Computational Fluid Dynamic (CFD) of Drying Process of Sewage Sludge

By

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13688

Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Engineering (Hons) (Mechanical)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Mr. Mohd Faizairi B Mohd Nor)

(MECHANICAL)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2014

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 as specified in the references and acknowledgements, and that the original work contained herein have been undertaken or done by specified sources or persons.

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MUHAMMAD FAQRURAZI BIN YUNOS

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Abstract

The Sewage Sludge (SS) is very high in moisture content in its raw state after mechanical drying process from the water treatment plant. It would be in the best state for power boilers after being dried. SS as solid fuel need to be dried to 30% of its moisture content before fed inside the boiler or incinerator for optimum burning. There is no industrial scale of utilizing SS as solid fuel in Malaysia, thus the experiment conducted is very important in getting the reference parameter. Experimental scale of SS dryer has been fabricated to study the drying process behavior and search for the optimum working parameters. However, as the designed parameters; length, diameter, and dryer rotational speed, are fixed, there are limitation in finding the best working process. Besides, detail behavior of drying process unable to be studied through experiment. In the present paper, the actual experimental design of the dryer is stimulated in Computational Fluid Dynamic software (CFD). Generic design allow to vary the design parameters in finding the optimum working data and detail behavior of drying process such as thermal distribution able to be verified. Accordingly, an experiment was carried out to find the actual heat distribution. Then, the simulation result on the heat distribution to SS is compared with experimental data and has been verified with deviation of 13.5% from the actual. Drying process of current design is not at optimum state and several improvement is necessary on its working parameters. The application of CFD software is practical to be applied for design process of SS dryer in order to have the best working parameters which ensure the best quality of output product.

CHAPTER 1: INTRODUCTION

1.1 Background Study

The volume of waste water produce by the entire world is increasing every year. In China, 42840 million tons of waste water is recorded in 2005 and the amount is keep growing at average of 5% every year. Landfilling, sea dumping and soil application (fertilizer) are several common method that being practiced to dispose the sewage sludge [2]. However, those methods give bad impact to the environment and disturb the existed ecology [2],[3], [4], [5].

Electricity usage in Malaysia was reported to be around 21817 MW in 2009 which 10% of increment from amount in 2008 [5]. Since 2001 to 2010, Malaysian Government had introduced a mechanism policy called Small Renewable Energy Power (SREP) to promote small scale electricity production which 5% of national electricity is expected from renewable energy. The effort was not turn into success and viable method of energy recovery should be implemented [6]. Although Malaysia has been involve in utilizing the renewable energy such as solar and hydropower but the country still depended on fossil fuel consumption. Biomass is a very reliable and practical source of alternative energy for Malaysia [5]. The abundant source of biomass waste could help to solve grave landfill problem due to improper waste management that trigger the soil pollution [6]. Therefore, this study will focus on its practicality as source of recovery energy in Malaysia through efficient drying process.

Drying process is very essential in order to make the sludge reliable in its energy extraction process as solid fuel. Thus, the finding of optimum parameters for drying process will be focused in this study by using Computational Flow Design (CFD) software from ANSYS. Then, verification process will be conducted to verify simulation data through experimental work.

1.2 Problem statement

Municipal waste pose problem to almost country especially in the increment of its volumetric quantity. Sewage sludge from the municipal waste water treatment also contributes to burden the problem. In Malaysia, common method of waste management is via landfill with lack of control measure in managing the pollution. Thus, it triggers to pollute the soil and underground water because many of the dumping sites are near the vicinity of water bodies [6]. Since 1994, the federal government has awarded Indah Water Konsortium (IWK) [11] to manage country's water treatment plant. Exponential growth of human population in Malaysia with rapid industrialization gives impact on the production of waste water [6].

The final solid product from the waste water is called as sewage sludge. IWK reported that the amount of sewage sludge will increase to double from the current amount in next 6 years [11]. Now, they are facing problem to manage the huge amount of sludge and better waste management method is a must to be implemented immediately.

After dewatering process, sewage sludge still contain an average of 80% water content which cause big problem to decompose it. As a result, sludge mechanical dewatering and conditioning is no longer be a feasible method to cater its exponential growing amount. Besides, from the research that has been conducted, sludge product after mechanical dewatering process is not reliable to be reused for agriculture or forestry and further treatment is necessary.

Thus, the idea of transforming the product to solid fuel could be one of the solutions shall be implemented. However, the high moisture content of sludge after the dewatering process is not feasible to be directly feed as solid fuel. In order for the solid fuel to be feasible, it must contain maximum 30% of moisture content for optimum burning. Therefore, dryer system must be install to enhance water elimination process to achieve as per required dryness.

1.3 Objective

The objectives of the study are:

1) To understand the drying process of sewage.
2) To study and stimulate the heat distribution of drying process.
3) To identify the optimum sewage sludge flow for the drying process of the existed dryer.
4) To verify the simulation data with experimental process.

1.4 Scope of Study

Thermodynamic

- Phenomena of distribution of heat form hot air under ideal gas condition.
- Determination of the most suitable equation of state that precisely reflects the thermodynamic changes.

Hydrodynamics Analysis in Computational Fluid Dynamics (CFD)

- Understand the turbulence model in the flow system.
- Model and show thermodynamics changes in term of CFD calculations and post-processing. i.e. (temperature, heat distribution and density).

CHAPTER 2: LITERATURE REVIEW

2.1 Sludge Properties

In recent development, method of sewage treatment has been improved on its functionality and viability. The end product could be managed in more proper solution and able to produce high quality of effluent that can be discharge with small impact to the environment. Mechanical plant encompasses 38% of public sewage plant in Malaysia under management of Indah Water Konsortium [11]. Nowadays, the mechanical plant is designed to be constructed in a package. This package plant can be installed quickly and only require smaller space compare to the traditional plant. Extended Aeration, Contact Stabilization, Bio-Filter, Sequenced Batch Reactors and Rotating Biological Contactor processes are common package for this type of plant [11]. Basically, all treatment plant will produce sewage sludge but the station to collect sludge may vary depending on the type of treatment plant.

2.2 Thermal drying

Sewage can be categorized to its physical, chemical, and biological characteristic [8]. Usually, dried sewage sludge contains heating/calorific value between 6 to 12 MJ/kg which similar to brown coal [3], [4]. In Germany, 53% of its dried sewage sludge is thermally processed either through combustion or gasification treatment method [3]. There are other thermal technologies that have been developed to extract energy from municipal waste such as such as pyrolysis, gasification, combustion, and co-combustion processes [4],[8]. However, direct combustion of solid biomass contributes 97% of world bio-energy production [4].

The composition of organic and inorganic matter of sewage is depending on the treatment process and sewage origin [8]. The biggest composition mass of sewage sludge is due to its water content. The feasibility to harness energy from the dried sludge is below 50% of its moisture content [3]. At this level of moisture, the sludge could be feed directly into the furnace and produce approximate 13 MJ/kg of heating value. However, the sewage from the outlet of the water treatment plant still contains 70%- 75% of intercellular water content although it has undergone mechanical dewatering process such as filter press [8], [11]. This level of humidity is not reliable to produce power [8]. Thus, various type of drying system has been established to solve the problem before it can be treated as thermal source to generate power [3].

Thermal drying with more than 300 ^{o}C will sanitized the waste sludge resulted of inactive pathogen and volatile chemicals. Low odors and easy handling characteristics on the dried sewage make it reliable to be used [7]. From the research that has been conducted, almost all process of thermal treatment of sewage sludge need to be dried first before it is feasible to be transforming into energy. Efficient method of drying process is compulsory to enhance the energy recovery from the sewage. There are many consideration of drying process that must take into consideration especially to get very good product for solid fuel.

In order to optimum the finding of drying parameter, simulation of thermal flow is necessary. Heat transfer between particles is a common process in the industries. For the study, the drying concept utilizes the concept of conduction and convection of thermal energy. The hot air will transmit heat energy through the tube surface to the sewage sludge. The direction of heat transmission is indicated with red color arrow in the picture below.

Figure below shows the design of the dryer.

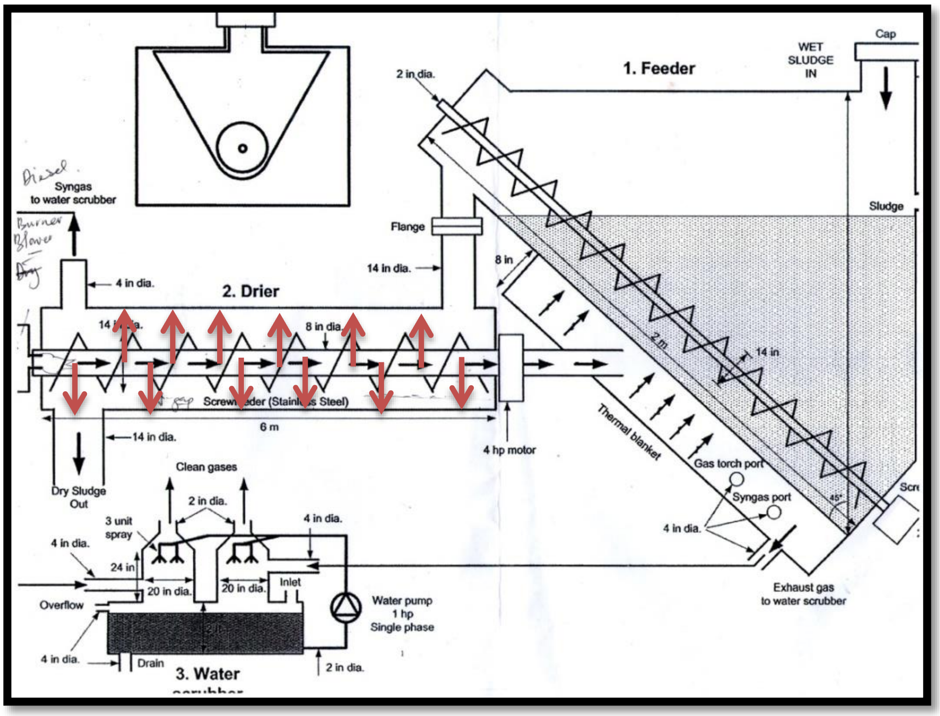


FIGURE 1: Drying and Feeding System

Transfer of heat through conduction of particle must be highlighted throughout the simulation process. Theoretically, an ideal gas requires much simpler equation compared to real gas operation. Because of its simplicity, it becomes favorable in engineering calculations because direct correlation with almost any of the thermodynamics system may be performed. However, the phenomena may be different at different fluid speed. If the speed of the gas is much less than their speed of sound, the gas density remains constant and the velocity of the flow increases. At low speed this assumption maybe valid however as the speed of the flow approaches the speed of sound, compressibility effect cannot be neglected.

2.3 Computational Fluid Dynamic (CFD)

The existent of Computational Fluid Dynamics software help in the study and been necessitated for efficient work of designing various type of heat exchanger. The quality of the simulation has been proven to be very effective in predicting the performance and behavior of different type of heat exchangers [9]. CFD is used for determine the fluid flow, heat transfer and chemical reaction by solving the numerical analysis from the mathematical equation for the reaction. Moreover, from the designed model, we able to test and troubleshoot the optimization of model's system by suggesting design modification. The software employs governing equation with simple principle in finding the solution. Moreover, CFD has the ability to resolve numerical problem on temperature gradients and flow parameters in a short time and reduced the experimental work that need to be carried out [9]. Improper design of heat exchanger components may lead to the non-uniformity or maldistribution in fluid flow which affect the heat exchanger performance [9]. The concept of heat transfer for the designed sewage dryer is similar to the characteristics of the shell and tube type of heat exchanger. High temperature interaction within the exchanger wall might cause deposited on the lining surface of the wall which resulted to reduce the coefficient of heat transfer.

By using CFD, any error can be investigated and helps to increase the efficiency of the process. Furthermore, the software allows the user to analyze the thermal characteristics of the dryer while it also has been proven to be the best tool in optimizing the design of dryer [9]. From the simulation data, different modifications could be structured by comparing several results and the best possible combination of variables could be determined. The software is flexible to conduct any kind of analysis such as prediction of fluid flow behavior to optimize design concept, while also integrating the scheme available in the CFD software. Generally, the simulation of the result yield around 80% to 98% of accuracy to the experimental results. The presence of CFD software has become integral for designing process as it able to eliminate the dependability to prototype [9]. Steady state thermal analysis using ANSYS software helps the user to calculate the effect of thermal load on a system or component. Temperature, thermal gradient, heat flow rates and heat flux in an object caused by thermal load that do not vary over time could be measured [9]. ANSYS software able to access the thermal properties of air by using CFD analysis features. It able to stimulate varies of temperature and air density. Thermal properties used must be in proper unit system and synchronized with properties selected to dimension the model as well as the units of any boundary system presence. This model of dryer adopted the principle of convection and conduction of thermal energy distribution [9]. Thus, in this study convection and conduction process will be highlighted to achieve the objective of the study. Heat transfer is a method in which energy is transferred between two different bodies due to a difference in temperature between the two [10].

There are three different modes in which this transfer of energy can take place:

1. Conduction
2. Convection
3. Radiation

However, for this study purpose, only two process will be highlighted which is convection and conduction process of heat transfer as they are much influence on the working principle of the dryer.

2.4 Conduction

Conduction is an energy transfer from energetic particles to less energetic surrounding particles [10]. The transfer of energy is under Fourier's Law as shown below.

$$q_x = -k\frac{dT}{dx}$$

where: q_x = Heat flux in the x-direction

k = Thermal conductivity

T = Temperature

2.5 Convection

Convection is a process of energy transfer between a solid and moving fluid which different in temperature gradient. The heat exchange of energy is given by Newton's law of cooling as shown below.

$$q = h(T_s - T_f)$$

where: q = Convective heat flux

h = Heat transfer coefficient

T_s = Temperature of the solid body

T_f = Temperature of the fluid body

2.6 First Law of Thermodynamics

According to the first law of thermodynamic, the energy transferred by the system must be conserved. It bring to the definition that amount of energy entering the system must be same with energy leaving the system. Thus, sets of equations must be implemented to relate the conservation of energy principles required to be met by the system.

$\Delta E_{system} = E_{in} - E_{out}$, E = energy

$E_{in} = E_{out}$

$\Delta E_{system} = q + w$

q = heat energy apply to/from system

w = work done to/from system

In this study, the energy principle applied on the system is only focus on thermal energy where there is no changes of system's volume. Thus, the energy applied on the system is work on following equation

$\Delta E_{system} = \Delta q$

Energy from the hot air is transfer to the inner wall of the heated shaft through convection process. The heated shaft than distribute heat energy to the dewatered sewage sludge through conduction process of heat transfer.

CHAPTER 3: METHODOLOGY

Since a pilot plant scale is inefficient and ineffective to be carried out, computational fluids dynamics (CFD) simulation is the best option to conduct a comprehensive and practical analysis. Series of simulations will be carried out to understand the wet model or condensation shock in the CFD. For this project, it involved investigation, prediction and validation of the flow behavior by means of CFD.

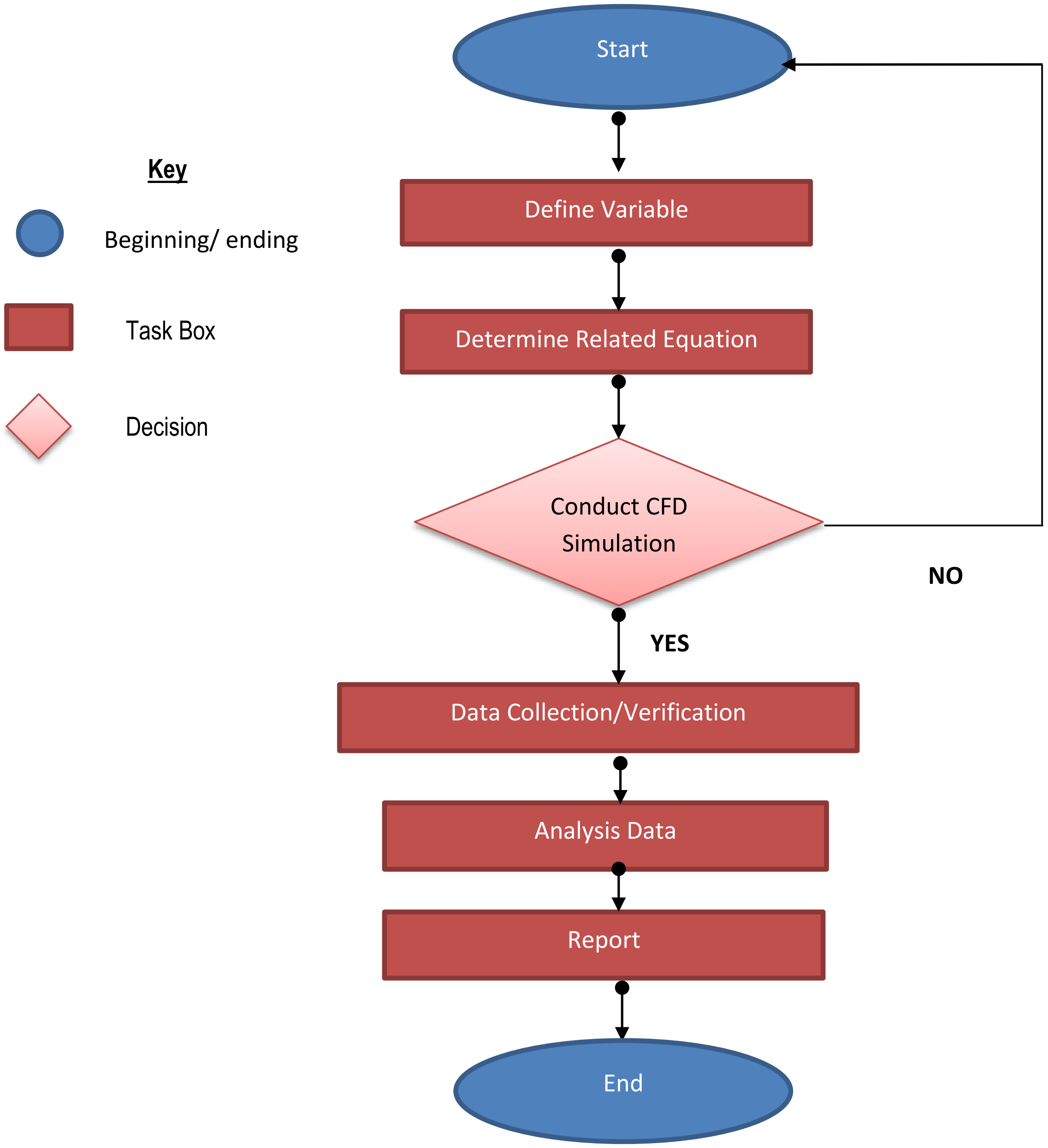


FIGURE 2: Simulation Methodology Chart

Below is the key milestone of conducting the CFD test.

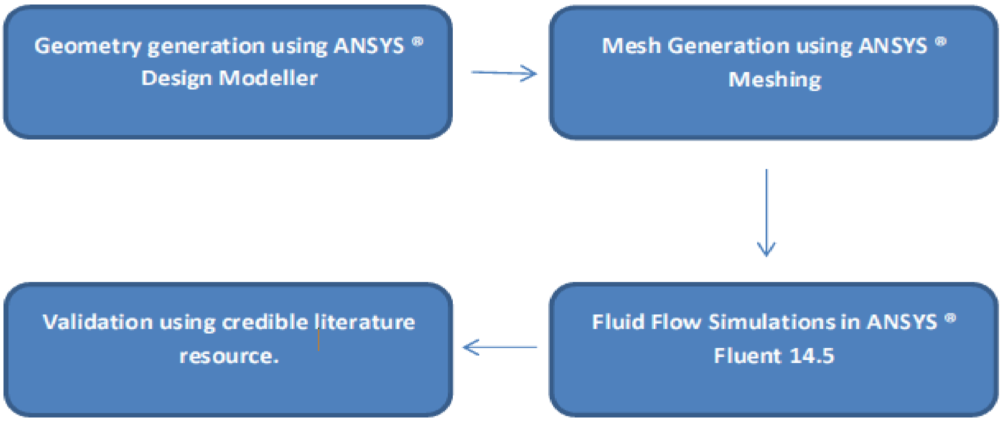


FIGURE 3: CFD simulation process [12]

In this project, author will focus in optimizing the sewage sludge dryer design. The concept of the dryer has been finalized as per illustrated in the schematic drawing in figure 1. However there are several parameters that need to be manipulated in order to achieve the optimum sewage sludge drying process. By using CFD, the parameter variables can be tested until the best parameters could be achieved. This paper will focus more on the simulation of the drying process using CFD. After the simulation process is completed, the data will be used for verification process. Verification process can be made by conducting several experiments using the pilot design drying machine that has been fabricated. Generally, the portion of this work is about 70% on the simulation process and 30% on the experiment for data validation.

3.1 CFD Design Process

In the first process of CFD, the dryer need to be modeled by using geometric design modeler. For this project, author decided to use Solid Work 2013 modeler to design the working concept of the sewage sludge dryer. The model can be designed either in 3- dimensional model or 2- dimensional model. It be an option for the user to choose the desired way to conduct the test. Of course, the 3-dimensional model is more accurate and the calculated data provided by the software will be more in detail. Author has divided the assembled sewage dryer into 3 domain; sludge, thin wall pipe, and hot air.

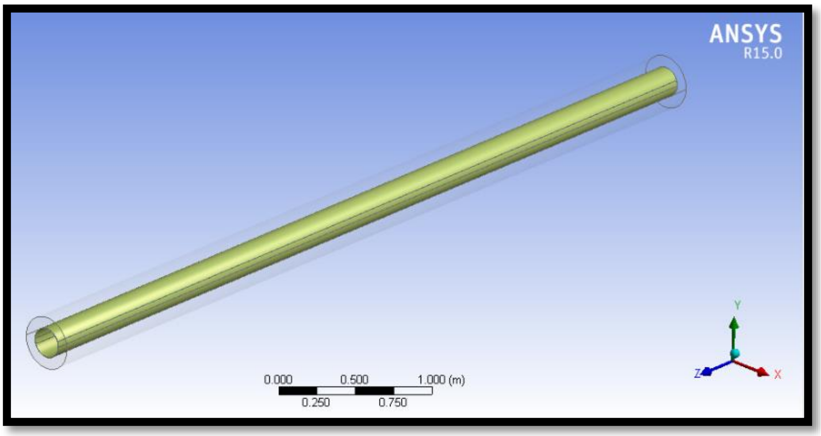


FIGURE 4 : Model designed in solid work 2013

Meshing generation is unstructured grid generation program which able to produce virtually unlimited sizes and complexity consisting several shapes of meshing grids that can be chosen by the user. The number of node and element resulted during meshing process determine the detail of heat distribution will be analyzed in the simulation process. However, this will take longer time for data to be processed.

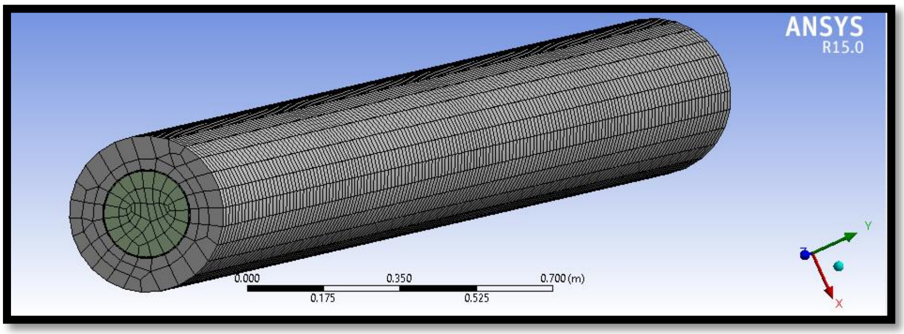


FIGURE 5 : Meshed model of sewage dryer

Then, the meshed geometry need to be specified its condition boundary before it can be transferred to Ansys Fluent within the Ansys Workbench platform for CFD calculation and setup.

Governing equation established can be stimulated using numerical methods; finite difference, finite element or finite volume by using Computational fluid dynamics (CFD) software. The governing equations are discretized and rewritten either at a point, an element or at a control volume. As the equations are written and solved in discretized form the domain or the geometry in which these equations will be solved also needs to be discretized. So as to facilitate this solution of governing equation using numerical methods several input need to be inserted to the solver:

1) Shape and size of the domain: this defines the region in which the equations are solved.
2) Discretize the domain: as it will be given to solve the governing equations in discretized form.
3) Identify the domain boundaries: as during solver set up appropriate boundary condition is needed [14].

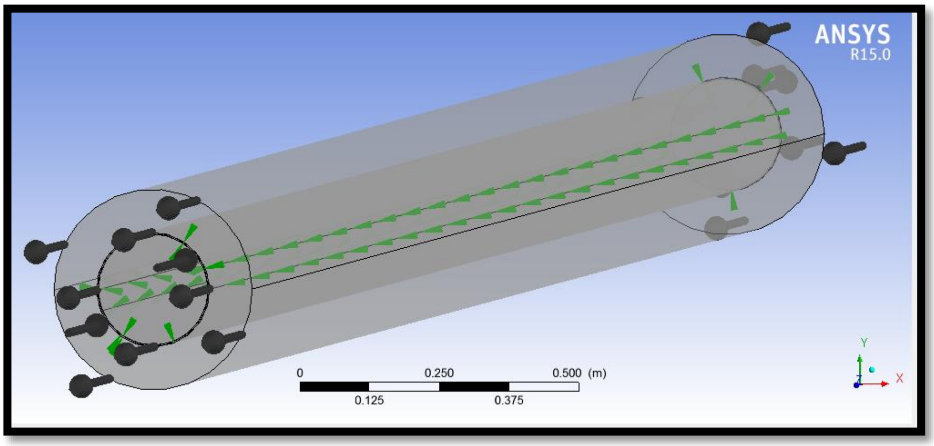


FIGURE 6 : Boundary condition setup of SS dryer in Ansys Simmulation

The uniqueness of boundary conditions is decided by the shape, size as well as value of known flow property on the boundary. Then, additional physical models such as steady state, turbulence, and asymmetrical input data required by the Ansys Fluent were added. This process followed by setting the solver parameters such as under-relaxation factor, convergence criterion and the most suitable discretization schemes.

Graphical model observation can be made to verify the output result from the Ansys Fluent. Post processing which analyses the reaction data are conducted on the generation of graphical displays consists of grids and contour from the output. Multiple plots encompass of several variables; pressure, temperature, velocity, mach number and other wet model properties are analyzed. If the result is intolerable and not meet targeted objective, troubleshooting will begin by manipulating those model variable properties and the equations inserted in the Fluent before conducting the simulation again. This process shall continue until a plausible result is obtained.

3.2 Verification Process

To validate the simulation data, test run on the experimental dryer is conducted. Two type of test run will be conducted to validate the data.

1) Non-insulated dryer test
2) Insulated dryer test

Non-insulated dryer test involve a test run on non-insulated dryer, where heat is expected to dissipate to the surrounding. The non-insulated dryer is shown as in the figure below.

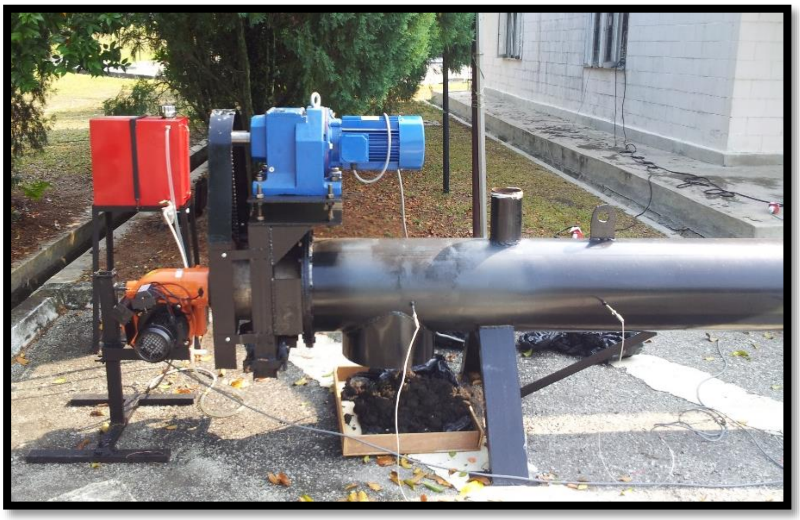


FIGURE 7: Non-insulated dryer

Insulated dryer test involve test run on insulated dryer, where heat is expected not to dissipate to the surrounding. The insulated dryer is shown as in the figure below.

FIGURE 8: Insulated dryer

The data then will be gathered and compared to study the behavior of the sewage sludge dryer.

Step for validation process

1) The dryer is allowed to dry run for 2 minutes to ensure there is no moisture or remain water left inside the dryer as it is located at outside the lab.
2) Then, dewatered sewage sludge is inserted to the storage tank located at the feeder of the dryer.
3) Preheat process is allowed on the dewatered sewage sludge inside the storage tank for 5 minutes.
4) The screw feeder is turned on to start the drying process.
5) The flow rate of sewage sludge flow along the 6 meter dryer is recorded.
6) The consumption of diesel for drying process is recoded.
7) The temperature of thermo-couple located along the dryer is read by using data logger and recorded.
8) Step 1 to 7 are repeated for insulated dryer test run.

CHAPTER 4: RESULT AND DISCUSSION

In this chapter, the result tabulated were obtained from the CFD simulations and test run on the actual sewage sludge dryer. The simulation were performed to investigate the drying process behavior of the sewage sludge dryer. The dryer is horizontal indirect dryer where it utilize hot air as medium of heat source. The hot air distribute along the hollow core shaft as shown in the figure 8 and heat transfer to the sludge by convection and conduction process. Heat transferred from the heating medium increase the sludge temperature and evaporates water content from the sludge surface. The water vapor is then sweep away by the hot air that rechanneled from the core shaft. Drying process is the heart of the whole process in producing quality dried sewage sludge. In conjunction to have optimum drying process, dryer must operate at optimum operating parameters. Performing simulation is one of the option can be used as it work as generic design where the researcher allow to manipulate the design parameter to have optimum working condition without invest big amount of money to fabricate another dryer.

The simulation was performed purposely to understand the behavior of heat transfer from the hot air flow along the core shaft to the dewatered sewage sludge. The drying process factor much influenced by the conduction and convection principle as refer to the concept design of the dryer. It is crucial to study the distribution of heat principle that possible to happen in the drying process in order to get the efficient working process of the system.

For this study, the simulation data will be verified by the actual dryer (experimental scale size) for simulation verification purpose. As author design and simulate the generic dryer by self-learning and through expert advices, thus it is important to synchronize the simulation data with the experimental result to obtain accurate design parameters for future design of the sewage sludge dryer.

4.1 Variables

1) Dimension of the drying machine
   - In this test the length and diameter of the drying machine will be emphasized.
   - The dimension will be referred base on the pilot design of the sewage dryer.
   - Manipulation of parameters in the simulation are conducted until optimum working parameters are achieved.
2) Specification of drying machine operation
   - Motor speed (velocity).
   - Mass flow rate of sewage sludge.
   - Temperature of the burner.

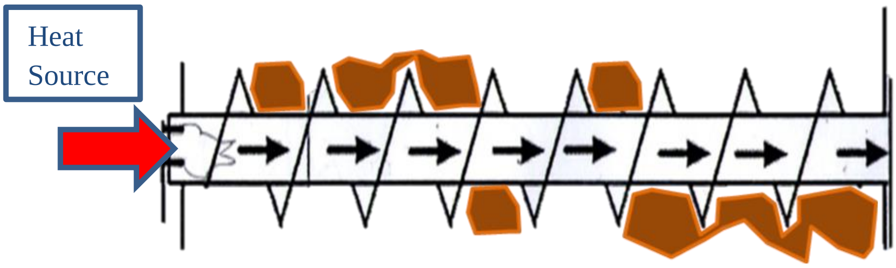
4.2 Assumption

During the simulation process, several assumptions have been made. The assumptions that apply on the modeling work are:

- There is no-slip adiabatic wall condition.
- Amount of heat supply by the burner is constant.
- Assuming the flow rate of hot air is constant throughout the dryer channel.
- There is no heat lost to the surrounding.

4.3 CFD simulation result

The model designed for the simulation is similar with the experimental dryer parameters at site. The main purpose of CFD simulation conducted is to study the behavior of heat distribution of current sewage sludge dryer. It is important to know insitu operating heat distribution before any design improvement made. After comparison and validation data process, author manipulate the sludge flow velocity to examine the best velocity for optimum heat transfer process. Heat distribution on a wall pipe surface resulted from CFD-Post as follows.



Generic design concept in the simulation

FIGURE 9 : Concept of sewage sludge dryer

Figure above illustrated the actual concept of indirect sewage sludge type dryer designed for the experimental purpose. The design of the dryer in the solid modeler must be as closed as existed concept for validation result purpose. The concept of model design in the modeler illustrated as shown in the figure below.

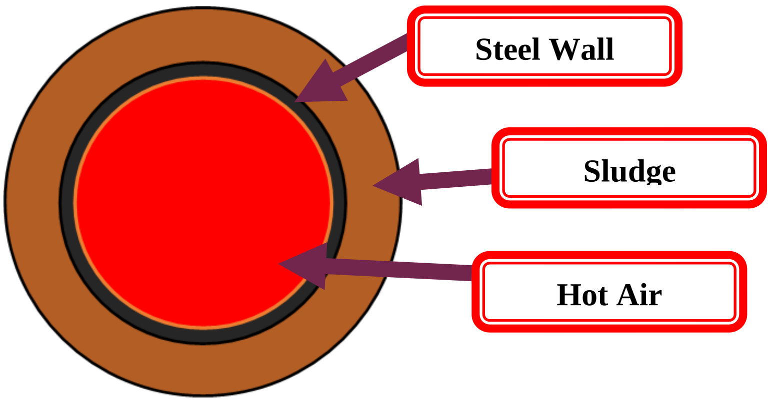


FIGURE 10 : Design concept in solid medeler

The geometry of the sewage sludge dryer is produced using the Solid Work Modeler. This model is produced as close to actual design parameters in purpose to study the heat distribution behavior of the hot air to the dewatered sewage sludge. However, there is certain alteration on the modeler dimension due to limitation and capability of equipment to process the data. Following is the boundary condition specification for simulation model.

Hot air shaft diameter = 0.25m

Wall thickness = 0.003 m

Dryer tube Diameter = 0.4m

Length of dryer = 6.0 m

Inlet hot air temperature = 360 ^{o}C (Set same as experimental value)

Hot air fow = 0.3 m/s

Sewage sludge flow = 0.033 m/s

4.4 Heat distribution behavior of hot air

Figure below illustrate the distribution of heat along the heated core shaft surface of the sewage dryer. The color contour with red is the hottest area and decreases as the color turn to blue. The distribution of heat transfer decreases as the location further from the heat source.

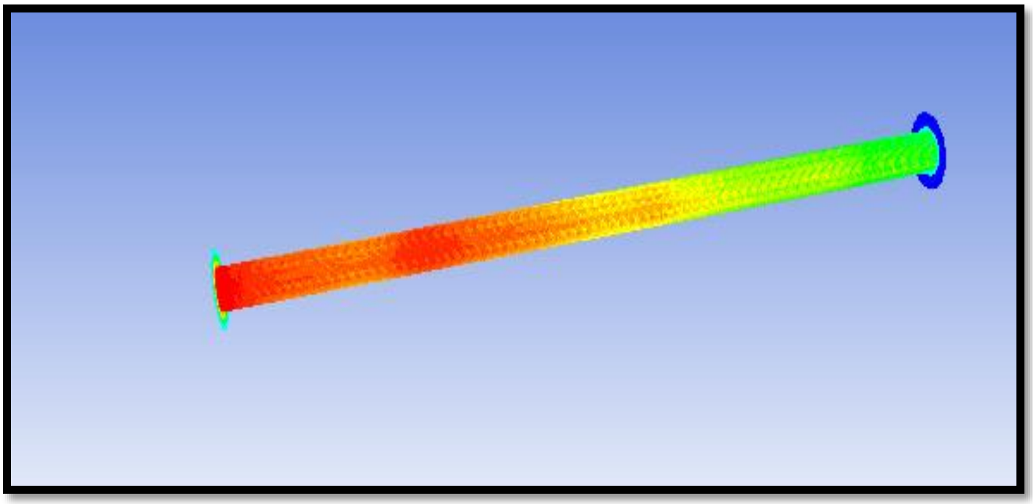


FIGURE 11 : Heat distribution of hot air

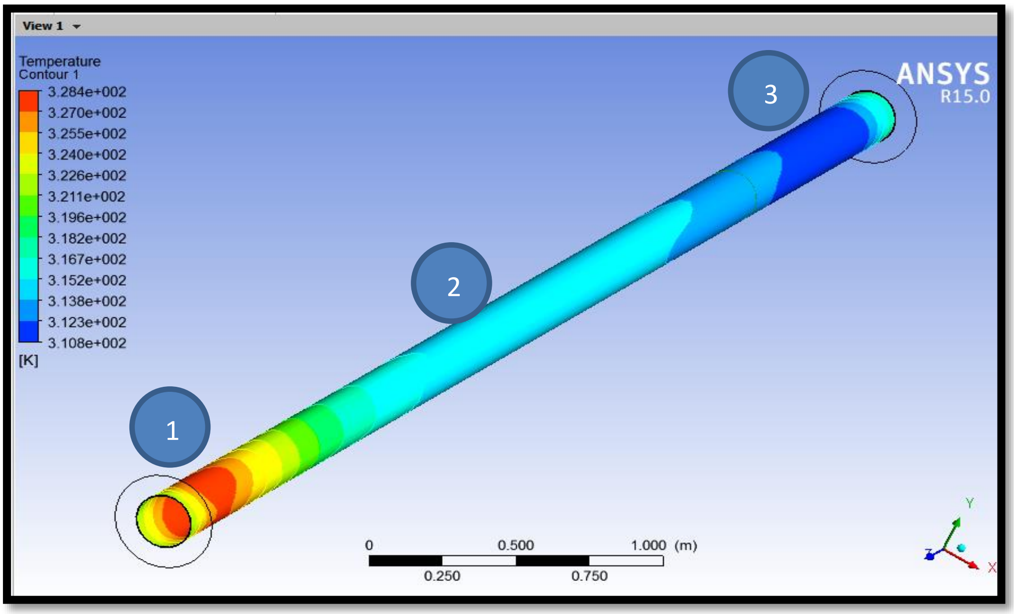


FIGURE 12 : Heat distribution on the pipe surface

The simulation process act as generic design where the user able to manipulate the working parameters in order to study the detail behavior of the heat distribution. Author has specify 3 points to be examined for the study as shown in the above figure. Point 1 located at the entrance of the hot air, point 2 located at the middle of the dryer (3m from the heat source) and point 3 is located at 6m form the heat source. The behavior of heat distribution along the dryer for current operating parameters are shown graphically in cross sectional area as shown in the figure below.

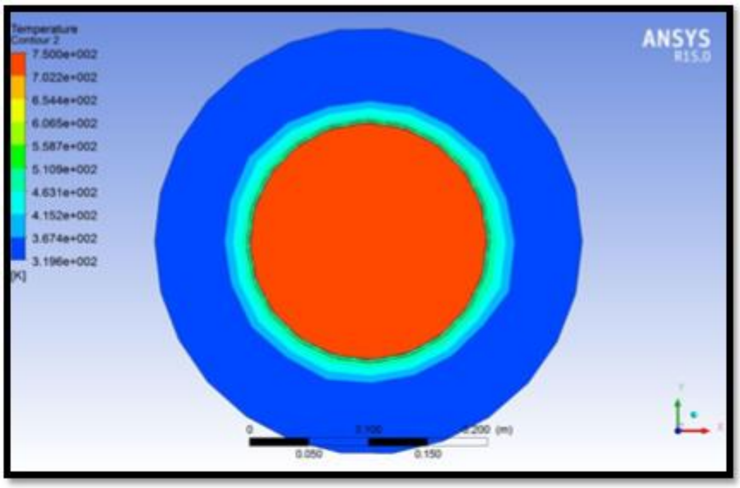


FIGURE 13: Cross sectional at point 1

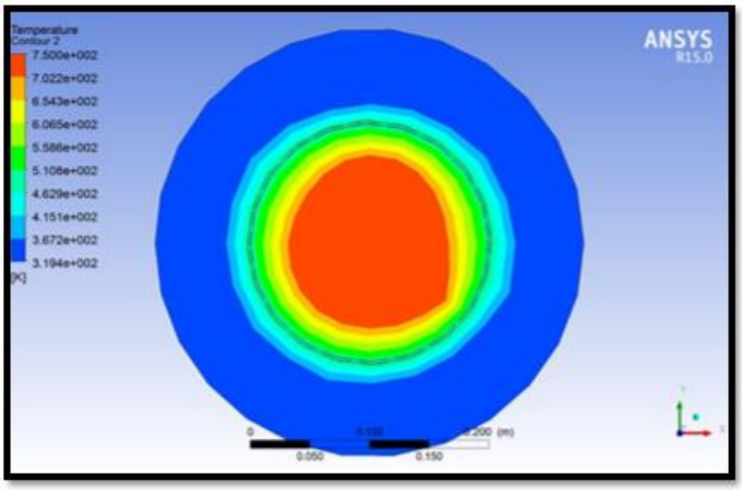


FIGURE 14: Cross sectional at point 2

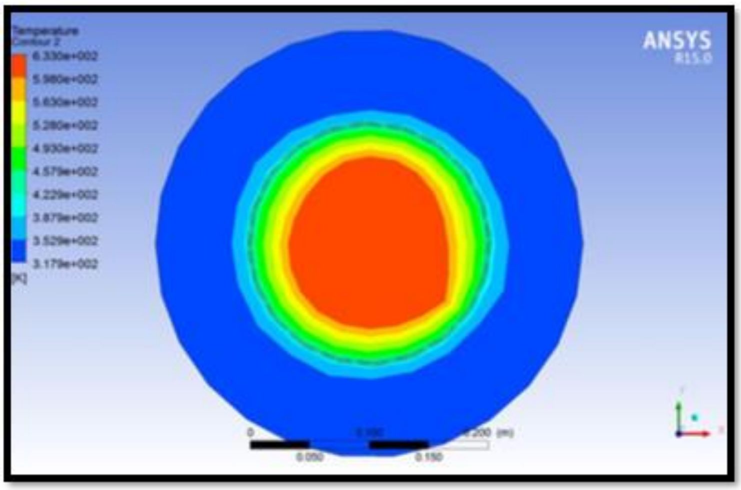


FIGURE 15: Cross sectional at point 3

The temperature of the hot air at outlet and inlet resulted from the simulation is as shown below.

Point 1: 360 ^{o}C. (inlet)

Point 3: 109.5 ^{o}C (outlet)

4.5 Verification Process (Test run)

Two type of test run have been conducted on the sewage dryer to verify the data gathered during simulation.

1) Normal operation of sewage dryer without insulation.
2) Insulated sewage sludge dryer

A test run has been conducted and several operating data has been recorded. Temperature has been recorded at 3 different locations along the sewage dryer to identify the behavior of heat distribution transmitted by the hot air inside the core shaft.

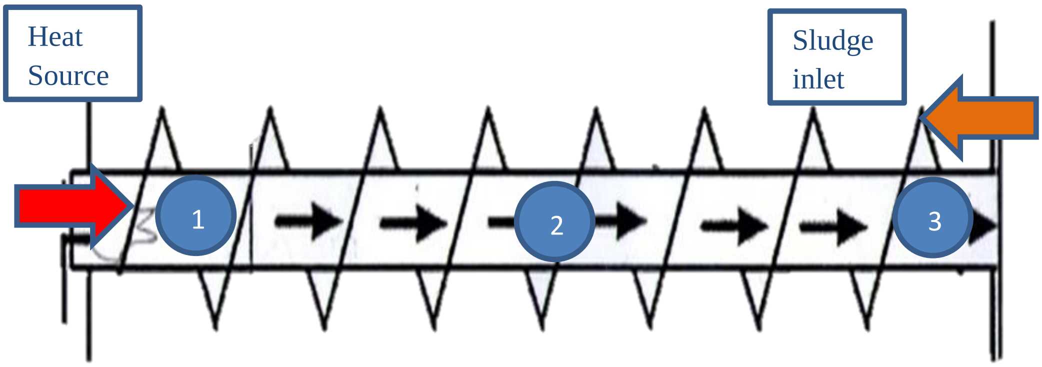


FIGURE 16 : Location of thermocouple

The drying process is based on the counter flow of heat exchanger process. This concept of design allow the sewage sludge to be-pre heated before enter the dryer. The hot air from the core shaft is designed to channel the hot air outlet to the sewage sludge storage tank, thus utilize the remaining energy.

Below are the resulted temperature of heat distribution for non-insulated dryer during the test run.

Distance from heat source (m)	Temperature (°C)
0	360
1	273
2	230
3	207
4	162.3
5	143
6	79

Figure 17: Hot air temperature along the insulated dryer

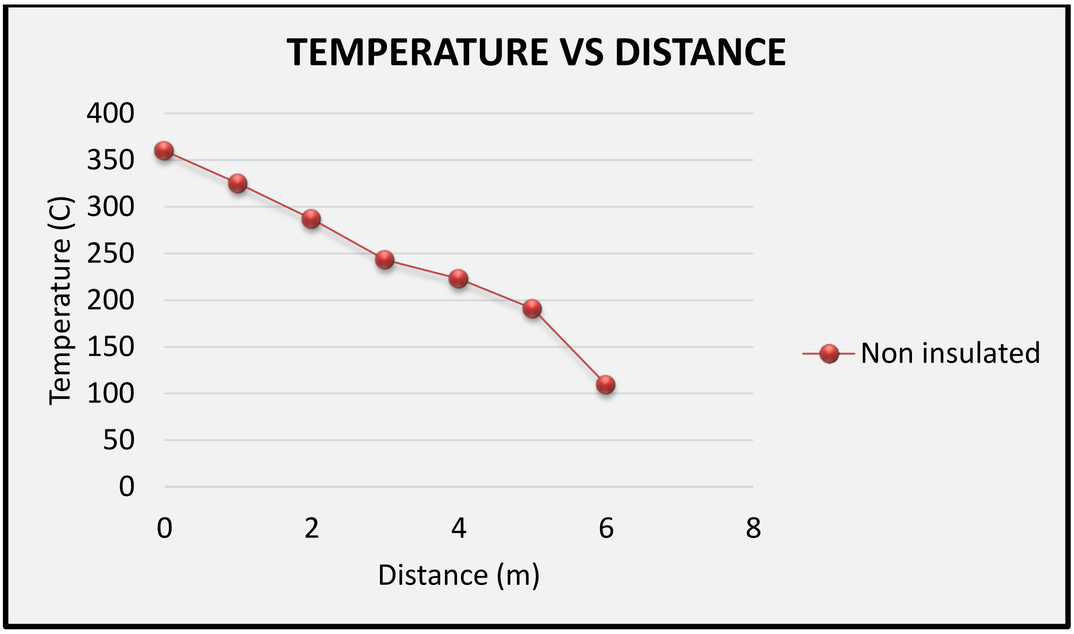


Figure 18: Graph of heat distribution of hot air along the heated shaft

Below are the temperature result of heat distribution for insulated dryer during the test run.

Distance from heat source (m)	Temperature (°C)
0	360
1	295
2	241
3	223
4	207
5	175
6	94.5

FIGURE 19 : Hot air temperature along the insulated dryer

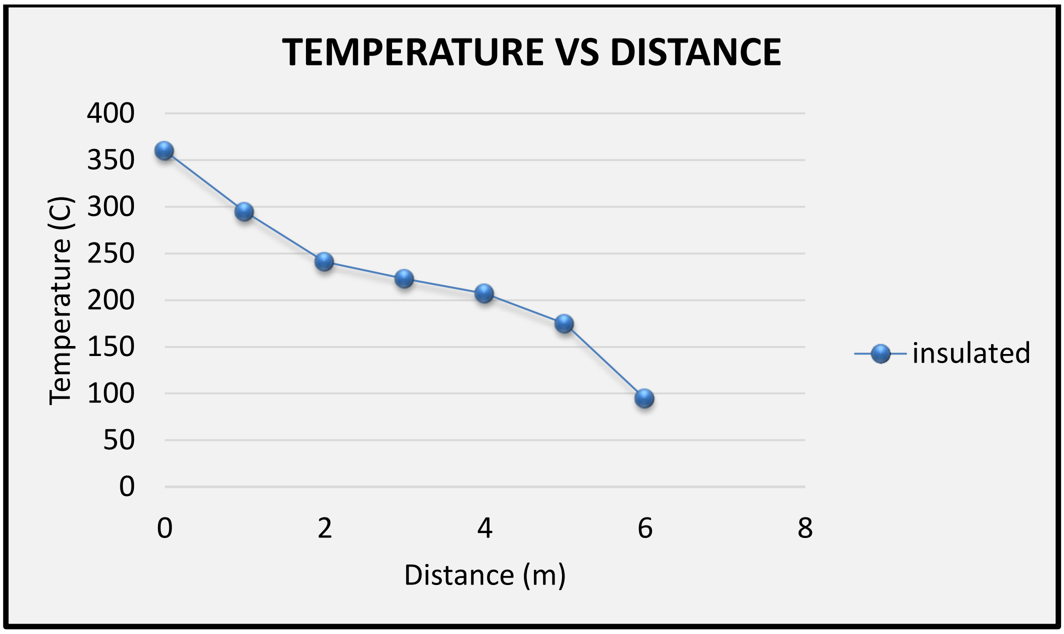


FIGURE 20 : Graph of heat distribution of hot air along the heated shaft

4.6 Comparison of experimental result of insulated and non-insulated of hot air temperature at the same point along the heated shaft.

Point	1	2	3
Temperature °C Non-insulated	360	207	79
Temperature °C Insulated	360	223	94.5

FIGURE 21: Temperature comparison at same point of location

The total time taken for sludge to move from inlet to the outlet is 3 minutes along the dryer channel and its actual operating rotation is 10 rpm. According to the data gathered, the distribution of heat decreases as the location further from the heat source. For comparison, insulated dryer results more efficient in heat distribution process. The decrement temperature gradient of insulated dryer is less than non-insulated dryer. Thus, insulated dryer is expected to produce more quality of end product of dried sewage sludge.

FIGURE 22: Insulation process on the dryer channel

For comparison purpose, experimental data of insulated dryer will be used for comparison purpose with the simulation data obtained. This is because the generic dryer model is designed to have no heat lost to the surrounding. Thus, insulated dryer is more reliable for comparison purpose.

4.7 Comparison of experimental and simulation inlet and outlet temperature

Temperature (°C)	Experimental	Simulation
Inlet	360	360
Outlet	94.5	109.5

FIGURE 23: Comparison of hot air inlet and outlet temperature

Percentage of error

$$\% \text{ Error} = \frac{\text{Simulation Outlet} - \text{Experimental Outlet}}{\text{Simulation Outlet}} \times 100$$

$$= \frac{109.5\ ^{o}C - 94.5\ ^{o}C}{109.5\ ^{o}C} = 13.7\%$$

4.8 Determine Sludge Output Temperature

In order to improve the heat distribution of the hot air to the sludge, author study the relationship between the sewage sludge flow speed and the output temperature of the sewage sludge. Slower flow of sludge gives more time for heat to transfer from the heated shaft wall to the dewatered sludge for drying purpose as total energy transfer through conduction process increases with the total time contact between the transfer media. The heat capacity of 65% dewatered sewage sludge is quite high which is (3.045 kJ/(kg·°C)) due to high energy consumption needed to evaporate the water content. Thus, efficient dryer need to be used to ensure less energy consumed for the drying process.

4.8.1 Heat Transfer Process

Basically, there are two major heat transfer process that involve in the drying process which is convection and conduction process.

4.8.1.1 Convection Process of Dryer

Convection process is referred as the process of heat transfer from one place to another resulted from the movement of fluid. The heat transfer per unit surface through convection is known as the Newton's Law of Cooling.

The equation for convection can be expressed as:

$q = h_c A \, dT$

where

q = heat transferred per unit time (W)

A = heat transfer area of the surface (m^2)

h_c= convective heat transfer coefficient of the process ($W/(m^2K)$ or $W/(m^{2o}C)$)

dT = temperature difference between the surface and the bulk fluid (K or ^oC)

Generally, forced Convection of Air is = 10 - 200 ($W/(m^2K)$)

This process occur in the drying process

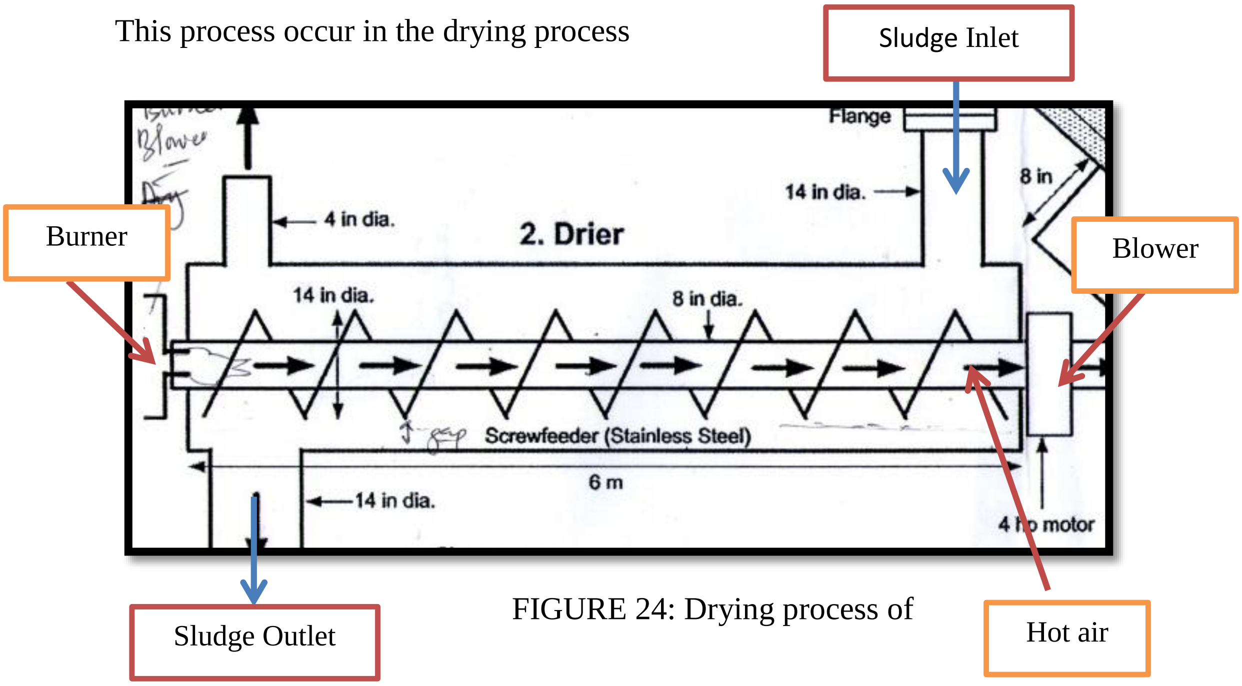


FIGURE 24: Drying process of

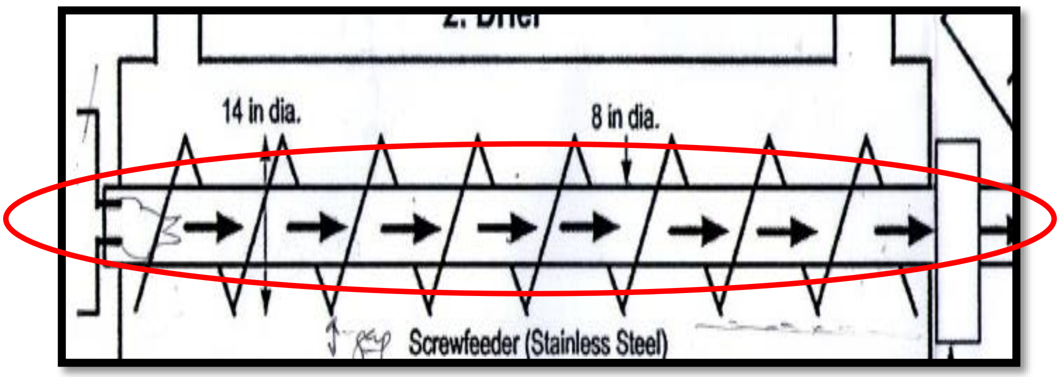


FIGURE 25: Convection process of heat transfer

The red circle marked on the picture above indicates the flow of hot air that involved in the convection process. Convection occur from heat transfer process from the hot moving fluid (heat source) to the inner surface wall of the screw cylinder shaft. This process of heat transfer contribute major influence of the whole drying process.

The heat transfer process mainly occur through convection process between hot air and inner pipe surface of the steel shaft. Therefore, maximum of energy transfer is calculated as follow

4.8.1.1.1 Energy transferred

$$\dot{Q}_{air} = h\,A\,t\,(t_{air} - t_{steel})$$

$\dot{Q}_{air}$ = Rate energy transfer of air

h= heat transfer coefficient; air = 95 W/(m^{2}K)

A= Area of heat transfer

t = duration time contact

t_{steel} = Steel wall temperature

t_{air} = Temperature of hot air

$\dot{Q}_{air}$ = 95 W/(m^{2}K) x 3.77 m^2 x (360-50)K

=111kW

4.8.1.1.2 Sewage sludge output temperature

Next, temperature difference of sludge for maximum heat transfer is calculated, which assumed no heat lost to surrounding. There are several parameters need to be identified first before final temperature of dried sewage sludge output could be determined.

1) Maximum of heat transfer with consideration of 65% of dryer efficiency

$$\dot{Q}_{hot\ air} = N_{dryer} \times Q_{sludge}$$

$\dot{Q}_{hot\ air}$ = Hot air energy

$\dot{Q}_{sludge}$ = Energy transfer to sludge

N_{dryer} = Efficiency of dryer; 0.65

Thus, maximum heat transfer rate to the sludge is

$\dot{Q}_{sludge}$ = 0.65 x (111KkW) = 72.17kJ/s,

2) Mass flow rate

The mass flow rate of sewage sludge inside the dryer is calculated through following formula.

$\dot{m}_{sludge}$ **= d x v / t**

d = Density of sewage sludge, 129 kg/m^3 [13]

v = Volume of sludge occupied in the dryer , 0.42m^3

t = time taken sludge move from input to output entrance, 180s

$\dot{m}_{sludge} = d \times \frac{v}{t} = 129 \times \frac{0.42}{180} = 0.3 kg/s$

3) Heat capacity of 65% dewatred sewage sludge

Dewatered sewage sludge that enter the dryer encompasses 65% of water and 35% of solid. Thus the heat capacity of sludge is calculated through the following formula.

$$C_{p65\%} = [Wf_{water}\ C_{water}] + [Wf_{sludeg}\ C_{sludge}]$$

Wf_{water} = Percentage water content, 0.65

C_{water} = heat capacity of water, 4.18 kJ/kg^{o}C

Wf_{sludge} = Percentage water content, 0.35

C_{sludge} = sludge capacity of sludge, 0.9 kJ/kg^{o}C [16]

$C_{p65\%}$ = 0.65 (4.18) + 0.35 (0.9) = 3.045 kJ/kg^{o}C

4) Temperature of sludge output

Optimum output temperature with highest energy transferred from the hot air is;

$$\dot{Q}_{sludge} = \dot{m}_{sludge}\ Cp\ (t_f - t_i)$$

$\dot{Q}_{sludge}$ = Maximum energy transfer to sludge; 72.17 kJ/s

$\dot{m}_{sludge}$ = mass flow rate of full capacity dewatered sewage sludge inside the dryer

Cp = heat capacity of 65% dewatered sludge

t_f = temperature outlet of sludge

t_i = temperature inlet of sludge

72.1kW = 0.3 kg/s x 3.045 kJ/(kg·°C) (t_f – 50 ^oC)

t_f = 129 ^oC

Thus, optimum output temperature of the drying process in current operating condition must be at least 129 ^oC of sewage sludge output.

Simulation data shows that the output sludge temperature for current operating parameter is 72 ^oC. Thus, current operating condition is not work at optimum level.

Maximum total energy transfer at current operating condition is;

$\boldsymbol{\dot{Q}_{sludge} = \dot{m}_{sludge}\, Cp\, (t_f - t_i)}$

$\boldsymbol{\dot{Q}_{sludge}}$ **= 0.3 kg/s (**3.045 kJ/kg^{o}C) (72 – 50) = 20.1 kJ/s

Q_{sludge} = 20.1 kJ/s x 180s = 3.6 MJ

4.8.1.2 Conduction process of Dryer

The convection process of the moving hot air will allow heat transfer through screw feeder to the sewage sludge by conduction process. Conduction is a process where the heat is moving from hot region to the cold region resulted of the collisions of material molecule caused by heating process. In this situation, the inner surface of the screw feeder is heated by the flow of the hot air. The conduction process is described in the picture below.

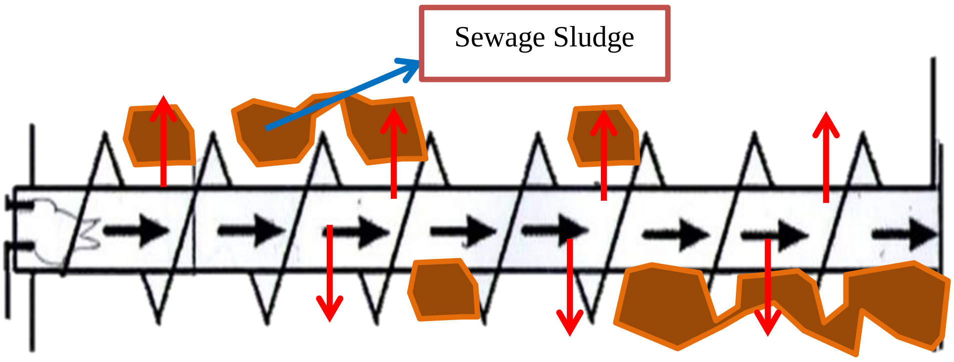


FIGURE 26: Conduction process of dryer

Theoretically, the burner able to provide maximum of 20MJ of total heat energy to dry 65% dewatered sewage sludge with current operating condition. However, the quality of sludge produce is still low which resulted only 20% of moisture reduction. Heat transfer quality could be improved by increase the total time contact between the sewage sludge and the heated shaft. As heat is transfer through conduction process between both media, the total heat energy transfer will increase as the time contact between sewage sludge and the heated shaft increases.

For actual operating dryer, the total heat transfer is expected to be less than analytical result above due to several factors such as heat lost to environment, material selection, designed constrain and etc. For an example, the distribution of heat from the hot air is not distribute evenly on the heated shaft. This is due to only one point of heat source located at the end of the dryer.

From the test run result of the dried sewage sludge product base on current operating condition, the dryer able to reduce approximately 20% of moisture content which the sludge output is expected to have another 45% of moisture content left.

Optimum dryness of sewage sludge to be as solid fuel is in range of 20% of moisture content. Thus, current operating condition need to be improved to meet the requirement. The working condition of the dryer could be manipulated to improve the final product quality. As working process for the dryer in distributing heat to the dewatered sewage sludge through conduction process, thus it is essential to highlight on the time contact between the dewatered sewage sludge and the heated shaft. The amount of heat transfer is depend on the total time of heat transfer as mention in the equation below.

$$\mathbf{Q_{conduction} = kAt\ (\ T_{hot} - T_{cold}\ )\ /\ d}$$

4.9 Energy consumption

The power consumption to dry the sludge determine the cost of the drying process. The reliability of the whole process is depend on the operating cost of the sewage sludge dryer and total energy content that able to be produced by the dried product.

This process involve calculation of total diesel consumption by the burner and energy consumption of auxiliary equipment's of the dryer. The energy used is determined by recording the total diesel consumption and energy rating of the equipment during drying process. The total energy is then calculated as follows

4.9.1 Actual Cost of drying process

- Total Diesel Consumption = 9.25 l/h
- 2 x 4hp motor (3KW) = 6 kWh
- 1 blower 220 Watt = 0.22kWh

As 1 kWh = 3600 kJ, thus total energy consume by the equipments are
(6.00 + 0.22) kWh = 22392 kJ

Total energy produce by burner & cost for drying process
1 Liter of diesel = 40 MJ [17]
9.25 Liter of Diesel Consumption for 1 hour = 370 MJ/h
Total usage energy = 370 MJ + 22.392 MJ = 392.4 MJ/h

Diesel Cost : RM 1.90 x 8 litre = RM 15.20
Electrical Cost : 6.22 kWh x RM 0.218 = RM 1.35 (base on TNB tariff)
Total Cost = RM 16.55 per hour of drying process.

4.9.2 Analytical analysis of fuel consumption

Analytical measure of the diesel consumption for current operating condition is calculated as follows

Maximum energy transferred from the hot air;

111kW x time taken for drying process, 180s = 20MJ

To determine the total amount of diesel consumption of actual drying process per hour is calculated as;

111kW x time per hour ; 3600s= 400MJ/h

The amount of analytical and actual diesel consumption has small range of deviation between both. Thus, the diesel consumption from the experimental data could be verified.

4.10 Simulation Process for optimum drying parameters

For further study, author has manipulate the flow rate of sewage sludge in the simulation to find the best operating value to achieve at least 129^{o}C of temperature output for maximum energy transfer. The output temperature with varies of sludge flow speed from the simulation process is tabulated as follows.

Sludge flow (m/s)	Sludge output temperature (^{o}C)
0.03	71.9
0.009	73
0.006	78.8
0.003	96.9
0.0009	138.6
0.0006	150.7
0.0003	162.3
0.00009	166.8

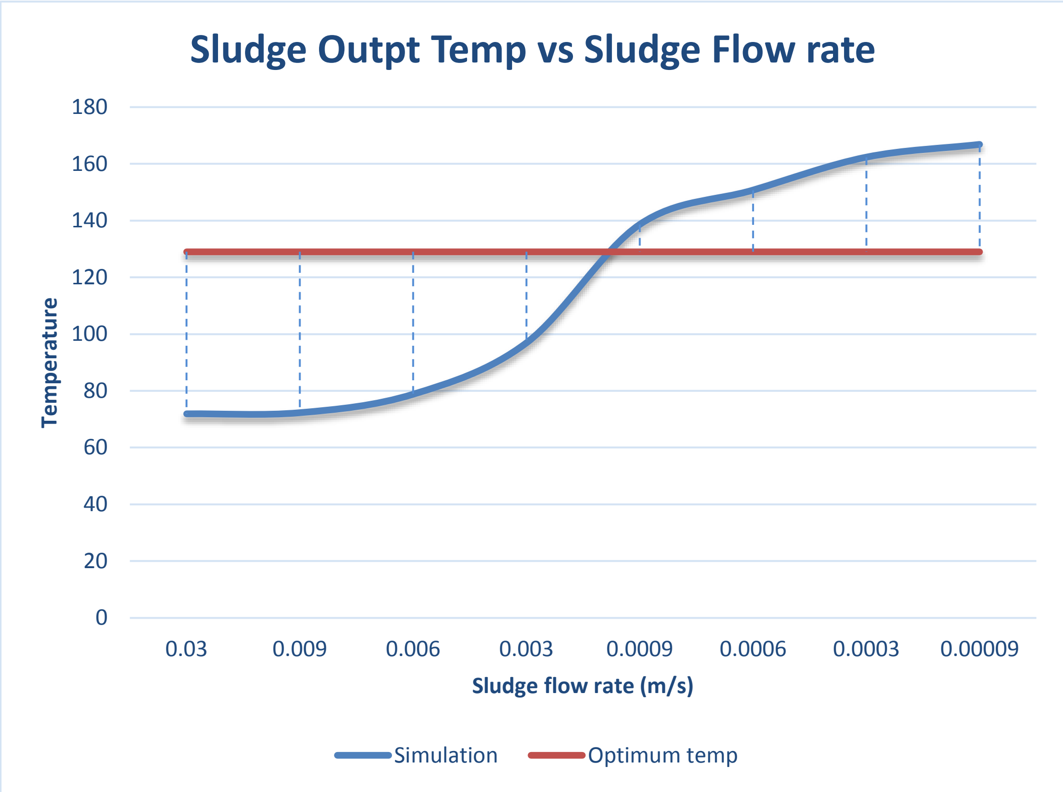


FIGURE 27: Sludge flow speed vs Temperature output

From the table above, the optimum sludge speed based on the current design is at the intersection of the graph result which calculated by interpolating the temperature range output in the yellow shaded box in the above table.

$$\frac{129-96.9}{138.6-96.9} = \frac{x-0.003}{0.0009-0.003}$$

X= 0.0014 m/s

Thus, the dryer must be operated at maximum speed 0.0014 m/s of sludge flow to receive maximum heat energy from the hot air. Below shows the heat distribution in cross sectional area along the sewage sludge dryer.

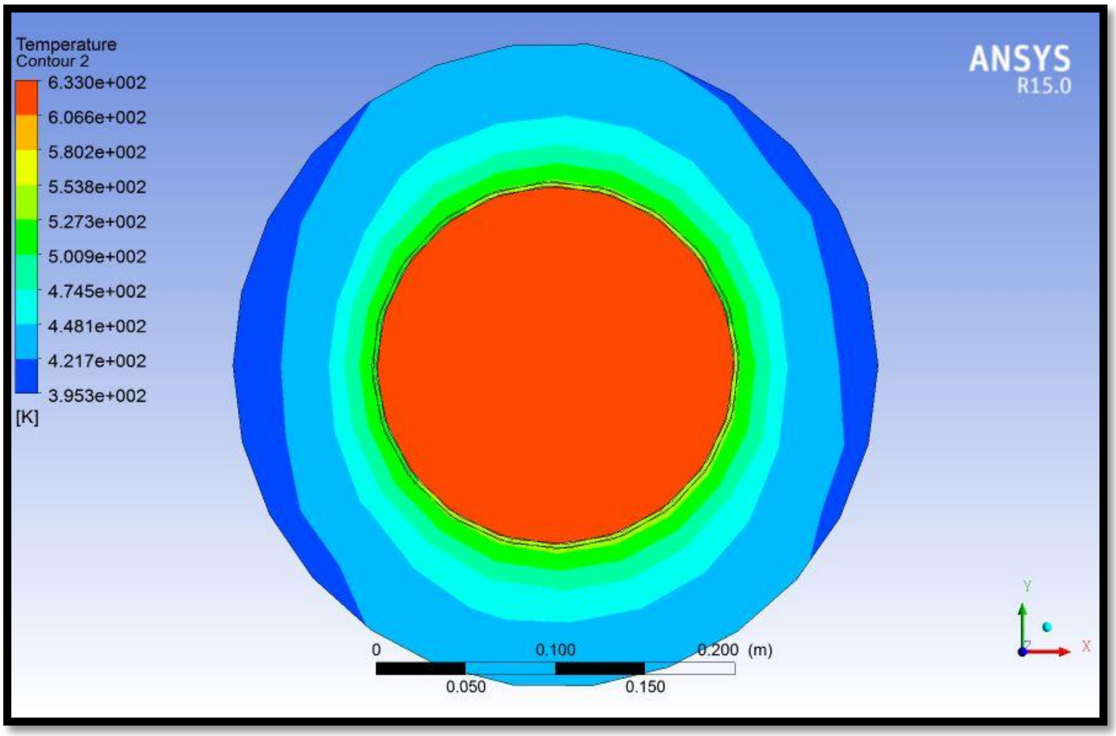


FIGURE 28: Heat distribution 0m distance from the heat source

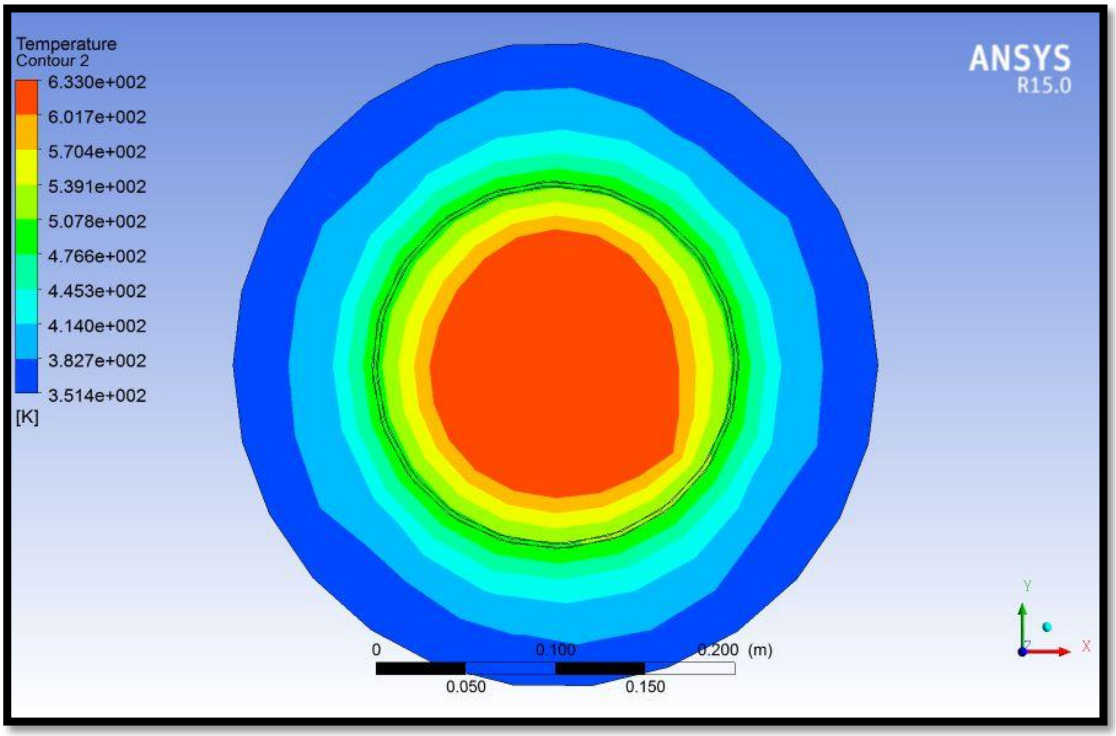


FIGURE 29 : Heat distribution 3m distance from the heat source

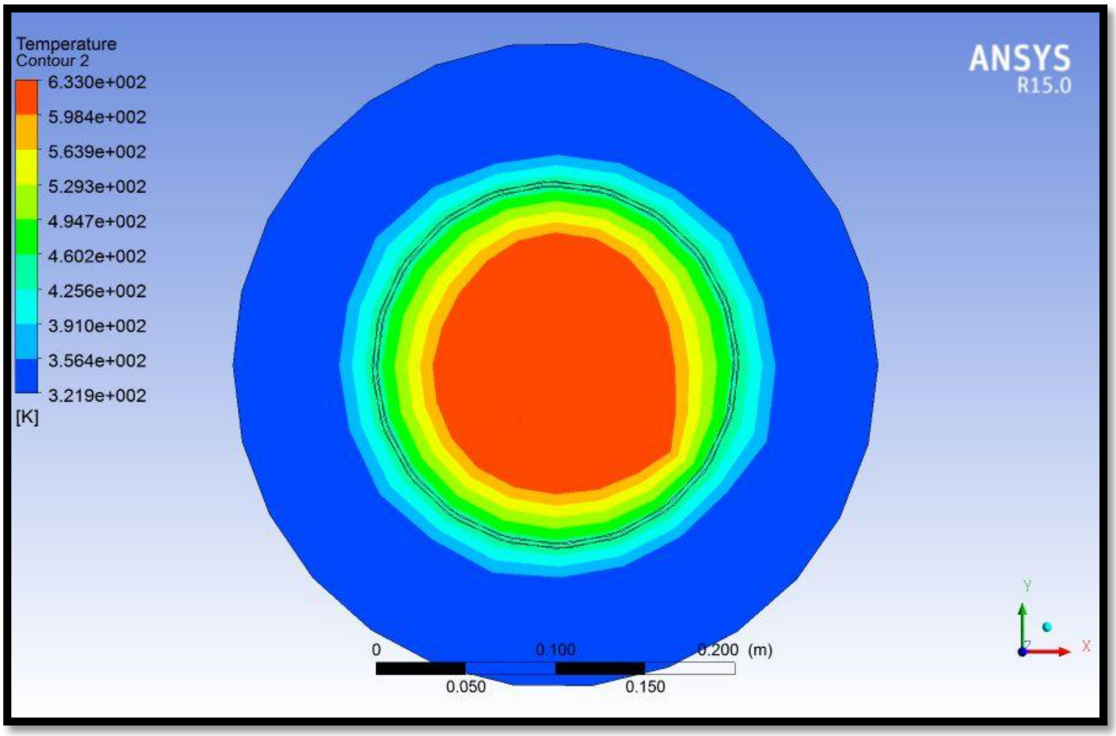


FIGURE 30 : Heat distribution 5.5m distance from the heat source

Refer to the simulation above, the heat distribution towards the sludge has been improved compare to the current operating condition. This is due to increment of time contact between the sludge and heated shaft. Thus is allow more heat to be transferred to the sludge. Total energy transferred from the heated shaft to the sludge is calculated through conduction process as explain in the following formula.

$$\mathbf{Q_{conduction} = kAt\ (T_{hot} - T_{cold})\ /\ d}$$

t_c= time contact between sludge and heated shaft

$Q_{conduction}$ = Total energy transfer to sludge

$\dot{m}_{sludge}$ = mass of full capacity dewatered sewage sludge inside the dryer

Cp = heat capacity of 65% dewatered sludge

T_{hot} = Surface temperature of heated shaft

T_{cold} = Temperature of sludge

Referring to the conduction formula above, with assumption that other factor is constant, the total energy transfer is highly influenced by the total time contact between the sludge and heated shaft. The higher the time contact between the sludge and heated shaft, the higher the total heat transfer to the sludge. However, another test run using the new proposed sewage sludge speed rate need to be conducted to verify the simulation data.

Amount of dried sewage sludge produce at 0.0014m/s sludge flow rate

$\dot{m}_{sludge}$ **= d x v / t**

d = Density of sewage sludge, 129 kg/m^3 [13]

v = Volume of sludge occupied in the dryer , 0.42m^3

t = time taken sludge move from input to output entrance, 4285.75s

$\dot{m}_{sludge}$ = 0.012 kg/s

Mass of sludge produce in 1 hour

$M_{sludge} = \dot{m}_{sludge} \times T_{hour}$

M_{sludge} = Total mass of sludge produce

$\dot{m}_{sludge}$ = mass flow rate of sludge;

T_s = second per hour.

$M_{sludge} = 0.012 \times \frac{3600\ s}{1\ hour} = 43.2$kgh

The total mass of final product of the sewage sludge produced is expected to remain 20% of water content. Hence, it will have 45 % reduction of its initial mass.

Therefore, the actual mass is

43.2kg – (0.45 x 43.2 kg) = 23.76 kg

Total energy contain from dried sludge product is; 23.76kg x 13 MJ/kg = 308.9 MJ

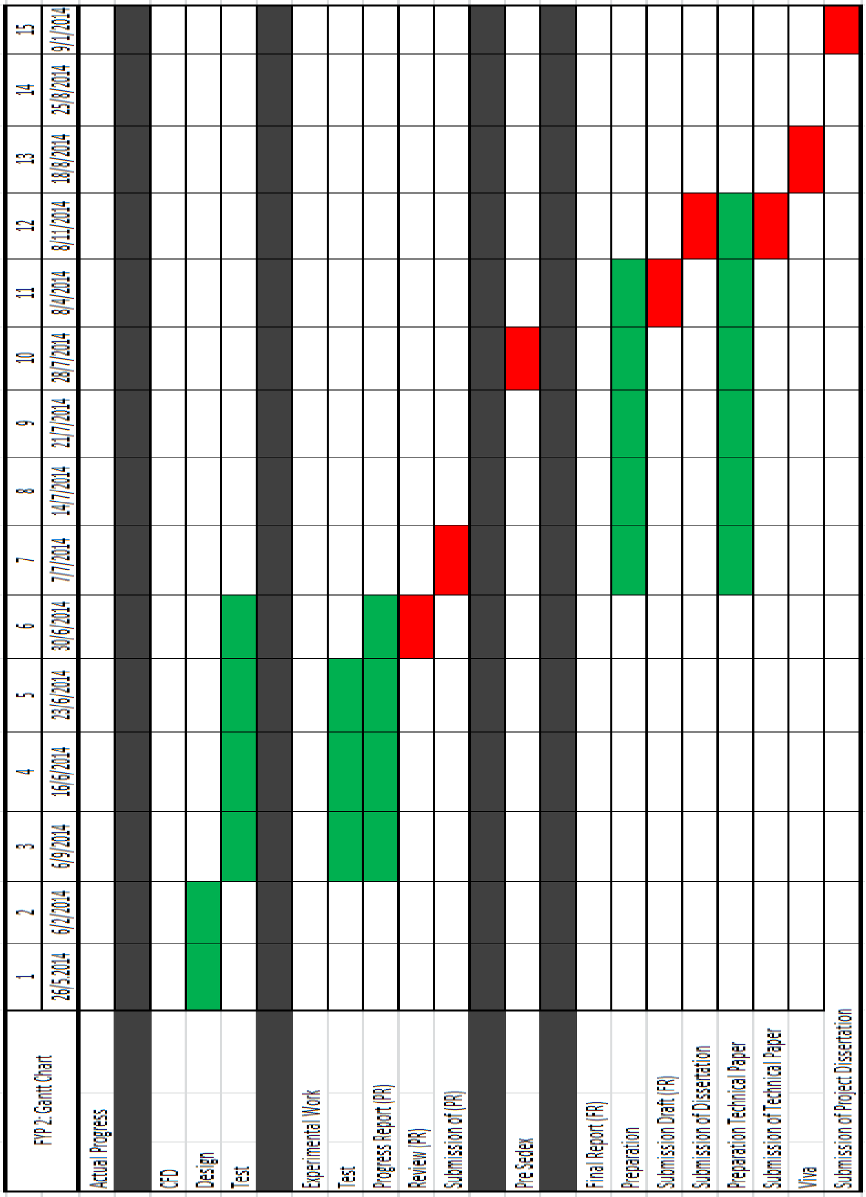
The total amount of sewage sludge stated in the calculation above is based on the improved operating condition of the sewage sludge dryer. In comparison, the amount of energy produce from the dried sewage sludge is lower than energy consumption for the drying process. However, in industrial scale, the process is still feasible as cogeneration system can be applied to lower the fuel consumption of the drying process.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The characteristic and study of sewage sludge based on result of related research have shown that it is very potential be used as solid fuel to generate power. Many methods have been proposed in order to extract the energy from the sewage sludge. Each method has its own advantage and reliability to recover the sludge energy but the drying process is very important. Every method needs the sewage product to be dried at least 20% of moisture content before proceed to further energy recovery process. A very good design concept of dryer is necessary in this process. Thus, computational fluid dynamic (CFD) test is important in order to study the effectiveness of the dryer and ensure the good product of solid fuel able to be produced. Simulation allow the user to have practical feedback when designing the real systems. This allow the user to study and identify the efficiency of the system without physically constructed. Consequently, the user may explore the best alternative at the same time, the overall cost of building could be diminished. Moreover, it could save tremendous time consumption in studying the design which refer to fast profit return. The result of the simulation on hot air temperature distribution inside the shaft is verified. Based on gathered result, the total heat energy transfer from the shaft to the sludge is related to the time contact between those two media. The higher the time contact, the higher the value of total heat energy transfer. However, the quality of the end product of the new proposed sludge flow speed need to be verified by conducting another experiment. After the verification process, the data could be used to design future sewage sludge dryer for the industrial application.

Appendices

Gant Chart of the 2nd Phase of the Project



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