USE OF LABORATORY MODELS IN THE DESIGN OF POTABLE WATER TREATMENT PLANTS

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Abstract

The aim of this article was to investigate the potential of laboratory water treatment testing methods to support the design of a drinking water treatment plant. The work investigated jar tests, dissolved air flotation, membrane processes and adsorption on activated carbon.

The use of laboratory tests allows the optimization of the design of the drinking water treatment plant and reduces the costs of further stages of project preparation. These tests result in projected chemical consumption, energy consumption and waste production estimates. All these values are important for the design of the treatment plant.

Keywords

Jar test, DAF, potable water treatment, design phase

1 INTRODUCTION

As climate change progresses, water resources are diminishing. Those that remain in abundance are often degraded by human activity. In addition to their protection as a proactive measure, processes for removing this pollution need to be addressed.

Currently, water quality requirements for human consumption continue to be tightened. This is also due to advances in the field of analytical technology and toxicology. Currently, one such requirement is the new European legislation European Council Directive 2020/2184 on the quality of water intended for human consumption [1], [2], which includes a number of changes for the water sector.

One of the objectives of this work was to determine the treatability of water from a polluted surface water source into drinking water. For this purpose, it was proposed that laboratory procedures and models be used, both conventional and modifications thereof. As part of the investigation, a variant jar test was also tested to mimic dissolved air flotation (DAF) conditions. Furthermore, membrane ultrafiltration was used. The aim was to investigate the possibility of mimicking the treatment processes on a laboratory scale in order to optimise the design of a new surface water treatment plant.

Various commonly used coagulants and flocculant aids were used in the work. Similarly, the effect of reaction pH on the progress of coagulation in the case of jar tests was investigated. In addition, the influence of the amount of 'air-saturated recycle water' within DAF was investigated.

In the case of membrane filtration, the permeate quality over time and the membrane fouling rate were investigated.

Micropollutants as a broad group of substances [3], [4] have been an established type of water pollution for some time. They are found in both surface water and groundwater, and of course they also occur in drinking water at very low concentrations, ranging from micrograms to nanograms per litre. They are both organic and inorganic substances of anthropogenic origin. Currently, pesticides and pharmaceuticals are the most commonly addressed. These are most commonly removed in water treatment by adsorption on activated carbon.

Potable water treatment is closely linked to the production of wastewater from its processes. This water can, under certain circumstances, be recycled and treated into drinking water. This can reduce the cost of the drinking water production process and the carbon footprint of the treatment plant [5].

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2 METHODOLOGY

Water sample collection

In the area of interest, water was withdrawn at the location and depth of the proposed intake structure. The sample was collected in 30 l HDPE canisters. The total sample size was 300 l. The pH, temperature, oxygen content, ORP and turbidity were measured at the site. The water was then transported to the laboratory. Field instrumentation from Hach Lange was used for the on-site measurements.

After transport to the laboratory, the pH and other parameters were measured again. This was done in order to detect any deviation caused by the transport of the sample. Such changes can be large, especially in the summer period. In our case, it was necessary to minimise the time between collection and testing, so the tests were carried out no later than 24 hours from the time of collection.

Jar coagulation tests

In this part of the work, the ideal conditions for the removal of contamination by conventional coagulation followed by sedimentation were investigated. The coagulants used were aluminium sulphate, PAX 18 and ferrous sulphate. Sulphuric acid was used to adjust the pH.

The jar test should be performed at comparable pH at different coagulant doses. This is the only way to ensure that the optimum found is global. A similar procedure is followed for the evaluation of each coagulation parameter [6].

Jar DAF tests

This is a modified version of the classic jar test. It uses modified jars – they include a port for bringing in air-saturated water and a port for sampling below the surface of the floated sludge. A saturator is therefore a necessary part of the equipment in addition to the mixing column. It is also necessary to take into account the influence on the test result of the quality of the water that is fed into the saturator.

It is important to pay attention to verifying the suitability of DAF, as it is not a suitable process for all types of water pollution [7].

Membrane filtration

Both untreated water and water treated by coagulation followed by sedimentation were used for membrane filtration testing.

The pre-treated water sample was pumped to the membrane module by a feed pump. The pump is controlled by a frequency converter. The filtration parameters are controlled by the PLC unit of the model.

The membrane module consisted of a PVC membrane. The tubing allows operation in both cross flow and dead-end mode.

Adsorption on activated carbon

Adsorption was tested by an embedding experiment. Different amounts of activated carbon were added to a pre-measured amount of water. This monitored the removal efficiency of the chemicals at a given time – in this case 15 minutes.

Another option is adsorption within a flow-through column. With this design, the influence of hydraulic retention time, filtration rate and, of course, the type of activated carbon can be monitored.

3 RESULTS

Based on the preliminary design, a series of laboratory experiments was proposed.

For the choice of coagulant and determination of coagulation conditions, jar tests based on the methodology of Pivokonsky et al. were used. The advantage of this procedure is the certainty of the determination, where the optimal values found are global optima, not local inflection points.

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Three different coagulants were tested in the jar tests – Polyaluminium Chloride (PAX 18), ferrous sulphate and aluminium sulphate. The highest turbidity removal values were achieved using aluminium sulphate, while the lowest turbidity removal was achieved using ferrous sulphate. Coagulation with Pax 18 resulted in a 14.2 mg/l increase in chloride content, which was unacceptable due to the high concentration of chlorides in raw water – adding more would exceed permitted limits for chloride concentration. As regards the global optimum dosage, the turbidity was 0.64 FNU in the case of ferrous sulphate, while in the case of aluminium sulphate, the turbidity after optimisation was only 0.10 FNU. Turbidity of raw water was above 75 FNU. The effects of coagulant dosage, the pH of the treated water, time and hydraulic gradient during fast and slow mixing were monitored during the tests. Based on these values, the volume of the coagulation tanks can then be designed. The effect of coagulant (aluminium sulphate) dose on turbidity for different raw water pH is shown in Fig. 1.

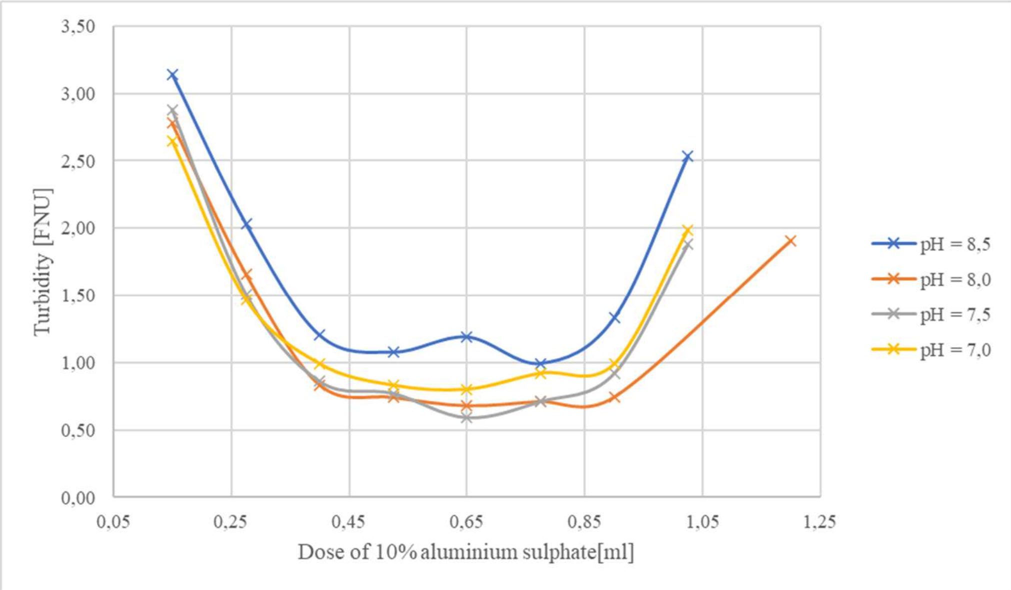

Fig. 1 Preliminary step in dosage optimization.

Another example of an optimization output is shown in Fig. 2. The goal of this step was to find the optimal speed for rapid mixing. A relatively high dependence of turbidity on mixing speed was observed during the rapid mixing stage in this case. The optimal speed was determined to be 100 rpm. The dependence of the change in turbidity value on the change in mixing speed was approximately linear. Increasing the mixing speed by 60% resulted in a turbidity increase of almost 250%.

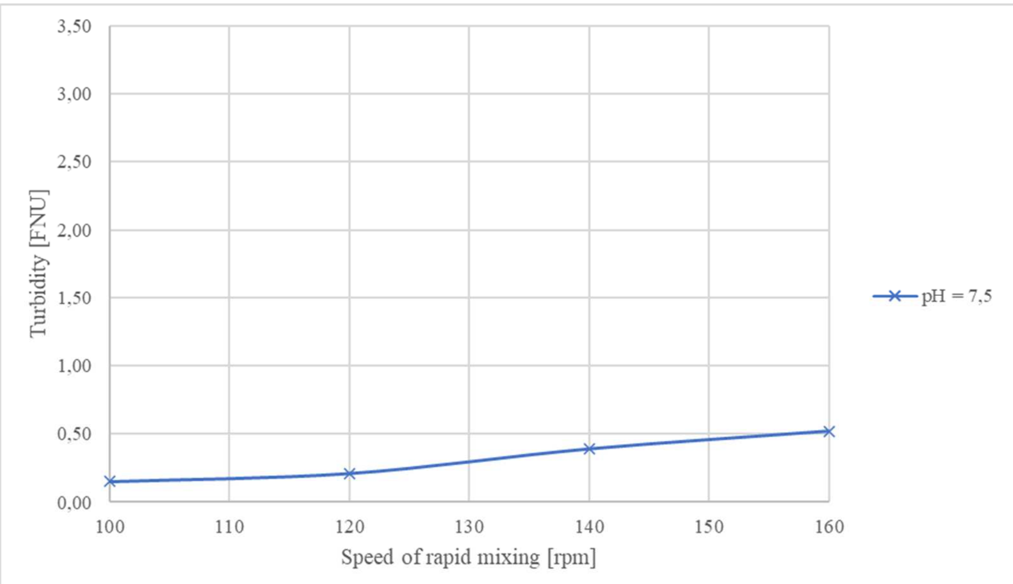

Fig. 2 Speed optimization of rapid mixing.

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In order to optimize flotation, modified jar tests were used during which saturated water was injected into beakers after a slow stirring process. Initially, problems were caused by the breakage of the sludge flakes formed. This breakage was caused by the high velocity of the injected water. The dosing system was modified to reduce the water flow speed. The sludge produced during flotation was subjected to physical and chemical analyses. The aim was to determine the suspended solids content and chemical oxygen demand. These parameters are important for the design of sludge disposal. The amount of sludge produced from the experiment is important for the design of storage tank volumes and for the determination of disposal costs.

The modified DAF jar test setup is shown in Fig 3. The sludge layer is clearly visible in the figure.

Fig. 3 Modified DAF jar test.

For microfiltration, after initial testing, it was proposed that water be used after coagulation and flotation as the first separation step. This was due to the rapid fouling of the membranes with raw water.

For membrane filtration, the membrane fouling process and its effect on the transmembrane pressure were monitored. Furthermore, the turbidity of the filtrate was monitored and found to be constant and within the limit set by the new European legislation, as shown in Fig. 4.

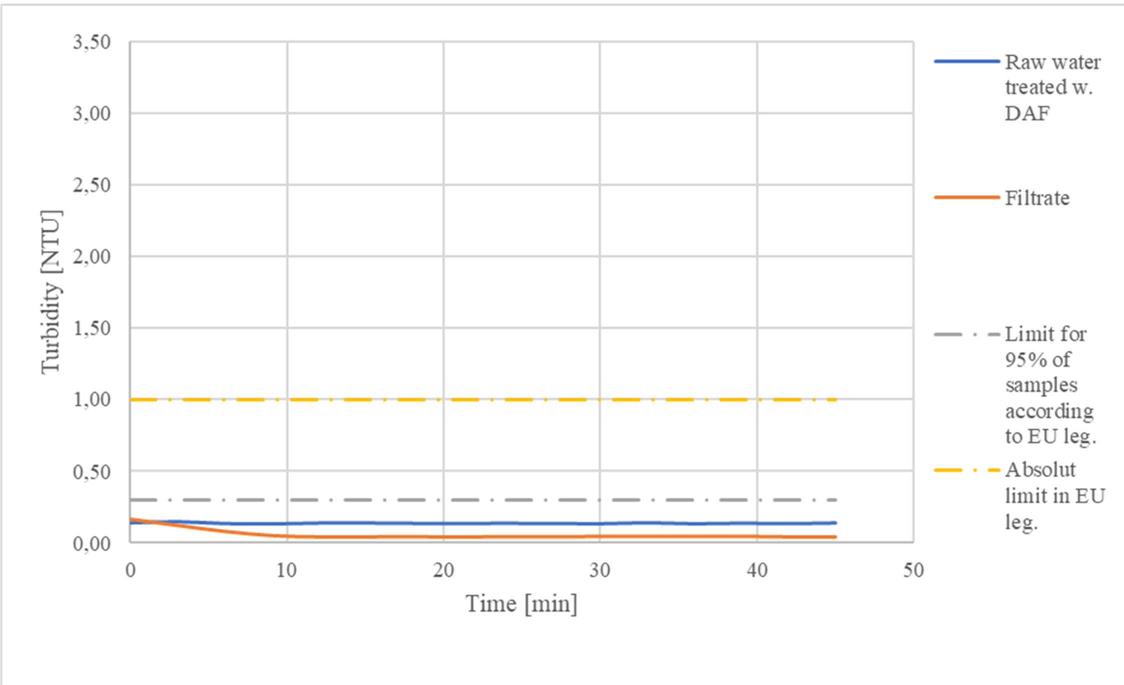

Fig. 4 Membrane filtration module fouling.

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4 DISCUSSION

The treatment process was simulated using laboratory procedures. The suitability of the use of DAF for the given pollution was demonstrated. The investigation of the DAF sludge found that the sludge could be discharged to the sewer. If it were thicker, the sludge would have to be disposed of by transfer to an appropriate facility due to exceeding the permitted values. Sludge disposal is one of the significant costs of operating a water treatment plant, so attention to this apparent detail is also needed when verifying the treatability of the water.

5 CONCLUSION

Different approaches to performing laboratory tests of drinking water treatability were studied. First of all, in the practical part, the effectiveness of the proposed processes for the treatability of the given water into potable water was demonstrated. The possibilities of replicating the processes on a laboratory scale were investigated and confirmed. Some shortcomings of DAF at laboratory scale were revealed in the course of the study. Certain modifications were made to the laboratory scale DAF model to reduce the impact of these deficiencies. The main problem was the influence of the turbidity value on the amount of added recycle. Further investigation of DAF with laboratory scale models is worthwhile, as it could be used to optimize the operation of treatment plants in the future, as is already being done with standard jar tests. Another possible process that can be pursued on a laboratory scale is gas stripping – which in practice is most often performed by air. This can remove, for example, radon or carbon dioxide from raw water. Specifically, the removal of carbon dioxide has a consequential impact on the calcium carbonate equilibrium within the water. Laboratory models for water treatment could also be incorporated into learning process so that students have the opportunity to experience the methods personally.

Acknowledgement

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