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Minimization of Spent Acid Waste from Galvanizing Plant in Malaysia

By Nalienaa Muthu , Faieza Abdul Aziz
& Profesor Dr. Rosnah Binti Mohd Yusuff
Faculty of Engineering University, Malaysia

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I. Introduction

Corrosion is a natural process of degradation caused by chemical reaction between steel which comes in contact with the environment or abrasive effects between steel and other material. Rusting is the most common and economically destructive form of corrosion. Potential damage that can be caused by corrosion is degradation of structures, machines, and containers. There are many approaches to protect steel from corrosion which can indirectly avoid damages caused by corrosion (Sastri, 2007).

Hot dip galvanizing process prevents corrosion of steel by providing a tough, durable barrier coating of metallic zinc which completely seals the steel from corrosive environment (Chandler, 1985). One of the main steps involved in galvanizing process would be removal of rust from the steel using pickling acid. In this project, the pickling acid used is hydrochloric acid because it is more economical and less hazardous. The fresh hydrochloric acid which is bought at certain price need to be disposed as scheduled waste which cost even more than the purchasing price of fresh hydrochloric acid.

The importance of this study is to come up with a better way to minimize the cost being spent for hydrochloric acid disposal. This project uses application of the Kleingarn acid management system to minimize wastage of hydrochloric acid in galvanizing process through optimization of hydrochloric acid. Hydrochloric acid is optimized by recovering the acid value and extending the life span of the hydrochloric acid. Extension of the acids life span helps in reducing the frequency of acid disposal, which in return helps in reducing the cost being spent for hydrochloric acid disposal.

Once the strength of hydrochloric acid has been reduced, the hydrochloric acid cannot be reused, it needs to be disposed as schedule waste whereby the disposal cost happens to be more than the initial acid purchase price (McClay, 2007). There are many methods in disposing spent acid wastes, such as containing it in drums and selling it to vendors and disposing the spent acid waste in dedicated waste disposal landfill (Patnaik, 2007).

The main problem that the project concentrates on is minimization of spent acid waste in galvanizing industry. Galvanizing companies are facing the high expenditure cost spent in disposing the hydrochloric acid as scheduled waste. Once the strength of hydrochloric acid has been reduced, the hydrochloric acid cannot be reused and it becomes spent acid. This spent acid needs to be disposed as schedule waste whereby the disposal cost happens to be more than the initial acid purchase price. McClay, (2007); Fresner, (2006) and Steward, (1995) were facing the same problems that the company in galvanizing industry is facing which is the high expenditure cost spent in disposing the hydrochloric acid as scheduled waste.

This study is being conducted to propose an improved waste management system for hydrochloric acid and it can also act as a cost reduction project. The main objectives of this project are to identify feasible method for disposing hydrochloric acid as scheduled waste in a galvanizing company and to implement the Kleingarn acid management system method and test the effectiveness in reducing the waste.

II. Hot Dip Galvanizing

The main purpose of galvanizing is to provide a protective coating to steel so that corrosion does not

Author α : Centre for Instructor and Advanced Skill Training (CIAST), Shah Alam, Selangor, Malaysia. e-mail: nalienaa@gmail.com
Auhtor σ : Department of Mechanical and Manufacturing Engineering, Faculty of Engineering University Putra Malaysia.
e-mail: dr.faieza.upm@gmail.com
Author ρ : PHD In Manufacturing System.
e-mail: rosnahmy@upm.edu.my

take place. Rusting is the most common and economically destructive form of corrosion (The Effects and Economic Impact of Corrosion, 2000). The process of galvanizing steel with zinc layer helps to form a barrier between steel and other corrosive elements, preventing it from corrosion which can cause dangerous damage. The galvanized steel coating of zinc also has excellent abrasion resistance (Hall, 1963). Hot-dip galvanizing is a form of galvanization. It is the process of coating iron, steel or aluminum with a thin zinc layer, by passing the metal through a molten bath of zinc at a temperature of around 450 °C (Hall, 1963). When exposed to the atmosphere, the pure zinc (Zn) reacts with oxygen (O_2) to form zinc oxide (ZnO), which further reacts with carbon dioxide (CO_2) to form zinc carbonate ($ZnCO_3$) (Volovitch, 2011).

Hot dip Galvanizing process can only be carried out in a galvanizing company and a galvanized material is only available in one color (Graham, 1970). The physical appearance of galvanized steel may vary from one galvanizing company to another due to the difference in additives used in their zinc kettle. However, the physical appearance does not change the initial functionality of galvanized zinc coating, which is to prevent steel from corrosion.

a) Pickling using Hydrochloric Acid

According to Tang (2012), every hot dip galvanizing process involves the steps of preparation and arrangement of untreated steel products, degreasing the steel, cleansing the steel, pickling, washing and cleansing the acid from steel, Pre-Fluxi chemical dipping, Molten Zinc dipping and at last there is the inspection step. Among these steps, the pickling process plays an important role in pre-treatment of the steel surface prior to chemical dipping and molten zinc dipping.

Tang (2012) also mentioned that the pickling process is a chemical procedure where the steel is dipped into a tank that contains one of these four acids, namely the sulfuric, nitric, hydrochloric or phosphoric acid solution. Although all of these strong acids can be used as pickling acid, hydrochloric acid is the much preferred acid for pickling process.

During the pickling process, any kind of impurities such as stains, inorganic contamination, rust, surface oxides and other contaminations are removed by a chemical reaction of the surface and the pickling solution. The final result of this pickling process would be that all layers of impurities dissolves as ions into the acid solution (Kittisupakorn, 2005).

The sulfuric, nitric, hydrochloric or phosphoric acid solution can be used for pickling process. Sulfuric acid was widely used by galvanizing companies for a long period of time, however, in recent years sulfuric acid has been replaced by hydrochloric acid for pickling process (Tang, 2012).

Although purchasing hydrochloric acid is more expensive compared to purchasing sulfuric acid, but hydrochloric acid tends to be a more preferred type of acid to be used for pickling process due to its waste disposal cost which is cheaper compared to disposing sulfuric acid as scheduled waste. Phosphoric acid is overall more expensive compared to both these acids (Chandler, 1985). Throughout this project, the focus will be on hydrochloric acid which is a commonly used acid in hot dip galvanizing companies in Malaysia for the surface treatment of steel products.

There are many advantages in using hydrochloric acid for pickling process compared with sulfuric acid. These advantages have been discussed by Tang (2012) and in (Surface Preparation of Structural Steel-Part 2 Communication from the Stichting Nederlands Corrosie Centrum). Hydrochloric acid is considered to be the better acid to allow faster cleaning rate at normal temperatures compared to other acids used for pickling process.

The galvanizers can attain better quality of galvanized product with complete coating and without visible patches by subjecting their products through the pickling process. Although this is just for visual enhancement, but materials that are not subjected to pickling will not look as attractive as the one that are subjected to pickling process. A complete coating will determine the galvanized materials standard.

b) Hydrochloric Acid as Scheduled Waste

The pickling bath is used in hot dip galvanizing process to remove impurities from the surface of steel and produce a clean surface (McLay, 2007). The concentration level and the contamination level of the hydrochloric acid that is used for this process will change and once it reaches an unaccepted level, it need to be disposed or discarded by sending to licensed specialist treatment operators to be neutralized using alkaline waste. This waste product which needs to be disposed is referred to as spent pickle liquor or acid waste. Spent pickle liquor or acid waste is the main source of waste in hot dip galvanizing industry.

The corrosive nature and presence of residual acid as well as high metal content are other reasons why spent pickling liquors are considered as hazardous wastes. Treatment of hazardous wastes involves costs and it's a job where regulations and certain rules need to be followed strictly. It cannot be taken for granted as the consequences can be very dangerous.

c) Methods for Regeneration of Hydrochloric Acid

Regeneration of spent pickling liquors is a process that involves reduction in the volume of hydrochloric acid wastes to be generated (Tang, 2012). Implementation of regeneration process or any type of a recovery process in hot dip galvanizing industry usually involve some extra investment and it is very important to ensure that skillful operators are deployed to handle the task so that the objective can be achieved. There are many regeneration methods available in galvanizing industry due to the interest shown by the industry owners to develop a better recovery process of waste acid.

i. *Pyrohydrolysis*

Agrawal (2009) have discussed on Pyrohydrolysis which is a process where the spent pickle liquor will be thermally decomposed in order to convert the spent pickle liquor back into hydrochloric acid and iron oxide. This process is carried out at a very high temperature plus with water vapor and oxygen. The spent pickle liquor is pumped into a pyrohydrolysers which will convert the Fe_2Cl_2 into components of Fe_3O and hydrochloric acid.

Regeneration of hydrochloric acid using pyrohydrolysis method is usually considered by companies operating in very big scale because this method is considered to be costly, due to the high energy cost involved in the installation and operation of pyrohydrolysers. This method is not environmental friendly due to the corrosive chloride and fluoride salts that exist in the dust emitted by this process. As such, any company that would like to install this system will also need to install dust collection system which will incur more cost (Agrawal, 2009).

ii. *Crystallization*

According to Brown (2006), initially, regeneration using crystallization method was used for regeneration of waste sulphuric acid. However, in the long run, regeneration using crystallization was also able to be performed for hydrochloric acid waste. The applicability of regeneration using crystallization for hydrochloric acid have been confirmed upon conducting some technical feasibility tests. It was also concluded that multi-stage crystal-lization need to be conducted in a series of CSTR-type crystallizers. The hydrochloric acid waste also needs to go through crystal recycling process in order to yield impurity-free.

This regeneration process via crystallization of ferrous sulphate, which involves a standard technique, does not have a size limitation. The newly regenerated hydrochloric acid might have some impact on the pickling process due to the dead-load of sulfate. This problem can be eliminated by adjusting the conditions of pickling rates to be at least equal to pure hydrochloric acid with an acceptable surface finish. (Magdalena, 2010 and Brown, 2006).

iii. *Hydrolytic Precipitation*

Based on George (2008), the regeneration of hydrochloric spent pickling liquors using hydrolytic precipitation method involves the process of vapor distillation under evapora¬tive hydrolysis conditions at temperatures as high as 250°C. When there are no other chloride salts present, hydrolytic distillation process proceeds to completion at around 175°C. However, when Magnesium chloride is present, a higher temperature is required for the hydrolytic distillation process be completed.

iv. *Solvent Extraction Route*

The solvent extraction route method is a popular regeneration method. This regeneration method is preferred because it produces less hazardous by-products in the process of treating spent pickling liquors. By using the solvent extraction route method $FeCl_2$ and $ZnCl_2$ can be separated from hydrochloric acid. This process can be a little costly compared to the normal disposal of spent pickling liquors. Since this method requires waste water treatment which not all galvanizing company gives priority to, it can incur more cost. The byproduct produced from the regeneration of hydrochloric spent pickling liquors need to go through post-treatment before it can be discarded (Kerney, 1994).

v. *Kleingarn Acid Management System*

By adopting this regeneration method, the costs of replacement of the spent pickling liquors with new could be reduced. This method needs less initial investment. Application of Kleingarn acid management system as regeneration method in hot dip galvanizing company helps in reducing waste volume by saving the amount of hydrochloric acid being used. This regeneration method also may ease the recycling of acid wastes (Stocks, 2005).

Kleingarn acid management system needs less initial investment and at the same time it helps in reducing spent pickling liquors volume. Regeneration of spent pickling liquor using Kleingarn acid management system can assist in increasing the acid strength and reducing the iron concentration at the same time. Experiments need to be carried out in order to obtain the optimum pickle rate using this regeneration method. This regeneration process can be repeated until the dedicated hydrochloric acid bath tank needs to be emptied for cleaning or repair. Once the dedicated hydrochloric acid bath tank is emptied, fresh solution should be made up using partly spent acid from other tanks plus fresh acid. The regeneration of hydrochloric acid using Kleingarn acid management system has many efficient and ecological advantages.

III. Materials and Methods

The problem was identified as need for reduction of the extra cost spent on hydrochloric acid disposal by optimising the hydrochloric acid usage. Project proceeds with the site visit at the galvanizing company to enable to see the overall process including the problem area and to ensure the understanding on the overall process flow. Focus was on the current hydrochloric acid pickling process and the hydrochloric acid waste disposal process. Specifically four methods were proposed to the galvanizing company to decide on applicability upon completion of literature review. After a brief discussion on the most appropriate method that can be applied for regeneration of hydrochloric acid, Kleingarn acid management system was chosen.

This experiment is conducted on one dedicated hydrochloric acid tank. This dedicated tank was used throughout the project experimentation. Next step would be conducting experiment of regeneration of Hydrochloric acid using Kleingarn acid management system to reduce the spent acid waste. The sample size of acid is taken on weekly basis in order to get the hydrochloric acid strength level and to determine the level of iron present in the dedicated tank.

Once the acid sample is taken from the dedicated hydrochloric acid tank, it is sent to the lab in the galvanizing company to test the hydrochloric acid strength level and iron level. This is done to confirm that the hydrochloric acid level and iron level are within the range set by the company. Once it is confirmed that the hydrochloric acid level and iron level are within the range set by the company, project goes ahead and continue with pickling process.

Once the hydrochloric acid strength and the iron content level is tested and found to be within the intended range which is set by the company the galvanizing process will follow the existing process flow. The pickling process will resume as usual. In this case, the pickled product is rinsed in the tank containing water and goes on to zinc bath and finally it is subjected to inspection.

However, if the hydrochloric acid level and iron level are not within the range set by the company, the regeneration of Hydrochloric acid methodology is applied. Fresh hydrochloric acid is added into the dedicated hydrochloric acid tank in order to increase the hydrochloric acid level and reduce the iron level. The amount of fresh hydrochloric acid to be added is determined using the equation as per Kleingarn acid management calculation.

Upon adding the amount of fresh hydrochloric acid, the new acid sample is taken from the dedicated hydrochloric acid tank and sent to the lab in the galvanizing company once again to test the new hydrochloric acid strength level and iron level. This is done to reconfirm that the hydrochloric acid level and iron level are within the range set by the company after adding in fresh hydrochloric acid.

This step is followed by collection of experiment data to validate the reduction rate of spent acid waste. The short and long term cost reductions are calculated by tabulating the experiment data collected for 20 weeks. The experiment data and calculation of cost reduction is being used to answer the second objective of this project which is to test the effectiveness of the chosen method for regeneration of hydrochloric acid.

IV. Results and Discussion

The regeneration of hydrochloric acid using Kleingarn acid management system was considered to be more feasible and practical method to be applied for disposing hydrochloric acid as scheduled waste in galvanizing company. This is because this method is conducted by topping up the existing hydrochloric acid with fresh hydrochloric acid based on the iron and chloride level. The lab testing to obtain the experiment results incur minimum cost.

a) The Experiment

This experiment was conducted using hydrochloric acid as the main chemical for steel pickling process. The experiment was conducted for a period of 20 weeks and the sample size of acid was taken on weekly basis. The lab facility in the galvanizing company was utilized to test the hydrochloric acid strength level and to determine the level of iron present in the spent acid waste.

i. *Hydrochloric Acid Bath Tank and Hydrochloric Acid*

Firstly, a dedicated hydrochloric acid bath tank was set up. The dedicated acid bath tank functions as per normal in the sense where it was fully utilized for production. The size of the acid bath tank is 6 meters length, 1.6 meters width and 2.0 meters height.

The fresh hydrochloric acid that is bought by the company from their vendor is at 34% concentration level. Hydrochloric acid is a strong acid with low PH value; as such the hydrochloric acid cannot be poured into the acid bath tank directly at the concentration level of 34%. The acid bath tank is made of steel and lined with fiber glass, so, using the hydrochloric acid at this level will cause damage to the tank by corroding it due to the hydrochloric acids high level of corrosiveness (Davis, 2000).

That is the reason why the hydrochloric acid is diluted from 34% of acid concentration to 16% of acid concentration. During the dilution process, the acid will be added into water contained in the acid bath tank instead of adding the water into the concentrated hydrochloric acid. This is done in this manner because adding water into concentrated hydrochloric acid can cause strong reaction and may cause acid splash which can be dangerous to the worker who is handling the dilution process (Olmsted, 1997).

Although the acid bath tanks height is 2.0 meter, but the hydrochloric acid solution will not be filled at the height of 2.0 meter. This is because, the hydrochloric acid solution in the acid bath tank needs some room to raise once the steel that needs to be pickled is immersed into the acid bath tank. This is the reason why the total amount of hydrochloric acid diluted in water is set to be at the height of 1.6 meter in the acid bath tank instead of the actual height of the acid bath tank which is 2.0 meter.

ii. *Pickling Process*

Iron should be present in the acid bath tank in order to help kick off the pickling process and to make the pickling process perform faster. Diluting the hydrochloric acid using the water taken from rinsing tank where there is iron present will help to expedite the pickling process. The optimum level of iron and hydrochloric acid need to be maintained because in case the solubility limit of iron in hydrochloric acid is exceeded then pickling will not take place.

When the pickling process takes place, the iron concentration of the pickle solution will increase in the acid bath tank as the acid strength decreases. Once the iron concentration increases out of the range due to pickling process, the spent pickle solution may be regenerated by the removal of a quantity of the spent acid and the addition of fresh acid.

iii. *Data Collection*

The hydrochloric acid sample to be tested which is taken from the dedicated acid bath tank is collected on weekly basis. The specific day to collect the sample was set to be every Wednesday. The reason behind this setting is because the hydrochloric acid strength reductions will not be significant if the sample is taken on daily basis. Taking the sample once a week gives the hydrochloric acid tank sufficient exposure to zinc and other materials due to the continues production for a period of one week. Another reason for taking the sampling in the mid of a week is because by doing the sampling on every Wednesday, the lab testing results can be obtained by the end of the day or latest by the next day which is Thursday and the project can determine the acidic level of the hydrochloric acid in the dedicated tank to decide on the addition of fresh acid. The experiment results have been tabulated into table form and presented below in table 1.

Table 1 : Experiment results

HCL TANK 1					
CHEMICALS	HCL (g/L)	Iron (g/L)	Addition Fresh HCL (tonnes)	New level of Hydrochloric acid upon top up (g/L)	New level of iron upon top up (g/L)
Range	90 – 140	60 - 90		90 – 140	60 – 90
MAX	140	90		140	90
MIN	90	60		90	60
Week					
1	135.00	78.00			
2	**86.00**	**93.00**	3.73	132.00	78.71
3	118.00	78.00			
4	**75.00**	**91.00**	4.11	128.00	77.02
5	129.00	78.00			
6	**83.00**	**94.00**	3.84	134.00	79.56
7	**80.00**	**98.00**	3.94	126.00	82.94
8	123.00	78.00			
9	**83.00**	**92.00**	3.84	127.00	77.86
10	98.00	78.00			
11	**87.00**	**91.00**	3.69	131.00	77.02
12	121.00	78.00			
13	96.00	78.00			
14	**79.00**	**95.00**	3.97	133.00	80.40
15	103.00	78.00			
16	**88.00**	**92.00**	3.66	126.00	77.86
17	104.00	78.00			
18	94.00	78.00			
19	**84.00**	**99.00**	3.80	134.00	83.79
20	**85.00**	**91.00**	3.76	125.00	77.02

iv. *Results with Acceptable Range of Hydrochloric Acid Strength*

For this project the hydrochloric acid level was maintained at the range of 9% to 14% under normal condition with iron present in the acid bath tank. The iron content level was maintained at the range of 6% to 9% (Hornsby, 1995).

Theoretically the hydrochloric acid solution in the acid bath tank was calculated to achieve 16% of hydrochloric acid concentration; however, the lab test result confirmed that the hydrochloric acid strength was at 13.5% with iron present and the iron content was at 7.8% as per the lab test result noted in week 1.

This is because distilled water was not used, whereas rinsing water which already contains certain level of iron chloride was used in the process for diluting the hydrochloric acid. Rinsing water is the water in the tank where the metal which has already gone through pickling process will be rinsed in. Since hydrochloric acid is corrosive, it tends to least corrode the metal immersed in it during pickling process.

Once the pickled metal is dipped into the rinsing tank for washing the metal, elimination process of pickling reaction products takes place. Example of the pickling reaction products are namely iron salts and iron oxides. These pickling reaction products will be stacking in the rinsing water tank (Taylor, 2002).

In week 1, the fresh hydrochloric acid was not added to the acid bath tank because both the hydrochloric acid strength and iron content were within the intended range.

Once both the hydrochloric acid strength and the iron content are out of the intended range, the pickle solution needs to be regenerated. This is done by removing a volume of the spent pickle solution and adding it with an equivalent volume of fresh 34% of hydrochloric acid in order to produce a pickle solution with strength of 9% to 14% and iron content at the range of 6% to 9%.

v. *Results with Low Hydrochloric Acid Strength*

Referring to the data obtained from the chemical lab test at week 2, the hydrochloric acid strength and the iron content showed 8.6% and 9.3% each. This value is out of the acceptable range, where the hydrochloric acid strength needs to be within 9% to 14% and iron content needs to be at the range of 6% to 9%.

Since the lab test data shows that the hydrochloric acid strength and the iron content are out of the intended range, certain quantity of pickled acid needs to be removed from the dedicated acid bath tank and replaced with fresh hydrochloric acid at the concentration of 34% to retain the hydrochloric acid strength and to enable the pickling process to take place at normal rate.

Refer to the calculation below for determining the volume of spent pickle solution to be removed and the iron concentration of the regenerated spent pickle waste:

Volume spent pickle solution = 6m × 1.6m × 1.6m

Volume spent pickle solution = 15.36 m ^3

Volume regenerated acid = 6m × 1.6m × 1.6m

Volume regenerated acid = 15.36 m ^3

Concentration of spent pickle solution = 8.6%

Concentration of fresh acid = 34%

Concentration of regenerated acid = 16%

The volume of spent pickle waste to be removed, r according to Eq. 1:

$$r = [(\text{Concentration of regenerated acid} \times \text{Volume regenerated acid})-(\text{Concentration of spent pickle solution} \times \text{Volume regenerated acid})] \div (\text{Concentration of fresh ac} \quad (1)$$

$$r = [(16\% \times 15.36m^3) - (8.6\% \times 15.36m^3)] \div (34\% - 8.6\%)$$

$$r = 4.475\ m^3 \div 1.2$$

$$r = 3.73\ \text{tonne}$$

To achieve a regenerated solution with a concentration of 16% of hydrochloric acid, 3.73 tonnes of spent pickle waste need to be removed from the acid bath tank and toped up with 3.73 tonnes of fresh 34% of hydrochloric acid. The amount of spent pickle waste that needs to be removed varies from week to week. The average amount of spent acid waste to be removed and topped up is 3.834 tonnes per week. The topping up process did not occur very often. There were weeks when fresh acid top up was not required as in week 1. The iron concentration of the regenerated spent pickle solution; z can be calculated using Eq. 2:

Volume of remaining pickle solution will be $= 15.36m^3 - 4.475m^3 = 10.885m^3$

$$z = (\text{Iron concentration of spent pickle solution} \times \text{Volume of remaining spent pickle solution}) + (\text{Iron concentration of fresh acid} \times \text{Volume of fresh acid})] \div \text{Volume of regenerated solution} \quad (2)$$

$$z = [(90 \times 10.885) + (0 \times 4.475)] \div 15.36$$

$$z = 63.78$$

The newly regenerated solution should contain 63.78 gram/liter of iron. The new regenerated spent acid waste solution therefore should contain 16% of hydrochloric acid strength and about 63.78 gram/liter of iron. These figures are based on the theoretical calculation. The hydrochloric acid strength and iron content in actual galvanizing industry varies due to the presence of other components in the acid bath tank such as iron chloride.

Upon subjecting the regenerated pickle solution to lab test, it was found that the new regenerated spent acid waste contains 13.2% of hydrochloric acid concentration and about 78.71 gram/liter of iron content. Although there are some differences in the theoretical value compared to the actual value, the hydrochloric acid strength and iron content are still within the intended range.

It was also observed during the experimentation that whenever the acid concentration in the hydrochloric acid tank decreases, the iron content will increase. This experiment was started with hydrochloric acid strength at a high side then as the time passes by and production continues, the acid concentration reduces as it converts iron oxides to iron chloride (Peter Maa, 2011). From the experiment data, it can be noticed that the fresh acid top up process is not done on weekly basis. In average the top up process is done every alternate week.

vi. *Waste Minimization*

The experiment results can be divided into five months. Table 2 displays the comparison between hydrochloric acid usage before and after implementing regeneration of spent acid waste using Kleingarn acid management system.

Table 2 : Comparison of hydrochloric acid usage before and after implementing regeneration of spent acid waste using Kleingarn acid management system

Top up per month (consist of 4 weeks)	Usage of hydrochloric acid upon implementing Kleingarn acid management system (tonnes)	Usage of hydrochloric acid by using traditional method (tonnes)	Savings (tonnes)
Month 1	7.84	12.00	4.16
Month 2	7.78	12.00	4.22
Month 3	7.53	12.00	4.47
Month 4	7.63	12.00	4.37
Month 5	7.56	12.00	4.44
Average	**7.67**	**12.00**	**4.33**

It is proven that prior to implementing Kleingarn acid management system, an average of 12.00 tonnes of hydrochloric acid is used in the pickling process. This data was taken by averaging the total amount of hydrochloric acid used for a period of 11 months. Whereas after implementation of Kleingarn acid management system, the average amount of hydrochloric acid used in a month has reduced to 7.67 tonnes.

By comparing the data obtained, we can witness that the project has achieved average savings of 4.33 tonnes of hydrochloric acid per month through implementation of Kleingarn acid management system. Although the fresh hydrochloric acid with 34% of concentration top up process involves some lab testing to be carried out, but the minimization rate of the hydrochloric acid used in a month proofs its worth.

vii. *Cost Calculation*

Average usage of 12 tonnes of fresh hydrochloric acid for 4 weeks is also equivalent to usage of 3 tonnes of fresh hydrochloric acid per week. Average usage rate of fresh hydrochloric acid through implementation of Kleingarn acid management system is 7.67 tonnes. Once the usage rate is divided into 4 weeks, it is equivalent to 1.9 tonnes per week. Table 3 shows summary of the cost calculation for hydrochloric acid disposal before and after implementing regeneration of acid using Kleingarn acid management system.

Table 3 : Cost calculation for hydrochloric acid disposal before and after implementing regeneration of acid using Kleingarn acid management system

For 20 weeks	Before regeneration method	After regeneration method
Volume of spent acid waste at RM625.00 per tone	12 tonnes per month	7.67 tonnes per month
Treatment time	5 – 10 mins	15 mins
Spent acid waste dump Frequency in weeks	6 weeks once for every 18 tonne	9.5 weeks once for every 18 tonne
Steel Pickled (according to plant capacity)	1000 tonnes	1000 tonnes

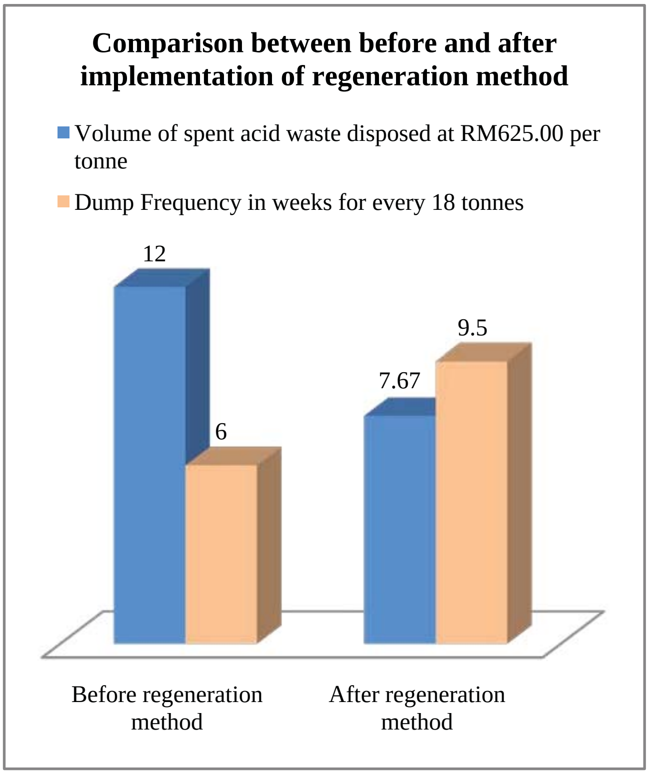
Note : 1 tonne = 1000kgs

Currently 18 tonnes of hydrochloric acid is being bought every 6 weeks once to be used as the pickling acid. However, upon implementing the Kleingarn acid management system, 18 tonnes of acid can be bought every 9.5 weeks once. By implementing this regeneration method, the acid purchase time have been extended from 6weeks to 9.5 weeks. As such, the fresh hydrochloric acid with 34% concentration's purchase frequency is reduced because the usage time is extended.

The amount of steel pickled in both cases is maintained at 1000 tonnes so that the comparison will be fair and not affected by any external factors. Disposal of spent acid waste is carried out every 9.5 weeks once for 18 tonnes of acid after implementation of regeneration method.

Implementation of regeneration using Kleingarn acid management system also helps to extend the hydrochloric acid dumping frequency. The hydrochloric acid dumping frequency has been extended from 6 weeks once for every 18 tonnes of spent acid waste to 9.5 weeks once for every 18 tonnes of spent acid waste.

Although the acid dumping frequency has only been extended for 3.5 weeks, in the long run, this value will contribute to a large amount of savings to the environment. This extension is healthy for the environment as lesser hazardous waste will be disposed in the future. Figure 1 helps to illustrate the comparison of volume of spent acid waste and spent acid waste dumping frequency before and after implementing regeneration of spent acid waste using Kleingarn acid management system



V. Conclusion

The effectiveness of the Kleingarn acid management system in reducing the scheduled waste was proven by extending the acid purchase time and by calculating the savings in monetary value. This project can be used by galvanizing company as a guidance in the process of scheduled waste minimization. Implementation of Kleingarn acid management system has helped to extend the existing acid purchase time from current duration of 6 weeks to a new extended duration of 9.5 weeks. Once the acid purchase time has been extended, the fresh hydrochloric acid purchase frequency can be reduced.

The amount spent for hydrochloric acid disposal as spent acid waste before implementation of regeneration using Kleingarn acid management system came up to RM7500.00 per month. The amount spent for hydrochloric disposal after implementation of regeneration using Kleingarn acid management system came up to RM4750.00 per month. Savings of RM2750.00 per month was observed. This savings is possible for the galvanizing company that implements Kleingarn acid management system to treat their spent acid waste. Although this savings does not look like a large sum, but in the long run, it will save the galvanizing companies a huge chunk of their expense for hydrochloric acid disposal as spent acid waste.

Once acid consumption is reduced, it automatically helps to extend the hydrochloric acid dumping frequency. By implementing Kleingarn acid management system, the acid dumping frequency has been extended from the original 6 week to extra 3.5 weeks. Extending the acid disposal time also means that lesser spent acid waste are being produced. This extension is healthy for the environment as lesser hazardous waste will be disposed in the future.

Application of the Kleingarn acid management system reduces waste volume, saves hydrochloric acid usage rate and increases the company's financial returns. The method used is simple, does not involve high costing and it is practical to be applied by any galvanizing company.

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