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Cleaning wastewater of wet scrubber in secondary lead smelters using cationic polyacrylamide

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This study shows the benefits of using high molecular weight cationic polyacrylamide (PAM) in the purification of wastewater discharged from a wet scrubber in secondary lead smelter for reuse. The effect of temperature, pH, filtration pressure, polymer dose and different types of filtration fabrics on filtration rate (f_x), efficiency (f_ε) and quality of the produced water for recycling have been investigated. Results revealed that the wastewater is a hot water suspension containing 420 g/m^3 water of solid lanarkite particles ($PbSO_4.PbO$) submicron in diameter. Successful rapid separation of the suspended solids takes place with the use of 5 g PAM /m^3 wastewater. Separation process involves shift of the zeta potential of the solid particles to a more negative value as a precondition for adequate flocculation. Hot conditions of wastewater improves filtration rate. Although filtration pressure increases filtration rate, extra pressure may deform floc structure causing low filtration efficiency. Increasing the pH value from its original value (4.8) to 7-8 benefits the purity of the filtered water. Filtration efficiency decreases in the order: cotton, silk screen and nylon. Impregnation of the cotton fabric with polystyrene has proven to show high filtration quality, chemical and mechanical stability and long service time compared to the non-impregnated fabric. The quality of the treated water is acceptable for recycling.

Key words: wastewater cleaning, purification, filtration, separation.

INTRODUCTION

Purification of wastewater has drawn increasing research awareness applying different treatment techniques such as physical, chemical, drum and disc filtration, membrane filtration, advanced and oxidation systems. Several laboratory tests and procedures has so far been developed such as vacuum filtration, pressure filtration (Bosley, 1977), permeation on preformed filter cakes (Iritani et al., 2005; 2007), sedimentation (Shirato et al., 1983), and coagulation/ flocculation process and sludge conditioning (Amuda, 2007). Other published methods include froth flotation (Rose et al., 1996) and flocculation sedimentation (IUPAC 1972,1990).

Concha and Christiansen (1986) showed that sedimentation is a primary stage in modern wastewater treatment plants. It reduces the content of suspended solids as well as the concentration of pollutant embedded in it. Addition of polymer has its aim to bring about flocculation of the suspended solids. Besra et al. (2004) observed that the conformation of the adsorbed polymer had a marked influence on the flocculation and hence on the separation properties of kaolin suspensions. The polymer configuration would be modified through pH adjustment as well as through the presence of surfactants. The expanded segments of the polymer chain had more probability of attaching simultaneously with more particles thereby facilitating flocculation by bridging. Hirosue et al. (1988) found that coagulating of red mud maintains the pH of solutions in suspensions within the range of 7 to 8 because the zeta potential of red mud in this pH range was less than approximately

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-13 mV. In general, this low potential value was necessary to coagulate fine particles.

Nasser et al. (2006) showed that cationic polymer chains adsorbs via hydrogen bonding interactions between the OH groups at the solid particles surface and the polymer's primary, amide functional groups. Sansalone et al. (2008) reported that significant decrease of turbidity, volume concentration and total suspended solids (TSS) generated by alum and ferric chloride consistently occurred at a ξ potential in the range of −15 to about −10 mV. Alum addition produced a charge reversal at dosing above 60 mg/L (18×10^{-5} M) while ferric chloride did not reverse charge. Sakohara and Nishikawa (2004) and Sakohara et al. (2008) also reported that it was necessary to cover the surface of the solid TiO_2 particles sufficiently by cationic thermo-sensitive polymer molecules to initiate floc compaction. The transition temperature of the polymer complex adsorbed on the TiO_2 particles was dependent on the ratio of the dosages of the cationic and anionic thermo-sensitive polymers.

Ebling et al. (2003) reported that chemical coagulation-flocculation aided the removal of suspended solids and phosphorus from intensive recirculation aquaculture effluent discharge. Two years later, Ebeling et al. (2005) evaluated six polymers to estimate the optimum polymer dosage for flocculation of aquaculture micro-screen effluent and to determine the overall solids removal efficiency. Results showed total solids removal was close to 99% via settling, with final TSS values ranging from as low as 10-17 mg/L. Dosage requirements were uniform, requiring between 15 and 20 mg/L of polymer. It had been shown that tertiary treatment of municipal wastewater by flocculation, adsorption and ultra-filtration was necessary but it was cost-effective (Goren et al., 2007).

Cheng et al. (2004) reported that novel amphiphilic copolymer with pendant tris(trimethylsiloxy) silyl group: synthesis, helped characterization and employment in DNA separation. Xiaomin, et al. (1995) described the development of polypropylene fiber needle-felt, for the filtration of mineral processing products. They showed that polypropylene fiber needle-felt proved to have longer service life, higher filtration efficiency, greater cake yield, lower cake moisture content and less metal loss when compared with the conventional woven filter cloth often used in mineral processing industry.

The zeta potential of a system is a measure of charge stability and control of all particle-particle interactions within a suspension. Understanding zeta potential is of critical importance in controlling dispersion and determining the stability of a nanoparticle suspension, that is, to what degree aggregation will occur over time. The zeta potential is the measure of the electric potential at the slip plane between the bound layer of diluents molecules surrounding the particle, and the bulk solution. This can be closely linked to the particle's surface charge in simple systems but is also heavily dependent on the properties of the diluents solution. A higher level of zeta potential results in greater electro-static repulsion between the particles, minimizing aggregation/flocculation. Samples with zeta potentials of between -30mV and +30mV typically tend to aggregate, although the precise stability threshold will vary according to particle type. Determining the stability of a sample, either to minimize aggregation for drug delivery and pharmaceutical applications (high zeta potential), or to facilitate the removal of particles too small to filter out for water treatment applications (low zeta potential) is of great importance in nanoparticle research.

The experimental regime of this work would provide technological knowledge to clean wastewater of wet scrubber in secondary lead smelters using cationic polyacrylamide to help rapid and stable flocs-formation easy for filtration**.** Successful rapid separation of the suspended solids takes place with the use of 5 g PAM /m^3 wastewater. Separation process involves shift of the zeta potential of the solid particles to a more negative value as a precondition for adequate flocculation. Hot conditions of wastewater improves filtration rate. Although filtration pressure increases filtration rate, extra pressure may deform floc structure causing low filtration efficiency. Increasing the pH value from its original value (4.8) to 7-8, benefits the purity of the filtered water. Filtration efficiency decreases in the order: cotton, silk screen and nylon. Impregnation of the cotton fabric with polystyrene has proven to show high filtration quality, chemical and mechanical stability and long service time compared to the non-impregnated fabric**.**

The objectives of this paper were:

(a) To determine the proper dosage of high molecular weight cationic polyacrylamide to achieve good flocculation using different filtration fabrics.

(b)To determine the effect of temperature, filtration pressure and pH of the wastewater upon filtration rate (f_x), efficiency (f_ε) and quality of the produced water for recycling.

(c)To determine the effect of impregnating cotton fabric with polystyrene on the filtration efficiency and service life of the filter pad and the use of different fabrics (cotton, nylon, silk screen).

MATERIALS AND METHODS

Wastewater sample: Lead Smelter and Refining Company of Egypt (10000 t lead/y) provided the wastewater sample from a wet scrubber furnished at the plant. Properties of the wastewater samples are given in Table 1. Polyester nylon and silkscreen Nr. 100 and 120 (ANYIDA brand, 165-30PW(s), Switzerland) and heavy cotton (1240 g/m^2, MISR ELBEIDA Dyers, Egypt) cloth samples were tested as filtration media using a laboratory filter press (0.04 m^2 area). Chemicals used for flocculation and chemical analysis were pure grade. Polyacrylamide cationic flocculent C446 of Cytec industries Inc., Bradford, UK is used for flocculation. Previous workers (Wang et al. 2009 and Li et al. 2004) as well as brands recommended successful use of the polymer for flocculation. Aqueous polymer solutions of 50 to 250 mg/L were used. Drops of chloroform were added to the polymer solution and

Table 1. The composition of the loaded wastewater coming out from the wet scrubber.

Sample	T°C	TS, ppm	Insol.solids (mg/L)	pH value	Particle size distribution (wt %)		
					<1 µ	<0.1 µ	<0.05 µ
1	45	420.5	420.2	4.2	100	40	25
2	42	424.8	418	4.8	100	30	40
mean	43	422.6	420	4.5	100	35	32.5

stored in a refrigerator for a maximum of 3 days.Polystyrene solution in acetone (1-2% by weight) was used for impregnating cotton cloth. Doubly distilled water was used for chemical analysis, whereas tap water was used for other purposes.

Description of the testing facility

Figure 1 shows a schematic diagram of the testing facility. The pH of the wastewater is carried out by running over lime. The flow process is as follows: Wastewater flows into a storage tank (to control the pressure head of water), and then passes through a suitable pipe whereby a polymer solution injected. The water-polymer mix is stirred in a tank fitted with a mechanical stirrer whereby flocculation sets in. Settling of the flocs takes place in a settling tank after which it was pumped to the filter press. Filtered water passes through a heat exchanger for cooling. Part of the cooled water passes to a pH-adjusting tank containing lime. The exit water passes through a valve (to control the volume flow rate) to be mixed with the other part of cold water in a rotating homogenizer. The output mixed cold water is recycled in the scrubber. Filter cake is dumped from the press, dried, mixed with potash and carbon fines for metal lead recovery in a rotary furnace at 1100°C for 30 m. The pH value of the treated water was equalized to a neutral in tank (7) using lime. The temperature of the treated water was cooled down to ≈ 30°C with the help of a heat exchanger before recycling. Sample of water in different sites of the treatment system was analyzed to determine the total suspended solids, TSS, organic matter, the filtration rate and filtration efficiency.

Impregnation of cotton with polystyrene

Impregnation was carried out using impregnating machine type Erhardt M74 Germany. The cotton fabric was first evacuated at 8 mm mercury before soaking in the polystyrene solution (1 to 2% by weight dissolved in acetone) for 10 m. After impregnation, polymer solution in excess was drained off the machine and the cotton fabric was centrifuged while wet at 3000 rpm using industrial centrifugation machine type Erhardt M63 (Germany) for 5 m. The process was repeated to attain different polystyrene uptake. The surface morphology of cotton fabrics taken from treated and untreated cotton fabrics were carried out using a JEOL "JSM Model 840 type" scanning electron microscope, Japan.

Method of measurements

A flow meter type GF -9460 of Gilmont, USA, managed the volume flow rate of the wastewater stream with the help of Pore size determined using a mercury porosimeter fitted with a Micromeritics pore sized type 9310, U.S. Pore size classification recommended by the Calvert (1990) and Sing et al. (1985) was adopted. Average particle size measurement was carried out with the help of XRF analyzer type NITON XL3p, USA. Lead in solid lanarkite particles and in water was determined gravimetrically as lead chromate by Fuman (1975). X-ray diffraction analysis was also carried out using a computerized Phillips X-ray diffractometer (XRD) model PW 1730, copper anticathode and nickel filter was used for the identification of the compositions of the solid particles. Ni-filter, Cu radiation (λ= 1.542Å) at 40kV, 30 mA and scanning speed 0.02° /s using X-ray powder data file, published by the American Society for Testing and Material (ASTM) was used. Extent of purity of filtrate was determined in terms of total solids content (TSS). TSS of the raw wastewater = 100 (blank) and of distilled water = 0. Extent of purity percentage for the purified water = (100 – measured TSS) x 100. Determination of filtration rate (f_x) was conducted by measuring the volume of the filtrate in L/min. Determination of purification efficiency (f_ε) was measured by determining the TSS in 1L water gravimetrically (by evaporation under vacuum). Particle size measurement was determined using a SediGraph-5100 particle analyzer, Micrometrics, USA. The zeta potential measurements of lanarkite suspended particles (average particle size: <0.1µm) prepared under various pH values were carried out in an electrophoretic mass transport analyzer EMTA 1202 of Micromeritics Instrument Corporation.

Service time of the filter fabric was determined as the time of filtration up to rupture or failure of the filtration process by visually tracing the turbidity of the filtrate. Scrubbing efficiency was determined by measuring the total solids content in 1L of the wastewater sample compared to the amount when no fumes comes out the stack of the scrubber by visual assessment. Determination of organic matter content was carried out gravimetrically after heating the solid residue at 650°C for 60 m.

RESULTS

Table 1 shows the properties of the wastewater coming out from the wet scrubber. It can be seen that it is acidic (pH = 4.3), hot (55°C in summer and 43°C in winter) and loaded with total suspended solids TSS of 420 mg/L made of ($PbSO_4$.PbO). The average particle diameter of these TSS amounts to 0.01 - 0.1 microns. Figure 2 shows the effect of addition of polymer solution (in mg/L) on the pH value and the Zeta potential (ζ) of the wastewater stream at 25°C. It is seen that the wastewater is slightly acidic (pH = 5) and gradually shifts to more alkaline with addition of the polymer (pH = 8 with 6 mg PAM). The zeta potential value, ζ, is 5 mV before polymer addition and acquires a negative value when pH = 4.5. The ζ shifts to more negative value of -17 mV with ≥ 4 mg polymer (pH amounts to >7 <10). An isoelectric point sets in with about 0.7mgl^{-1}PAM and a constant value of about -15 mV with 4 mgL^{-1}PAM.

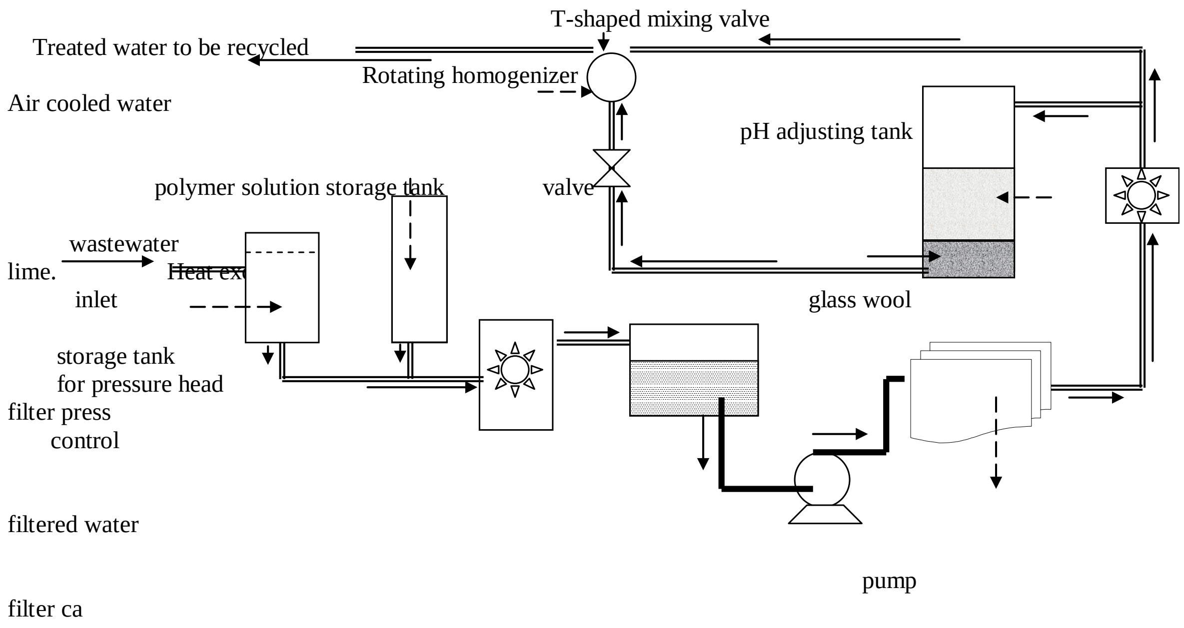


Figure 1. A schematic diagram of the experimental test rig. *The flow process: wastewater is fed into a storage tank (to control the pressure head of water). Wastewater then passes through a suitable pipe whereby a polymer solution is injected. The water –polymer mix is homogenized in a tank fitted with a mechanical stirrer whereby flocculation sets in. Settling of the flocs takes place in a settling tank after which it is pumped to the filter press. Filtered water passes through a heat exchanger for cooling. The cold water partially passes to a pH adjusting tank contains lime. The exit water passes through a valve (just to control the volume flow rate) to be mixed with the other part of cold water in a rotating homogenizer. The output mixed cold water is recycled in the scrubber. Filter cake is dumped is dried, mixed with potash and carbon fines for metal lead recovery in a rotary furnace at 1100°C for 30 min.

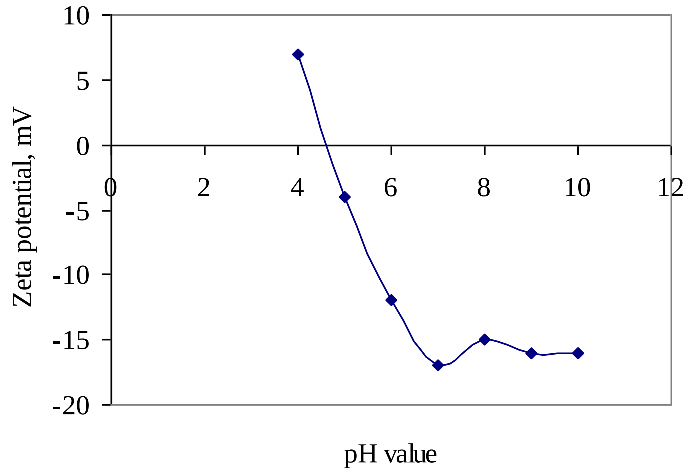


Figure 2a. Effect of pH value on the Zeta potential (ζ) of wastewater with no polymer at 25°C.

Figure 3 shows the effect of the polymer weight added to the wastewater on the time required to form flocs at different temperatures up to 60°C. It is seen that flocculation rate is directly proportional to the PAM dosage and temperature. Figure 4a illustrates the effect of filtration pressure on both the extent of filtration rate and purity of the filtered water using silkscreen Nr.100 fabric. It can be seen that filtration rate increases with the corresponding increase in pressure. However, filtration under relatively high pressure produces less pure water.

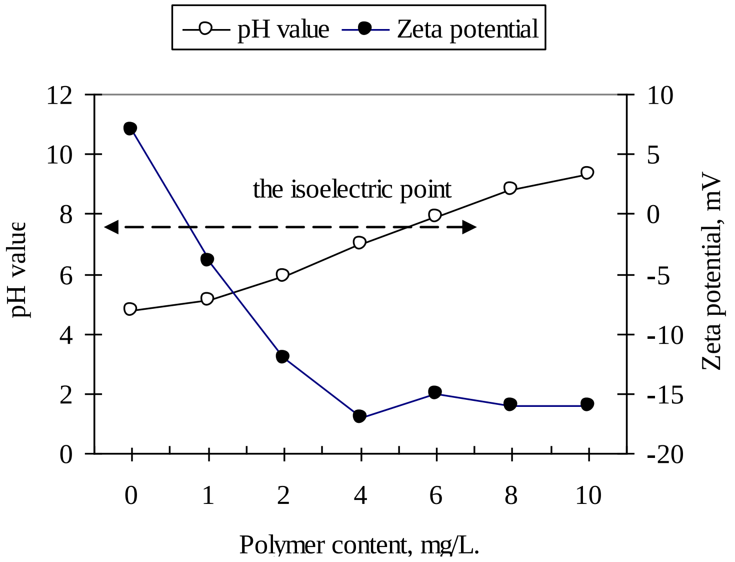


Figure 2b. The effect of polymer addition in mg/L on the Zeta potential (ζ) and pH value of the wastewater stream.

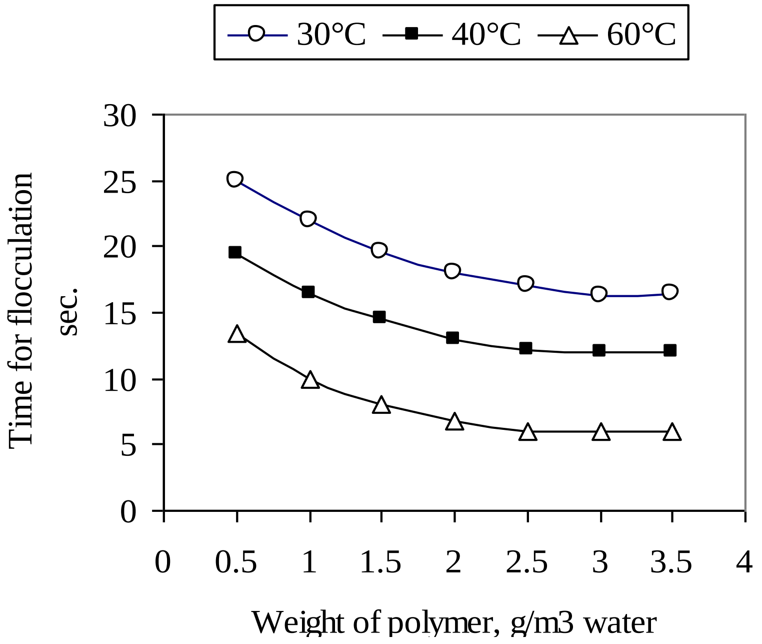


Figure 3. Effect of weight of polyacrylamide in wastewater on time (sec.) required for flocculation.

An industrial norm of filtration rate amounting to ≥45 L/min is achieved at 160 kPa. Figure 4b shows the results of a similar set of experiments using cotton fabric, silkscreen and Nylon cloths under the same filtration conditions. It is seen that filtration rate decreases in the order: cotton, nylon and silkscreen. With any cloth type, filtration rate increases with increasing the filtration pressure. Figure 5a shows the effect of temperature on the quality of the filtered water using cotton cloth (P= 140 kPa, 3g polyacrylamide/m^3, filtration rate = 40 L/min/m^2). It is seen that temperature improves the water purity up to 60°C (95% separation of solids). However, the water quality slightly decreases with further rise in temperature up to 90°C. Figure 5b shows Arrhenius plot of polyacry-

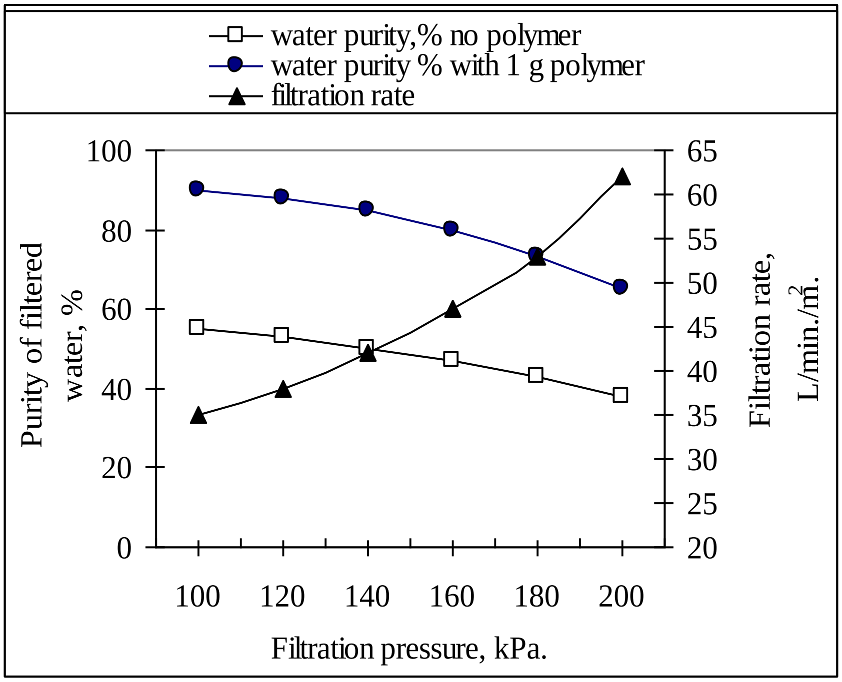


Figure 4a. Effect of pressure on the extent of filtration using silk screen 100.The industrial norms

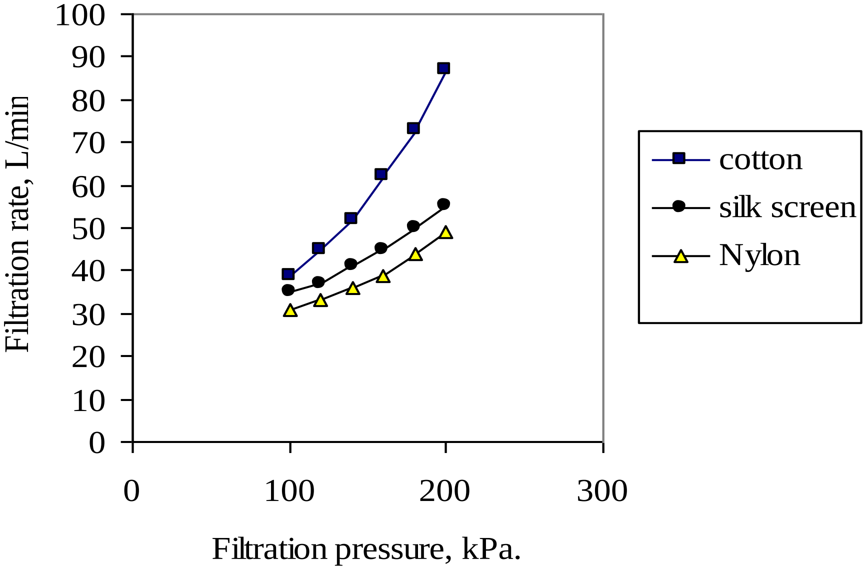


Figure 4ab. Effect of filtration pressure on the filtration rate using Cotton fabric, silkscreen and Nylon filters (T= 25°C).

lamide activity whereby an activation energy amounting to ΔE = 7786 kJ/mol (the value of ΔE in kcal/mol units is computed by determining the slop of the points in Figure 5b and then multiplying the product by 4.18 to obtain the value in kJ/mol).

Figure 6a shows the effect of flow velocity of wastewater on the mean diameter of the flocs. It is seen that at low velocity range 0.2-0.3 m.s^{-1}, a 20% decrease in floc diameter takes place. Increasing the flow velocity up to ≈ 0.4 m/s drastically decreases the floc size by

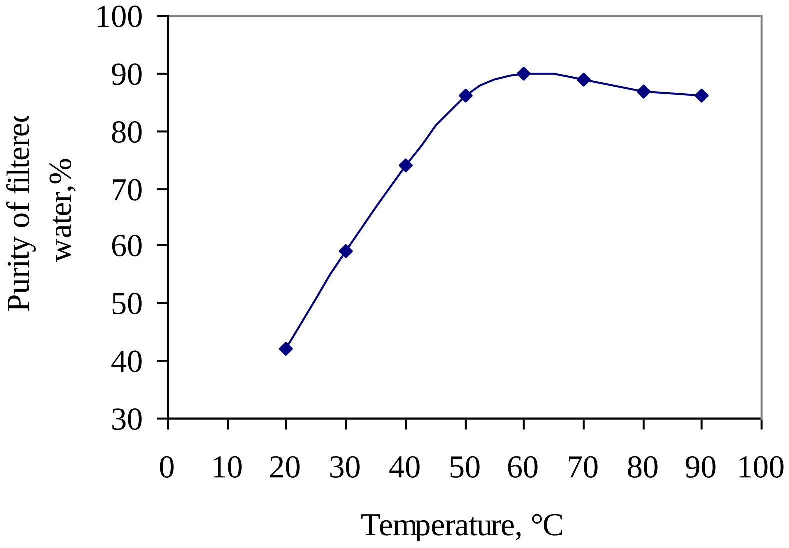


Figure 5a. Effect of temperature of wastewater on the purity extent of the filtered water using cotton fabric as a filtering medium (P= 140 kPa, 3g polyacrylamide/ m^3, filtration rate = 40 $L/min/m^2$).

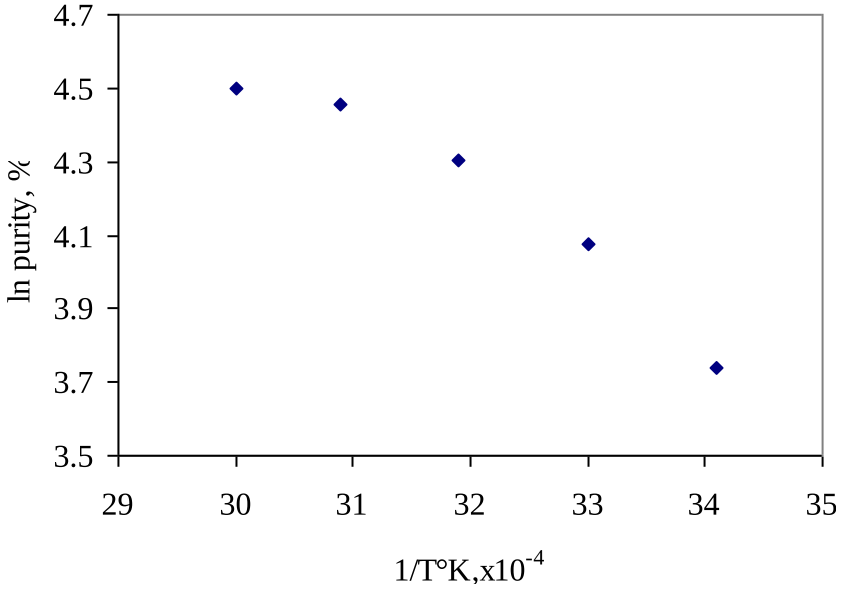


Figure 5b. The Arrhenius plot.

about 85%. Flocs are nearly destroyed at velocity > 0.3 m/s. In other words, fine particles of the solid lanarkite are again released. Figure 6b shows the effect of water velocity of flocculated wastewater on the filtration efficiency and the purity of the filtered water. It is seen that the two properties increase with increase in velocity passing through a maximum at 3 m/s. Filtration efficiency and purity of the filtered water drop off at lower or higher velocity values.

Figure 7a shows the effect of pH value of the flocculated wastewater on the extent of filtration efficiency using three filtering media (T= 35°C, p = 100 kPa). Results show that a significant filtration efficiency value is brought about at pH 8 whereby it decreases with more acidic or alkaline solutions. Figure 7b shows the effect of polyacrylamide addition to the scrubbing water on the filtration efficiency and temperature of the wastewater coming out from the scrubber. It is seen that the

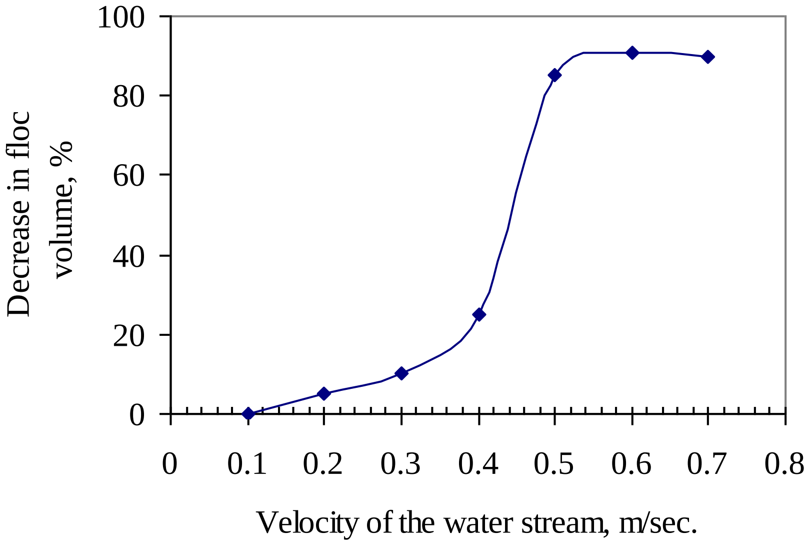


Figure 6a. Effect of velocity of the wastewater stream on the mean diameter of the formed floc.

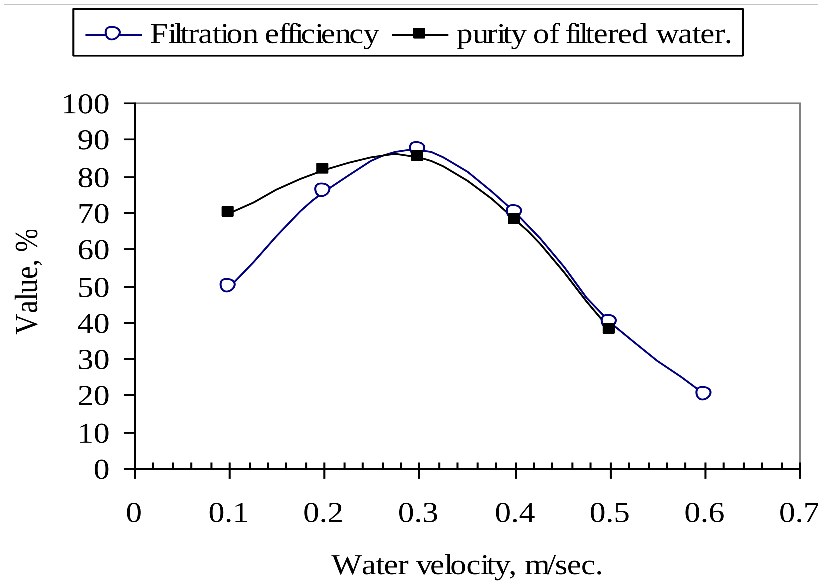


Figure 6b. Effect of water velocity on filtration efficiency and water purity. Un-impregnated cotton fabric, T=30°C and at 160 kPa ----Industrial norm.

temperature of the exit water increases from 43°C to 58°C with the addition of 6 g polyacrylamide/m^3 water. Scrubbing efficiency also displays a gradual increase with polyacrylamide addition.

Figure 8a shows the effect of number of impregnations with 1% (by weight) polystyrene (in acetone) on the pore size distribution of the cotton fabric. It is seen that voids of the woven fabric have >0.01 mm in diameter. Pores smaller than 50 Å, but larger than 10 Å in diameter (meso pore size) are blocked after the fourth impregnation. Figure 8b shows SEM images of the cotton fiber surface morphology before (a) and after impregnation (b) with the polystyrene solution. Figure 8c, depicts the presence of large and small pores in the treated cotton fabric, many small pores exist on the wall of a large pore after impregnation with polystyrene solution in acetone. Figure 9a illustrates the effect of polystyrene uptake of cotton fabric on both the filtration rate and purity of the filtered

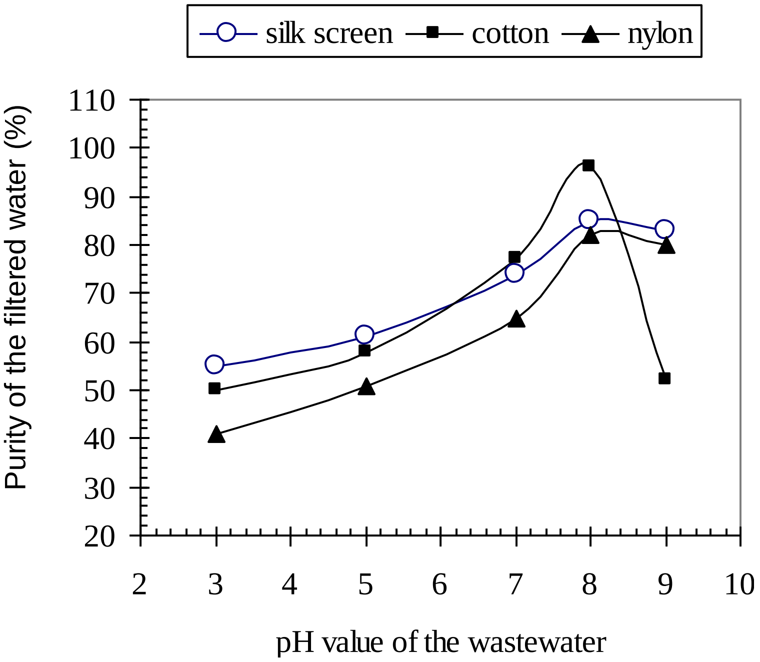


Figure 7a. Effect of pH value on the extent of purity of the filtered water(T= 35°C, fp = 100 kPa ---- industrial norm).

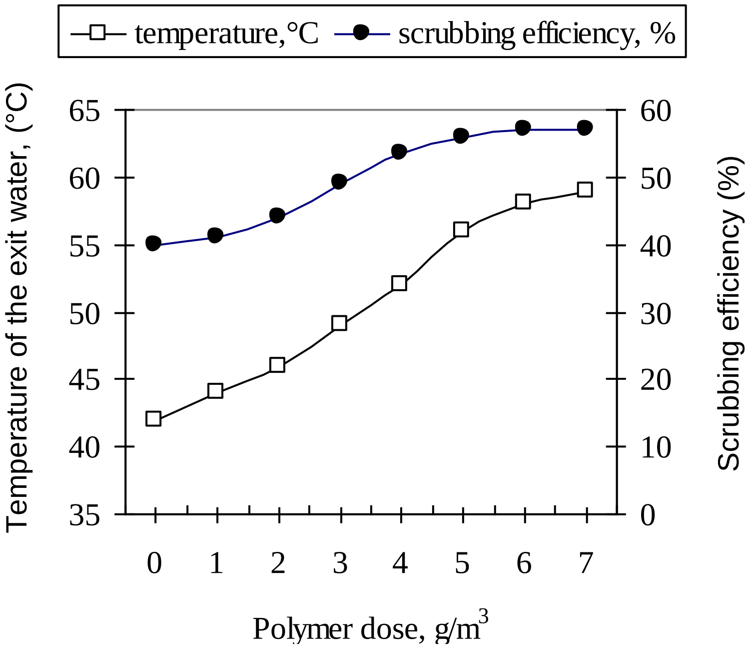


Figure 7b. Effect of polyacrylamide dose on the temperature of the scrubbing wastewater coming out from the scrubber.

water while Fig 9b shows the uptake effect on the service time of cotton fabric. It can be seen that filtration rate decreases gradually with the corresponding increase of polystyrene uptake. Polystyrene impregnation increases the water purity up to 95% and increased the service time of the fabric from 4 months to 12 months upon 8% polystyrene uptake. Figure 10 shows the XRD pattern of the solids separated from the wastewater purged from

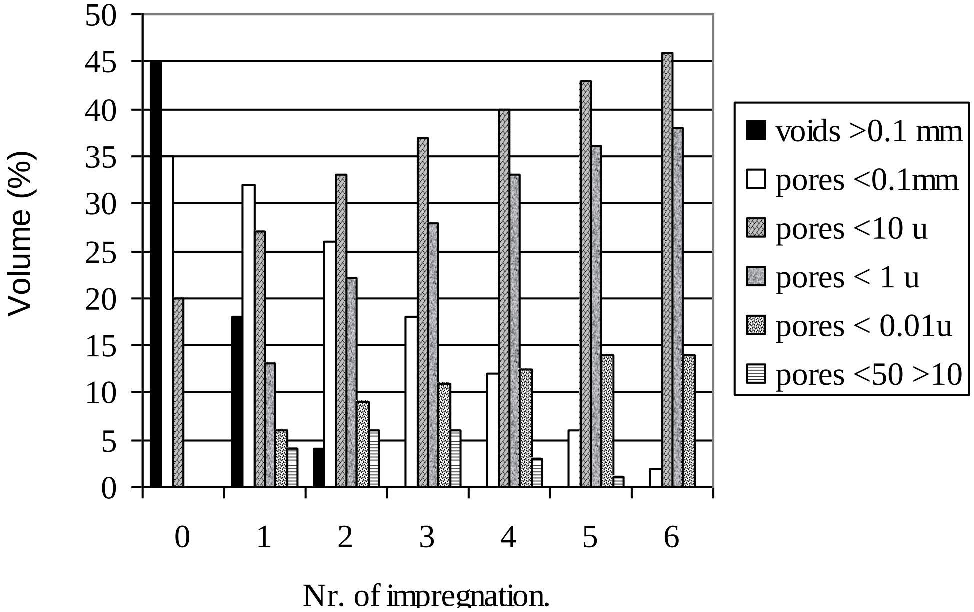


Figure 8a. Effect of number of impregnation with 1% polystyrene solution (in acetone) on the pore volume with different size of the cotton fabric.

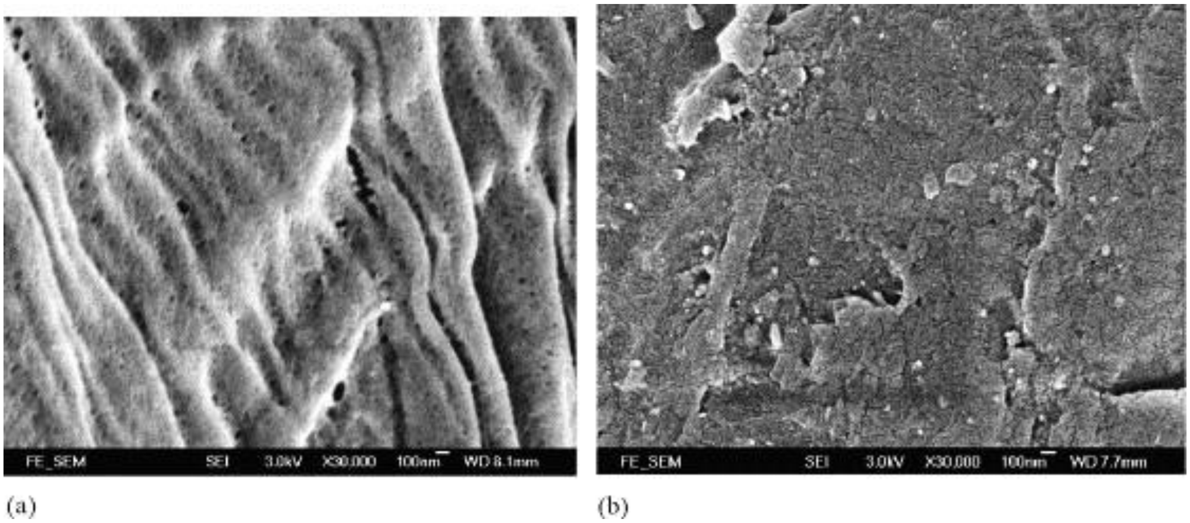


Figure 8b.. Cotton fiber surface morphology before and after impregnation with the polystyrene: (a) untreated cotton fiber surface and (b) treated cotton fiber surface.

the wet scrubber of secondary lead industry and after pH control. The compounds are determined from the ASTM cards. Lanarkite ($PbSO_4.PbO$) is the most detected. Other compounds of PbO, PbO_2, PbS and K_2SO_4 are also detected but with less extent.

From the experimental results it can be seen that hot water suspension containing 420 g /m^3 water of solid lanarkite particles ($PbSO_4.PbO$) submicron in diameter can be cleaned. Successful rapid separation of the suspended solids takes place with the use of 5 g PAM /m^3 wastewater. Separation process involves shift of the zeta potential of the solid particles to a more negative value as a precondition for adequate flocculation. Hot conditions of wastewater improves filtration rate. Extra pressure of filtration may deform floc structure causing low filtration efficiency. Increasing the pH value from its original value (4.8) to 7-8 benefits the purity of the filtered water. As with the filtration media, the filtration efficiency decreases in the order: cotton, silk screen and nylon. Impregnation of the cotton fabric with polystyrene

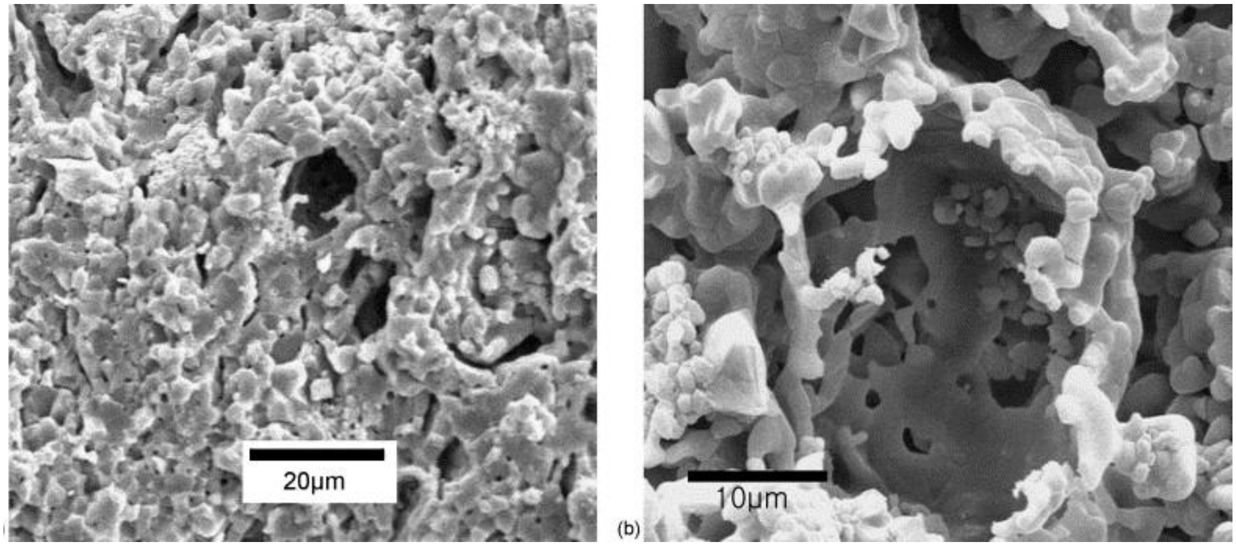


Figure 8c. SEM images showing (a) the presence of both large and small pores in the treated cotton fabric (b) details of a large pore, many small pores exist on the wall of a large pore after impregnation with polystyrene solution in acetone.

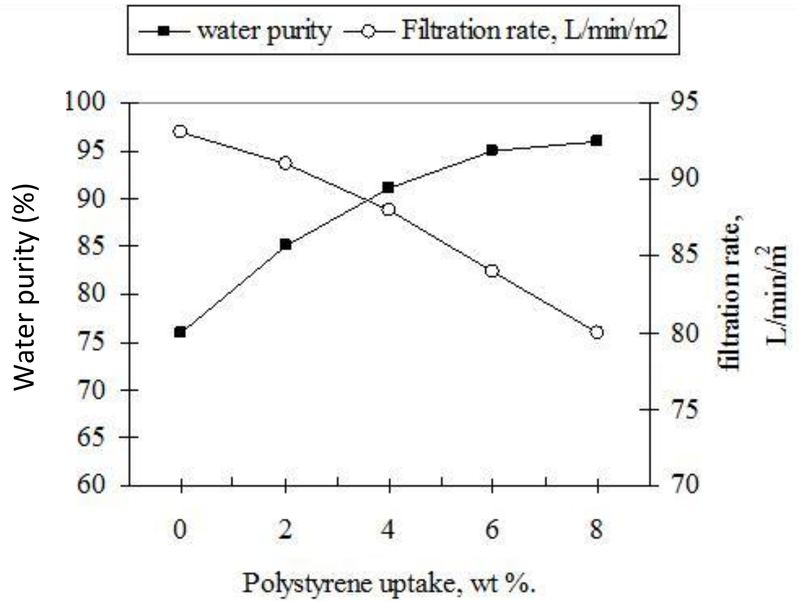


Figure 9a. Effect of polystyrene uptake of cotton fabric on flow rate and the extent of purity of water.

improved filtration quality, chemical and mechanical stability and long service time compared to the non-impregnated fabric. The quality of the treated water is acceptable for recycling.

DISCUSSION

Secondary lead is produced by smelting spent acid lead batteries in a short rotary furnace working at 1450°C. Fugitive emissions (fumes) of lanarkite ($PbO.PbSO_4$) are purged in flue gases during the recovery process (Rabah 1998). The temperature of the exit gases amounts to 750-850 °C, after which the gases are cooled down to ≈ 290 °C in summer and ≈ 220 °C in winter during pass in steel duct to the scrubber. Particle size analysis of the fugitive solid particles shows that all are < 0.01 µm. A wet scrubber fitted with water atomizers is installed to

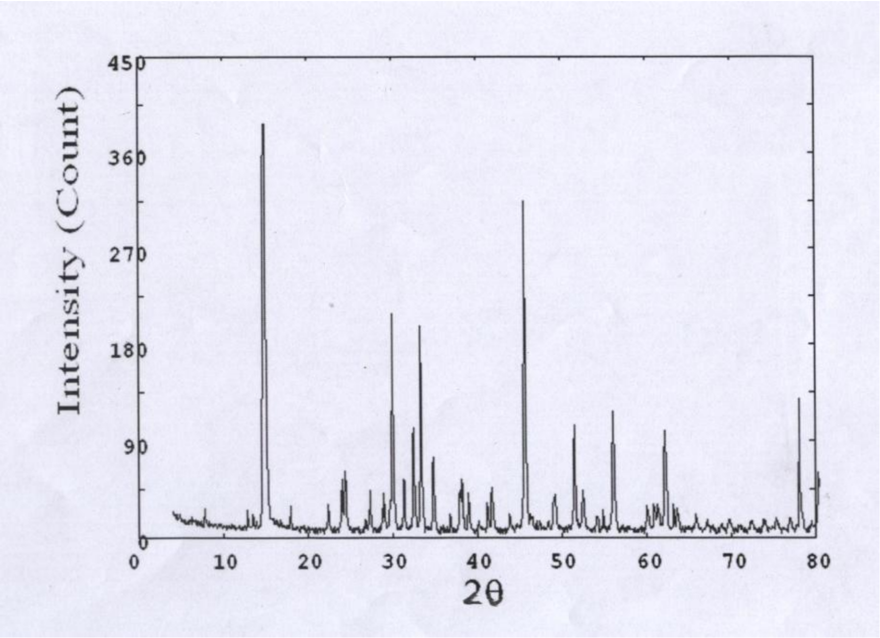
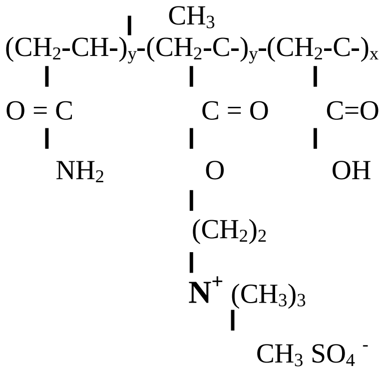


Figure 10. The XRD pattern of the solids separated from the wastewater purged from the wet scrubber of secondary lead industry.

confine these fugitive emissions. In the scrubber, lanarkite particles are scrubbed by impingement on water. Table 1 show that the exit wastewater is hot, acidic and loaded with 420 g TSS /m^3 water. Acidity results from sulfuric acid fumes that escaped during the smelting process. The pH is controlled to be slightly alkaline by running over potash solution. Table 3 shows the solids detected from the XRD examination. Different lead oxides reformed upon thermal reactions are liable to take place during the smelting process (1450°C). Potassium carbonate exudes from the pH control panel (Figure1).

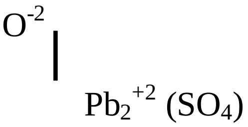
Feasibility of the polymer and the model of flocculation

The chemical structure of cationic PAM is as follows (Tekin et al., 2005):



$$\begin{array}{lll} & \mathrm{CH_3} & \\ (\mathrm{CH_2\text{-}CH\text{-}})_y\text{-} & (\mathrm{CH_2\text{-}C\text{-}})_y\text{-} & (\mathrm{CH_2\text{-}C\text{-}})_x \\ | & | & | \\ \mathrm{O=C} & \mathrm{C=O} & \mathrm{C=O} \\ | & | & | \\ \mathrm{NH_2} & \mathrm{O} & \mathrm{OH} \\ & | & \\ & \mathrm{(CH_2)_2} & \\ & | & \\ & \mathrm{N^+\,(CH_3)_3} & \\ & | & \\ & \mathrm{CH_3\,SO_4^-} & \end{array}$$

Floc formation takes place by coulombs' interaction between the positively charged nitrogen (of the amide group of the polymeric chains) and the negatively charged oxygen atom of the suspended lanarkite particles.



$$\begin{array}{l} \mathrm{O^{-2}} \\ \quad | \\ \qquad \mathrm{Pb_2^{+2}\,(SO_4)} \end{array}$$

According to Coulombs law, the force of flocculation is proportional to the product of the charge magnitude of the polymer chain and the solid particles and decreases with the distance between the two charges. In this respect, the used polymer has proven to be a lot more beneficial. It increases both the charge density (Anastassakis, 2005) and the contact angle at the solid/liquid interface leading to a decrease in the distance (IUPAC, 1990). The polymer has multi chains that confirm its efficacy on bridging solid particles to form compact flocs. Results are in agreement with Besra et al. (2004) and Yu (1996). However, the development of floc size with PAM dosage confirms that the coulomb interaction is also directly proportional to the number of the polymer chains and the negativity of its ζ value. It is worth noting that management of the pH value of the wastewater to faint alkaline by addition of potash solution favors flocculation as it helps to maintain the ζ of PAM at a highly negative value (-15 mV).

Effect of temperature

Water temperature coming in and out the scrubber is 43°C and 54°C respectively. The difference results from the quantity of heat that transfers from scrubbed hot lanarkite by impingement to water droplets. The quantity of heat can be calculated from:
(1) the mass and temperature of solid particles,
(2) the mass and temperature of the feed water and
(3) the change in enthalpy of air (3000 m3 /h).
Wet scrubbing involves three basic steps:
(i) Transport of the hot solid particles to the closest distance of approach of the sprayed water droplets leading to collision or impingement.
(ii) Wetting of hot solid particles with a water film.
(iii) Propagation of the water film with excess cold water to form hydrated particle. Under the thermal ingredient, heat transfers from the hot solid phase to water and a thermal equilibrium is approached.
(iv)The loaded water droplets collect to form a milky drain (wastewater). Presence of PAM in the water increases its viscosity and improves steps (ii) and (iii). Temperature of the outlet water (T_{ow}) can be calculated from the following equation:

$$T_{ow} = [m\bullet_{fg} (T_{ig} - T_{og}).Cp_g + m\bullet_s (T_{is} - T_{os}).Cp_s] - m\bullet_w. (T_{ow} - T_{iw}).Cp_w - k.f._r$$

Where: T= temperature (°K), m°, m• = mass flow rate (kg/h), *Cp*= specific heat, (kJ/kg.K), k = constant, f = fraction of energy transfer and r = radiation constant. The subscript f = for flow, i = for inlet, o = for outlet or exit, s = for solids, g = for gases and w = for water.

The calculated values for k, f, and r, amount to 0.15, 0.38 and 0.09 respectively. The T_{ow} value amounts to 54°C in summer and 48°C in winter. In the light of the above model, the exit temperature of wastewater favors flocculation and the filtration rate. Formation of flocs is an energy-driven process (ΔE value=7786 kJ.mol, Figure 5b). The ΔE value is low indicating that the force of flocculation is weak so it can be enhanced by temperature rise. In addition, temperature improves filtration rate due to decreasing the water viscosity from 0.8904 cps^{-1} at 25°C to 0.5468 $cp.s^{-1}$ at 50°C. Low viscous fluids pass more freely in the pore system. The water quality decreases with increasing temperature more than 60°C and up to 90°C. This is anticipated to the more decrease in water viscosity (0.3147 cps^{-1}) that helps water to draft solid particles during the filtration process which takes place more faster.

The filtration mechanism and effect of pressure

The filtration process denotes free pass of water molecules having lower diameter compared to the pore mean free path. Solid flocs with larger diameter would be retained on the filter medium. On the other hand, fouling phenomenon of the filter pad may take place when solid particles move slowly under the gravitational force and adhere to the surface of the pores followed by compaction. The pore mean free path then becomes narrower. Gradually, the accessible pore system would close whereby early fouling might be avoided by good flocculation and moderately increasing the filtration pressure. Results of Figure 4 indicate that pressure exerts extra mechanical force on water to pass through the porous system of the filter media. Reasonably, some solid fines may slip with the filtrate. The quality of the filtered water would thus decrease. The inferior separation of solid fines implies that high pressure may force such particles to move through the pore and hardly block the pore mean free path.

Effect of water velocity

Increasing the flocculent dosage brings about information of stable large-sized flocs. The mean diameter of flocs agglomerated with 3 g PAM/m^3 wastewater amounts to nearly 0.5 mm, which appears acceptable. However, aggressive movement of the flocculated water (FW) during transportation may decrease the floc size. Results demonstrate that increasing the velocity of the FW over the laminar flow conditions (≥ 0.3 m/s) destroys flocs and releases fine particles under the action of turbulence. Deformation takes place when the applied mechanical force outweighs the flocculation force. In other words, transportation of the FW under laminar flow conditions is highly recommended to ensure floc stability.

The effect of pH and the stability of the filter fabric

Adjusting the pH value of the loaded wastewater from its original value (4.8) to ≈ 8 benefits the quality of the filtered water. Although further increase of the pH value to 9 or more is in favor of adsorption of the polymer, a rapid and drastic degradation of the chemical stability of the filter media might take place. In addition, the extent of water quality decreases because of alkalinity. Three different fabrics were examined for filtration. However, the chemical stability is found in the order: cotton, silkscreen and nylon fabrics. Impregnation of the cotton fabric with polystyrene is rather of interest. Impregnation gradually fills in the voids of the cotton fabric so that only narrower pore system with sizes between 50Å and 0.01mm predominates. The fouling phenomenon decreases. Such pore morphology is more suitable for filtration provided that the cotton fabric becomes more resistant to chemical degradation and mechanical wear. Figure 8b shows the morphology of the cotton fabrics before and after impregnation. The quality of the filtered water has been examined. Table 2 shows the water

Table 2. The quality of the treated water compared to the standard.

Item	mg/L (max.)		
	Standard	Untreated wastewater	Treated
Temperature, °C	35	54	32
pH value	6.5-7.8	4.3	7.5
TDS	450	740	500
Ash of dissolved Solids	320	350	330
Turbidity	NTU 50	300	42
Suspended solids	60	420	55
Organic matters	12	36	10
Sulfate	50	280	35
Cyanide	0.1	-	-
Silicate	24	40	22
Nitrate	5	3	2
Chloride	40	95	45
Phenol.	1	3	-
Hg	0.05	0.1	0.1
Pb	0.5	280	0.5
Pesticides	0.2	-	-
Fecal Coli form count (No. in 100 ml)	5000	-	-

Table 3. The XRD data.

ds	Intensity %	Compound	ASTM card No.
6.90	100	$PbSO_4$	22-667
5.73	4	$PbSO_4$	1-390
4.25	11	$PbSO_4$	1-390
3.45	46	$PbSO_4$	5-577
3.12	34	PbO	11-543
2.99	11	$PbSO_4$	26-1156
2.74	55	K_2CO_3	11-0287
2.68	40	K_2CO_3	11-549
6.91	100	K_2CO_3	11-549
2.81	35	PbO_2	5.561
2.67	20	K_2CO_3	14-803
2.15	50	PbS	75-0743
2.06	100	PbO_2	26-1156
1.90	23	PbS	27-1202
1.73	20	PbS_2O_7	26-1156

quality is nearly free of organic matter as PAM-loaded solids are filtered to form cake. The treated water quality is acceptable for reuse in the wet scrubber. The calculated efficiency of purification amounts to 90.5%.

Recovery of metal lead from the filter cake

The filter cake was dumped from the filter press after passing compressed air for 10 m in the filter press for easy dumping. The detached charge was left for natural dryness. It was then mixed with soda ash-carbon mix, pelletized to 6-8 mm pellets with 1% PVA (for adhesion) and finally smelted in the rotary furnace at 1100 °C for 30 m. Slag so formed is recycled with a new coming cake charge.

PRELIMINARY PROCESS ECONOMICS

A preliminary process economics of the items of concern shows that the annual running cost amounts to nearly USD 22400 and the price of the products (recyclable water and filter cake) amounts to USD 25000. The net gain amounts to 11.4%.

Conclusion

The conclusion of this study, is that wastewater of lead smelter contains 420 g lanarkite/m^3 and is a hazardous polluting resource when drained in the Town network. Cleaning this wastewater can be successfully managed by using high molecular weight polyacrylamide for flocculation and filtration. Parameters favoring the efficiency of the method are:

(1) Using a polymer solution of 3 g/m^3 wastewater to flocculate the solid suspensions.

(2) Conveying the flocculated wastewater at laminar flow conditions for filtration.

(3) Filtering the slurry under a moderate pressure of 160 kPa maximum.

(4) Cotton fabric impregnated with polystyrene is most suitable for filtration as it improves the chemical and mechanical stability of the fabric particularly in alkaline medium.

(5) Adjust the pH value of the treated water at slightly alkaline using lime and

(6) Cooling the treated water to < 40°C.

The output of the study is as follows:

(1) Successful separation of the solid lanarkite particles in a filter cake.

(2) Conserved water resources by cleaning the wastewater for recycling.

(3) Abatement of pollution hazards of lead dissemination in the environment.

(4) Development of a simple method and the working facility is rather available.

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