DESIGN AND FABRICATION OF WATER LEVEL CONTROL VALVE FOR ACID FILLING SYSTEM

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Declaration by Author

This dissertation is composed by my original work, and it does not contain material previously published or written by another person except where due reference has been made in the text. The content of my dissertation is the result of work I have carried out since the commencement of my research project and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution.

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Nomenclature

Nomenclature	Caption
A	Cross-sectional area
D	Hydraulic diameter of the pipe
D_e	Equivalent diameter
f	Friction factor
g	Gravity acceleration
H_2SO_4	Sulphuric acid
h_L	Head loss
K_L	Local loss coefficient
L	Pipe length
PE	Polyethylene
PP	Polypropylene
PLC	Programmable Logic Controlle
R	Radius for the bending pipe according to the center
Re	Reynolds number
t	Time for filling battery container
V	Volumetric flow rate
v	Mean velocity
x_t	Parasolid format
$(Z_2 - Z_1)$	Height difference of the pipe
ε	Absolute roughness coefficient

ρ	Density
μ	Dynamic viscosity of the fluid
$2D$	Two dimensional
$3D$	Three dimensional

Abstrak

Asid pengisian sistem adalah salah satu proses pembuatan yang penting untuk penghasilan bateri asid. Kajian ini adalah untuk mereka bentuk satu sistem untuk menyediakan kadar aliran asid yang sama ke dalam setiap bahagian bekas batteri dengan menggunakan injap kawalan. Selain daripada kadar aliran, kajian ini juga perlu memberi masa pengisian bekas bateri adalah kurang daripada 30 saat.

` Sistem untuk kajian telah direka. Kehilangan tekanan dan jumlah kadar aliran sistem dikira. Aliran dalam sistem disimulasi dengan penggunaan simulasi Ansys dan keputusan menunjukkan bahawa sistem reka bentuk dapat memberikan kadar aliran yang sama selepas masa persediaan dapat dijalankan dan juga dengan pemasangan injap kawalan.

Abstract

Acid filling system is one of the important manufacturing process to lead acid battery. The study is to design a system to provide the constant acid flow rate into every division of the battery by using control valve. Other than the constant flow rate, the study also has to provide the filling time of the battery container is less than 30s.

The system for the study has been designed. The head loss and volume flow rate of the system are calculated. The flow in the system is simulated by using Ansys simulation and the results show that the design system is able to provide constant flow rate after having some set up time and with the installation of control valve.

1.0 Introduction

Lead-acid battery, the oldest type of the rechargeable battery and it was invented by a French physicist who called Gaston Planté. This battery is having a very low energy-to-weight ratio and also low energy-to-volume ratio, but it able to produce high surge current. This shows that the cells have a large power-to-weight ratio. This battery is attractive for the use in automobile starter motors as those features and also low cost.

Lead-acid batteries are widely used in many fields, such as automobile, transportation and also telecommunication industries. The traditional application of lead-acid battery includes starting, lighting and ignition (SLI), industrial batteries and special batteries [1].

There are few stages for the manufacturing process of the lead-acid battery such as oxide and grid production process, pasting and curing, assembly of the elements, acid filling process, charging and discharging, final assembly, and lastly is the inspection and dispatch process. Acid filling process is one of the lead-acid battery manufacturing process which play as an important role to the performance of the lead acid battery. This process is important to the performance of the battery because the level of lead acid in every division of the battery can affect the battery life span and performance. The level of the electrolyte or acid need to be optimized and filled until the same level to enhance the life span of the battery. If the acid level is too high, too low or different volume of acid level in every division, the performance and life span of the battery will be affected. Therefore, an acid filling system with constant and accuracy filling rate is very important for the battery manufacturer.

The small scale manufacturer of the lead acid battery will have problems on the acid filling process. In this final year project, a device will be designed to solve the problem. The device will help to improve the acid filling system with acceptable accuracy on the filling rate and volume.

1.1 Problem Statement

Small scale battery manufacturer is facing the difficulty on the control of the filling rate of the electrolyte in the acid filling process for the battery. This leads to the problem that the electrolyte level in every division of the battery may differ from each other. This can affect the performance of the battery.

1.2 Objective

The objectives of this project are

1. To design a device that can provide the same volume flow of electrolyte into every division of the battery.
2. To design a device that can provide the time for acid filling process that is less than or equal to 30 seconds for one battery.

2.0 Literature Review

2.1 Reynolds number

For circular pipe, the Reynolds number of the fluid is calculated by the following equation.

$$Re = \frac{\rho v D}{\mu}$$

Equation 1 Reynolds number equation

Where,

$$\rho = density\ of\ the\ fluid, (\ kg/m^3)$$
$$v = mean\ velocityof\ the\ fluid, (m/s)$$
$$D = hydraulic\ diameter\ of\ the\ pipe, (m)$$
$$\mu = dynamic\ viscosity\ of\ the\ fluid, (kg/m \cdot s)$$

Meanwhile, for the non-circular conduits, the Reynolds number of the fluid need to be calculated by replacing the hydraulic diameter of the pipe, D to the equivalent diameter, D_e.

$$D_e = 4 \times \frac{Cross - sectional\ Area}{Wetted\ Perimeter}$$

Equation 2 Equation of equivalent diameter [2]

The type of flow in the pipe with the respective range of Reynolds number is shown in figure 2.1. When Reynolds number of the flow is less than 2000, it is a laminar flow. When the flow is with the Reynolds number that greater than 2000 but less than 4000, it shows transition flow in the flow system. Transition flow is the flow that with the laminar and turbulent flow at the same time. Lastly, for the flow that with the Reynolds number greater than 4000, it is a turbulent flow [2] [3].

a) laminar flow: $Re_D < 2000$

b) transition flow: $2000 < Re_D < 4000$

c) turbulent flow: $Re_D > 4000$

Figure 2.1 Reynolds number for different type of flow [4]

2.2 Head loss

Pressure drop or head loss always occur in the pipe system as when fluid is flowing through the pipes, friction will occur when the flow regime change [5]. In a piping system, the head loss of the system is the total of the major loss and minor loss. Normally, major loss is the pressure loss that considered in the straight pipe [6]

2.2.1 Major loss

For the calculation of the major loss in the pipe, Darcy-Weisbach equation is one of the choice and it is more precise compare other equation [7]. Darcy-Weisbach equation can be said as a complex method for calculating head loss, but it is the most acceptable method as it can be used to calculate a lot of types of regime. These regimes include laminar flow, turbulence flow in horizontal and also vertical pipe [8] [9]. Head loss is expressed by the Darcy-Weisbach equation,

$$h_L = f \frac{L}{D} \frac{v^2}{2g}$$

Equation 3 Darcy-Weisbach Equation [10] [6]

Where h_L *is the head loss*

f *is friction factor*

L *is pipe length*

$$v \text{ is average flow velocity}$$
$$g \text{ is acceleration of gravity}$$

$$h_L = (Z_2 - Z_1) + f\frac{L}{D}\frac{v^2}{2g}$$

Equation 4 Darcy-Weisbach formula for vertical pipe [6]

Where $Z \text{ is the height of the pipe}$

Equation 3 is only applicable on horizontal pipe while equation 4 only applicable on vertical pipe.

Every type of pipe must have friction factor, even the friction factor for the smooth pipe must also have certain value. There is only certain type of pipe can be considered as smooth pipe, for example, plastic and glass. This is because the no-slip behavior always produced by the microscopic surface roughness of the pipes on the molecular level. For different type of flow and pipe, there are different ways to calculate the friction factor [6].

For laminar flow in the smooth pipe, the flow with Re<2300, the following equation, $f = \frac{64}{Re}$ can be used to calculate the friction factor of the pipe [6] . For laminar flow in the hydraulically smooth pipe, the Darcy- Weisbach friction factor can be estimated by using the Blasius (1911) formula,

$$f = (100Re)^{-1/4}$$

Equation 5 Blasius (1911) formula [6]

Hydraulically smooth pipe is the pipe that with roughness of the pipe wall is less than the thickness of the laminar sub layer of the turbulent flow [11].

If the Reynolds number for the flow is higher than 2300, which means is transition flow or turbulence flow. There are two methods can be used for calculated the Darcy-Weisbach friction factor for the two types of flow mentioned. These two methods are Colebrook equation and another equation given by S.E.Haaland [6]. The equations are as follow:

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Equation 6 Colebrook Equation [6]

$$\frac{1}{\sqrt{f}} = -1.8 \log\left(\frac{6.9}{Re} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right)$$

Equation 7 S.E.Haaland Equation [6]

The difference of these two equations is Colebrook equation has implicit relation for friction factor while the other equation is explicit related with friction factor [6]. The approximate implicit friction factor will be more accurate than the approximate explicit friction factor [12].

Other than approximate the Darcy-Weisbach friction factor by calculation, the friction factor can also be approximated from Moody chart. Moody chart covers a very wide range of flow parameters. Moody chart is very useful as the wide range of parameters that included in the chart, almost every type of pipe used are included in Moody chart [6]. The Moody chart is shown in Figure 2.2. From Figure 2.2, it shows that the friction factor can be estimating by using the Reynold number and the roughness of the pipe material which already known and vice versa. Figure 2.3 shows the roughness value for some of the piping materials. These roughness value can be used for the calculation.

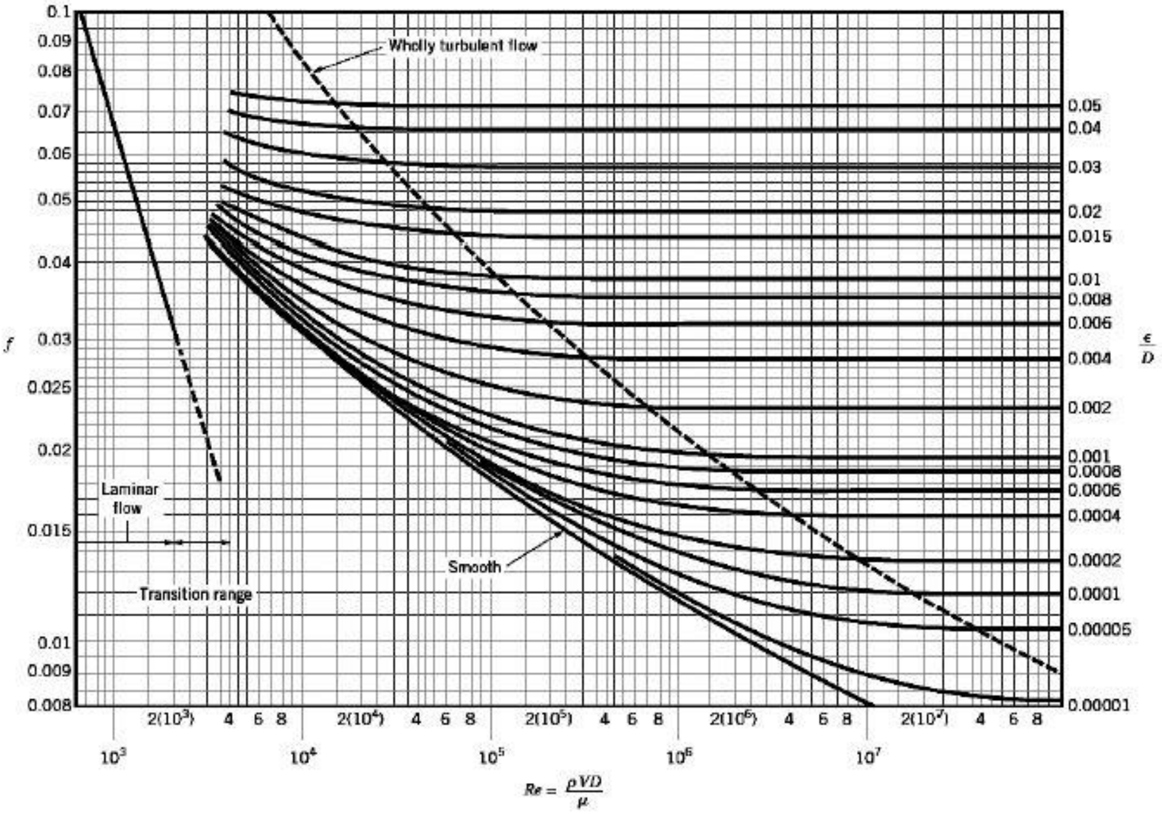

Figure 2.2 Moody chart [6]

Pipe Material	Absolute Roughness, ε	
	feet	microns
drawn brass or copper	0.000005	1.5
commercial steel	0.000150	45
wrought iron	0.000150	45
asphalted cast iron	0.000400	120
galvanized iron	0.000500	150
cast iron	0.000850	260
wood stave	0.0006 - 0.003	200 - 900
concrete	0.001 - 0.01	300 - 3000
riveted steel	0.003 - 0.03	900 - 9000

Figure 2.3 Roughness for piping material [13]

2.2.2 Minor loss

Other than the major loss, it is also need to consider minor loss of the piping system. In some situation, minor loss may play as larger role in the head loss of the piping system. The minor loss will be found at these areas such as entrance or exit of the pipe, sudden expansion or contraction, valves (open or partially close) and also gradual expansion or contraction [6]. The common equation that use for the calculate the minor loss of the piping system is shown below

$$h_L = K_L \frac{v^2}{2g}$$

Equation 8 Minor loss equation

Where K_L is local loss coefficient

v is average flow velocity

g is acceleration of gravity

For the loss coefficient of sudden contraction or expansion and the gradually expansion or contraction in the entrance and exit of the piping system, it can calculate by following the figure 2.4, 2.5, 2.6, 2.7 and 2.8. In figure 2.4 and 2.5, the loss coefficient of the rounded and sharped entrance for the piping system can be estimated based on the graph in the figures according the parameters considered respectively. The loss coefficient of the conical and sharped exit of the piping system can also be estimated based on the graph shown in figures 2.6 and 2.7. Figure 2.8 shows the graph that used to estimate the loss coefficient of the 90 degree bending pipe according to different diameter of the pipe.

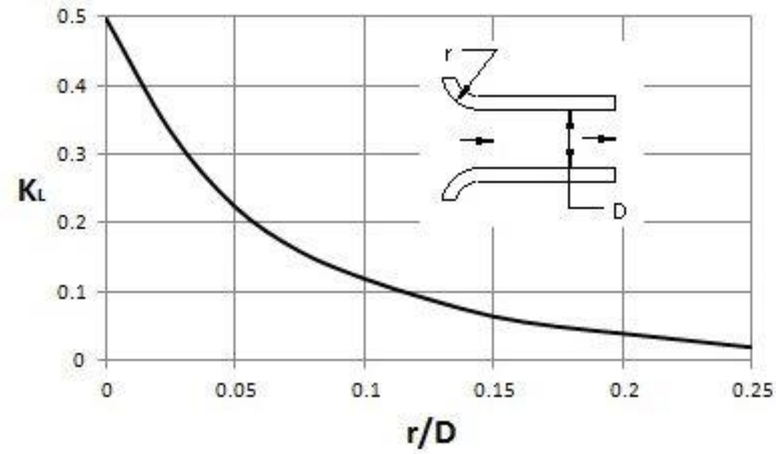

Figure 2.4 Loss coefficient of rounded edge entrance [14]

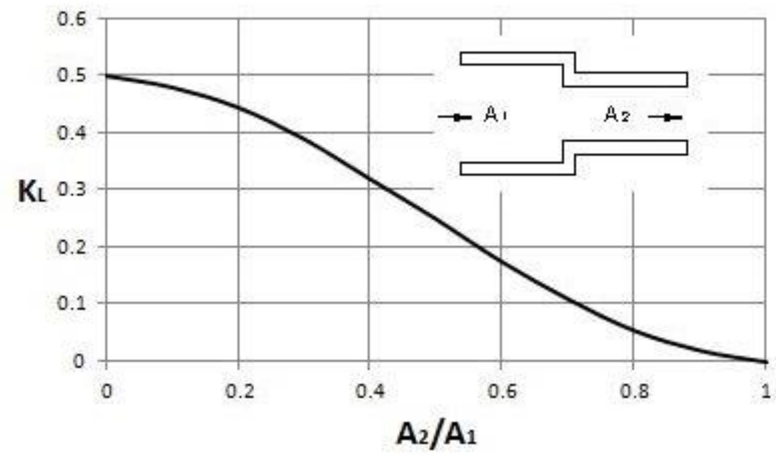

Figure 2.5 Loss coefficient of sharped edge pipe entrance [14]

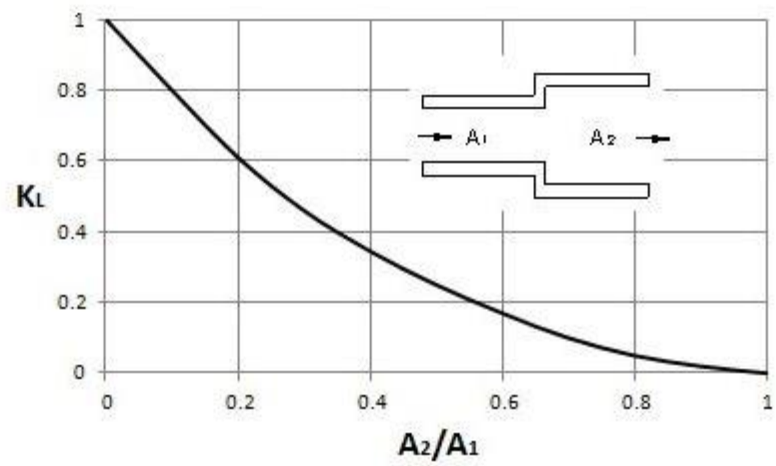

Figure 2.6 Loss coefficient of sharped edge exit [14]

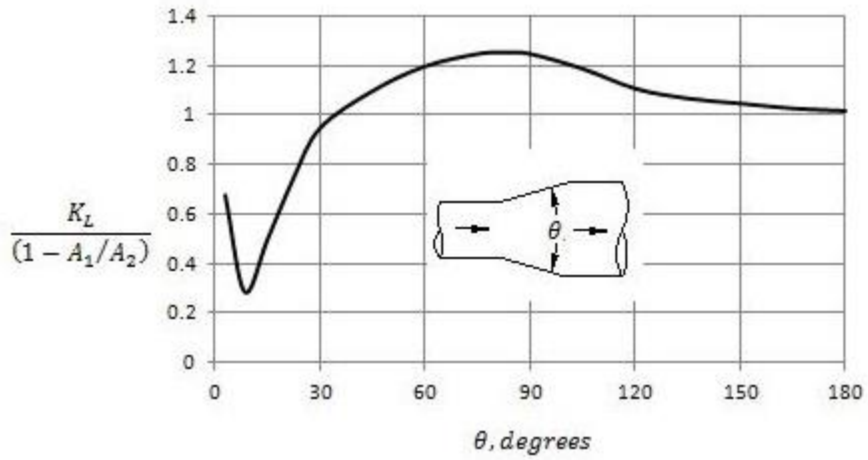

Figure 2.7 Loss coefficient of conical exit [14]

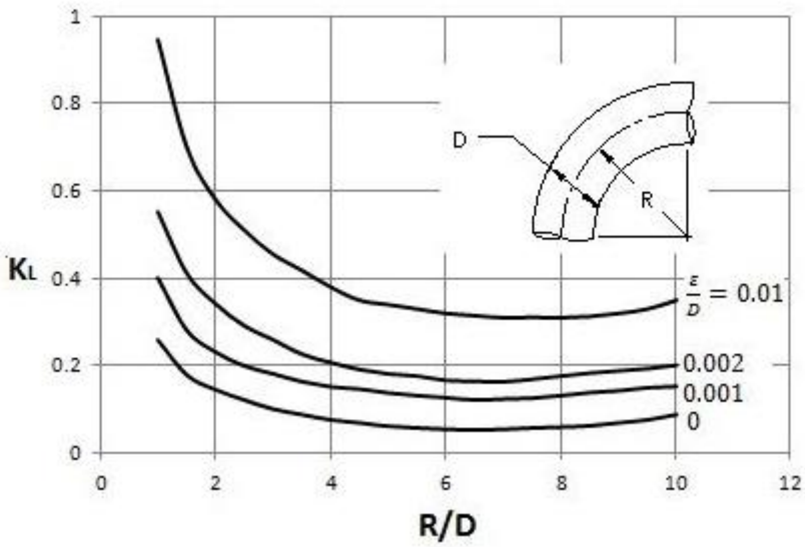

Figure 2.7 Loss coefficient of 90 degree bending pipe [14]

2.3 Materials for the device

Plastic materials is very useful for the acid application field. Different type of plastic materials has different performance. For low concentrated sulphuric acid, Polypropylene (PP) and Polyethylene (PE) are the plastic materials which are applicable on it. Polypropylene (PP) can be used for the sulphuric acid with the concentration range from 0 to 50% [15]. In Table

2.1, it shows some of the similarities and differences of the Polypropylene (PP) and Polyethylene (PE).

Table 2.1 Differences between Polypropylene (PP) and Polyethylene (PE) [16], [17]

Differences between Polypropylene (PP) and Polyethylene (PE)
• Polypropylene has higher melting point than polyethylene • Polypropylene has a stronger resistant to chemicals and organic solvent than polyethylene • Polypropylene is stiffer and rigid than polyethylene • Polypropylene can use to produce the optically clear product while polyethylene is only able to produce a translucent product

2.4 Fabrication method

There are many ways to fabricate a plastic product, these methods include blown film, extrusion blow moulding, extrusion profiles and sheet, injection blow moulding, injection moulding, insert moulding, plastic machining, thermoforming, vacuum forming, some of the extrusion process and also 3D printing [18] [19]. Within all these methods, there only some of the methods are suitable for fabricating the designed device. The fabrication methods that suitable for the designed device include injection blow moulding, extrusion blow moulding, injection moulding and also 3D printing [18] [19].

3D printing process is more customized and suitable for fabricating the prototype unit. 3D printing process needs much longer time than other manufacturing processes to produce a part. Therefore, it is not realistic to choose this method to manufacture the product as other processes may only take few seconds or 1 minutes while 3D printing requires few hours [20]. 3D printing is also an economical way to produce the prototype unit as it does not need to create any tooling to fabricate the part [20].

The ranges of materials for 3D printing is very wide and polypropylene is one of the materials that can be used for 3D printing [19].

3.0 Methodology

This project will undergo few processes which are design process of the device, calculating head loss and volume flow rate of the system and lastly fluent simulation of the device.

3.1 Designing process

The design idea is focusing the way to split the sulphuric acid from one inlet to 6 outlets with the constant flow rate of acid from the 6 outlet. The design device is construct by using SolidWorks software and shown in Appendix 1.

The material selected to build the designed device will be polypropylene. As the discussion made in material selection in literature review, polypropylene is one of the plastic material that is suitable for the usage under the low concentration of sulphuric acid. Polypropylene is also one of the materials that can used for 3D printing process. Therefore, polypropylene will be chose as the material for the device.

The fabrication method for the device is 3D printing. As 3D printing is the more economical way to fabricate the prototype unit compare to others fabrication way. This is because no mould model need to be built before fabricate the device. This can cut down the fabrication time and cost when using 3D printing to fabricate the prototype unit.

3.2 Result calculation

Some of the data need to be calculated for the whole system. These data include head loss of the system, volume flow rate and time to fill up the battery casing.

3.2.1 Head loss

Before calculate the head loss of the system, the Reynolds number of the system need to be calculated. This is to get known the type of flow in the pipe. The equation used to calculate the Reynolds number is shown in Equation 1. After the Reynolds number of the system have been found, the type of flow of the system will be known by refer to figure 1.

$$Re = \frac{\rho v D}{\mu}$$

$$\rho = density\ of\ the\ fluid, (\ kg/m^3)$$
$$v = mean\ velocityof\ the\ fluid, (m/s)$$
$$D = hydraulic\ diameter\ of\ the\ pipe, (m)$$
$$\mu = dynamic\ velocity\ of\ the\ fluid, (kg/m \cdot s)$$

a) **laminar flow:** $\mathrm{Re}_D < 2000$

b) **transition flow:** $2000 < \mathrm{Re}_D < 4000$

c) **turbulent flow:** $\mathrm{Re}_D > 4000$

After getting known the Reynolds number of the pipe, head loss of the system can be calculated. Head loss of the system includes major loss and minor loss. The formula uses for the calculation for the head loss of the system is the Darcy-Weisbach equation as this equation is the most acceptable method as it can be used to calculate a lot of types of regime. These regimes include laminar flow, turbulence flow in horizontal and also vertical pipe [8] [9]. The Darcy –Weisbach equation used for the calculation of the major loss in the system will be shown in below, equation 2 will be used to calculate the major loss of horizontal pipe while equation 4 will be used to calculate the major loss of vertical pipe region.

$$h_L = f \frac{L}{D} \frac{v^2}{2g}$$

Where $h_L\ is\ the\ head\ loss$

$f\ is\ friction\ factor$

$L\ is\ pipe\ length$

$$v \text{ is average flow velocity}$$

$$g \text{ is acceleration of gravity}$$

$$h_L = (Z_2 - Z_1) + f\frac{L}{D}\frac{v^2}{2g}$$

Where $Z \text{ is the height of the pipe}$

The minor loss of the system will be calculated by using the equation 8, minor loss equation,

$$h_L = K_L\frac{v^2}{2g}$$

Where K_L = local loss coefficient

v is average flow velocity

g is acceleration of gravity

3.2.2 Volume flow rate

The volume flow rate of the system will be calculated so that the time for filling the battery casing can be calculated. This is because the volume flow rate of a system will be constant, therefore, the volume flow rate of the system can be used to find out the time needed to fully fill the battery casing. The equation will be used for the calculation of volume flow rate is

$$V = Av$$

Equation 9 Volumetric flow rate equation [21]

Where $V \text{ is the volumetric flow rate } (m^3/s)$

$A \text{ is the cross} - \text{sectional area } (m^2)$

$v \text{ is the mean velocity } (m/s)$

3.3 Simulation

The design device is saved in parasolid(x_t) format in order to import to Ansys software. The model imported is a solid domain. This solid domain will be used for fluid structure interaction study. A fluid domain is generated from the import solid domain.

Then, the fluid domain is meshed while the solid domain is being suppressed. Specific name is applied on every end point of the device for the boundary condition setup. This device contains one inlet and 6 outlets.

For the simulation of the design device, the simulation is run for transient flow. The flow study in this simulation is laminar after the calculation of Reynolds number done for the design device. There are two phases of fluid, the primary phase is air while the secondary is sulphuric acid, which is the fluid that flow into the device. The density and viscosity used for the sulphuric acid in Ansys fluent are $1260 kg/m^3$ and 0.001392 $kg/m \cdot s$ respectively. In the boundary condition of fluent, the velocity inlet with $0.1 m/s$ is applied to the inlet of the device. The volume fraction of sulphuric acid is set to 1 as it is the fluid that will flow into the device. All the 6 device outlets' pressure are set to 1 atm (101325 Pa). The backflow volume fraction of the sulphuric acid is set to 0 as backflow is not the desired situation in this fluent model. The dynamic mesh is disabled as the fluid will not affect the mesh of the component when the sulphuric acid is flowing through the components. The reference value of the boundary condition is referred to the device inlet while the reference zone is set with the whole fluid domain.

For the solution methods and solution control, all of the setting is remained as default setting. While for solution initialization, hybrid initialization is chosen as the initialization method. For the calculation activities part, the data that wished to export are chosen and set up the auto-save for those data according to the demand. Then, the calculation is run according to the time step size, number of time step and maximum iteration per time step that already been set up.

4.0 Results and Discussion

4.1 Design

Figure 4.1 shows the overall system design for the acid filling system while figure 4.2 shows the “splitter” design to control the volume flow rate of the system. In the acid filling system shown in figure 4.1, the acid tank is designed as an open tank system. This is to easier the acid refilling process during the acid filling process. The open tank designed also to ensure the air can escape from the tank but not go into the pump. The sulphuric acid in the acid tank is pumped into the piping system by the acid pump. This piping system is connected with the splitter which shown in figure 4.2. The idea of the splitter design is using a conical splitter to split the fluid evenly into all directions and flowing out from six outlets. The 2D drawing of the splitter can refer to Appendix 1. When the sulphuric acid is pumped is reached the splitter, the splitter split the sulphuric acid from one inlet channel to the six outlet channels that are connected with nozzles. There are control valves applied at the beginning of the nozzles, these control valves are used to control the flow of the acid into the battery container in the acid filling system.

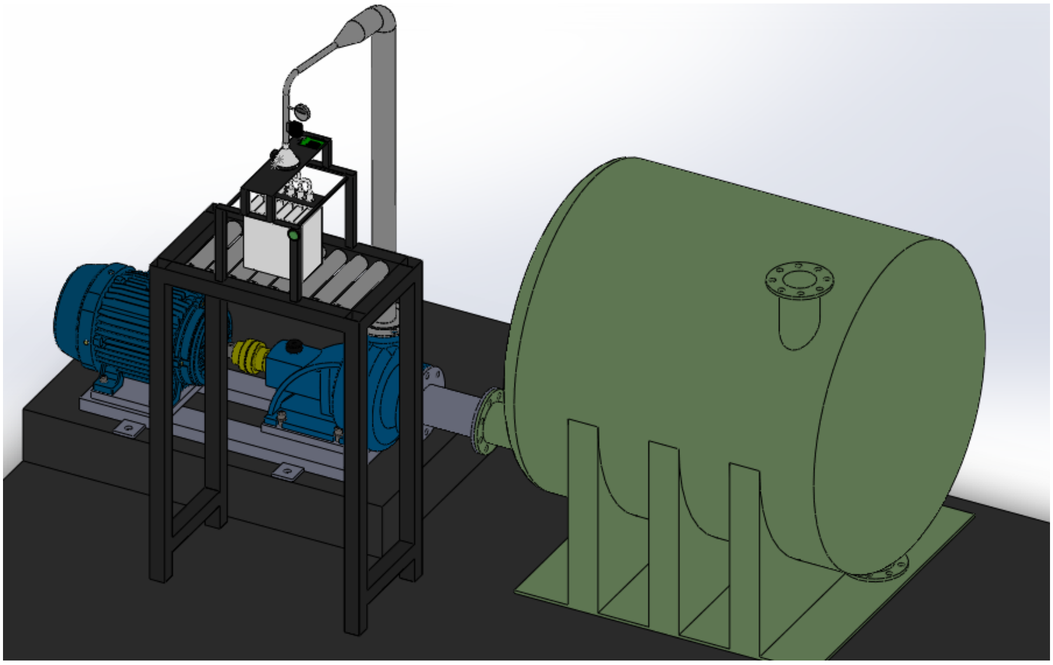

Figure 4.1 Overall System Design

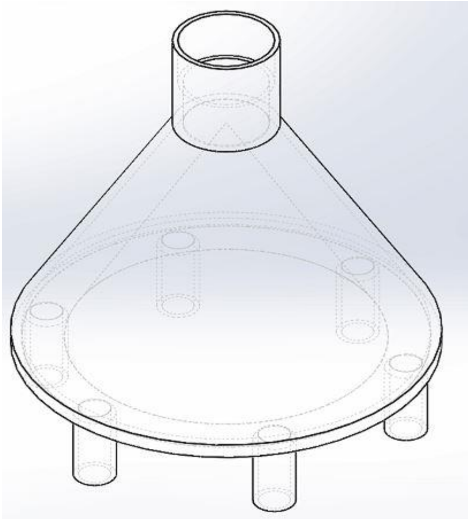

Figure 4.2 Splitter Design

4.2 Head loss of the system

4.2.1 Reynolds number

The major loss that will occur in the pipe regions is shown in figure4.3 which shown below. Before calculating the major loss of the pipe regions, the Reynolds number for the region need to be calculated to get to know the type of flow in the region. The type of flow regime in the pipe region need to be known so that the friction factor to be used in the calculation of major loss can be estimated.

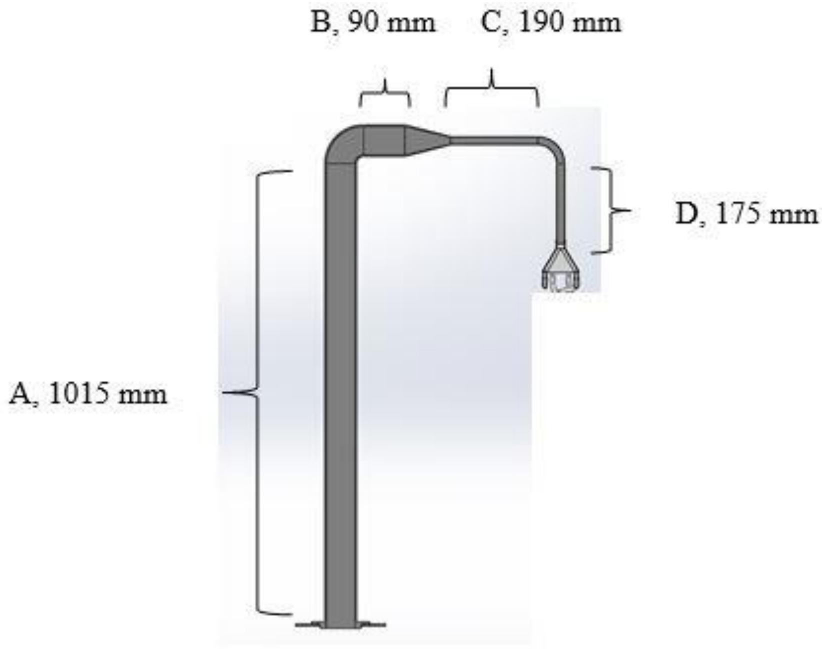

Figure 4.3 Major loss region for the pipe

The Reynolds number of the pipe system is calculated by the equation 1(refer to literature review). The mean velocity of the system is equal to $0.1 m/s$. The density and dynamic viscosity of the sulphuric acid are equal to 1260 kg/m^3 and $0.00275 Pa \cdot s$. The diameter of the respective pipes is shown in table 4.1 which pipe A and B with 0.06235 m and pipe C and D with 0.016m respectively.

Table 4.1 Reynolds number of the pipe system

Parameter	Pipe A	Pipe B	Pipe C	Pipe D
Density(kg/m^3)	1260	1260	1260	1260
Mean velocity(m/s)	0.1	0.1	0.1	0.1
Diameter(m)	0.06235	0.06235	0.016	0.016
Dynamic viscosity($Pa\ s$)	0.00275	0.00275	0.00275	0.00275
Reynolds number	2856.76	2856.76	733.09	733.09

From table 2, The Reynolds number of pipe A and B are equal to 2856.76 while the Reynolds number of pipe C and D are equal to 733.09. By referring to figure 1, pipe A and B are having transition flow while pipe C and D are having laminar flow. The calculation of the Reynolds number can refer to Appendix 2.

4.2.2 Major loss

After identify the type of flow in the pipe, the friction number can be estimated. The friction factor of the turbulence flow can be estimated from Moody chart which shown in figure 2. The absolute roughness coefficient,ε of the polypropylene pipe is around 0.000015 [22]. Therefore, the relative roughness,ε/D of pipe A and B are equal to 0.002405. By refer to Moody chart in figure 2.2, the friction factor of these two pipes is estimated as 0.046. Meanwhile, the friction factor of the laminar flow pipe can be calculated by the following equation.

$$f = \frac{64}{Re}$$

Therefore, the friction factor of the laminar flow pipes is equal to 0.087. The friction factor of the regions of the pipe is shown in table 4.2. The calculation of the friction factor can refer to Appendix 2.

Table 4.2 Friction factor of different region of the pipe

Pipe	A(vertical)	B(horizontal)	C(horizontal)	D(vertical)
Type of flow	Transition	Transition	Laminar	Laminar
Friction factor, f	0.046	0.046	0.087	0.087

After the friction factor of the pipes have been found, the major loss of the pipe is calculated by using these two equations. The major loss of horizontal pipe is calculated by using equation 3, while for vertical pipe, equation 4 is used.

Table 4.3 Major loss of the pipe

Pipe	A	D	B	C
Height difference, Z2-Z1	1.0150	0.1750		
Friction factor,f	0.0460	0.0870	0.0460	0.0870
Pipe length,L	1.0150	0.1750	0.0900	0.1900
Diameter,D	0.0624	0.0160	0.0624	0.0160
Mean velocity,v	0.1000	0.1000	0.1000	0.1000
Gravitational acceleration,g	9.8100	9.8100	9.8100	9.8100
Major loss	1.0154	0.1755	0.0000	0.0005

From table 4.3, region A has the largest major loss within all the regions in the pipe, which is 1.0154 m, followed by region D with 0.1755 m. Region C has 0.0005 m while for region B, the major loss is around 0. The total major loss of the pipe is equal to 1.914 m. In splitter, there are two parts which can be counted as major loss.

In the splitter device, there are two regions which occur major loss for the whole system. The flow regime in the splitter is laminar flow as it is almost same as the enlarge diffuser in other pipe system. The flow in the splitter is depending to the flow that enter the splitter. If the flow enter the diffuser is turbulence flow, it may change to another flow regime when passing through the enlarging cross section. Meanwhile, if the flow enter to the diffuser is the laminar flow, the flow regime will not be changed when the flow passes through the enlarging cross section [23]. Therefore, the type of flow in the splitter is highly depending to the upstream pipe. The flow in upstream pipe which is the pipe region D in figure 4.3. Pipe region D is having a laminar flow. Therefore, the flow in the splitter will be laminar too. The friction factor used for calculation in the splitter will also followed the friction factor of pipe region D which is 0.0870. The two regions that major loss occur in the splitter are region E and G which shown in the figure 4.4. The major loss of these two regions will be calculated by equation 4 and the result is shown in table 4.4. Due to the splitter has 6 region G, the major loss of that region need to time 6 times and add to the major loss of region E. The total major loss of the splitter is equal to 0.1066 m. For the calculation of the major loss of the system, it can be referred to Appendix 2.

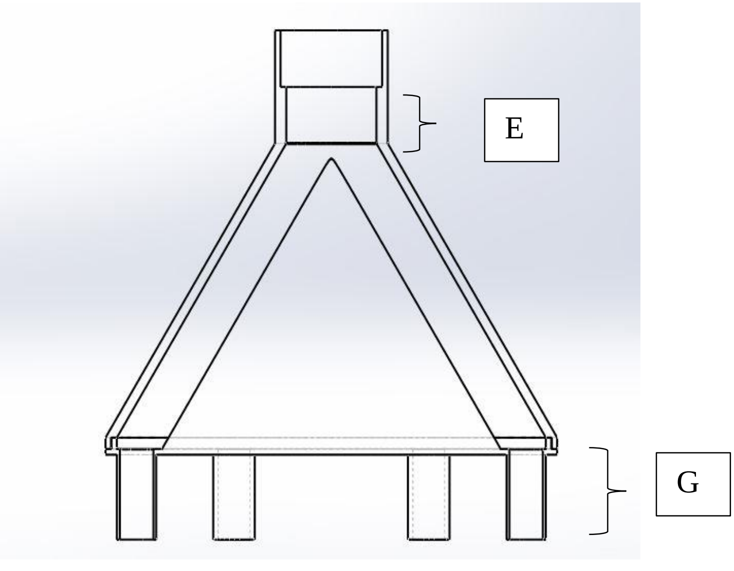

Figure 4.4 Sectional view of the 'splitter'

Table 4.4 Result of major loss in the splitter

Part	E	G
Height difference, Z2-Z1	0.0100	0.0160
friction factor,f	0.0870	0.0870
Pipe length,L	0.0100	0.0160
Diameter,D	0.0160	0.0060
mean velocity,v	0.1000	0.1000
gravitational acceleration,g	9.8100	9.8100
Major loss	0.0100	0.0161

4.2.3 Minor loss

The loss coefficient of the section which shown in figure 4.5 is estimated based on figure 2.8. The relative roughness of this section is equal to 0.002405. The R for the pipe is 50 mm and D is 62.35mm. The R/D ratio is equal to 0.8. From the graph shown in figure 2.8, the loss coefficient of this section is estimated as 0.56.

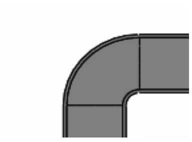

Figure 4.5 First bending region in the pipe

Figure 4.6 shows the gradual contraction region in the pipe. The diameter of A1 and A2 are equal to 0.06235 m and 0.016 m respectively. The loss coefficient in this region is estimated from the graph in figure 2.5 by using the value, $A_2/A_1 = 0.066$. The loss coefficient of this region is equal to 0.5. The calculation part can refer to Appendix 2.

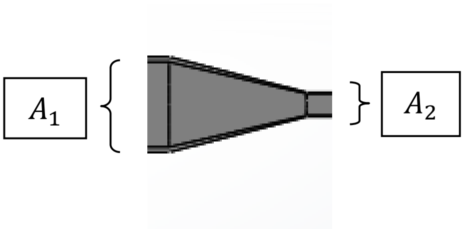

Figure 4.6 Gradual contraction region in the pipe

This pipe section shown in figure 4.7 is having R value with 50mm and D value 16. The R/D ratio is 3.125 and the relative roughness is equal to 0.002405. From figure 2.8, the loss coefficient of this pipe section is estimated as 0.30.

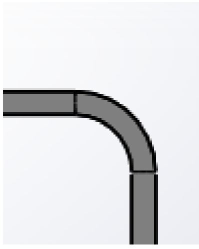

Figure 4.7 Second bending region of the pipe

Minor loss of splitter

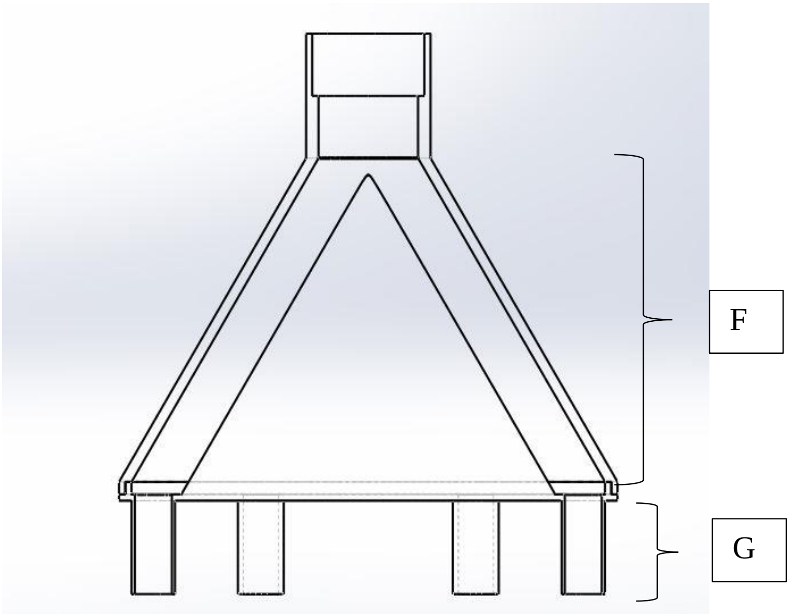

Figure 4.8 Minor loss region in splitter

The minor loss of the splitter will occur in region F and G are labelled in figure 4.8. The loss coefficient in region F is estimated as 1.06 based on figure 2.7. The loss coefficient of region G is estimated to 0.5 for every channels based on figure 2.5. The calculation part can refer to Appendix 2.

The total minor loss for whole system is calculated by using equation 8.

$$h_L = [(0.5 \times 6) + 1.06 + 0.3 + 0.5 + 0.56] \frac{(0.1)^2}{2 \times 9.81}$$
$$= 2.762 \times 10^{-3} m$$

The total head loss of the system,

$$h_L = 0.1066 + 1.1914 + 0.002762$$
$$= 1.3008m$$

The total head loss for the system is equal to 1.3008 m. The current design of the acid tank is located on the floor, so a large height difference pipe is needed. From table 4.3 and table 4.4, the vertical pipe with largest height difference, which is region A shows the most significant effect to the head loss of the system. Therefore, the head loss of the system can be reduced by decreased the height difference of the vertical pipe. The height difference of the vertical pipe can be reduced by increasing the base height for the acid pump and also acid tank. The height difference of the vertical pipe is the factor that has the most effect on the head loss of the system in this design.

4.3 Simulation of the flow in “Splitter”

In figure 4.9, the volume fraction of sulphuric acid (H_2SO_4) flow in the splitter and nozzles is represented by different colours. From figure 4.9, the volume fraction of the sulphuric acid is fully filled in the system when it is showing red colour in the system and blue colour when there is no sulphuric acid in the system.

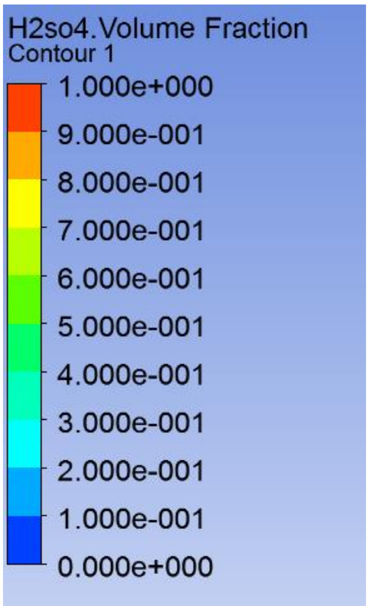

Figure 4.9 Volume fraction of sulphuric acid

From the figures 4.10, 4.11, and 4.12, the result of the volume fraction of sulphuric acid show that the flow of acid in the system is not having constant flow in the six outlets. From figure 4.10, it can be observed that the volume fraction of sulphuric acid in the outlets is different at the same height level.

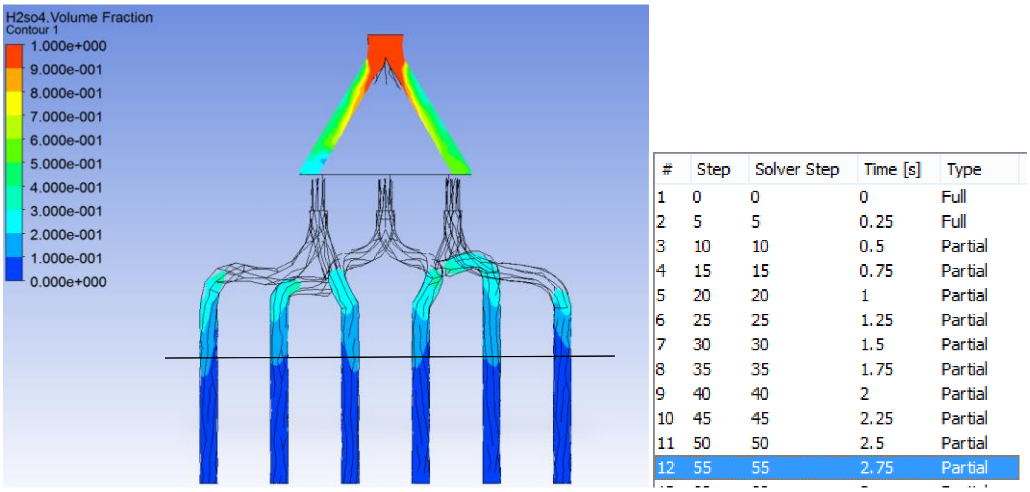

Figure 4.10 Volume fraction level of sulphuric acid at 2.75 s