Improved Safety and Value for Paper Pulp Waste Associated with Bottle Cleaning

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Improved Safety and Value for Paper Pulp Waste Associated with Bottle Cleaning: Development of a Treatment Process for Alkaline Paper Slurries from Brewery Labels

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List of Acronyms

CAPEX – Capital Expenditure

FEED – Front End Engineering Design

OPEX – Operating Expenditure

TAPPI – Technical Association of Pulp and Paper Industry

INTRODUCTION

Material recycling has grown to become a common process worldwide for many types of consumer and industrial products. Of these materials, perhaps the most well-known is the recycling of post-consumer beverage containers, such as glass beer bottles. Beer bottles present a unique format for recycling in that certain breweries will reuse bottles returned to them following washing and inspection. The reuse of these bottles thus provides an economic incentive to breweries as it costs less to reuse bottles than to purchase new ones, and also provides environmental benefits by certain measures (Mata & Costa, 2001).

This process involved in the reuse of these bottles does still produce some waste streams created during bottle cleaning, which must be treated prior to disposal. Such issues are exacerbated in Newfoundland and Labrador, with the province having the highest usage rate of bottles of any province in Canada (Beer Canada, 2019). One such issue is the production of paper waste during label removal from previously used bottles. The process of label removal often involves soaking the bottles in a caustic solution, which dissolves the adhesive binding it to the glass leaving behind clean bottles and a waste stream consisting of highly alkaline paper (Molson Brewing, Personal Communications). This moist paper product is therefore hazardous to handle due to the potential for caustic burns, and is also unsuitable for recycling. Instead, this waste is securely transported to a landfill site for safe disposal. Ever Green Recycling, a St. John's-based recycling group, became aware of this issue through their work with local brewing companies. As a non-profit organization employing individuals coping with mental illness, the group saw the opportunity to implement a process treating this

paper as a potential for growth of the organization, and as a result, growth in their employees' skillset.

This discussion manifested the project described herein, led by Memorial University professors Dr. Christina Bottaro of the Department of Chemistry, and Dr. Kelly Hawboldt of the Department of Process Engineering, and students under their supervision. The project involves the preliminary design and cost analysis of a process for the neutralization of label waste coming from local breweries into an Ever Green operated plant. This report details the procedures, results, and conclusions from such a study to provide Ever Green Recycling a procedure for future development and establishment of such a process.

Objectives

The overarching goal of this project is to neutralize the alkaline paper waste coming from local breweries and return it to a form that is acceptable for recycling. From previous communications, a feed rate to the process of 1 tonne of alkaline paper per week has been established from past experience (Vinny Bhat, personal communications, 2018). The given process must first neutralize the label pulp using an acid in a primary reaction, after which the material must be dewatered and dried to allow for proper transport of the material and acceptable quality for reuse. The process used must be simple and safe to use accounting for the skills of the employees of the plant, and in aligning with Ever Green Recycling's employment mandate. Beyond neutralizing the pulp, the process must also dewater and dry it such that the label pulp can be packaged for shipment in the organization's existing baler.

Following this, this report will provide design recommendations, as well as sizing estimates and a cost analysis to determine both the capital expenditure (CAPEX) and operational expenditure (OPEX) of the process. The project will then conclude with recommendations for future work in this area.

BACKGROUND & REVIEW

An initial review of literature was performed to determine what current information existed on the process of paper stock neutralization. As a whole, however, pH adjustment in paper stock slurries is only mentioned as being a step in other processes, and seldom is there focus on the neutralization process alone. Furthermore, most pulp and paper plants have high levels of automation and use processes that are impractical for Ever Green's purposes, therefore, the process developed here adapts what knowledge is available from industrial and scientific literature to the requirements of Ever Green Recycling.

Controlling the pH of paper stock is immensely important in the paper industry, with many processes being pH-sensitive (McKinney et al., 1996). In industry, the most common acid used is sulfuric acid, which leads to some benefits given its strength and effectiveness (Biermann, 1996). However, sulfuric acid as a feed chemical is highly corrosive and toxic, posing dangers to workers who handle it ("Sulfuric Acid: OHS Answers," 2019). Because the Ever Green Process described herein is to be operated in a plant with numerous other processes and has workers with little training in dealing with corrosive compounds, it was decided that a safer and weaker acid should be employed instead for this process. Here, citric acid will be employed following

discussions between project partners, whereas it is weaker than sulfuric acid but is still cost effective and suitable for use with paper stock.

EXPERIMENTAL METHODOLOGY

In this project, two types of experiments were performed according to the type of unit operation it related to, those being i) neutralization experiments, and ii) dewatering and drying experiments. This section discusses the methodology behind each experiment, along with the references to the techniques applied to reinforce their validity.

Neutralization Experiments

Neutralization experiments were performed using 400 mL beakers and were mixed using a Fisherbrand™ CompactDigital™ overhead mixer to provide agitation to the beaker's contents during the reaction. Approximately 100 grams of pulp was then weighed out and added to the beaker, after which 100 mL of water was added to the paper in the beaker, and the combined contents were mixed for 60 minutes at 200 rpm. The pH was measured both before and after addition of the water to understand the effect of water addition to the paper using a Thermo Scientific™ Orion Star™ A211 pH Benchtop Meter using a method adapted from the Technical Association of the Pulp and Paper Industry (TAPPI) standard TAPPI 529 om-88 as described by Strlič et al. (Strlič et al., 2004). At this point, a mass of citric acid (Sigma Aldrich, #MKCG2579) was added to the mixture, which was then allowed to mix together for another 60 minutes, with the pH being checked at 30 minutes of reaction time and at the end of the mixing time. Results are therefore shown as a function of the mass of citric acid added and the time spent stirring.

<u>Drying Experiments</u>

Dewatering experiments were performed by suction filtration. Moisture content could then be calculated by comparing to the wet mass to the dry mass: dry mass was found by putting a known weight of neutralized pulp in a drying oven and drying it overnight at 80°C and weighing The change of moisture content using each dewatering method could then be analyzed.

EXPERIMENTAL RESULTS

<u>Neutralization Experiments</u>

The results of the neutralization experiments are tabulated in Appendix A and shown below. It was found here that the pH of the paper averaged 13.06±0.14 units, which decreased to 12.92±0.19 units upon mixing the paper with water due to dilution effects. The effectiveness of citric acid addition, varying between 3 and 5 grams per 100 g of wet caustic pulp, is shown in Figures 1 and 2. Figure one shows the pH of the paper-water mixture, and Figure 2 illustrates the corresponding paper pH after filtration.
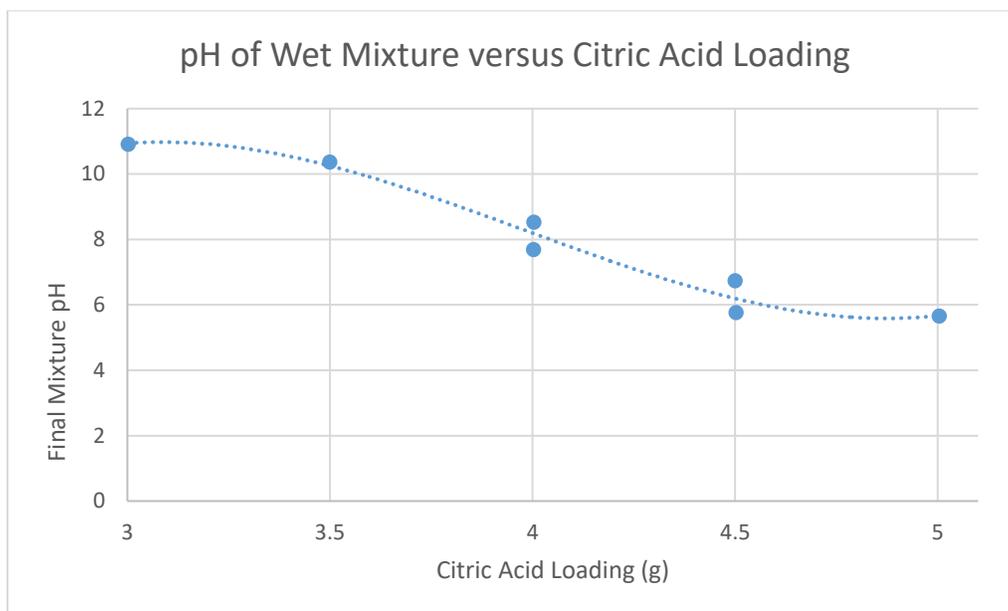
Figure 1: Plot of Mixture pH versus Citric Acid Loading

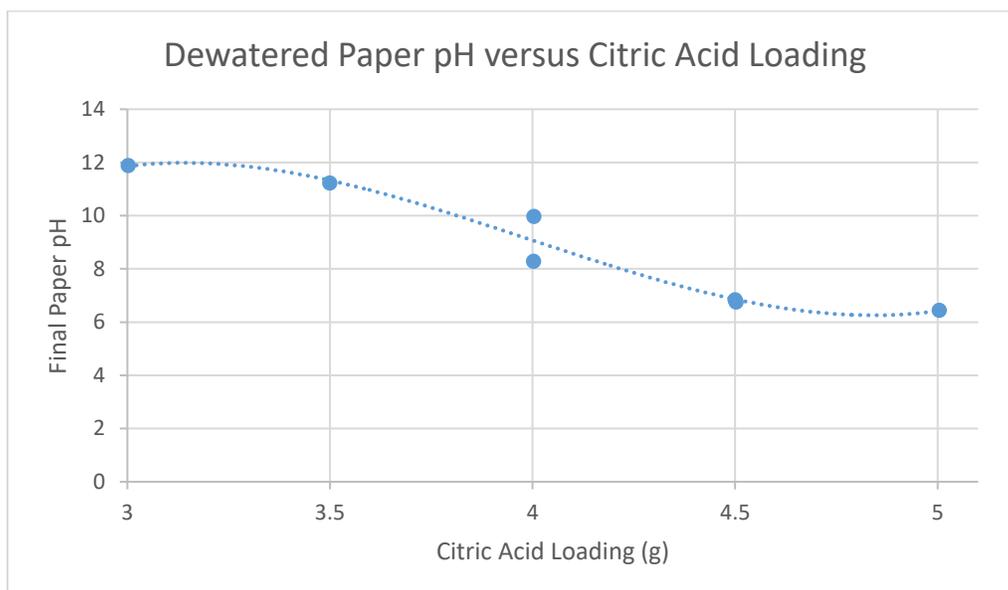

Figure 2: Plot of Paper pH versus Citric Acid Loading

The results demonstrated in these figures show a standard neutralization pattern, with pH changing rapidly with respect to loading near the neutralization point in comparison to other regions of the plot. The pH here was also closest to neutral at a loading of 4.5 grams per 100 grams of paper, indicating that a loading near this value is

optimal for neutralization. Where the true paper pH can only be calculated after decanting the water and analyzing the dried pulp, however, the corresponding pH of the dewatered paper mixture can also be analyzed as shown in Figure 2, which demonstrates an average pH of 6.24±0.54 at the 4.5 gram loading. The higher standard deviation compared to the wet slurry (Figure 1) is likely attributed to the non-homogeneity of the mixture. Further testing may eliminate some uncertainty in this value; however, it should be noted that pH is very sensitive to mild fluctuations in concentration of the reacting acid or base, and some variance should therefore be expected.

<u>Drying Experiments</u>

Experiments involving drying of the material revealed a large mass of water being present in the paper, even after vacuum filtration. Vacuum filtration was capable of removing approximately 100 mL of water in each of the experiments performed, thus accounting for the majority of the water added during neutralization. The remaining water would then appear to be associated with the bound water in the paper, which averaged 75.9% of the original pulp mass. Such a high level of moisture can be attributed to the capacity of paper for absorbing water, which is quite high and demands the use of higher energy techniques for dewatering, which also may require a thermal drying process if a lower moisture content is required. Further analysis into techniques for water removal will be presented in the upcoming section on equipment selection.

Table 1: Paper drying data

LABEL	MASS OF WET PULP (G)	MASS OF DRIED PULP (G)	PERCENT MASS DECREASE (%)
A	105.285	25.514	75.767
B	118.557	25.870	78.179
C	95.395	25.410	73.363
D	98.869	27.945	71.735
E	123.057	25.860	78.985
AVERAGE	108.233	26.120	75.867

EQUIPMENT SELECTION

Following the analysis of a process on a lab scale, scale-up and equipment selection typically follows in the procedure of process development. This involves analyzing the process requirements discovered during the lab-scale phase and applying practical engineering knowledge to determine the impacts of increased volumes on such physical parameters as heat transfer and fluid mechanics, as well as economic impacts such as cost and product quality. The following subsections detail this process as it pertains to each unit operation of the label pulp neutralization process, providing preliminary equipment selection and sizing which can be applied to a full plant process. A Process Flow Diagram (PFD) is presented in Figure 3 to better illustrate the process overall.

LABEL	ITEM DESCRIPTION
E-1	DEWATERING PRESS - SCREW TYPE
E-2	DRYING UNIT
P-1	NEUTRALIZED SLURRY PUMP
P-2	NEUTRALIZED SLURRY PUMP
V-1	NEUTRALIZATION VESSEL WITH AGITATOR
V-2	SLURRY EQUALIZATION VESSEL
V-3	DEWATERED PULP STORAGE

PAPER

WATER

CITRIC ACID

V-1

NEUTRALIZED SLURRY

P-1

V-2

SLURRY FROM STORAGE

P-2

E-1

DEWATERED PAPER

V-3

E-2

DRIED PAPER

NOTES:
1. EQUIPMENT SIZES, QUANTITIES, AND MATERIALS ARE TO BE DETERMINED.
2. CONTINGENT ON MOISTURE CONTENT OF PULP FOLLOWING DEWATERING AT E-1, DRYING UNIT E-2 MAY NOT BE REQUIRED. DRYING METHOD STILL BEING DECIDED UPON.
3. VESSEL V-2 IS USED HERE TO EQUALIZE FLOW COMING OFF OF THE BATCHWISE NEUTRALIZATION PROCESS BEFORE THE SEMI-CONTINUOUS DEWATERING PRESS.
4. COMPOSITIONS ARE TO BE DETERMINED
5. NEUTRALIZATION VESSEL SEQUENCING TO BE ADDED IN FUTURE DOCUMENTATION

PREPARED FOR EVERGREEN RECYCLING

PROCESS FLOW DIAGRAM OF LABEL PULP NEUTRALIZATION PROCESS

ORIGINATED BY D. HOPKINS

SIZE 8.5X11	FSCM NO	DWG NO N/A	REV P0
SCALE N.T.S.		13-May-2019	SHEET 1 OF 1

Figure 3: Process Flow Diagram for the Ever Green Process

Neutralization Vessel

The primary unit operation in this process is that of the neutralization vessel. In this vessel, the alkaline paper described in the previous section must be reacted with an acid to lower its pH to neutrality. This process must be careful so as to mix the reactants thoroughly, otherwise the end product could have an inconsistent pH throughout the slurry and be unsuitable as a product.

Fortunately, this process has been studied thoroughly by stakeholders in the pulp and paper industry in reference to many other reactions used in standard paper making. The extent of study in this field in particular owes to the complex properties of paper when mixed with water, as paper-water mixtures form viscous, non-Newtonian fluids at higher pulp levels (Bakker & Fasano, 1998). Due to these properties, vessels involved in the mixing of paper must be designed properly such that they are able to provide mixing throughout the bulk volume of the mixer, while also not agitating so much that the fibers in the paper begin to break down.

For this reason, agitating tanks for paper stock tend to be specially designed with mixing blades that encourage flow throughout the entirety of the mixture and not to damage the paper fibres too much. To account for both of the above comments, agitators for mixing paper stock typically use slow speeds to protect the paper along with a large blade size to improve both mixing quality and efficiency (Moseley & Wyczalkowski, 2009).

The volume of this vessel is a separate design question and depends on how much paper will be processed in a given run. It will take less time of the working schedule if all the paper from a week is processed in a single tank, however this would

also increase storage costs and result in the build-up of large amounts of caustic paper in the facility. Instead, processing could occur in batches several times per week, which despite increasing operating costs from labour, would have the benefit of requiring a smaller, less expensive agitation vessel, and would also likely lead to a lower chance of process bottlenecking due to limitations in capacity downstream. Here, feed of paper for one week has been used as an estimate for costing purposes. This predicts 1000 kg batches of paper. It is estimated that the pulp will have a density similar to dry paper, meaning that altogether a 2000 L volume would be required in the vessel (1000 L of paper and 1000 L of water). The volume of the citric acid is neglected here as it is insignificant in relation to these volumes. Dimensions of the vessel can then be obtained based on common paper industry dimension ratios. Selecting a proper ratio here is important, as noted by agitation company Dynamix, as slimmer tanks leading to higher costs due to inefficiencies in the mixing process. The group therefore recommends a liquid level to diameter ratio of 0.8 in most mixing applications (Dynamix Agitators Inc., 2015). In addition to this, clearance, or headspace is needed on mixing vessels in order to provide a space in case of overfilling. Standards for this are sparse, and thus it is hard to determine exactly how much clearance is required. This consideration should be investigated thoroughly with the vendor prior to purchase.

Dewatering Press

Following neutralization, the paper must be first dewatered to remove much of the bulk water in the paper slurry. This is normally accomplished using a dewatering press, a piece of equipment that uses mechanical pressure to force water out of the paper. This operation is commonplace in numerous unit operations of paper recycling,

normally in a design akin to a screw press (Worrell & Reuter, 2014). A press for a usage such as this would normally consist of an inlet hopper which feeds into the screw portion, which gradually presses the material against the two screw blades and the screen until being pushed out of the other end. Due to the nature of this mechanical action, the inlet consistency is generally restricted to 10% (Worrell & Reuter, 2014), thus permitting the water volume added in the experimental section, or even higher amounts should there be a requirement to do so in future scale-up work. Therefore, this first stage formulates a good dewatering section to achieve the primary level of water removal required in this process.

Dimensionally, dewatering presses can take up a wide variety of sizes depending on capacity. With reference to the throughput required by Evergreen, something akin to the CP line-up of presses provided by Vincent Corp matches well, such as the CP-4 with its intake capacity of 150-500 lb/h and dimensions of 4 ft. long by 1.2 ft. wide by 2 ft. tall (Vincent Corp, 2013). Other screw press providers can design for similar sizes and capacities. Therefore, the space requirement is not overly large and fits well with Evergreen's goal of minimizing the overall space requirement of this new process.

Dryer

Following dewatering, the paper may not be at a moisture content acceptable for being fed into the bailer due to the limitations of mechanical dewatering on the water content of paper. As such, a dedicated dryer may follow the dewatering operation. Designs for this have been presented in the past, and normally utilize heated air blown over the mass of paper to achieve proper drying. Given the batch nature of this process, a batch dryer is likely among the most appropriate options, for which tray-

based and through-circulation dryers are common, per Moyers and Baldwin, writing in Perry's Chemical Engineer's Handbook. Adding to this, they note that tray type dryers tend to be operationally expensive due to the large requirements for labor involved in the process, and therefore through-circulation is likely the best fit given the needs of Evergreen Recycling (Moyers & Baldwin, 1997).

Dryers for paper have been designed in the past, however, in the current review, there were no models discovered that were of a suitable size for the given process. For example, New Eco-Tec of Germany produces a line of belt dryers that use convective drying, and have in the past been used to dry paper for recycling, though at a very large scale. These models use a belt to transport paper down the length of the drying chamber (NEW eco-tec, 2019). This type of dryer is covered in the textbook by Peters, Timmerhaus and West as being a conveyor dryer. The descriptions from this text also indicate that a screw conveyor-based dryer could work well in this case, though the actual mechanisms in either case do not vary significantly. Screw conveyors also share the benefit of being compact, and their limited capacity is not an issue here (Peters, Timmerhaus, & West, 2003).

Pumps

The pumping of highly viscous slurries requires specialized equipment due to the complex rheology of the mixture in question. In medium consistency pulps, however, there is risk of air entrapment in the pulp slurry itself, creating risk of cavitation and pump failure due to higher gas contents (Lindsay & Gullichsen, 1994). The group recommends that centrifugal pumps be used in this manner only when degassing is applied as well, in the case of slurries where it is known that gas has been entrained

therein(Lindsay & Gullichsen, 1994). Pumping can also be achieved with less complexity at lower consistencies, meaning that more water is added to the paper before pumping (in this case, during mixing), however it is noted here that this does, evidently, lead to the consumption of additional water, increasing overall costs (Ye & Li, 2017). Specialty vacuum pumps can be used (Ye & Li, 2017), however the unique designs used here are difficult to describe in this section, and would make cost estimation difficult as well. With this in mind, the presence of air in commercial slurries is likely associated with high intensity pulping processes, and so the more gentle mixing process desired here may not lead to the incorporation of much air in the mixture overall. It is thus suggested that once a mixing vessel is selected in the design portion of this project that a query is posed to the equipment designer on this issue, as they will likely have detailed information on the amount of air incorporated into paper slurries by their mixing equipment. Additionally, the equipment designer will likely be able to provide better recommendations on the specific type of pump for use with their equipment. For cost analysis, however, the centrifugal pump will be selected as a basis for cost estimates, as it is the most universal pump described in literature.

COST ANALYSIS

CAPEX

Capital costs for equipment were determined according to empirical correlations and quotation information where available, however, due to the early stage of this project, it should be noted that all costs are approximate and may change in the later design and engineering phases due to the specificity of the required equipment and materials of construction. This cost analysis is intended mainly as a guide to determine

the order of cost that can be expected of the process equipment and ancillaries required here, and is therefore approximate.

Beginning with the mixing tank, empirical correlations from the textbook "Plant Design and Economics for Chemical Engineers" by Peters, Timmerhaus, and West was utilized. Mixing tank costs are highly dependent on the power input required (Peters et al., 2003), which unfortunately due to the complex rheology of the paper slurry is very hard to ascertain. Peters, Timmerhaus, and West also provide a less specific format involving vessel volume, which will instead be used here. The main working volume for this tank, as previously established, will be roughly 2000 L. Peters et al. provide an estimate here of roughly $15,000 USD for this unit (2002 dollars), though costs may be higher than this due to the specialized agitator required for this process (Peters et al., 2003)

The cost of the screw press was determined according to Garrett's 1989 text "Chemical Engineering Economics", in which he lists the cost of various filter types based on their surface area. Again, this is not known at this stage of the design process, however, taking the lower half of the range (it is not expected that surface area would be exceptionally high for a filter press of this scale) costs between $20,000 and 40,000 USD can be expected (1989 dollars) (Garrett, 1989).

The cost of the dryer is highly dependent on several operational and design factors in the drying process, which unfortunately cannot be ascertained at this point in time. As a range, vibratory conveyors can cost anywhere from $10,000 to $50,000 USD per Peters, Timmerhaus & West, at the low end of the capacity range, and assuming 304 stainless steel is sufficient (for a neutral pH, damp material, it likely is sufficient,

though 316 could be employed for extra precaution at elevated costs). The average of these costs was taken as the cost estimate here (Peters et al., 2003).

Costing for the two storage tanks is performed according to Garrett, who covers the cost of several small containment vessels in his text. Here, Peters et al. suggest a capacity 1.5 times that of the equipment being serviced, thus yielding roughly 3000 L for the first vessel (Peters et al., 2003). The next has a volume that is harder to ascertain, and thus it will be assumed that 2000 L is adequate. For these, assuming they are manufactured as dished head tanks, costs can be estimated by Garrett as $5500 for the 2000 L tank and $7500 for the larger tank (Garrett, 1989).

The two pumps required are more difficult to estimate in terms of cost as the cost estimation methods for these are almost entirely reliant on pump duty, which cannot be obtained from the information available at this point. Peters et al. do provide some basic estimates for pump cost based on flow rate, however, with pumps rated between 1 liter per second and 10 liters per second (a reasonable volume flow range for the purposes stated here) being priced between $1500 and $3000 USD (2002 estimate) (Peters et al., 2003). It is important to note here that these pumps are generic centrifugal pumps, and thus the more complex pump designs required for pumping highly viscous flows, such as those for paper stock, may come at a higher cost. In the interest of maintaining conservative estimates in cost, the $3000 estimate will be applied to this discussion (thus $6000 per pump).

These capital costs are summarized in table 1 below, where adjustments for inflation (Antweiler, 2019) and currency (Statistics Canada, 2019) have been made.

Table 2: Summary of Capital Costs

EQUIPMENT	BASE COST	CURRENCY ADJUSTMENT (USD/CAD)	INFLATION ADJUSTMENT	FINAL COST (CAD)
MIXING VESSEL	$15,000	$0.84460	1.4826	$26,330.80
SCREW PRESS	$30,000	$0.84460	1.4826	$52,661.61
DRYER	$30,000	$0.63722	1.1871	$55,888.07
STORAGE VESSELS	$13,000	$0.84460	1.4826	$22,820.03
PUMPS	$6,000	$0.63722	1.1871	$11.177.61

Leading to a total predicted equipment cost of $168,878.12. In addition to this, various other capital costs will be associated with the project and can be estimated with the assistance of rates provided by Peters et al. Here, the group states that direct project costs can be estimated as fractions of the equipment cost, and are as follows (Peters et al., 2003):

- Installation=39% Equipment cost

- Instrumentation=43% Equipment Cost

- Piping=31% Equipment Cost

- Electrical=10% Equipment Cost

- Buildings=15% Equipment Cost

- Yard Furnishings=12% Equipment Cost

- Service Facilities=55% Equipment Cost

In this process, instrumentation requirements are minute, and service facilities are likely not required, leaving the total estimated direct cost at $180,699.59. Furthermore, indirect costs associated with the project, including engineering services, construction costs, legal, contractor costs, and contingencies are estimated by Peters et

al. at 32%, 34%, 4%, 19%, and 37% of the equipment costs respectively (Peters et al., 2003), yielding a cost of $212,786 and bringing a total cost of $562,364.14. It should be finally noted that this final number is subject to considerable variance, with Peters et al. reporting uncertainties of ±20% or greater for pre-design estimates (Peters et al., 2003). The cost estimates here should therefore be reserved as being an order-of-magnitude estimate more than anything, and must be continually revisited in the Front End Engineering and Design (FEED) phase of the project and onwards.

OPEX

Operational expenditures, such as the cost of materials, water, and electricity, represent annuity payments during the time in which a process is operational, and are thus critical to understanding the cost of a project over its life. In this section, these costs are estimated and put forward as an annual cost. Electricity costs will however be omitted as knowledge of the electricity requirement for the process cannot be determined at this stage in the process and must be determined from equipment specifications. In doing so, several assumptions will be made, and are stated as follows:

1. Feed rate of label paper is limited to 1 tonne per week
2. Water costs are based on current (August 2019) prices

In addition to this, labour costs will not be estimated as they would be more accurately estimated by Ever Green Recycling once the human operational requirements have been determined. Cost estimation thus begins by estimating the cost of citric acid required for neutralization. Fortunately, numerous groups have published the costs of citric acid in the past, with data shown in Table 1 below.

Whereas these purchases were made for industrial processes themselves, they should provide a fairly accurate representation of the cost of citric acid to be expected for this process, however it should be noted that market changes could influence this in future. The below estimates were calculated in Canadian dollars by using the average USD/CAD exchange rate in the year of the estimate, and then using the Statistics Canada Price Indices to estimate the price in modern Canadian dollars (Statistics Canada, 2019).

First, the cost of citric acid has been determined from published estimates from various sources. Citric acid prices, as described by Ciriminna et al., have experienced substantial variations in the past few decades due to the presence of a cartel on the industry for many years, followed by the discovery of novel, inexpensive methods for production of the compound. They note prices of $715/ton occurring in 2015 during a production peak, though duties have since been applied to many of these products through anti-dumping laws (Ciriminna, Meneguzzo, Delisi, & Pagliaro, 2017). The Witchita Falls (TX) water treatment plant, for instance, has reported prices of $0.84-$1.17 USD in quotes received for food grade citric acid, however, where food grade is likely in excess of the requirements needed here, these prices may overestimate the true price of citric acid in the operating process (City of Witchita Falls, 2017). Using the average of these values, and the optimal dosage of 4.5 grams of citric acid per 100 grams of paper, the final cost comes out to 4680 pounds per year required, and a cost between $3931.20 and $5475.60 per year.

Water costs come from the City of St. John's water metering policies and can be divided into per volume costs as well as a monthly charge for the meter itself based on size. The monthly line size-based charge is difficult to determine on its own whereas it requires an inspector or professional engineer to size the line first, which cannot be accomplished here. Costs for the meter range from $29.30/month for a 5/8" meter to $3359.40 for a 10" meter (City of St. John's, 2019), and so it is imperative to first determine what water meter is necessary based on the overall feed volume to the plant. The volume required annually for the process itself can be calculated however, and is found from the water requirement per gram of paper derived in the experimental section as:

$$\frac{100\ mL}{100\ g} = \frac{1\ mL}{1\ g} * \frac{1L}{1000mL} * \frac{1000g}{1kg} = \frac{1L}{kg} * \frac{907.185kg}{ton} * \frac{52\ tons}{year} = \frac{47{,}173.52\ L}{year}$$

The city of St. John's charges $1.63 per cubic metre of water used (City of St. John's, 2019), therefore, the final approximate cost for water would come out to just $61.32 per year, a minute cost in comparison with the cost of the meter itself.

The total annual cost of the process then is $3,992.52 up to $5536.92, neglecting the cost of the water meter which will not be completed here due to the lack of a qualified individual for this design task. The cost per ton then is $76.78-$106.47, however, these estimates will likely end up being lower than true costs as they do not account for energy consumption and labour, which will be determined in the design phase. Still, this information can serve as a valuable basis through which further development of this process can occur.

CONCLUSIONS & RECOMMENDATIONS

The treatment of waste materials continues to be a paramount issue in the majority of processing industries, with many sectors spending a great deal of money to treat hazardous materials from their processing units. As shown here, the brewing industry is no exception, and the corrosive waste paper developed here must be treated if it is to have any potential for recycling.

The process outlined here provides a conceptual effort at describing the requirements for a treatment process involving the neutralization of such a caustic label paper, and details the chemical and equipment requirements as well as the costs associated with such a process. The effort is again aimed at the pre-FEED/conceptual design phase of the process design procedure, with future work being required to further refine the details presented here into an industrial process. From here, it is thus recommended that Ever Green Recycling, should they choose to move on to future project phases, partner with a consulting engineering firm with specializations in pulp and paper in order to outline the specific design of each piece of equipment, which in itself will lead to better overall cost estimates based on the foundation of this report. With the support of future engineering work, it is hoped that a solution to this waste disposal issue can be finally resolved in a cost effective and green manner.

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