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Thermal System Design for Sulfuric Acid Dilution Device - A Case of Awash Melkassa Aluminum Sulphate and Sulfuric Acid S. Co

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***Abstract:** Preparation of the diluted sulfuric acid not only causes chemical burns, but also secondary thermal burns because of dehydration. However, the domestic acid company only supply the (98-98.5 percentage) of concentrated sulfuric acid to the customer. Thus, customers have no choice, and manually dilute the concentrated sulfuric acid at home while they face the problem of strong acid dilution hazards. In response to this problem, the main objective of this thesis is to design an acid dilution system of $4\ m^3/s$ capacity that delivers (1 to 97 ww%) diluted acid concentration. The main components of the system are pipelines, heat exchanger, storage tanks, pumps, mixing device, valves and fittings. The method used for developing the overall conceptual design of the acid dilution system is inferring the existing worldwide acid dilution system experience using solid work 2016 for modelling and mathematical investigation, and M.S Excel 2016 for iteration. The required flow rate of both concentrated sulfuric acid and diluent water is calculated for each output concentration, and the heat load as well as final temperature during dilution is determined and validated.*

Considering the allowable velocity and surface roughness for each material as the design variable with two conflicting objectives of pressure drop and pipe diameter over each output concentration, among the seven recommended concentrated sulfuric acid pipe materials the carbon steel is selected. Moreover, stainless steel is used for diluent and cooling water piping and the appropriate dimension of the pipe is determined. In addition, the size of tank capacity per day with time is determined using a simple finite difference method. Moreover, other auxiliary system equipment's, like pump, static mixer, valve is selected as per requirement.

***Keywords:** Acid dilution device, Pipe material, Storage tank*

I. INTRODUCTION

The origin of this study is, the Awash- Melkassa Aluminum Sulfate and sulfuric acid Share Company (AMASSASC) is the only chemical company in Ethiopia that produces sulfuric acid with 98.5 % weight concentration. However, the customer requires at different concentration less than the initial concentration.

In addition, steady demand grows because H_2SO_4's favorable properties make it useful in preparing a variety of products. For example,H_2SO_4's hygroscopic nature is ideal for drying synthesis gases in the chemical and petrochemical industries. Moreover, several applications require at different dilution range. Like fertilizer production, synthesis gas drying, etching and pickling baths, mine-ore processing, refinery catalysis, manufacture of paper, detergents, dyes, drugs, car batteries, plastics, and production of various chemicals.

The users of sulfuric acid requires sulfuric acid at different concentration level. The requirements varies as both from time-to-time and organization to organization based on the application. Nevertheless, the company has no acid dilution plant. They only supplies the final product of concentrated sulfuric acid (98 to 98.5 weight percent) amount to the customer as it is, while almost no customer uses sulfuric acid at this range of concentration.

Moreover, due to the only company, the customer have no choice to purchase the lessen sulfuric acid concentration. The only option they have is diluting this concentrated sulfuric acid manually at home. However, the process of placed water in sulfuric acid is extremely dangerous, as the water completely ionizes small amounts of water in concentrated amounts of sulfuric acid will boil and form an acidic mist, which is highly acidic, and damaging if inhaled. This aggressive nature of the chemical can causes permanent blindness, internal burns, respiratory track irritation, and possibly death. Sulfuric acid is an extremely dangerous chemical that must be handled with caution. In addition, the sulfuric acid dilution process is very exothermic (when dissolving in water), several safety precautions shall be taken with the handling, storage, dilution and transportation of sulfuric acid.

According to the current situation of AMASSASC, it is important to provide sulfuric acid with different dilution level due to couple of reasons. First, to meet customers need and protect the beneficiaries from any acid dilution hazards. Second, to ensure the sustainability of factory effectiveness. In response to this problem, this thesis investigate the optimum sulfuric acid dilution device that can work for various concentration level.

The Acid Dilution System

The Powell acid dilution system uses sulfuric acid in-line-mixing system or an in-line-blending system. Usually these systems dilute 98% or 93% sulfuric acid to lower strengths such as 70%, 50%,30% or lower.

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Any strength lower than the strong acid can be produced. Depending on the final sulfuric acid strength, large amounts of heat are generated during the dilution. When this amount of heat becomes significant, the dilution temperatures can boil the sulfuric acid at atmospheric pressure. Many companies use very expensive graphite or silicon carbide heat exchangers with the sulfuric acid under pressure requiring special piping materials and insulation to protect the workers from approximately 100 to 120°C temperatures. In a system where the sulfuric acid product strength is 10% or lower, the sulfuric acid can be diluted with water with no heat exchangers required since the heat of dilution is low. The Powell system construct the piping material using polyethylene fusion welding pipe and fittings. 98% sulfuric acid would typically use PTFE lined pipe and fittings. Other materials can be used depending on the purchasing company's specification. The instrumentation utilized for the sulfuric acid dilution system are Rosemount magnetic flow meters, pressure transmitters, temperature transmitters, Micro Motion mass meters and Masoneilan control valves are used. Other instruments such as Yokogawa transmitters and Fisher control valves can be supplied (powellfab, 2007).
The Wastech Acid Dilution Systems (ADS) are designed for diluting sulfuric acid to a lower concentration required for process use. These systems start with water and add acid until the desired concentration is achieved. The lower concentration chemical is then pumped to a holding tank for storage and use. The Wastech ADS includes all plastic wetted components for corrosion resistance and a fully automated control system (Wastech, 2015) .
Concentrated H_2SO_4 is diluted by varying amounts and the temperature changes associated with dilution are measured. The heat released during dilution is a result of the hydration of the various ions formed upon dissociation of the acid (Shakhashiri, 1983).
The unit consists of a Dilution Chamber, followed by a Heat Exchanger. Dilution Chamber is used for diluting concentrated sulphuric acid to the desired concentration and the Heat Exchanger is used for bringing down the temperature of dilute acid to desired temperature. The Heat Exchanger is of shell and tube type to dilute the acid. The acid should be added slowly to cold water to limit the buildup of heat. If water is added to the concentrated acid, enough heat can be released at once to boil the water and spatter the acid. Sulfuric acid reacts with water to form hydrates with distinct properties (kjhil, 1999).
The Noritake acid dilution system uses the dilution system continuously produces sulfuric acid at a consistent concentration through inline dilution of concentrated sulfuric acid. Dilution to the designated strength is performed in the dispersion mixer, and sulfuric acid that reaches high temperatures due to heat of dilution is cooled to the designated temperature with a heat exchanger. (Noritake, 2001)

II. DESIGN METHODOLOGY

This section describes the methods used to complete the objectives of this paper.

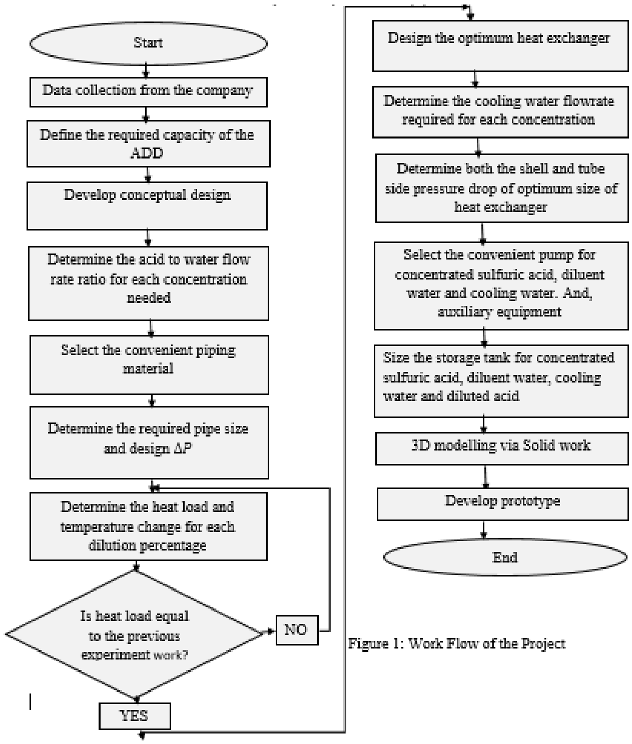

Figure 1: Work Flow of the Project

A. Collected Data and Gathered Information

- The condenser outlet temperature is around 25 ℃ according to the interviewed.
- The boiler preheater can receive starting from 40 ℃ input temperature.
- According to the interviewed, customer's need vary from time to time, company to company, industry to industry and people to people so that it is hard to know when will be the maximum and minimum demand reached in yearly or monthly bases. And, there is no research is done until know.
- Currently the company produces $2.36\ ton/hr$ and $20{,}000\ ton/yr$ in yearly basis. Moreover, the final sulfuric acid product is 98 to 98.5 % by weight.

B. Defining the Required Capacity of Acid Dilution Device

Table 1: Product mix and capacity of AMASSASC.

Sulfuric acid (98% + 0.5 w/w %)	20,000 tpa
Oleum (25 % free SO_3)	5, 000 tpa
Aluminum sulfate (17 % $Al_2\ O_3$)	13, 600 tpa
Hydrogen peroxide (50 % $H_2\ O_2$ w/w %, min 50 %)	5, 500 tpa

Taking average active hours per day = 8 hrs. (This eight hrs. per day is determined, considering the minimum average time so that one operator per day can cover the workload)

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$$\dot{m} = 20 \times 10^6 \ kg \ per \ year = 6849.31 \ kg/hr$$

$$\dot{Q} = \frac{\dot{m}}{\rho} = \frac{6849.31 \ kg/hr}{1831 \ kg/m3} = 3.74 \ {m^3}/{hr} \cong 4 \ {m^3}/{hr}$$

C. Develop Conceptual Design

The concept for the acid dilution device design is developed to allow dilution of highly concentrated sulfuric acid. And, widely plays an important role in the chemical industry. Usually, it is carried out with the use of the so-called mixing concentrated sulfuric acid with demineralized water. The following figures represents the conceptual design of main parts of acid dilution device as well as overall assembly.

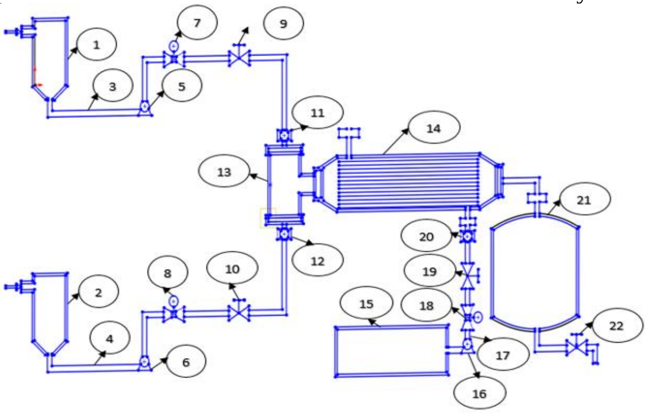

Figure 2: Conceptual design of sulfuric acid dilution device two-dimensional layout.

Legend

1- Concentrated sulfuric acid storage tank
2- Diluent water storage tank
3- Concentrated sulfuric acid pipeline
4- Diluent water pipeline
5- Concentrated sulfuric acid pump
6- Diluent water pump
7- Concentrated sulfuric acid flowrate control valve
8- Diluent water flowrate control valve
9- Concentrated sulfuric acid shut off valve
10- Diluent water shut off valve
11- Concentrated sulfuric acid check valve
12- Diluent water check valve
13- Mixing device
14- Shell and tube heat exchanger
15- Cooling water storage tank
16- Cooling water pump
17- Cooling water pipeline
18- Cooling water flow rate control valve
19- Cooling water shut off valve
20- Cooling water check valve
21- Diluted acid storage tank
22- Diluted acid shut off valve

D. Methods of Data Analysis

In order to achieve the required objective, this study will use design data book. Then the data will analyzed by using governing equation in each analysis and some empirical relation formulas. The software's used on this thesis were, SOLID WORK, and M.S Office 2016. An excel program has been developed to determine the tank size used for acid dilution device, to select the appropriate acid piping material, to determine the pressure drop over the diluent water and cooling water piping system assembly in each concentration level, to determine the dimension of parts, to select the appropriate system equipment's. In addition, to size and optimize the shell and tube heat exchange as per the heat load liberated during the dilution process. Further optimization of the design, by the help of excel, it became easy to check the effect of change in various parameters like baffle spacing and shell length on pressure drop and overall heat transfer coefficient.

E. Determination of the Acid to Water Proportion

The conservation of mass principle for a general steady-flow system with multiple inlets and outlets can be expressed in rate form as:
Steady flow

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \qquad (kg/s)$$

This implys :

$$(\rho V A)_{H_2SO_4,in} + (\rho V A)_{H_2O,in} = (\rho V A)_{H_2SO_4,out}$$

After setting the capacity of the acid dilution device, the mass flow rate can be determined as $\dot{m}_{H_2SO_4,out} = \rho_{H_2SO_4}$ (for each concentration, $\frac{Kg}{m^3}$) $\times \dot{Q}_{H_2SO_4,out}$

Now, mass is conserved before and after the dilution helps to determine both the mass and volume flow rate of the inlet concentrated sulfuric acid and diluent water.

$$\dot{m}_{H_2SO_4,in} = \dot{m}_{H_2SO_4,out} \times \frac{\text{weight percent concentration}_{H_2SO_4}}{100} \qquad (2)$$

$$\dot{m}_{H_2O,in} = \dot{m}_{H_2SO_4,out} \times \frac{(100 - \text{weight percent concentration}_{H_2SO_4})}{100} \qquad (3)$$

Then,

$$\dot{Q}_{H_2SO_4,in} = \frac{\dot{m}_{H_2SO_4,in}}{\rho_{H_2SO_4}(\text{at } 98.5\,\% \text{ and inlet temperature}, 30\ ^\circ C)} \qquad (4)$$

$$\dot{Q}_{H_2O,in} = \frac{\dot{m}_{H_2O,in}}{\rho_{H_2O}\,(\text{at STP})} \qquad (5)$$

F. Enthalpy of Diluting a Concentrated Sulfuric Acid

The addition of a strong sulfuric acid to water generates heat; that is, the reaction is exothermic.
When we add concentrated sulfuric acid to water, the reaction $H_2SO_4(l) \rightarrow H^+(aq) + HSO_4^-(aq)$ take place.
Calculate ΔH^o for this reaction given that the standard state heat of formation for $H_2SO_4(l)$, $H^+(aq)$, and $HSO_4^-(aq)$ are $-813.989 \ kJ/mol_{rxn}$, $0 \ kJ/mol_{rxn}$ $(defined)$, and $-885.75 \ kJ/mol_{rxn}$, respectively.

$$\Delta H^o = [\Delta H^o_{f,HSO_4^-} + \Delta H^o_{f,H^+}] - \Delta H^o_{f,H_2SO_4}$$

$$= [(-885.75 + 0) - (-813.989)] = -71.76 \ kJ/mol_{rxn}$$

(By the time, no constraint of diluent water for the needed concentration range (mostly it works on one time (batch dilution process) or in the case of manual dilution) (dpuad, 2016)

$$\Delta H^o(kJ/mol \ of \ H_2SO_4) = 11.114 \times \ln(mol \ of \ H_2O/mol \ of \ H_2SO_4) + 33.119 \qquad (6)$$

(By the time, constraint of diluent water. Mostly in case of continuous dilution system)

G. Storage Tank Sizing

The main factors that will determine the size of the tank are plant production rate as well as the acid dilution device capacity. And, the maximum capacity of the storage tank is determined for a day.

Fluid Level System

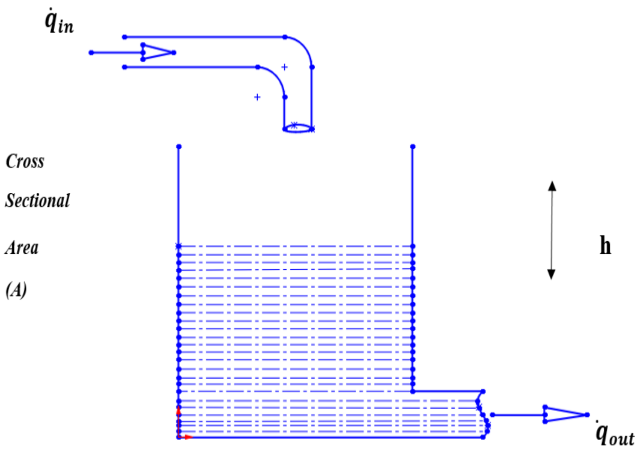

Figure 5: First order fluid level system.

Figure above shows a first order fluid level system where $\dot{q}_{in}$ and $\dot{q}_{out}$ are the flow rate coming from the source and the flow rate delivered to the system. Let h be the height liquid at time t and it rises by an amount dh after a time dt due to an inflow of $\dot{q}_{in}$.

Considering the following quantities during the interval dt:

$\text{The net flow from the source} = q_i dt$

$\text{The net storage in the tank} = A dh$

$\text{The net flow to the system} = q_o dt$

From conservation of mass

Quantity of fluid flowing in = Additional storage + Quantity of fluid flowing out

$q_i dt = A dh + q_o dt$

Rearranging

$$\frac{dh}{dt} = \frac{1}{A}(q_i - q_o) \qquad (7)$$

Equation (7) is a first order differential equation. It relates fluid level h with time t.

The following finite difference technique can be used to obtain the approximate solution. Select discrete points (nodes or grid points) in time and approximate the time derivative of h by the expression.

$$\frac{dh}{dt}_{at\ t=t_1} \approx \frac{h_i - h_{i-1}}{\Delta t}$$

III. RESULT AND DISCUSSION

A. Analytical result of concentrated sulfuric acid to diluent water proportion for each diluted acid concentration level

Table 2: Required flow rate result of sulfuric acid and diluent water amount for each concentration output.

% H_2SO_4 (w / w%)	H_2SO_4 $(\frac{kg}{s})$	H_2O $(\frac{kg}{s})$	% H_2SO_4 (w / w%)	H_2SO_4 $(\frac{kg}{s})$	H_2O $(\frac{kg}{s})$
1	0.006158	1.10019	50	0.431434	0.77857
2	0.012417	1.097994	51	0.442634	0.767457
3	0.018777	1.095615	52	0.453935	0.756162
4	0.025238	1.093055	53	0.465337	0.744685
5	0.031799	1.090313	54	0.476839	0.733026
6	0.038461	1.087389	55	0.488443	0.721185
7	0.045225	1.084283	56	0.500147	0.709162
8	0.052089	1.080994	57	0.511952	0.696957
9	0.059053	1.077524	58	0.523858	0.68457
10	0.066119	1.073872	59	0.535865	0.672001
11	0.073286	1.070038	60	0.547972	0.659251
12	0.080553	1.066022	61	0.560181	0.646318
13	0.087921	1.061824	62	0.57249	0.633203
14	0.09539	1.057444	63	0.5849	0.619906
15	0.10296	1.052882	64	0.597411	0.606428
16	0.110631	1.048138	65	0.610023	0.592767
17	0.118402	1.043212	66	0.622735	0.578924
18	0.126275	1.038104	67	0.635549	0.5649
19	0.134248	1.032815	68	0.648463	0.550693
20	0.142322	1.027343	69	0.661478	0.536305
21	0.150497	1.021689	70	0.674594	0.521734
22	0.158773	1.015853	71	0.687811	0.506981
23	0.167149	1.009835	72	0.701129	0.492047
24	0.175627	1.003636	73	0.714547	0.476931
25	0.184205	0.997254	74	0.728067	0.461632
26	0.192884	0.99069	75	0.741687	0.446152
27	0.201664	0.983945	76	0.755408	0.430489
28	0.210545	0.977017	77	0.76923	0.414645
29	0.219526	0.969907	78	0.783152	0.398619
30	0.228609	0.962616	79	0.797176	0.38241
31	0.237792	0.955142	80	0.8113	0.36602
32	0.247076	0.947487	81	0.825526	0.349448
33	0.256461	0.939649	82	0.839852	0.332694
34	0.265947	0.93163	83	0.854279	0.315757
35	0.275534	0.923428	84	0.868806	0.298639
36	0.285221	0.915045	85	0.883435	0.281339
37	0.295009	0.906479	86	0.898164	0.263857
38	0.304899	0.897732	87	0.912994	0.246193
39	0.314889	0.888803	88	0.927926	0.228347
40	0.324979	0.879691	89	0.942957	0.210319
41	0.335171	0.870398	90	0.95809	0.192109
42	0.345464	0.860923	91	0.973324	0.173717
43	0.355857	0.851266	92	0.988658	0.155143
44	0.366351	0.841426	93	1.004094	0.136387
45	0.376946	0.831405	94	1.01963	0.117449
46	0.387642	0.821202	95	1.035267	0.098329
47	0.398439	0.810817	96	1.051004	0.079027
48	0.409336	0.80025	97	1.066843	0.059543
49	0.420335	0.789501			

B. Analytical result of dilution enthalpy, temperature change and required cooling water flowrate for each diluted acid concentration level

Table 3: Analytical result of dilution enthalpy and temperature change for each weight percentage of sulfuric acid:

% H_2SO_4 (w / w%)	kcal/kg solution	Delta T (°C)	% H_2SO_4 (w / w%)	kcal/kg solution	Delta T (°C)
1	2.51	2.52	50	63.35	104.67

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2	4.64	4.70	51	64.07	107.01
3	6.39	6.52	52	64.76	109.35
4	8.51	8.78	53	65.43	111.69
5	10.33	10.75	54	66.07	114.02
6	12.08	12.69	55	66.70	116.36
7	13.78	14.62	56	67.29	118.70
8	15.43	16.53	57	67.87	121.03
9	17.05	18.44	58	68.42	123.35
10	18.63	20.35	59	68.94	125.66
11	20.17	22.25	60	69.43	127.96
12	21.69	24.16	61	69.89	130.24
13	23.17	26.07	62	70.33	132.50
14	24.63	27.98	63	70.74	134.75
15	26.06	29.90	64	71.11	136.96
16	27.46	31.83	65	71.45	139.15
17	28.85	33.77	66	71.76	141.30
18	30.21	35.71	67	72.03	143.41
19	31.54	37.67	68	72.27	145.48
20	32.86	39.64	69	72.46	147.49
21	34.15	41.62	70	72.62	149.45
22	35.42	43.61	71	72.73	151.35
23	36.68	45.61	72	72.80	153.17
24	37.91	47.62	73	72.81	154.91
25	39.12	49.65	74	72.78	156.56
26	40.32	51.69	75	72.70	158.11
27	41.49	53.75	76	72.55	159.55
28	42.65	55.82	77	72.34	160.86
29	43.78	57.90	78	72.07	162.03
30	44.90	60.00	79	71.73	163.03
31	46.00	62.11	80	71.30	163.86
32	47.08	64.23	81	70.80	164.49
33	48.15	66.37	82	70.20	164.89
34	49.19	68.53	83	69.49	165.04
35	50.22	70.69	84	68.68	164.89
36	51.23	72.88	85	67.74	164.41
37	52.22	75.07	86	66.65	163.54
38	53.19	77.28	87	65.41	162.23
39	54.14	79.50	88	63.98	160.41
40	55.08	81.74	89	62.33	157.98
41	55.99	83.98	90	60.43	154.82
42	56.89	86.24	91	58.23	150.79
43	57.77	88.51	92	55.66	145.68
44	58.63	90.80	93	52.63	139.21
45	59.47	93.09	94	49.00	130.97
46	60.28	95.39	95	44.55	120.35
47	61.08	97.70	96	38.94	106.30
48	61.86	100.02	97	31.51	86.92
49	62.62	102.34			

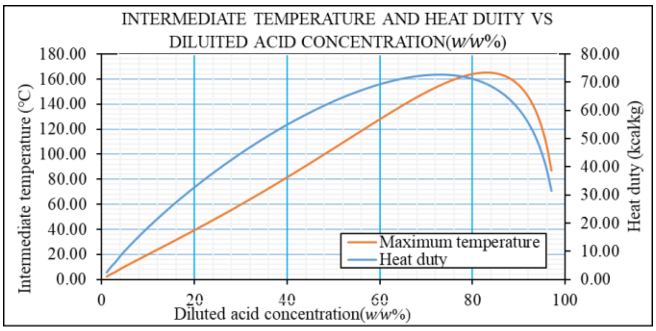

Figure 6: Intermediate temperature and heat duty as a function of diluted acid concentration.

Table 4: Range of both intermediate temperature and heat duty over the whole concentration level.

	Heat duty (kcal/kg)	Delta T(°C)
Maximum Value	72.81	165.04
Minimum Value	2.51	2.52

The above results of this study is validated with the experimental result given on article (SGL Group, 2016)

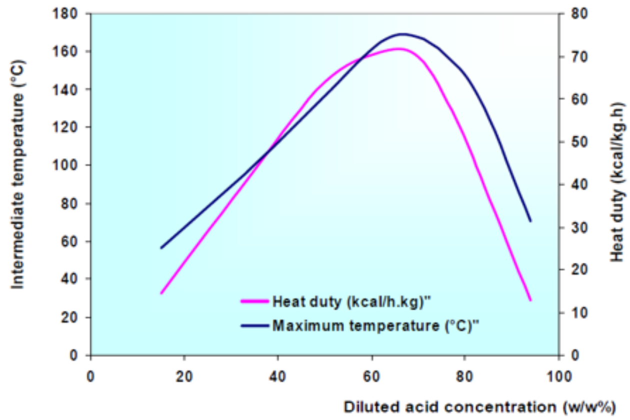

Figure 7: Heat duty and temperature as a function of diluted acid concentration in DIABON heat exchanger experimental result (SGL Group, 2016)

- As shown on the graph, the heat liberated during the reaction is first increases sharply with concentration output then it reaches peek point finally decreases with concentration output. Because, in the case of continuous acid dilution system the flow rate of diluent water for required concentration output was specified, and, that is not enough water for the reaction happens after the critical concentration output. Therefore, the reaction cannot generate the whole heat energy.

C. Analytical Analysis of Concentrated Sulfuric Acid Piping Material

These materials have different surface roughness values that surface roughness has an effect on friction resistance. It turns out that the effect is negligible for laminar pipe flow, but turbulent flow is strongly affected by roughness. Therefore, one of the objective of this study is choice of the safe, efficient and economical piping material for conveying highly concentrated sulfuric acid.

The following table shows maximum recommended sulfuric acid velocities and surface roughness value in various materials, at 98.5% H_2SO_4 concentration and temperature of 30°C (Sulfuric acid piping techmanual, 2005)

Table 5: Maximum recommended concentrated sulfuric acid velocity and surface roughness value of representative material (Sulfuric acid piping techmanual, 2005)

Material	Velocity [m/s]	Surface roughness [Ɛ, mm]
Cast Iron	3	1.5
Ductile Iron	2	2.6
High Silicon Iron (4%)	2.1	2
Carbon steel	0.5	3
Alloy 20	1.8	1.9
Alloy c-276	3	2.3
304L ss(Ap)	1.5	0.5

The following table shows the summary of results:

Table 6: Summery result of pressure drop per length and pipe diameter for acid piping material.

No	Material	Pipe Diameter (m)	Pressure Drop Per Length (ΔP)(Pa/m)
1	Alloy c-276	0.02128	42700.7
2	Cast Iron	0.02128	34487.1
3	High Silicon Iron (4%)	0.02543	15019.1
4	Ductile Iron	0.02607	14977.2
5	Alloy 20	0.02747	9667.33
6	304L ss(Ap)	0.03009	3835.44
7	Carbon steel	0.05212	142.504

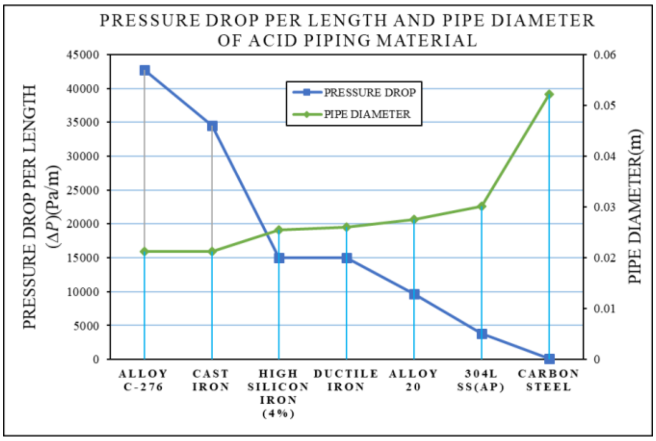

Figure 8: pressure drop per length and pipe diameter of different acid piping material.

D. Analytical Result of Diluent Water - Piping System

Stainless Steel

The roughness of ordinary stainless steel material is 2×10^{-6} (Bruce R. Munson, 2013)

Fixed variable Volume flowrate of diluent water $\dot{Q}_{H_2O,in}[\frac{m^3}{s}]$ for each output concentration.

Max diluent water velocity (V) = $0.5\ {}^{m}/_{s}$, since the velocity must be the same with the preset concentrated sulfuric acid fluid velocity.

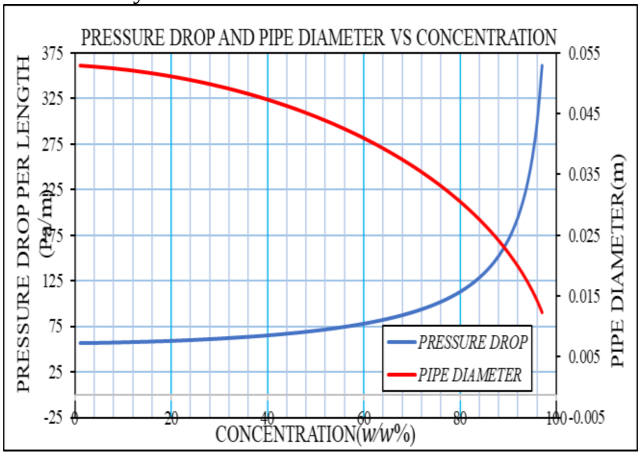

Figure 9: Pressure drop and pipe diameter as a function of diluted acid concentration for stainless steel diluent water piping material at fixed average velocity.

This graph nature looks the inverse of the graph happens on the concentrated sulfuric acid pipe material. Hence, unlike the flow rate of concentrated sulfuric acid, the required flow rate of diluent water is decreased with concentration output. In addition, when the pipe diameter graph decreases the pressure drop increases.

Table 7: Range of both pressure drop per length and pipe diameter of stainless steel piping material over the whole concentration level for diluent water.

	Pressure Drop Per Length (pa/m)	Corresponding Pipe Diameter (m)
ΔP_{max}	361.0754	0.012314
ΔP_{min}	56.85608	0.05293

Table 8: Corresponding parameter result at minimum pressure drop for stainless steel piping material for diluent water.

Weight concentration of sulfuric acid $H_2SO_4(w/w\%)$	1 %	Equivalent roughness ratio of sulfuric acid pipe $(\frac{\varepsilon}{d})$	3.78×10^{-5}
Volume flow rate of sulfuric acid $\dot{Q}_{H_2SO_4}$ $(\frac{m^3}{s})$	0.0011	Friction factor of sulfuric acid pipe $(f_{H_2SO_4})$	0.024124
Diameter of sulfuric acid pipe $(d_{H_2SO_4})$(m)	0.05293	Head loss of sulfuric acid pipe per length$(h_{f\ H_2SO_4})$	0.005807
Reynold number $(Re_{H_2SO_4})$	26333.3	Pressure drop of sulfuric acid pipe$(\Delta P_{H_2SO_4})$	56.85608

Taking minimum pressure drop and corresponding pipe diameter size Now, Fixed variable: Flow rate of diluent water $\dot{Q}_{H_2O,in}[\frac{m^3}{s}]$ for each output concentration

Pipe diameter (D) = 0.05293 m

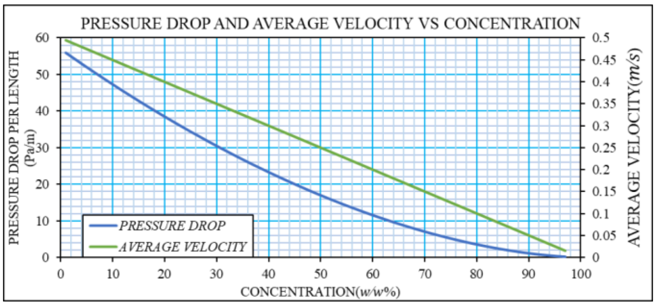

Figure 10: Pressure drop and average velocity as a function of diluted acid concentration for stainless steel diluent water piping material at fixed pipe diameter.

- In a similar manner, at a fixed pipe diameter, unlike the concentrated acid pipe material, both the pressure drop and average velocity decreases with concentration output increases.

Table 9: Considering the minimum pressure drop, range of both pressure drop per length and average velocity of stainless steel piping material over the whole concentration level for diluent water.

	Pressure Drop Per Length (Pa/m)	Average Velocity ($^{m}/_{s}$)
Maximum Value	55.84461	0.494922
Minimum Value	0.154445	0.014998

E. Analytical Result of Cooling Water - Piping System

Stainless Steel

Fixed variable

Volume flowrate of cooling water $\dot{Q}_{H_2O,in}[\frac{m^3}{s}]$ for each output concentration

Max diluent water velocity (V) = 0.5$^{m}/_{s}$, since the velocity must be the same with the preset velocity of both concentrated sulfuric acid and diluent water fluid velocity.

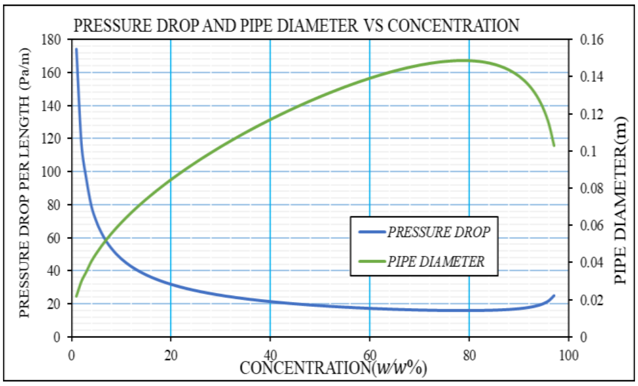

Figure 11: Pressure drop and pipe diameter as a function of diluted acid concentration for stainless steel cooling water piping material at fixed average velocity.

- This graph shape property directly related to the cooling water flowrate with concentration and indirectly related to the heat load liberated in each reaction over the concentration output. As a result, the pressure drop graph decreased initially and then increased. Conversely, the pipe diameter increased initially and the decreased.

Table 10: Range of both pressure drop per length and pipe diameter of stainless steel piping material over the whole concentration level for cooling water.

	Pressure Drop Per Length (pa/m)	Corresponding Pipe Diameter (m)
ΔP_{max}	174.1419	0.021731
ΔP_{min}	15.9847	0.148624

Table 11: Corresponding parameter result at minimum pressure drop for stainless steel piping material for cooling water.

Weight concentration of sulfuric acid $H_2SO_4(w/w\,\%)$	79 %	Equivalent roughness ratio of sulfuric acid pipe $(\frac{\varepsilon}{d})$	1.35 $\times 10^{-5}$
Volume flow rate of sulfuric acid $\dot{Q}_{H_2SO_4}\,(\frac{m^3}{s})$	0.008674	Friction factor of sulfuric acid pipe $(f_{H_2SO_4})$	0.019044
Diameter of sulfuric acid pipe $(d_{H_2SO_4})$(m)	0.148624	Head loss of sulfuric acid pipe per length$(h_{f\,H_2SO_4})$	0.001633
Reynold number $(Re_{H_2SO_4})$	73941.6	Pressure drop of sulfuric acid pipe$(\Delta P_{H_2SO_4})$	15.9847

Taking minimum pressure drop and corresponding pipe diameter size

Now,

Fixed variable: Flow rate of sulfuric acid $\dot{Q}_{H_2O,in}[\frac{m^3}{s}]$ for each output concentration.

Pipe diameter (D) = 0.148624 m

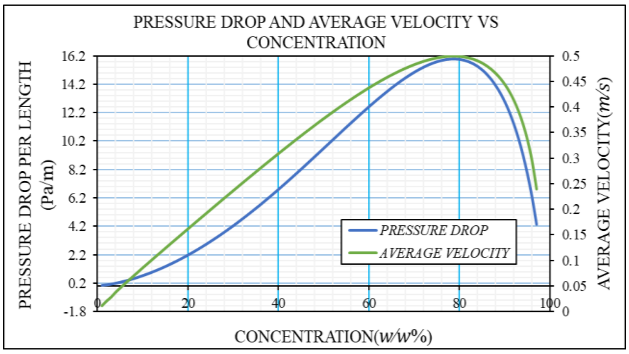

Figure 12: Pressure drop and average velocity as a function of diluted acid concentration for stainless steel cooling water piping material at fixed pipe diameter.

- At a fixed pipe diameter, the maximum pressure drop happens when the cooling water is maximum that is when the maximum heat energy is liberated when 73 % of concentrated acid was drawn.

Table 12: Considering the minimum pressure drop, range of both pressure drop per length and average velocity of stainless steel piping material over the whole concentration level for diluent water.

	Pressure Drop Per Length (Pa/m)	Average Velocity ($^{m}/_{s}$)
Maximum Value	15.98471	0.5
Minimum Value	0.02126	0.010689

F. Analytical Result of Storage Tank Capacity

Concentrated Sulfuric Acid Storage Tank

The current capacity of the company is $2.36\ ton/hr$.
This implies the volume flow rate of the concentrated sulfuric acid is
$q_{H_2SO_{4,in}} = 1.3104\ m^3/hr$
When the diameter of the tank is 1 meter.
Then, cross sectional area becomes $A = \frac{\pi d^2}{4} = 0.7854\ m^2$
The maximum concentrated sulfuric acid tank size should be determined when the required concentrated sulfuric acid flow rate is minimum. i.e 1 % of diluted sulfuric acid is needed Invoking the previous result, $q_{H_2SO_{4,out}} = 0.006158\ li/s$.
Then the height of fluid (h_{fluid}) will become 13.11814 meter.
Therefore the needed volume of the storage tank will be
$V = \pi r^2 h = 10.303\ m^3$
$2\pi r^3 = 10.303\ m^3 \Rightarrow r = 1.18\ m$
The cross sectional area (A_c) = $\pi r^2 = 4.37\ m^2$

Diluent Water Storage Tank

When the flowrate of diluent water is maximum i.e 1% of concentration is required, the maximum tank size will determined.
$q_o = 1.10019\ li/s = 0.0011\ m^3/s$
When tank diameter is 1 meter, cross sectional area becomes
$A = \frac{\pi d^2}{4} = 0.7854\ m^2$
The maximum diluent water tank size should be determined when the required diluent water flow rate is maximum. i.e 1 % concentrated sulfuric acid is needed.
Invoking the previous result, $q_{H_2O_{,out}} = 1.10019\ li/s = 0.0011\ m^3/s$
Then the height of fluid (h_{fluid}) will become 40.336 meter. Therefore the needed volume of the storage tank will be

The volume of fluid is
$V = \pi r^2 h = 31.68\ m^3$
$2\pi r^3 = 31.68\ m^3 \Rightarrow r = 1.715\ m$
The cross sectional area (A_c) = $\pi r^2 = 9.2375\ m^2$

Cooling Water Storage Tank

Similar to the diluent water tank the continuous flow is only for discharging the cooling water from the source tank. Thus, to determine the maximum required tank size for a day, just follow similar procedure using the same governing equation and boundary condition.
When the flowrate of cooling water is maximum, the maximum tank size will determined. Invoking the previous result, the maximum cooling water flowrate is $8.67\ li/s$. This is when maximum heat is liberated at 79 % acid concentration required.
$q_o = 8.67\ li/s = 0.00867\ m^3/s$
When tank diameter is 1 meter, cross sectional area becomes
$A = \frac{\pi d^2}{4} = 0.7854\ m^2$
Using the above governing equation of fluid level, then the height of fluid (h_{fluid}) will become 317.26 meter. Therefore the needed volume of the storage tank will be
The volume of fluid is
$V = \pi r^2 h = 249.2\ m^3$
$V = 2\pi r^3 = 249.2\ m^3 \Rightarrow r = 3.41\ m$
The cross sectional area (A_c) = $\pi r^2 = 36.53\ m^2$

Diluted Sulfuric Acid Storage Tank

When the flowrate of diluent water is minimum, i.e 1% of concentration is required, the maximum tank size will determined.
$q_i = 4\ m^3/hr = 0.00111111\ m^3/s$
When tank diameter is 1 meter, cross sectional area becomes
$A = \frac{\pi d^2}{4} = 0.7854\ m^2$
Then the height of fluid (h_{fluid}) will become 40.743 meter. Therefore the needed volume of the storage tank will be

The volume of fluid is
$V = \pi r^2 h = 32\ m^3$
$2\pi r^3 = 32\ m^3 \Rightarrow r = 1.72\ m$
The cross sectional area (A_c) = $\pi r^2 = 9.3\ m^2$

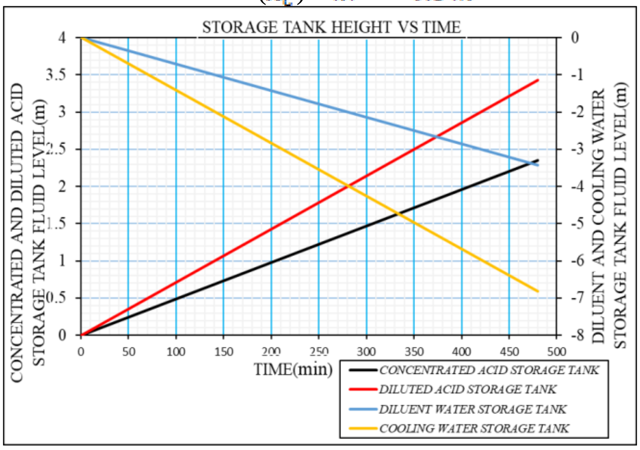

Figure 19: Fluid level (h) as a function of time (t) of storage tanks for acid dilution device.

- The increasing graph shows the net volume of the system tank is positive and increasing with time, while the decreasing graph shows the tank once charged then continuously discharge.

Table 19: The required maximum cylindrical storage tank size per 8-hour period

Name	Volume(m^3)	Height (m)	Diameter (m)
Concentrated acid storage tank	10.303	2.35	2.36
Diluent water storage tank	31.68	-3.42	3.43
Diluted acid storage tank	32	3.43	3.44
Cooling water storage tank	249.2	-6.82	6.83

Three-Dimensional Modelling of Acid Dilution Device

The following figure shows the final three-dimensional design of the acid dilution device using solid work 2016.
The table below shows materials with specification used for developing the acid dilution device

Table 20: The materials with specification for the acid dilution device.

№	Item		Specification	Quantity
1	Tank	Concentrated acid storage tank	2350 × ø 2360 [mm]	1
		Diluent water storage tank	3420 × ø 3430 [mm]	1
		Cooling water storage tank	6820 × ø 6830 [mm]	1
		Diluted acid storage tank	3430 × ø 3440 [mm]	1
2	Piping	Concentrated sulfuric acid pipe	4000 × ø 52 [mm]	1
		Diluent water pipe	4000 × ø 53 [mm]	1
		Cooling water pipe	4000 × ø 149 [mm]	1
3	Static Mixer (Dispersion Mixer)	Type 14	Fluid flow range (40 – 90 L/min) Weight - 3.5 kg (Quartz version),Outer diameter ø 127 mm (mksinst, 1961)	1
4	Heat Exchanger	Shell	7320 × ø 289 [mm]	1
		Tube	7320 × ø 16 [mm]	64
		Flange	ø (254 × 131) mm × 4 bolts, with bolt hole ø 22.4 mm	2
		Baffle	Single segmental baffle	52

Table 21: Equipment's with specification for acid dilution device.

№	Equipment	Type	Specification	Quantity
1	Pump	Concentrated sulfuric acid pump	NKM- G 32 - 125.1/140 T 0, 25	1
		Diluent water pump	NKM- G 32 - 160.1/169 T 0, 37	1
		Cooling water pump	NKM- G 50 - 250/263 T 4	1
2	Valve	Flow rate control valve	C - 06	3
		On/off valve	C - 40	4
		Check valve	DV-14	3

Figure 28: Over all 3D design of the sulfuric acid dilution system.

IV. CONCLUSION

From the general contents of this paper results the following point was drawn.

In this study, the main work began after determining the required capacity of the acid dilution device based on the capacity of the case company and thus the required flow rate of both concentrated sulfuric acid and diluent water was setted for each concentration output, as per this flow rate the reaction generates large amount of heat. Among this various reaction the maximum ($72.81\ kcal/kg\ of\ solution$) amount of heat is released when 73 % of concentrated acid was drawn but the temperature raised up to $165.04°C$ when 83 % of concentrated acid was drawn.

Among the seven-concentrated sulfuric acid piping material, the carbon steel piping is by far the most economical material of construction for conveying strong sulfuric acid. However, it has its limitations in terms of operating conditions. Carbon steel in the presence of strong sulfuric acid will corrode to form a thin film of iron sulphate on the surface of the metal. For this reason that the use of carbon steel is limited to handling acid at low velocities. Fortunately, due to the low velocity constraint the pressure drop becomes minimum and this happen at minimum concentration of acid, because low flow rate of acid is required. i.e. Carbon Steel[ø = 0.05212 m, ΔP =142.504 Pa/m].

Similarly for diluent and cooling water piping stainless steel was used to convey the water at required flow rate, and the following are the the pipe diameter and the maximum pressure drop over the complete concentration. i.e. stainless steel for diluent water piping [ø = 0.053 m, ΔP = 55.85 Pa/m], stainless steel for cooling water piping [ø = 0.149 m, ΔP = 16 Pa/m]. This optimum value of pressure drop was obtained when maximum flow rate of fluid was required after fixing the piping diameter. Moreover, this happens when minimum concentration is required a case of diluent water and maximum heat is liberated a case of cooling water. i.e. 73% of concentrated acid was required.

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