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Physiochemical Characteristic of Sago (*Metroxylon Sagu*) Starch Production Wastewater Effluents

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Abstract - The physiochemical characteristics of sago starch production wastewater effluents was recently studied. Sago wastewater effluent samples were obtained from a sago factory located in Sarawak, Malaysia and sent to accredited laboratories for particle size distribution and water quality analyses. The findings of this study concluded that sago wastewater effluents from this region are whitish and greyish brown (pH 4.20) in color with majority supra-colloidal or settable suspended solids of particle size ranged from 4.477 µm to 1.18 mm (of 95% volume). The starch content of this wastewater effluents are less than 7% whilst the pollutant parameters (total suspended solids, biochemical oxygen demand and chemical oxygen demand) measured 10,900 mg/L, 5,820 mg/L and 10,220 mg/L, respectively. Pre-filtration of the wastewater effluents has resulted reduction of the pollutants content as high as 66% of total suspended solids, 20% of biochemical oxygen demand and 22% of chemical oxygen demand while improved pH in a range of 0.05-0.45%.

Index Terms - Sago factory wastewater effluents, particle size, total suspended solids, biochemical oxygen demand and chemical oxygen demand

1. INTRODUCTION

In Southeast Asia, approximately 60 million tonnes of sago (*Metroxylon Sagu*) starch are produced annually either by mechanical or traditional methods [1]. Plenty of average size sago mills are found in tropical countries and a study carried out by Bujang et al. (1996) to investigate the total water consumption and wastewater effluents production by the factories reported that approximately 600 sago logs are processed in one of the mills in Sarawak, Malaysia, daily and the water consumption during the operation is approximately 5 L/s (18 tonnes/h) whilst the wastewaters generated as the factory wastewater effluents are approximately 30 L/min (1.8 tonnes/hr) [2]. Therefore, approximately 237.6 tonnes of wastewater containing approximately 7.1 tonnes of total solids would be generated daily for an operation of 12 hours [2]. These wastewater effluents are not suitable to be reused and recycled in the process and thus the voluminous amount of wastewater would be discharge out of the facotry into nearby river. In Malaysia, it was reported that the amount of starch contained in sago pith solid waste and wastewaters accounted for nearly half of the total annual imports of starch of the year [3]. Again, the report stated that about the same amount of starch residues were being discharged into rivers as sago factory wastewater effluents. However, only a few of the factories implemented wastewater treatment facilities for environment conservation purposes. This is most probably due to the economical risk and unreliable treatment efficiency although they are aware of the need for such measures [4-6]. Therefore vigorous researches have been carried out to solve the predicament faced by local sago processing industries and the environmental governing authorities [3].

During sago starch extraction process, sago trunks are washed, debarked, rasped prior to hammer milling or pulping process (Fig. 1). The sago barks (20% of the total trunk weight) normally are sun-dried and utilized as firewood or transformed into various valuable products [7-12]. After rasping and hammermilling processes, the starch in the slurry are extracted and left to be settled, then compacted and agglomerated before being air-dried by using thermo-oil heating to turn them into powder form for marketing (Fig. 1) [13]. During the entire production process, large amount of water (20 litres of wastewater per kg of sago starch production) would be discharged as sago wastewater effluents which are rich in carbohydrates, fibres and dense suspended solids, unextracted starch, cellulose (fibrous residue from pith), nitrogenous compounds, cyanoglucosides and insoluble fibres [2, 5, 14-15]. These effluents, containing high concentration of organic matters (such as protein, lipids and carbohydrates), are reported to be acidic (pH 3.4 to 4.7; depending on the concentration of pollutants) and emitting obnoxious fouling smell thus causing pollution and deteriorating the environment quality globally [16-21]. In common practice, these sago wastewater effluents are directly being discharged out of the factories into nearby river [2, 22].

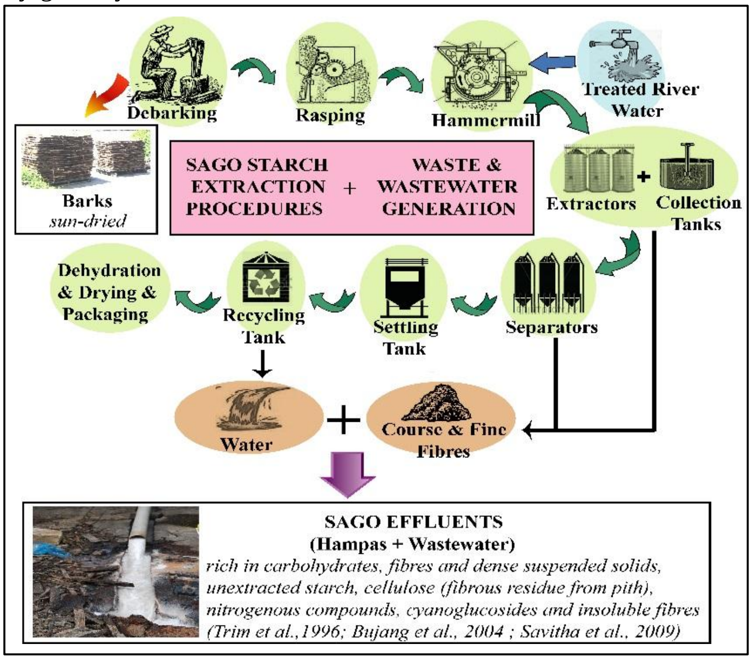

Fig. 1 Wastewater Effluents Generated from Sago Starch Extraction Process

2. CHARACTERISTIC OF SAGO SOLID WASTE AND LIQUID WASTE

2.1. *Solids in Sago Wastewater Effluents*

Solids found in sago wastewater effluents can be categorized into three phases, i.e., floatable/light phase, suspended phase and settable/heavy phase. Floatable solids are coarse fibrous matters or "*hampas*" whilst the suspended solids are formed of non-settable solids, fine and very fine settable solids. Settable solids in sago wastewater effluents majority formed of residue starch content. Generally, suspended solids are formed of settable and non-settable (supra-colloidal) particles with particle sizes >1 µm diameter, possess either organic or inorganic characteristic. Non-settable suspended solids are finer with specific gravity nearly or less than density of water thus are more difficult to separate due to smaller particles possess greater surface area which would lead to more fluid drag and retarding the separation performance [23].

2.2. *Density /Specific Gravity of Constituents in Sago Wastewater Effluents*

Sago wastewater effluents are generally formed of sago pith properties and water, therefore the density of sago pith basically reflects and represents the general behaviour of the wastewater generated. The coarse fibrous matters or *"hampas"*, which are volatile, were reported to possess a density less than water, which ranged approximately 0.16 to 0.31 g/cm^3 whilst the suspended solids are formed of non-settable solids, fine and very fine settable solids with specific gravity ≈ 1.0 [2,24-27].

2.3. *Composition and Chemical Properties of Sago Wastewater Effluents*

The recent sago pith wastes or "*hampas*" are form of lignocellulosic and cellulose fibres (amylose, cellulose, hemicellulose and lignin) in majority, moisture, fine/light suspended organic matters in starch such as protein, ash, fat/lipid in minority content and inorganic minerals (iron, magnesium, potassium, calcium, manganese, and so on) in trace elements form [4,28-30].The total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentration of sago factory wastewater effluents reported in past researches were in the range of 66 to 12,936 mg/L, 900 to 3,444 mg/L and 780 to 12,409 mg/L, respectively [18-21, 31-33]).

2.4. *Particle Size of Sago Starch*

Sago pith waste or "*hampas*" also found to contain large amount of starches, which are formed of ash, protein, fat and so on composition with micron granule sizes [4, 28-29, 34-36]. Sago starches are found in particle diameter size ranged from 5 µm to 65 µm diameter, with average granule size of 30 µm diameter [34, 38-41]. Therefore, sago factory wastewater effluents would contain massive amount of solids with particle size range from 5 µm diameter to millimetres size.

2.5. *Current Situation on Sago Pith Wastes Management*

The coarse-sized solid particles can be easily removed by using sedimentation basin or mechanical filtration devices [19,42]. Various researches and studies were carried out since the past decades to transform these retained (by sedimentation/filtration) sago "*hampas*" into reusable materials [18, 22, 43-48]. The residue effluents passing the sedimentation/filtration processes would contain less heavy/coarse-sized solid particles but majority finer suspended solids which do not settle easily or required lengthy settling time. According to Bujang et al. (2005), removal of large/coarse particles or "hampas" from raw sago factory wastewater effluents indirectly would stabilize the effluents and aid the subsequent treatment efficiencies [19].

3. OBJECTIVE OF THE STUDY

In the latest report of Bujang (2015a) revealed that the current starch harvesting process is capable of achieving approximately 97 to 98% of starch content if compared to 30 to 40% extraction in 15 years ago [13, 35, 37, 49]. Therefore, the characteristic of the sago effluents generated from the recent sago starch extraction process from a localised sago mill is studied in order to evaluate the changes of TSS, BOD, COD and pH over time as well as to investigate the particle size distribution of solids in the sago wastewater effluents, physical appearance (color, density and texture) of sago pith and effluents and comparison between filtered and unfiltered sago wastewater effluents for future development of a feasible and efficient wastewater treatment system for localised sago starch production factories.

4. MATERIALS AND METHODS

4.1. *Determination of Sago Pith Bulk Densities and Color Changes*

A sago log was obtained from the sago mill located at Pusa, Sarawak, Malaysia, debarked and the color changes after debarking were observed. Half of the sago pith log was cut into several pith cubes in different dimensions then weighed in each subsequent 20 days (until the moisture loss reading become stabilized). The bulk density of each cube over the period of measurement was determined by using Eq. 1.

$$Density_{wet} = \frac{Mass\ of\ Cube}{Volume\ of\ Cube}$$

(Eq. 1)

4.2 . *Determination of Particle Size Distribution of Sago Factory Wastewater Effluents*

Sago factory wastewater effluents were obtained from the outlet of a sago mill located at Pusa, Sarawak. The sago factory wastewater effluents were prepared in 500 mL Polyethylene Terephthalate (PET) storage bottle and this sample was sent to Permulab Sdn Bhd, a company providing environmental testing services and accredited under Laboratory Accreditation Scheme of Malaysia (SAMM No.127) who meets the requirements of MS ISO/ISE 17025: 2005, for particle size distribution analysis. Due to the detectable particle size range for the particle size analyser are ranged from 0.02 to 2,000 µm, the sago factory wastewater effluents were also sieved with 3.35 mm and 1.18 mm laboratory test sieves to estimate the maximum size of solids contained in the wastewater effluents.

4.3. *Determination of Chemical Parameters of Unfiltered and Filtered Sago Factory Wastewater Effluents*

Chemical parameters, i.e., TSS, turbidity, BOD, COD and pH, are inter-related and their increment/reduction may concatenate and concomitant with each other as it is most probably affected by microbial activities and oxidation process of organic matters [19,50]. In this study, unfiltered and filtered (passing 1.18 mm laboratory test sieve) sago factory wastewater effluents were prepared and sent to a water quality testing laboratory, Nabbir Laboratory (Sarawak) Sdn Bhd (MS ISO/IEC 17025 Testing; SAMM No.202), which is accredited by

Natural Resources and Environment Board (NREB) Sarawak, Malaysia and Department of Environment (DOE) Malaysia for chemical (TSS, BOD, COD and pH) analyses. The analyses were carried out over a period of 13 days for both unfiltered and filtered sago factory wastewater effluents samples.

5. RESULTS AND DISCUSSION

5.1. *Observed Colour of Sago Pith and Its Bulk Densities over Time*

Freshly cut and debarked sago logs were in whitish longitudinal stria form with soft spongy and flimsy texture (Fig. 2a). Exposure of sago pith to air would cause oxidation and its colour was observed to change from whitish (Fig. 2b) to brownish (Fig. 2c) and ultimately into dark brown colour (Fig. 2c) with growth of fungus and mould. Sago pith in this research was found containing high moisture whilst the bulk density of the sago pith used in this research are averagely 0.563 g/cm^3 (freshly cut) during Day 1 and decreased to an ultimate density of 0.272 g/cm^3 (completely dried) during Day 20 (Fig. 3). Prolonged storage time of debarked logs had caused rapid oxidation and drying (moisture loss) of cellulose, hemicelluloses and starch content under room temperature of 27 °C to 34 °C, which directly decreased the mass of the pith cubes and finally reduced the bulk density and affect the behaviour (floating) of the solids in the wastewater. During the 40 mins sago processing operation in factory, freshly debarked sago logs (piths) are rasped and pulped, the density of the fibrous content in the wastewater effluents shall be proximate to 0.563 g/cm^3 or less (due to starch content reduction during extraction process or prolonged debarked piths storage period practiced by some factories) [13].

Fig. 2. Sago Piths Textures and Color Changes over Time due to Oxidation Process

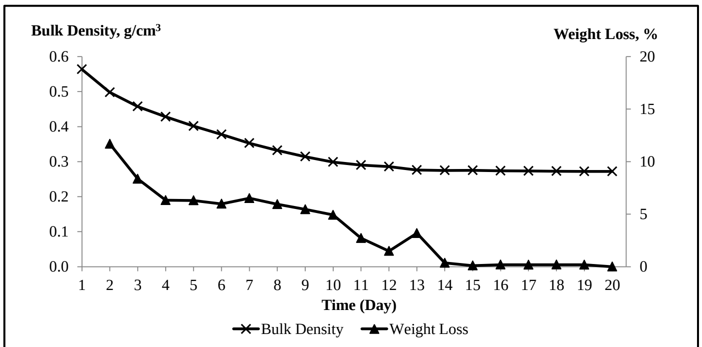

Fig. 3. Bulk Densities and Weight Loss of Debarked Sago Pith kept under Room Temperature of 27 °C to 34 °C over Storage Period of 20 days

5.2. *Observed Colour of Sago Factory Wastewater Effluents*

The colour of the raw sago factory wastewater effluent samples observed was initially whitish and greyish in colour during the day (Day 1) of collection from the factory's outlet pipe. The colour of wastewater effluents changed swiftly after an hour of collection which turned into slightly grey brownish slurries. The wastewater effluents settled swiftly into upper, middle and lower layers due to its different densities of the substances, i.e., the settable, suspended and floatable solids content. Floatable contents were minimal and generally formed of very coarse and fibres in strips and chips form. The suspension wastewater was in grey brownish colour whilst the settable (lower) portion was majority filled with large amount of coarse and fine settlements (Fig. 4a) and observed to be in pale and whitish colour. The wastewater effluents, stored in capped Polyethylene Terephthalate (PET) storage bottle under room temperature of 27 °C to 34 °C, were found remained in slightly grey brownish colour wastewater with whitish settlements and very minimal changes were observed in the subsequent ten days. On the Day 15, the wastewater effluents were observed to be in cloudy and pale brownish wastewater with whitish settlements (Fig. 4b). The changes of colour from clearer greyish brown to cloudy brown is most probably due to the degradation of organic content in the effluents reacted to the microbial activities and anaerobic conditions [51]. On the Day 20, the effluents transformed into darker brownish wastewater with more compacted whitish settlements (Fig. 4c). The changes of colour are most probably caused by the formation of metallic sulphides that led to the colour darkening of the effluents [51].

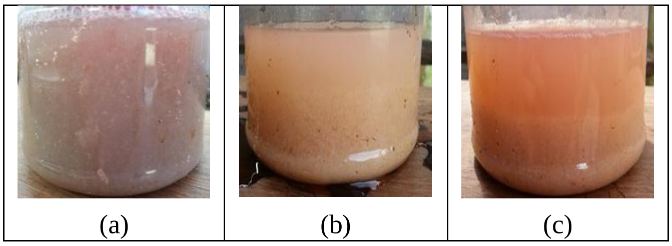

Fig. 4. Changes of Colour of the Sago Factory Wastewater Effluents Sample on the (a) First Day, (b) 15th Day and (c) 20th Day of Storage Period under Room Temperature of 26 °C to 34 °C

5.3. *Particle Size Distribution of Sago Factory Wastewater Effluents*

It was found that all the solids contained in the sago factory effluents had passed through the 3.35 mm laboratory test sieve whilst small portion was retained on 1.18 mm laboratory test sieve. Therefore, it can be concluded that the maximum size of solids contained in the wastewater effluents ranged between 1.18 to 3.35 mm diameter. The result of the particle size analysis (Fig. 5) carried out on the sago factory wastewater effluents revealed that solids formed the sago factory wastewater effluents are > 4.477 µm (minimum size) of particle size which are either supra-colloidal or settable suspended solids with particle size range > 1 µm diameter. Particles sized between 2,000 µm to 3,350 µm diameter are less than 0.5% of the total volume of the solids content.

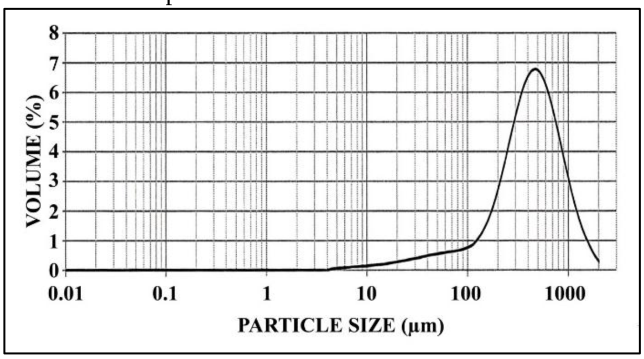

Fig. 5. Particle Size Distribution of the Raw Sago Factory Wastewater Effluents

5.4. *Starch Content of Sago Factory Wastewater Effluents*

From the result of analysis carried out by Permulab Sdn Bhd, the solids size ranged < 65 µm diameter (maximum size from literature reviews) and most probable to be starch residues entrapped in "*hampas*" and very fine solids suspended in sago factory wastewater effluents are found to be approximately 7% of the total volume of solids in the wastewater. This result concluded that the sago starch fraction contained in the sago factory wastewater effluents are < 7% of the total volume of effluents.

5.5. *Chemical Parameters of Unfiltered and Filtered Sago Factory Wastewater Effluents*

The TSS, BOD and COD levels of unfiltered and filtered sago factory wastewater effluents samples over a period of 13 days were tested and recorded. TSS, BOD and COD levels of the unfiltered sago wastewater effluents in this study, obtained from the region of Sarawak, Malaysia, are 10,900 mg/L, 5,820 mg/L and 10,220 mg/L, respectively. TSS concentrations of sago factory wastewater effluents stored for a short period of time (13 days) did not show drastic changes. The reduction rate of TSS for unfiltered sago factory wastewater effluents was 9.13% (Fig. 6), which is 2.5% higher than reduction rate of filtered sago factory wastewater effluents over a period of 13 days. Pre-filtration process was capable in reducing TSS level of approximately 61-66%.

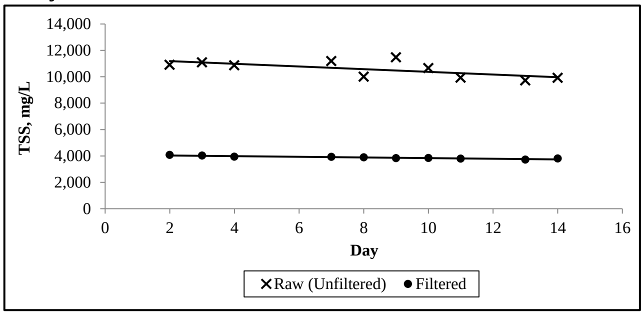

Fig. 6. Total Suspended Solids (TSS) Concentration of the Raw (Unfiltered) and Filtered Sago Factory Wastewater Effluents Samples over a Period of 13 Days

Both BOD and COD levels for unfiltered and filtered sago factory wastewater effluents showed high deterioration along the storage period (13 days) whereas the BOD and COD levels increased vigorously, approximately 62.54% (BOD) and 55.77% (COD) for unfiltered wastewater effluents whilst 36.10% (BOD) and 25.05% (COD) for filtered wastewater effluents after a storage period of 13 days. The reduction rate, as a result of filtration of the wastewater effluents with 1.18 mm sieve, for BOD and COD are as high as 20% and 22%, respectively. Fig. 7 and Fig. 8 show that deterioration rate of BOD and COD started to decelerate since Day 4 and changes almost stagnant after Day 10.

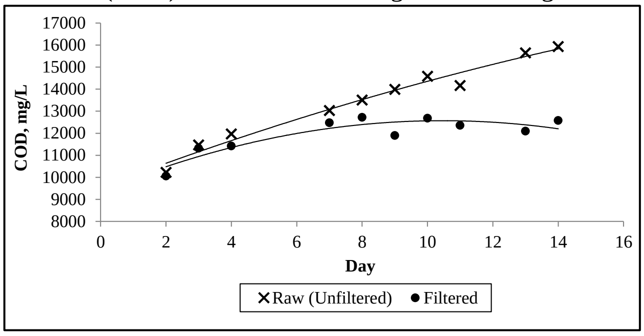

Fig. 7. Chemical Oxygen Demand (COD) Concentration of the Raw (Unfiltered) and Filtered Sago Factory Wastewater Effluents Samples over a Period of 13 Days

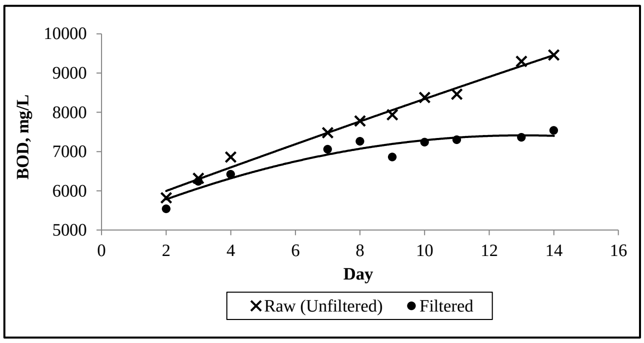

Fig. 8. Biochemical Oxygen Demand (BOD) Concentration of the Raw (Unfiltered) and Filtered Sago Factory Wastewater Effluents Samples over a Period of 13 Days

In this research, the filtration of sago wastewater effluents by using 1.18 mm sieve showed a significant reduction (61 to 66%) in total suspended solids concentration. Filtered sago factory wastewater effluents are found to degrade faster than raw (unfiltered) sago factory wastewater effluents. Reduction of total suspended solids has improved the quality of other pollutants, i.e., biochemical oxygen demand and chemical oxygen demand levels) as reduced amount of total suspended solids may stabilize the effluents and subsequently enable microbial activities to take place. Pre-filtration acted as a practical, implementable and efficient measure to be applied in sago factory wastewater effluents treatment to delay the deterioration of water quality of stored wastewater effluents and to protect the nearby rivers.

The pH of both filtered and unfiltered sago factory wastewater effluents were observed to become more acidic with the increased storage time, with pH values drop of 20.71% (for unfiltered effluents) and 16.71% (for filtered effluents), respectively. This implies that pH of unfiltered effluents deteriorated faster than filtered effluents. The pH of sago factory wastewater effluents are initially acidic, ranged 3.5 to 5.6 due to the presence of dissolved solids, starch and trace elements [52]. The decrease or deterioration of pH for sago factory wastewater effluents from 4.20 to 3.33 along the storage time is most probably due to the decomposition processes which produced carbon dioxide and indirectly released hydrogen ions in the wastewater. Higher hydrogen ions reduced/lower pH in the wastewater. For unfiltered sago wastewater effluents loaded with massive fibres and coarse solids, the microorganism activity might be retarded by the bulk content [19]. This is due to the excessive decomposition activities and lowering of pH inhibited the growth of microorganism and bacteria and thus retarded the organic matters uptake by microorganism and bacteria. The pH (3.54 to 4.25) of filtered sago factory wastewater effluents with reduced total suspended solids content are found slightly higher or improved (Fig. 9). The acidity of the sago factory wastewater effluents is found proportional to BOD and COD levels where increase of BOD and COD levels inevitably decrease pH values in the wastewater effluents.

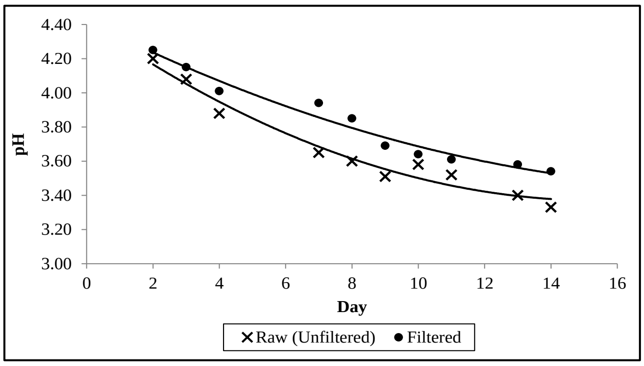

Fig. 9. pH Levels of the Raw (Unfiltered) and Filtered Sago Factory Wastewater Effluents Samples over a Period of 13 days

6. CONCLUSION

This study is carried out to study the physiochemical characteristic of sago wastewater effluent obtained from the Pusa, Sarawak, Malaysia. The results concluded that sago wastewater effluents from this region are whitish and greyish brown (pH 4.20) in color with majority supra-colloidal or settable suspended solids of particle size ranged from 4.477 µm to 1.18 mm (of 95% volume). The starch content of this wastewater effluents are less than 7% whilst the pollutant parameters (TSS, BOD and COD) measured 10,900 mg/L, 5,820 mg/L and 10,220 mg/L, respectively. Pre-filtration of the wastewater effluents has resulted reduction of the pollutants content as high as 66% of TSS, 20% of BOD and 22% of COD while improved pH in a range of 0.05-0.45%.

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