

Fig. 2. Residual turbidity in relation to the coagulant concentration for the different experiments: a) preliminary series, b) series 1, c) series 2, d) series 3

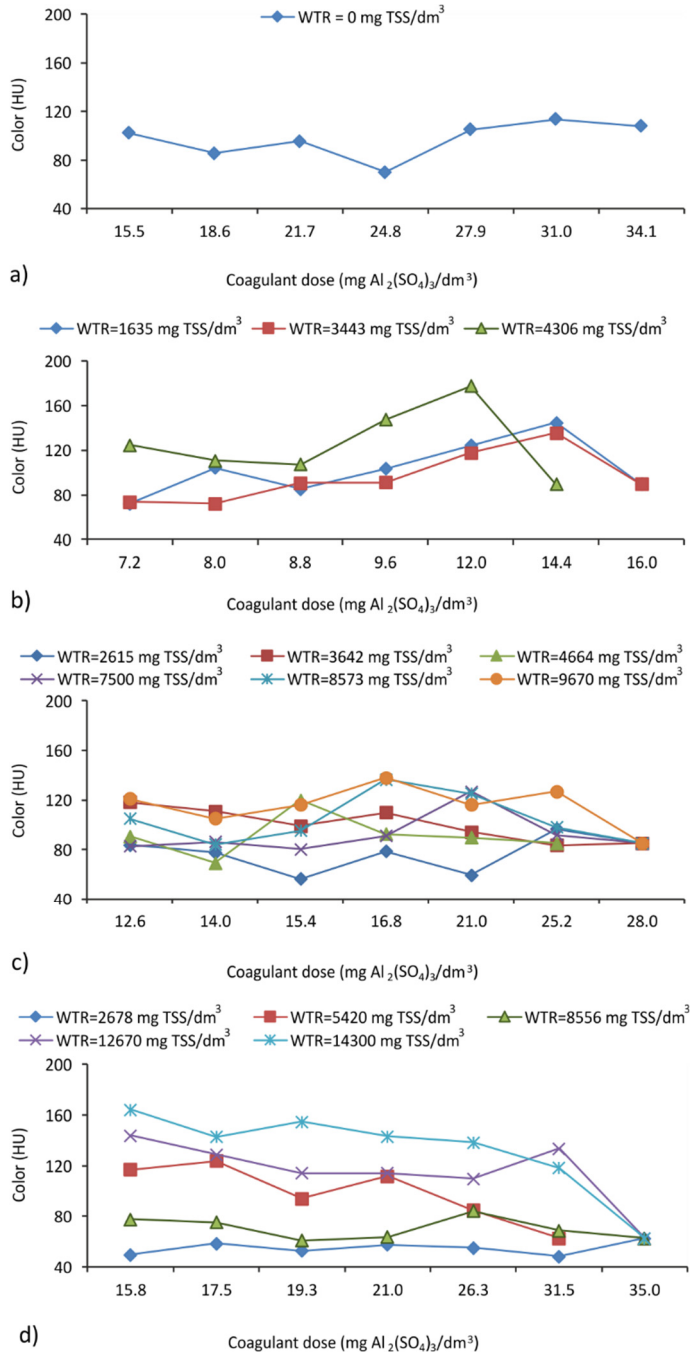


Fig. 3. Residual colour in relation to the coagulant concentration for the different experiments: a) preliminary series, b) series 1, c) series 2, d) series 3

For the low initial turbidity value (Series 1, 21 NTU) the best turbidity RE (78.9%) was observed for the WTR with low TSS concentration (1635 mg/dm^3) and 7.2 mg/dm^3 of $\text{Al}_2(\text{SO}_4)_3$ (i.e., for a coagulant reduction of 45%). The colour RE is also high for these conditions reaching 67.1%. The values at the final effluent were 72.3 HU and 5 NTU. The turbidity results are lower than the maximum desirable limit for achieving good filtration (10 NTU according to USEPA [2]).

The turbidity removal and colour removal did not improve for either high WTR doses or higher coagulant doses. For the WTR with the increased TSS concentration of 4306 mg/dm^3 (i.e., 2.6 times higher than the low tested TSS concentration) of WTR the RE of both parameters did not show any improvement (up to 27.9% for colour and up to 37.1% for turbidity) than the RE obtained with the control experiment (with no WTR and 100% of the initial coagulant dosage). The effluent values of colour and turbidity were between 107.1 HU and 177.5 HU and between 11.4 NTU and 20.4 NTU.

Zhou et al. [7] investigated the reuse of polyaluminium chloride mixed sludge on the turbidity removal in the coagulation-flocculation processes and have defined an appropriate dosage of $60 \text{ cm}^3/\text{dm}^3$ (i.e., a recycling ratio of 12%) as effective for the removal of approximately 89% of initial turbidity for initial values below 45 NTU.

For the raw water turbidity of 95 NTU (Series 2, Fig. 2b), the best results were achieved when residue of the low concentration of TSS (2615 mg/dm^3) was added and for an initial coagulant dose of 12.6 mg/dm^3 (i.e., with 55% of reduction in the coagulant dose). For these conditions, the RE was 94.6% for colour and 92.9% for turbidity. The values of the final effluent were 56.2 HU and 6.9 NTU, which are according to the maximum desirable limit for achieving good filtration defined by [2].

For WTR with increased TSS concentrations (between 1.4 and 3.7 times the tested TSS concentration), the RE did not increase, independently of the initial coagulant concentration. For WTR with concentrations higher than 7500 mg TSS/dm^3 (i.e., more than 3 times higher the tested TSS concentration), the RE for both parameters was even worse than the values obtained for the control experiment (with no WTR and 100% of the initial coagulant dosage). In this case, the effluent values of colour and turbidity were between 80 HU and 138 HU and between 11 NTU and 19.4 NTU, respectively.

Similar results were observed for series 3 (218 NTU). The best RE for both parameters (96.9% for colour, and 96.7% for turbidity) was obtained for the WTR with low TSS concentration (2678 mg/dm^3) and coagulant dose of 19.3 mg/dm^3 (i.e., with 45% of reduction in the coagulant dose). The values at the final effluent were 49.8 HU and 7.4 NTU, which are good values for achieving afterwards filtration. For either WTR with high TSS concentrations or coagulant doses, the RE was not improved and for TSS concentrations higher than 8556 mg/dm^3 (i.e., more than 3 times higher the tested TSS concentration) the RE were even better for the experiments with no addition of residue.

This trend in worsening the RE of both parameters as the dose of WTR increases might be related to the increase of organic matter released from the alum-sludge as its dose increases. The trapped organics in the residues are released at high WTR doses

leading to removal efficiency decline. Some studies have noted the increasing in solid levels after recycling WTR, which have led to the increase in influent turbidity [25]. This might mean that, for certain doses of residue, the quantity of organics released into the water was not efficiently removed because the aluminium sulfate concentration was not sufficient to destabilize the surface of colloids. Therefore, for these doses of WTR, it would have been necessary adding more coagulant.

pH of the water samples after jar test experiments slightly decreased ranging between 7.2 and 7.6 in the three series, which means this parameter did not change too much when WTR were added. The hydrolysates distribution of aluminium hydroxide in the WTR can be influenced by low pH values (<6), as observed by Zhou et al. [7], resulting in low RE of organics and turbidity. The pH interferes with the balance between the reactions of organic functional groups with hydrogen ions and Al hydrolysis products. At low pH, hydrogen ions out-competed with metal hydrolysis products for organic ligands and the RE of organics and turbidity can decrease [26].

As referred by Suman et al. [27], when destabilized particles of WTR are mixed with raw water, it increases the number of both collision sites and charge neutralization sites, resulting in the increasing of floc aggregation in the flocculation process, and decreasing of settling rate. The increasing in turbidity removal has occurred for recycling rates of WTR up to 10% and for raw water turbidity between 25 NTU and 200 NTU. Therefore, the addition of WTR can result in increasing of turbidity and colour removal, because the residual aluminium sulfate in the residue can be used for organics precipitation. For the increased doses of residue, the organics concentration increases and may be necessary adding more coagulant.

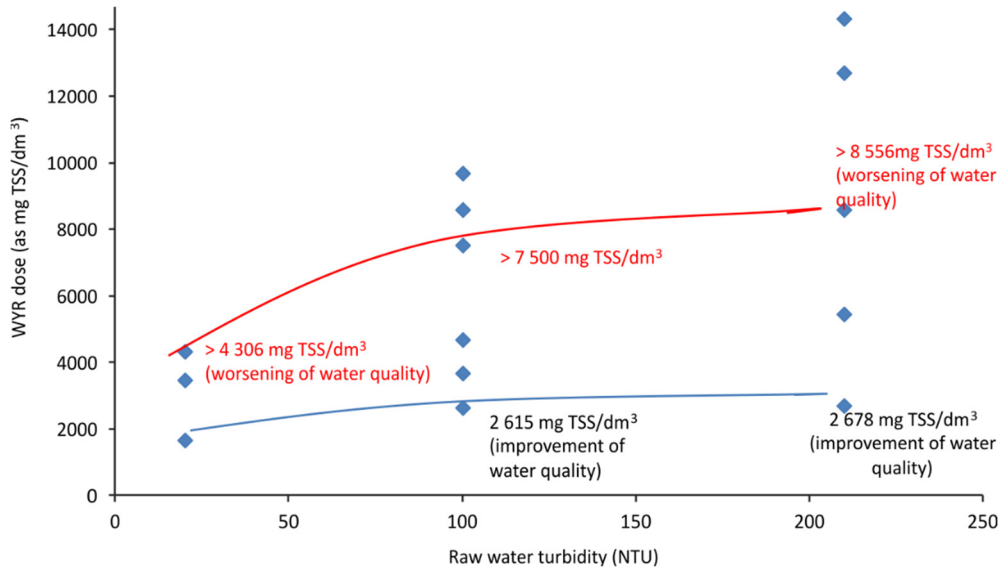


Fig. 4. Relationship between recycled WTR (as TSS) and raw water turbidity

Wu and Huang [28] have also used jar test experiments for applying WTR for the removal of low turbidity in the coagulation-flocculation process and observed an improvement in the settling characteristics of the sludge. They also observed a more compact flocs structure than the obtained with the coagulant alone, suggesting that the addition of residues lead to a better settling processes.

The results obtained in each experiments allowed a graphic relationship between the raw water turbidity and the ideal dose of WTR to be applied (Fig. 4). The blue line reflects the ideal dose of WTR to be added for an efficient removing of the turbidity. The red line shows the maximum WTR dose that can be applied until the water quality starts to decrease. It can also be observed that as the raw water turbidity increases from approximately 20 to 100 NTU, it is needed to increase the dosage of residue in approximately 60%, whilst for raw turbidity values between approximately 100 and 200 NTU the required increase in WTR is only 2.5%.

The results of this research suggest that WTR can be recycled for increasing turbidity and colour removal, but only up to 1635 mg TSS/dm³ (for raw water turbidity of 21 NTU), and up 2678 mg TSS/dm³ (for raw water turbidity between 95 NTU and 218 NTU). This practice, would decrease the needed of raw coagulant dosages.

4. CONCLUSIONS

The results of this research allow to conclude that water treatment residues (WTR) can be satisfactory applied for the removal of turbidity and colour in DWTP for raw water with turbidity between 21 and 218 NTU. The applications of residue doses between 1635 and 2678 mg TSS/dm³ has allowed a turbidity reduction from 78.9% to 96.7% and colour reduction from 67.1% to 96.9%, and an additional reduction of coagulant consumption (aluminium sulfate) between 45% and 55%. Therefore, recycling WTR to the coagulation-flocculation processes of DWTP can allow reduction of operational costs with reagents, besides allowing the reuse of residues produced in the same plant.

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