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Treatment of highly concentrated dye solution by coagulation/flocculation–sand filtration and nanofiltration

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ABSTRACT

Treatment of highly concentrated C.I. Acid Black 210 dye solution using direct coagulation/flocculation–sand filtration (without sedimentation) and nanofiltration has been investigated in this paper. It was found that none of the treatments were able to fully decolourise the dye solution, but nanofiltration permeate quality was better, based on colour, residual dye, pH, and total organic carbon. The red colour for the sand filtration filtrate might be due to the formation of stable aluminium–sulphonic acid complexes. The sand filtration breakthrough after coagulation/flocculation is estimated at around 45 min. For nanofiltration of highly concentrated dye (> 1000 mg/l), the separation factor analysis had confirmed that the mechanism of dye molecules attached to the membrane surface is irreversible adsorption.

1. Introduction

Colour that appears in industrial wastewater could be due to dye(s) application [55], plant component i.e. lignin, tannin as well as its biodegradation product e.g. melanoidin [5]. The presence of colourant in surface water is aesthetically undesirable and causes disturbance of the aquatic biosphere due to reduction of sunlight penetration and depletion of dissolved oxygen. Some colourants are toxic

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and mutagenic and have the potential to release the carcinogenic amines. Due to their recalcitrant properties, colourants can also contribute to the failure of biological processes in wastewater treatment plants [55]. In some applications, coloured treated water is also not suitable for water reuse.

As the legislation related to environment is becoming tougher in many countries due to an increase of public awareness, decolourisation of industrial wastewater requires much effort from scientists and engineers to sustain the related industries. Generally, there are two decolourisation methods: by destruction of colourant molecules (e.g. chemical oxidation and bio-oxidation) and the other is by separation of colourants from water (e.g. coagulation/flocculation, sand filtration and membrane separation). As they are likely to be effective methods for decolourisation [56] and the concentrated colourant could be turned into a useful product (e.g. compost [38] and brick [6]), two separations processes i.e. direct coagulation/flocculation–sand filtration (CF–SF) and nanofiltration (NF) have been used in this study.

Slow sand filtration is known as a simple option for water treatment and has a filtration rate of about 0.1–0.5 m^3/m^2 h [46]. Due to dyes' high solubility, flocs that are generated from the coagulation/flocculation of soluble colourants are difficult to settle [29]. After coagulation/flocculation, sand filtration could remove colourant flocs by attaching them to the sand grain or to previously retained flocs (ripening).

Performance of slow sand filtration depends on the chemicals used for pre-treatment. Addition of a metal coagulant has been reported to improve the removal of colour (measured as absorbance at 254 nm), turbidity and phosphorus [19]. Aluminium sulphate is reported to have minimal head lost compared to $AlCl_3$ and $FeCl_3$ during direct coagulation-sand filtration of effluent from extended aeration treatment [19]. However, the application of aluminium based coagulant alone is not sufficient during long term experiments. Polymer (e.g. low cationic polyacrylamide) was reported to enhance direct sand filtration performance by minimising the decline of turbidity removal before sand filter became clogged [17]. It has also been reported that alum+cationic polymer increases the filter run time and increases the flow-rate [46].

In order to reduce the cost, direct coagulation-sand filtration is preferable to coagulation-sedimentation-sand filtration. It has been reported that coagulation-sedimentation-sand filtration has double capital cost than direct coagulation-sand filtration [2]. Several studies on colourants removal via coagulation-sedimentation-sand filtration have been reported [41,10,56] but published studies on direct coagulation/filtration-sand filtration for coloured wastewater is lacking. Furthermore, greater water recovery is possible by removing the sedimentation step.

Nanofiltration (NF) has been recognised as a key tool for wastewater recycle/reuse. Its application for treatment of coloured wastewater have been reported by several investigators [15,45,11,7,26,57]. Nanofiltration (NF) is positioned between reverse osmosis (RO) and ultrafiltration (UF) and its permeability is around 1.5–30 l/m^2 h bar. Nanofiltration membranes carry quite distinctive properties such as pore size (1–5 nm) and surface charge density which influences the separation of various solutes. However, some studies have reported that nanofiltration was unable to produce colourless permeate [55].

The objective of this study is to investigate the performance of CF–SF and NF processes towards decolourisation of C.I. Acid Black 210 dye solution. Due to its extensive application in industry, the treatment of C.I. Acid Black 210 dye was subjected to few studies e.g. chemical oxidation [18], biological treatment [37,32], coagulation/flocculation [54], coagulation-sedimentation-sand filtration [56] and direct nanofiltration [57].

2. Methodology

2.1. C.I. Acid Black 210 dye

The Durapel Black NT (DBNT) dye (contain $>30\%$ C.I. Acid Black 210 dye) was purchased from Town End (Leeds) plc, (United Kingdom) and used without further purification. Sodium sulphate generally used as diluents (personal communication with Dr Adrian Hayes, Technical Director, Town End (Leeds) plc,). A dye mass of 20 g in powder form was dissolved in Milli-Q Plus, 18.2 MΩ cm (Millipore) water to make 5 l solution at a concentration of 4000 mg/l [25,54,56]. The colour of dye solution is visible at minimum concentration of 10 mg/l.