diameter	220mm
Height	500mm
Thickness of sand screen	20mm
Gap between sand screen	10mm

4.1.2. Importing the 3D drawing into Rocky DEM simulation software

To import the 3D drawing, the format of the drawing must be in stereolithography (stl) format as the Rocky DEM software can only read in that format. The imported 3D drawing can be seen in Figure 4.2.

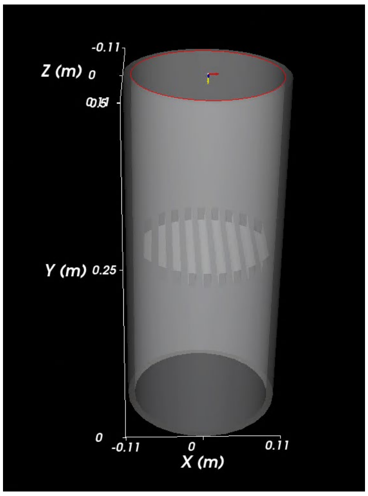
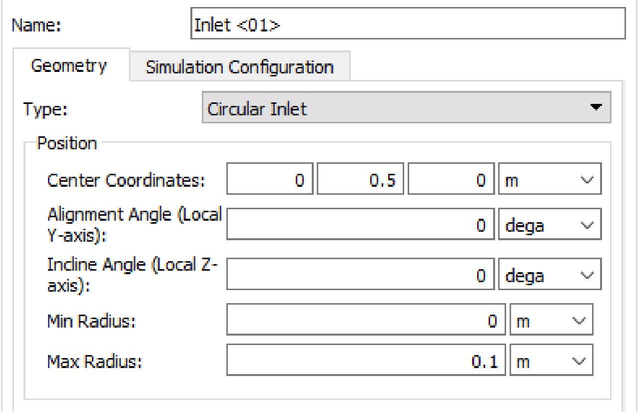


Figure 4.2 3D drawing as seen in Rocky DEM software

From Figure 4.2, the red circle at the top of the pipe is acting as the inlet where particles will flow from. The properties of the inlet are:



Name: Inlet <01>
Type: Circular Inlet
Center Coordinates: 0 0.5 0 m
Alignment Angle (Local Y-axis): 0 dega
Incline Angle (Local Z-axis): 0 dega
Min Radius: 0 m
Max Radius: 0.1 m

Figure 4.3 Properties of the inlet

4.1.3. Creating the geometry of particle

To simulate the particles, firstly, the shape and properties of the particles need to be determined. Rocky DEM has the tools to create the particles and Figure 4.4 and Figure 4.5 shows the shape and the properties of the particle respectively.

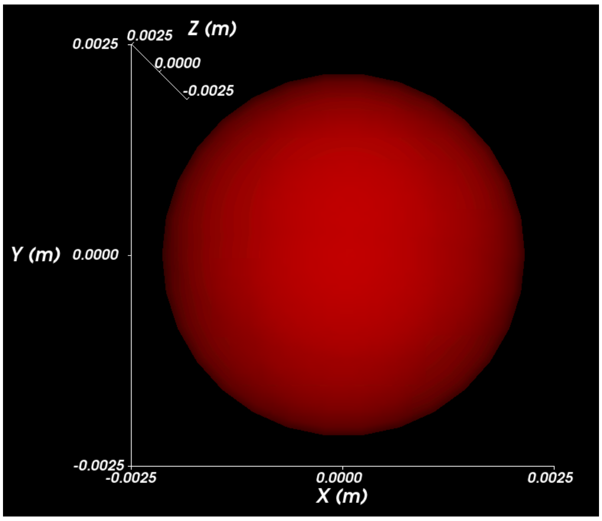
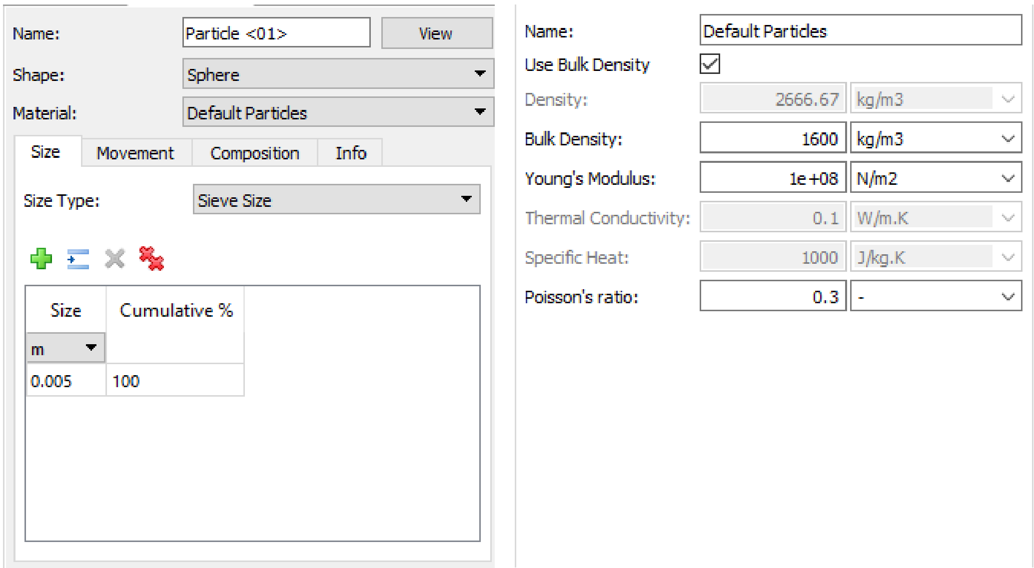


Figure 4.4 Shape of particle


Name: Particle <01>
Shape: Sphere
Material: Default Particles
Size Type: Sieve Size

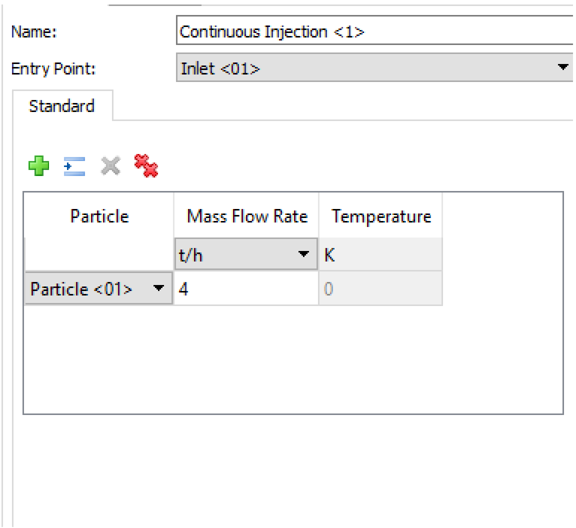
Size	Cumulative %
m	
0.005	100

Name: Default Particles
Use Bulk Density ☑
Density: 2666.67 kg/m3
Bulk Density: 1600 kg/m3
Young's Modulus: 1e+08 N/m2
Thermal Conductivity: 0.1 W/m.K
Specific Heat: 1000 J/kg.K
Poisson's ratio: 0.3 -

Figure 4.5 Properties of particles

4.1.4. Simulating the sand particles through the pipe

For the simulation part, the flow rate of the particles needs to be determined first before the simulation can begin as shown in Figure 4.6.



Name: Continuous Injection <1>

Entry Point: Inlet <01>

Particle	Mass Flow Rate	Temperature
	t/h	K
Particle <01>	4	0

Figure 4.6 Flow rate of sand particles entering the pipe

For this research, the flow rate of the sand particles will be constant through all simulation.

Figure 4.7 shows the results of the simulation. The sand particles entering the pipe is set to 10 seconds and another 10 seconds is to see whether the sand can still flow through the pipe or it will clog the pipe.

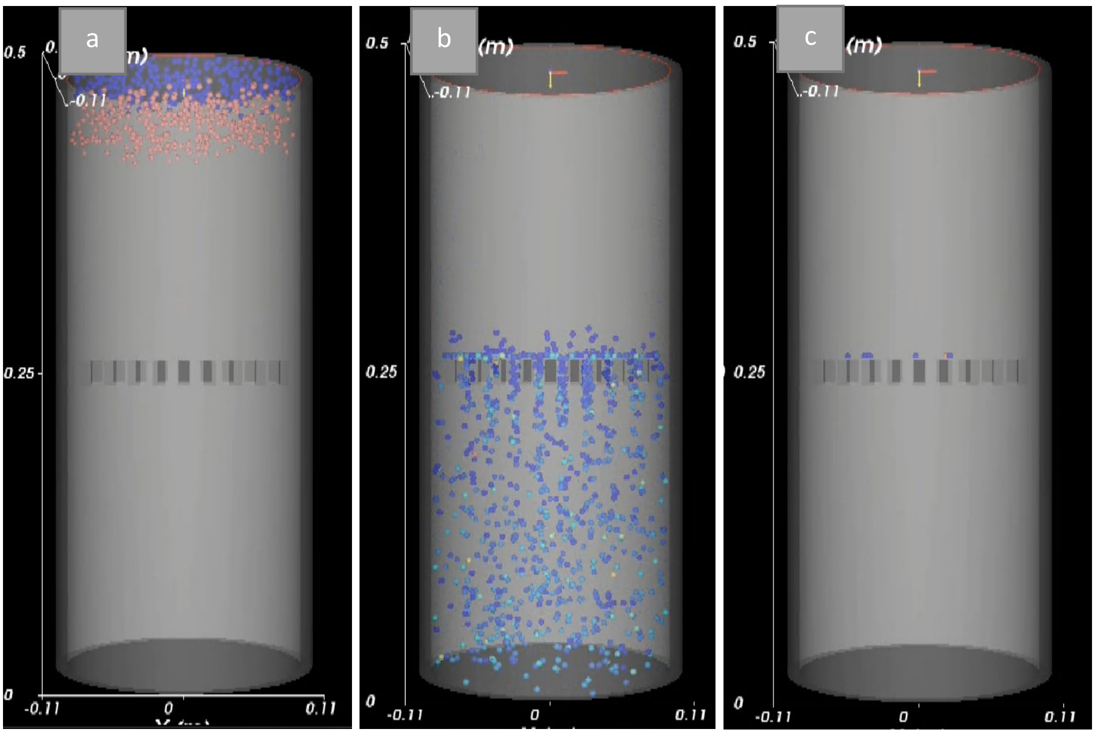


Figure 4.7 Results of the simulation for pipe with the first geometry sand screen(**a.** Sand entering the pipe at 0s **b.** sand stop entering at 10s. **c.** Results of the simulation at the end of 20s)

4.1.5. Conclusion

From the result of the simulation in Figure 4.7, it can be concluded that the first geometry of the sand screen did not cause the pipe to clog even after 10 seconds of sand entering the pipe with 4 t/h flow rate. This may be because the gap between the cylinder of the sand screen is too big (10 mm) for the sand particles (5 mm) and the sand can easily flow through the sand screen.

4.2. Simulation of the Second Sand Screen Geometry

4.2.1. 3-Dimensional drawing of pipe

For the second simulation, the geometry of the sand screen is rectangular shape with size in the range of 7mm to 14mm in the middle of the pipe as shown in Figure 4.8. The drawing is done in ANSYS software and saved in stereolithography format.

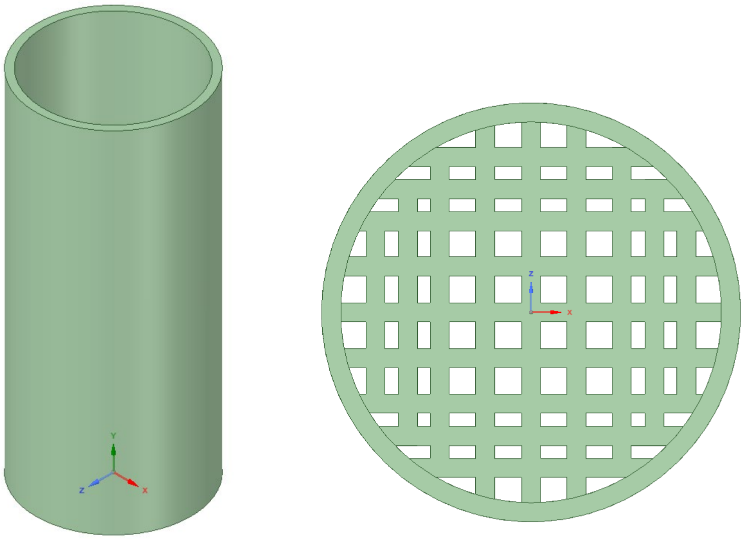


Figure 4.8 3D drawing of pipe with the second sand screen geometry

Properties of the drawing are as below:

Table 4.2 Properties of the second 3D drawing

Inner Diameter	200mm
Outer Diameter	220mm
Height	500mm
Thickness of sand screen	20mm
Gap between sand screen	7mm – 14mm

4.2.2. Importing the 3D drawing into Rocky DEM simulation software

The method of importing as the same as first pipe geometry. The imported 3D drawing can be seen in Figure 4.9.

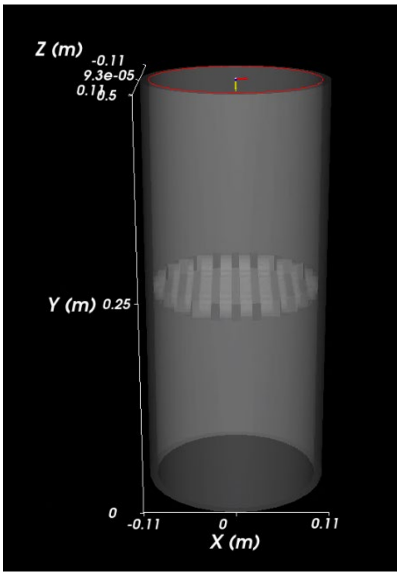


Figure 4.9 3D drawing as seen in Rocky DEM software

4.2.3. Creating the geometry of particle

The geometry of the particles is the same as the first simulation.

4.2.4. Simulating the sand particles through the pipe

For this simulation, the flow rate is also the same as the first sand screen geometry’s simulation.

Figure 4.10 shows the results of the simulation. The sand particles entering the pipe is set to 10 seconds and another 10 seconds is to see whether the sand can still flow through the pipe or it will clog the pipe.

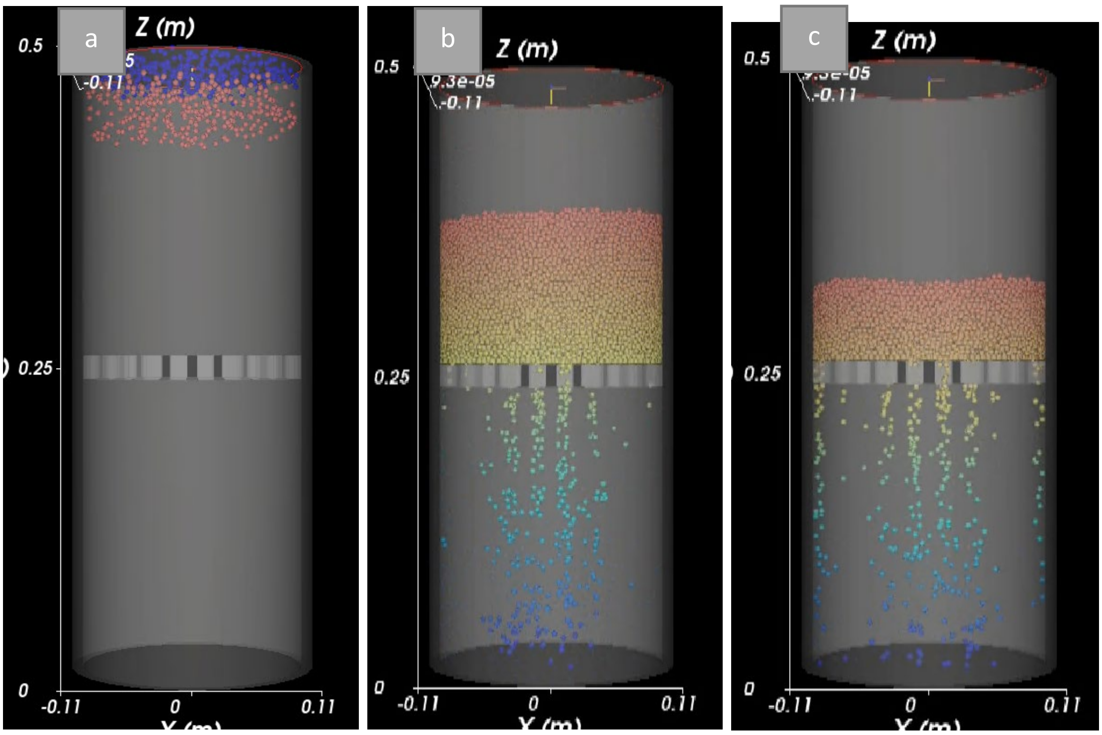


Figure 4.10 Results of the simulation for pipe with second geometry sand screen (**a.** Sand entering the pipe at 0s **b.** sand stop entering at 10s. **c.** Results of the simulation at the end of 20s)

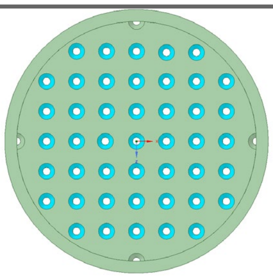
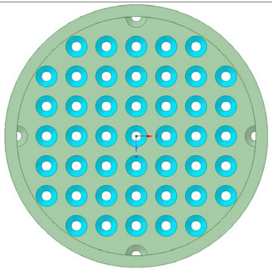
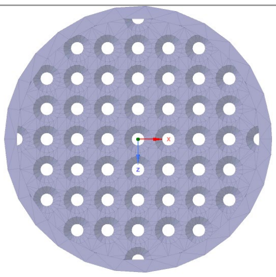
4.2.5. Conclusion

From the result of the simulation in Figure 4.10, it can be concluded that the second geometry of the sand screen did cause the pipe to clog after 10 seconds of sand entering the pipe with 4 t/h flow rate, but the sand still can flow through the sand screen but at a slower rate. If the simulation is extended longer, all the sand particles can go through the sand screen. In conclusion this geometry can cause the pipe to clog while the first geometry did not.

4.3. Simulation of the Third Sand Screen Geometry

For the third sand screen geometry, there are three different hole size and three different particles' sizes. Table 4.3 shows the 3D drawings for all three pipes with their specification. The outer and inner diameter of all these pipes are 220mm and 200mm respectively. The height of 500mm is also constant for all three pipes

Table 4.3 3D geometry of pipes

	3D geometry	**Hole diameter**
1		6mm
2		8mm
3		10mm

4.3.1. Simulation for 5mm sand particles

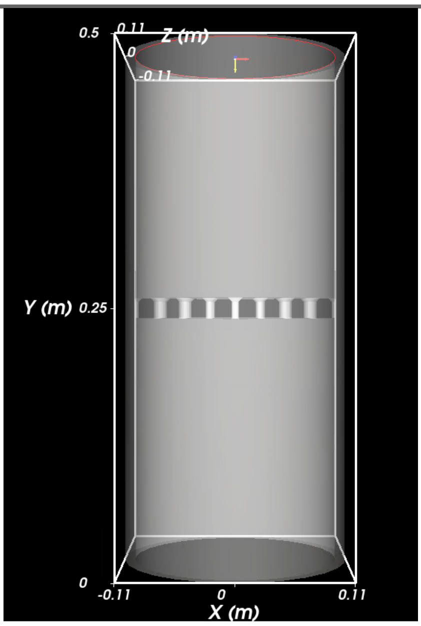
4.3.1.1. Geometry of sand particles

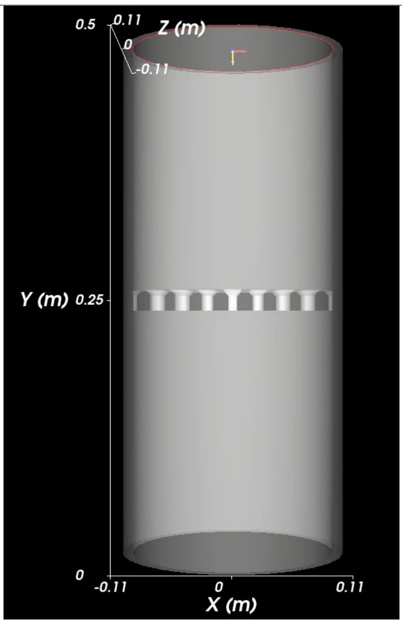
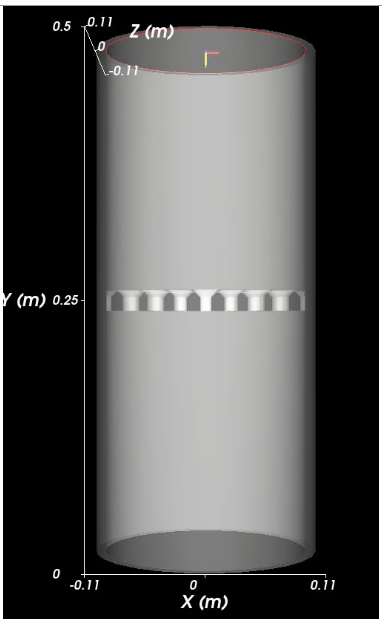
The geometry and properties of 5mm sand particles is the same as figure 4.4 and 4.5

4.3.1.2. Importing the 3D drawing into Rocky DEM simulation software

The method of importing as the same as first pipe geometry. The imported 3D drawing can be seen in Table 4.4.

Table 4.4 Imported 3D geometry

	3D geometry	**Hole diameter**
1		6mm

2	0.5 0.11 Z (m) 0 -0.11 Y (m) 0.25 0 -0.11 0 0.11 X (m)	8mm
3	0.5 0.11 Z (m) 0 -0.11 Y (m) 0.25 0 -0.11 0 0.11 X (m)	10mm

4.3.1.3.Simulating the sand particles through the pipe

For this simulation, the flow rate is set to 4 t/h.

Figure 4.11, 4.12, and 4.13 shows the results of the simulation for pipes 6mm, 8mm, and 10mm holes respectively. The sand particles entering the pipe is set to 5 seconds and another 10 seconds set is to see whether the sand can still flow through the pipe or it will clog the pipe.

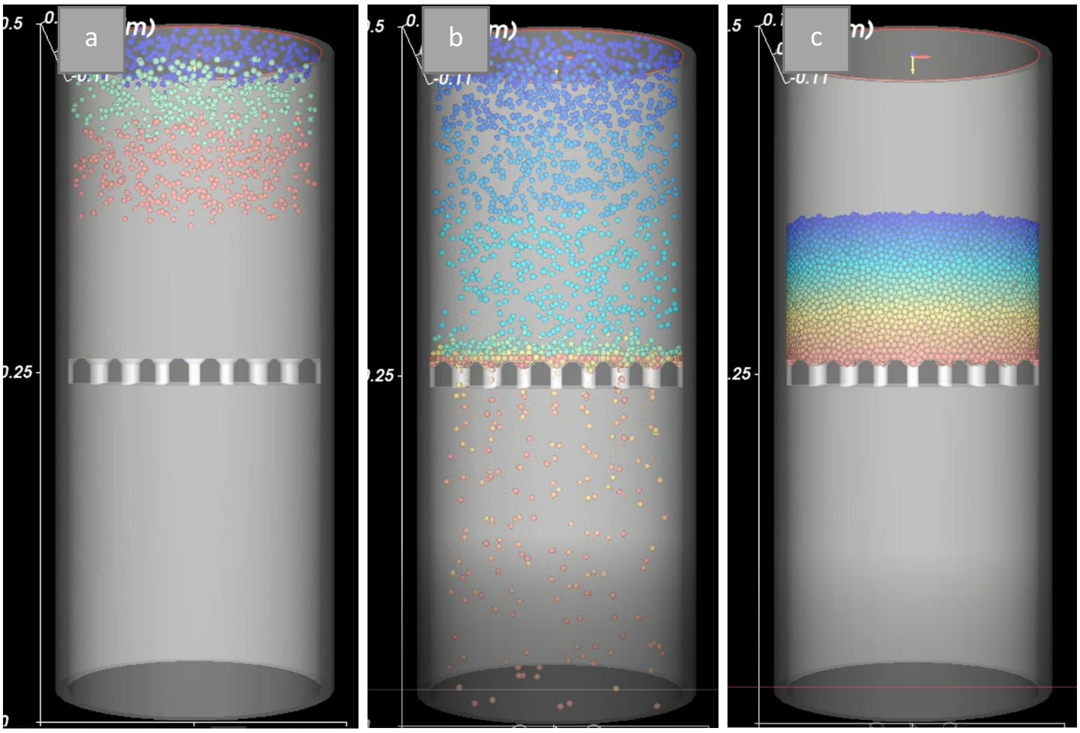


Figure 4.11 Results of the simulation for the pipe 6mm holes with 5mm particles (**a.** Sand entering the pipe at 0s **b.** sand passing through the sand screen at 3s. **c.** Results of the simulation at the end of 10s)

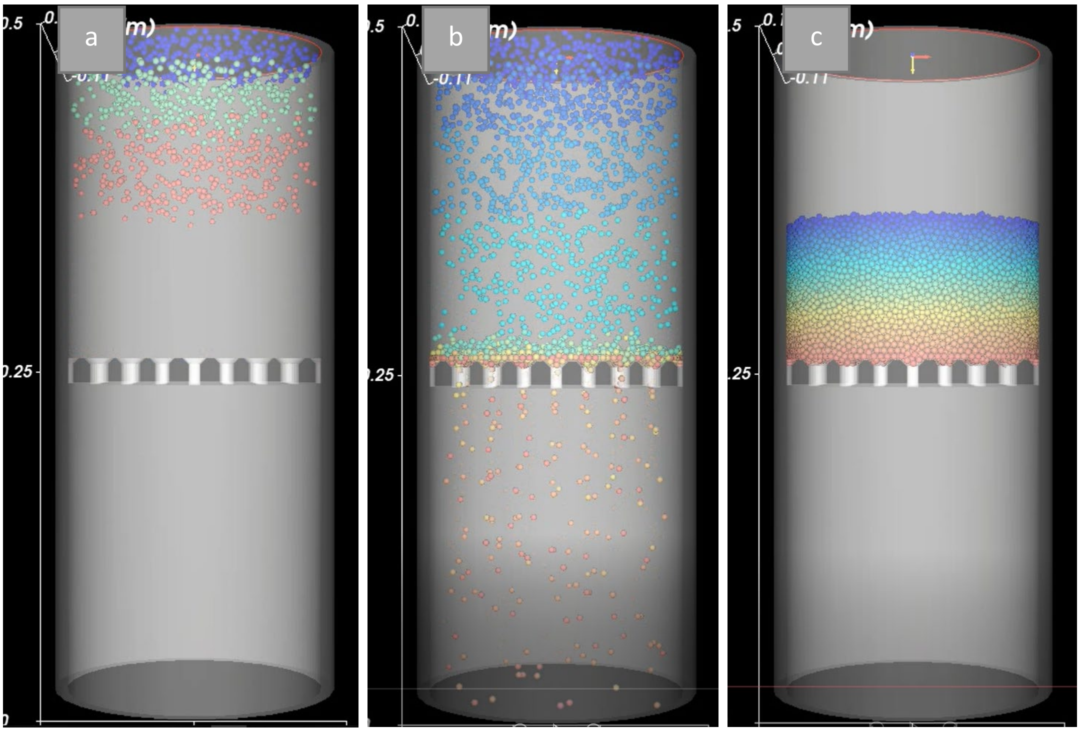


Figure 4.12 Results of the simulation for the pipe 8mm holes with 5mm particles (**a.** Sand entering the pipe at 0s **b.** sand passing through the sand screen at 3s. **c.** Results of the simulation at the end of 10s)

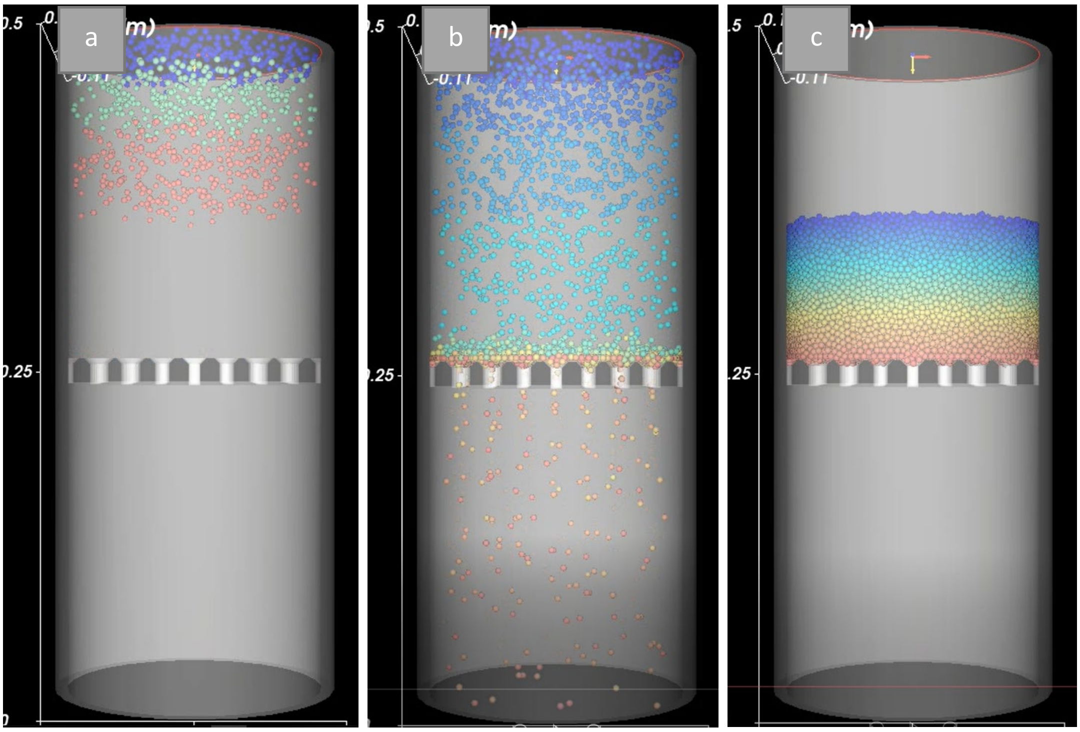


Figure 4.13 Results of the simulation for the pipe 10mm holes with 5mm particles (**a.** Sand entering the pipe at 0s **b.** sand passing through the sand screen at 3s. **c.** Results of the simulation at the end of 10s)

4.3.1.4. Conclusion

From the result of the simulation in Figure 4.11, 4.12, and 4.13, it can be concluded that the third geometry of the sand screen did cause the pipe to clog starting on 6s after the simulation started. The particles are completely clogged at the sand screen due to no movement can be seen after 10 s of the simulation. This may be because of the design of the holes where a few particles are blocking one hole at the same time.

4.3.2. Simulation for 3mm sand particles

4.3.2.1. Geometry of sand particles

The geometry and properties of 3mm sand particles is the same as figure 4.4 and 4.5, except the diameter of the particles is set to 3mm.

4.3.2.2. Importing the 3D drawing into Rocky DEM simulation software

The imported geometry can be seen in table 4.4

4.3.2.3.Simulating the sand particles through the pipe

For this simulation, the flow rate is set to 0.5 t/h. Figure 5.14, 5.15, and 5.16 shows the results of the simulation for pipes 6mm, 8mm, and 10mm holes respectively. The sand particles entering the pipe is set to 5 seconds and another 10 seconds set is to see whether the sand can still flow through the pipe or it will clog the pipe.

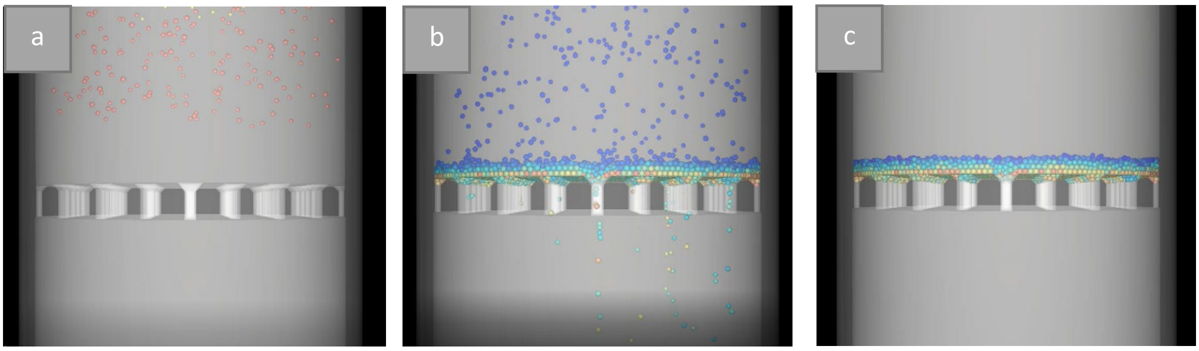


Figure 4.14 Results of the simulation for the pipe 6mm holes with 3mm particles **(a.** Sand entering the pipe at 0s **b.** sand started to clog at 4s. **c.** Results of the simulation at the end of 10s)

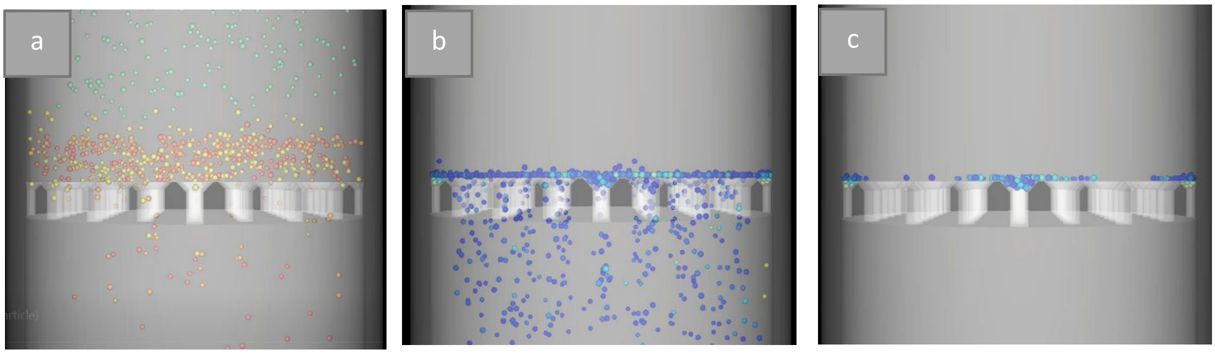


Figure 4.15 Results of the simulation for the pipe 8mm holes with 3mm particles **(a.** Sand entering the pipe at 0s **b.** sand stop entering at 5s. **c.** Results of the simulation at the end of 10s)

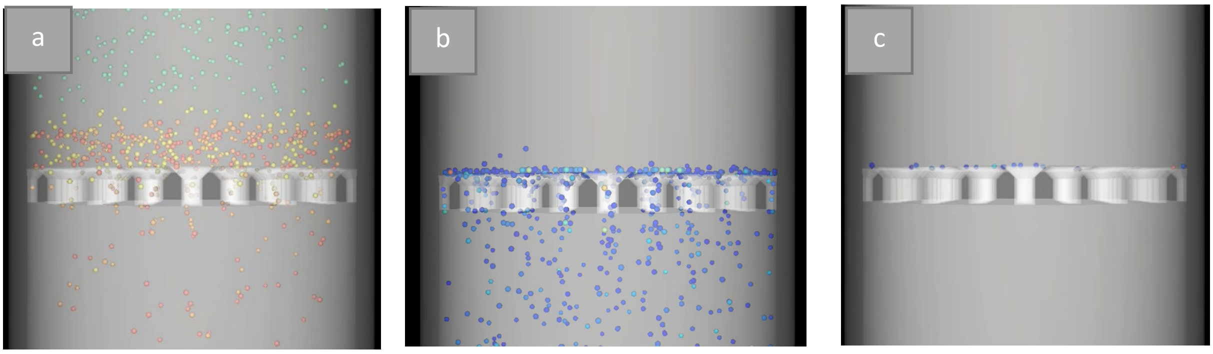


Figure 4.16 Results of the simulation for the pipe 10mm holes with 3mm particles **(a.** Sand entering the pipe at 0s **b.** sand stop entering at 5s. **c.** Results of the simulation at the end of 10s)

4.3.2.4.Conclusion

The result from figure 4.14 shows that the particles started to clog at 4s as only a little of the sand particles can past through the sand screen. By comparing it to the 5mm particles, we can see that there is an improvement which is mainly due to the size of the particles being reduced. Secondly, figure 4.15 and figure 4.16 shows that the sand particles did not clogged in both pipes. This is because the size of the holes of each pipe is bigger that the hole in figure 4.14. In addition, results in figure 4.16 shows that there are fewer sand particles stuck on the sand screen compared to figure 4.15.

4.3.3. Simulation for 2mm sand particles

4.3.3.1. Geometry of sand particles

The geometry and properties of 3mm sand particles is the same as figure 4.4 and 4.5, except the diameter of the particles is set to 3mm.

4.3.3.2. Importing the 3D drawing into Rocky DEM simulation software

The imported geometry can be seen in table 4.4

4.3.3.3.Simulating the sand particles through the pipe

For this simulation, the flow rate is set to 0.5 t/h.

Figure 4.17, 4.18, and 4.19 shows the results of the simulation for pipes 6mm, 8mm, and 10mm holes respectively. The sand particles entering the pipe is set to 5 seconds and another 10 seconds set is to see whether the sand can still flow through the pipe or it will clog the pipe.

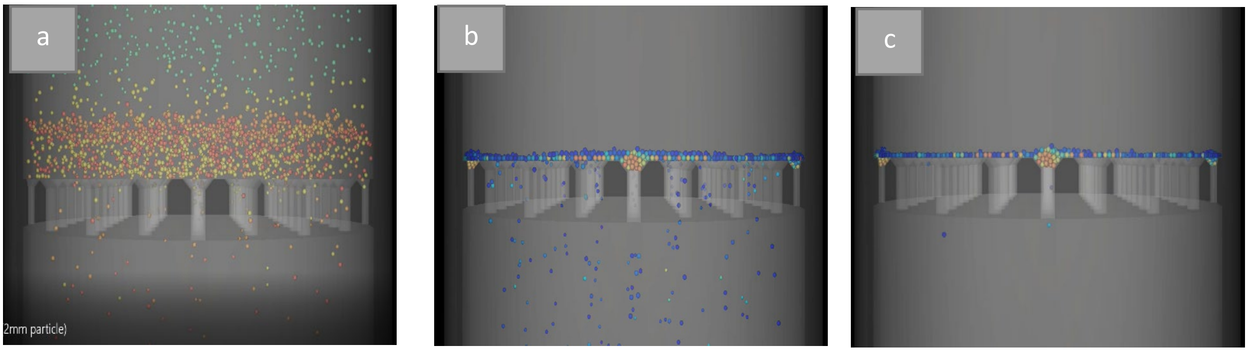


Figure 4.17 Results of the simulation for the pipe 6mm holes with 3mm particles (**a.** Sand entering the pipe at 0s **b.** sand stop entering at 5s. **c.** Results of the simulation at the end of 10s)

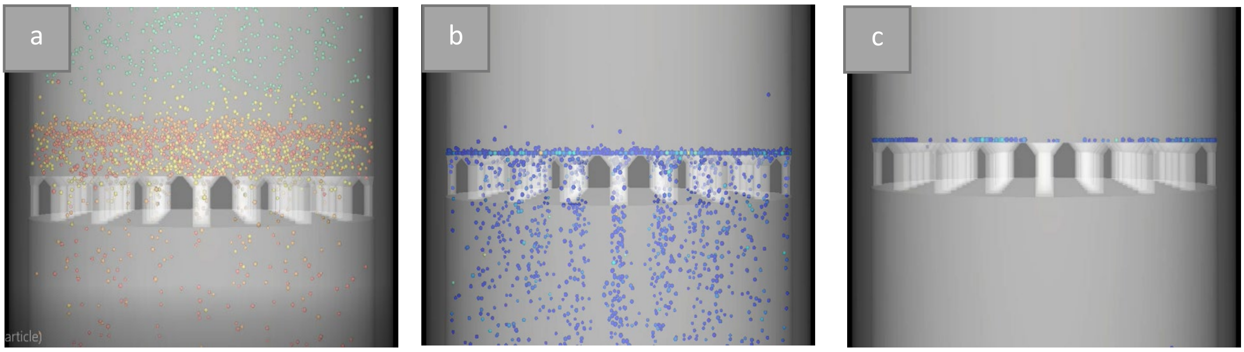


Figure 4.18 Results of the simulation for the pipe 8mm holes with 3mm particles (**a.** Sand entering the pipe at 0s **b.** sand stop entering at 5s. **c.** Results of the simulation at the end of 10s)

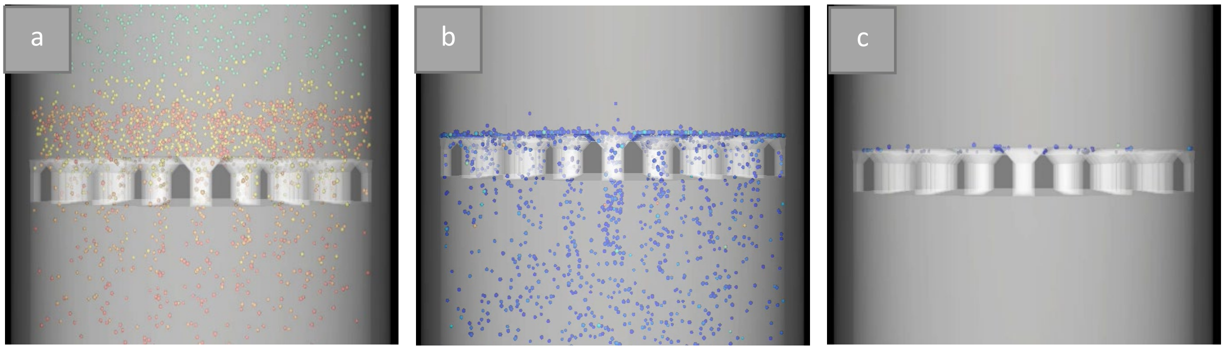


Figure 4.19 Results of the simulation for the pipe 10mm holes with 3mm particles **(a.** Sand entering the pipe at 0s **b.** sand stop entering at 5s. **c.** Results of the simulation at the end of 10s)

4.3.3.4.Conclusion

The result from figure 4.17 shows that the particles started to clog at 4s as only a little of the sand particles can past through the sand screen, but the sand particle can still pass through at a slower rate. By comparing it to the 3mm particles, we can see that there is an improvement which is mainly due to the size of the particles being reduced. Secondly, figure 4.18 and figure 4.19 shows that the sand particles did not clogged in both pipes. This is because the size of the holes of each pipe is bigger that the hole in figure 4.17. In addition, results in figure 4.19 shows that there are fewer sand particles stuck on the sand screen compared to figure 4.18.

Chapter 5: Conclusion and Recommendation

5.1. Conclusion

Summarizing the outcome of the research, it can be concluded that a few of the sand particles can be stuck inside the pipe if an object such as sand screen is located inside the pipe, no matter what design of the sand screen is. In this simulation, the pipe with 10mm hole sand screen design has the best result as almost all of the sand particles can pass through the sand screen. This is due to the hole of the sand screen is the biggest and the sand particles is the smallest, which is 2mm, which allow the sand particles to be easily pass through the sand screen.

5.2 Recommendations

This simulation was done without the roughness of the sand screen being described to the sand screen and the simulation was done using gravity alone, without using fluid in the simulation. By doing this, the simulation can be more accurate and closer to real life situation of wellhead. This is because the roughness of the sand screen can affect the sand particles, making it harder to pass through. Next, by including the effect of fluid, such as crude oil flow with the sand particles, the sand particles may pass through the sand screen more swiftly. Lastly, this project can also be further improve by refining the mesh size of the sand screen, which will take a longer time to simulate, but the simulation will be more accurate.

References

Anderson, R., Coates, G., Denoo, S., Edward, D., & Risnes, R. (October, 1986). Formation Collapse in a Producing Well. *The Technical Review 34*, 29-32.

Anderson, T. B., & Jackson, R. (1967). A fluid mechanical description description of fluidized beds. *Industrial and Engineering Chemistry Fundamental, 6*(4), 527-539.

Butlanska, J., Arroyo, M., & Gens, A. (2009). Homogeneity and symmetry in DEM models of cone penetration. *Proceedings of the 6th International Conference on the Micromechanics of Granular Media*, 425-428.

Climent, N., Butlanska, J., Arroyo, M., & Gens, A. (2011). Triaxial and cone penetration tests in a discrete analogue of Toyoura sand. *Proceedings of Second International FLAC/DEM Symposium.*

Cook, B. K., Lee, M. Y., DiGiovanni, A. A., Perkins, E. D., & Williams, J. R. (2004). Discrete element modelling applied to laboratory simulation of near wellbore mechanics. *International Jpurnal of Geomechanics*, 19.

Crook, T., Willson, S., Yu, J. G., & Owen, R. (2003). Computational modelling of the localized deformation associated with borehole breakout in quasi-brittle materials. *Journal of Petroleum Science and Engineering, 38*(4), 177-186.

Cundall , P. A., & Strack, O. L. (1979). A discrete numerical model granular assemblies. *Geotechnique, 1*(29), 47-65.

Cundall, D. O., & Potyondy, P. A. (2004). A bonded-particle model for rock. *International Journal of Rock Mechanics and Mining, 41*(8), 1329-1364.

Cundall, P. A. (1971). A computer model for simulating progressive large scale movement in blocky rock systems. *Proceedings of the Symposium International Society of Rock Mechanics*.

Dorfmann, A., Rothenburg, L., & Bruno, M. S. (1997). Micromechanical modelling of sanf production and arching effects around a cavity. *International Journal of Rock Mechanics and Mining Sciences, 34*, 3-4.

Ferziger, J. H., & Peric, M. (1999). *Computational methods for fluid dynamics (2nd ed.).* Berlin, DE: Springer.

Hoomans, B. B., Kuipers, J. M., Briels, W. J., & van Swaaij, W. M. (1996). Discrete particle simulation of bubble and slug formation in a two-dimensional gas-fluidesed bed. A hard-sphere approach. *Chemical Engineering Science*(51), 99-118.

Kafui, K., Thornton, C., & Adams, M. (2002). Discrete particle-continuum fluid modelling of gas-solid fluidised beds. *Chemical Engineering Science, 96*, 2395-2410.

Kawaguchi, T., Tanaka, T., & Tsuji, Y. (1998). Numerical simulation of two-dimensional fluidized beds using the discrete element method (comparison between the two and three-dimensional models). *Powder and Technology, 96*, 129-138.

O'Connor, R. M., Torczynski, J. R., Preece, D. S., Klosek, J. T., & Williams, J. R. (1997). Discrete element modelling of sand production. *International Journal of Rock Mechanics and Mining Sciences, 34*, 3-4.

O'Sullivan, C. (2011). Particulate Discrete Element Modelling: a Geomechanics Perspective. Spon Press, Taylor & Francis.

Rahmati, H., Jafarpour, M., Azadbakht, S., Nouri, A., Vaziri, H., Chan, D., & Xiao, Y. (November, 2012). Review of Sand Production Prediction Models. (J. Ancheyta, Ed.) *Journal of Petroleum Engineering, 2013*, 1-16.

Sulem, J., Vardoulakis, I., Papamichos, E., Oulahna, A., & Tronvoll, J. (1999). Elasto-plastic modelling of Red Wildmoor sandstone. *ournal of Mechanics of Cohesive-Frictional MaterialsNo, 4*(3), 215-245.

Sylvester, B., & Ikporo, O. (2015). Effect of Sand invasion on Oil Well Production: A Case study of Garon Field in the Niger Delta. *The International Journal Of Engineering And Science (IJES)*, PP.64-72.

Tsuji, Y., Kawaguchi, T., & Tanaka, T. (1993). Discrete particle simulation of 2-dimensional fluidized-bed. *Powder Technology, 77*, 79-87.

Willson, S. M., Moschovidis, Z. A., & Cameron, J. R. (October, 2002). New model for predicting the rate of sand production. *SPE/ISRM Rock Mechanics Conference*, 152-162.

Xiong, Y. Q., Zhang, M. Y., & Yuan, Z. L. (2005). Three dimensional numerical solution method for gas-solid injector. *Powder Technology, 160*, 180-189.

Xu, B. H., & Yu, A. B. (1997). Numerical simulation of the gas-solid flow in a fluidized bed by combining discrete particle method with computational fluid dynamics. *Chemical Engineering Science, 52*, 2785-2809.

Zhu, H. P., Zhou, Z. Y., Yang, R. Y., & Yu, A. B. (2007). Discrete particle simulation of particulate systems: theoritical developments. *Chemical Engineering Science, 13*(62), 3378-3396.