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Tuning of an Advanced Control System on a Membrane Process for Tannery Wastewater Purification and Chromium Recovery Purposes

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Abstract

Tannery wastewater represent a hazard to the environment due to its high content of chromium. Conventional methods to purify this wastewater stream are available, but not capable to recover back chromium to the tannery process. Membranes appears to be a promising technology to achieve both targets of water purification and recycling of chromium.

The economic feasibility of the here proposed process relays on fouling minimization, in order to maximize the life of the employed membrane modules and as a consequence to keep the operational costs low. The use of an advanced control system capable to predict fouling incurrence and to adapt the operating conditions to sub-boundary ones appears to be the best strategy.

In this work, the proposed process, including the advanced control system, was simulated within HYSYS. By means of performed simulation runs, it was possible to avoid irreversible fouling operating conditions, still obtaining an adequate level of tannery wastewater treatment and relevant chromium recovery rates. Both the predictive and the adaptive part of the control system exhibits high reliability. The developed strategy appears therefore promising to encourage the use of membrane technologies for this application with feasibility from a technical and economic point of view.

Keywords: advanced control system, tannery wastewater, membranes, fouling, chromium recovery

1. Introduction

Leather tanning is a wide common industry all over the world. In leather processing, water is one of the most important medium, almost 40-45 L water on kg of raw-hide or skin is used by tanneries for processing finished leathers.

Throughout the years, many conventional processes have been carried out to treat wastewater from tannery industry: unfortunately, in this case, biological treatment methods give rise to an excessive production of sludge, whereas physical and chemical methods are too expensive in terms of energy and reagent costs.

In this work, a membrane process based on NF membrane modules was adopted to treat the tannery feedstock after primary conventional treatment. In a first step, all parameters of the process comprehending boundary flux parameters were found in literature (Stoller et al., 2016). It was therefore possible to simulate the process on ASPEN HYSYS to check the long-term behavior of an advanced control system based on the boundary flux concept, able to maintain the operating conditions of the process such to avoid irreversible fouling formation issues.

2. Methods

The control system has three parts: a simple PID controller, a predictive part and an adaptive one. The predictive part supports the PID controller suggesting proper set-point values as a function of time, given by the model integrated in the customized membrane unit, which calculates the boundary flux values and is reported elsewhere (Stoller and Serrao, 2017). The successful outcome of the batch process is based on the validity of the parameter values given to the model, which may not be guaranteed. For this reason, parallel to this, the adaptive part estimates for the next 10 minutes the process outcome at different α values, expressed by a decimal percentage value towards the previous (or fixed) one. After 10 minutes, the measured flux plot is compared, and, in case of deviation, a proper α value is set to the model for future use by triggering again the calculations of the predictive part.

3. Results And Discussion

The capacity of the plant was fixed at 1 m^3/h with a membrane area of 2.51 m^2 and a target recovery value of 90% of the initial feedstock. Given the tannery waste water as feedstock, it was checked that the control system was able to predict the outcome of the operation and how it behave after a change of the α value.

The used input for this simulation is reported in Table 1.

Table 1. Input for the Nanofiltration simulation

σ	95.0 %	**Pb**	10 bar
β	0.0 bar	**α**	0.00014 $lh^2m^2bar^{-1}$
ρ1	0.0 bar l mg^{-1}	**w**	2.50 lhm^2bar^{-1}
m1	0.000023 $l^2h^{-1}m^{-2}bar^{-1}mg^{-1}$		

As a first step, the PI feedback controller was optimized, by adopting the static Ziegler-Nichols tuning method. The obtained results are shown in Fig.1 and Table 2.

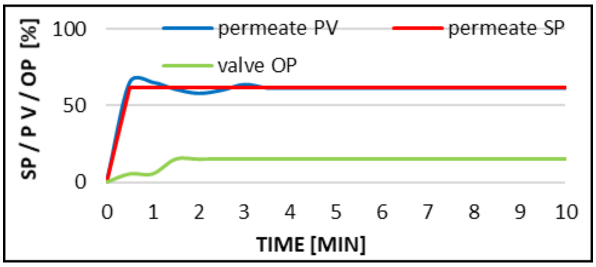

Figure 1. Control of the membrane process at Jp^{SP} servo.

Table 2. Control system parameters

INPUT		OUTPUT	
Kp	4.0	**Rise time**	20 s
τp	1 s	**Time to 1st peak**	30 s
Kc	0.8	**Decay ratio**	0.33
Tr	15 min	**Settling time (±8%)**	138 s

The starting value of α is hereafter labeled α* an given as a percentage. The predictive part of the controller checks at the beginning at different permeate setpoint values Jp^{SP} the outcome, choosing the one that permits the target recovery always being lower than the relevant Jb value (green line in Fig. 2). In this work, the Jp^{SP} value is equal to 21.03 l h m^{-2}.

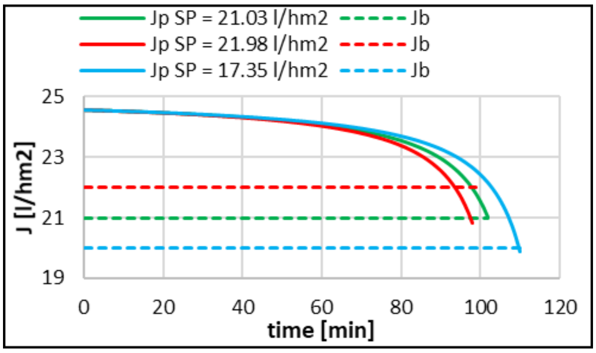

Figure 2. Output of the predictive controller for α* = 100%

Operation starts with this Jp^{SP} value and, parallel to this, every 10 minutes the historical data is analyzed to calculate the α value.

In this work, a t = 30 min, the α* value was set step-wise to 120% as a disturbance. At t = 40 min, when the adaptive part of the controller triggers, the check was performed and found unsuccessful. The predictive part was started again to evaluate, at α* = 120%, the outcome of the operation. The resulting output is shown in Fig. 3.

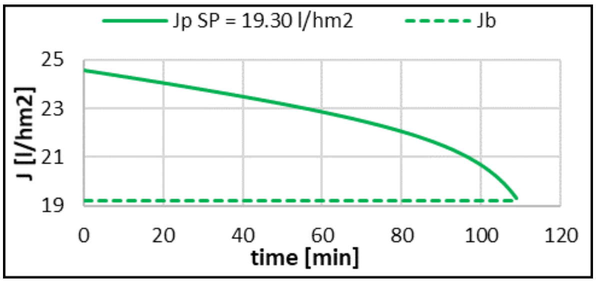

Figure 3. Output of the predictive controller for α* = 120%

In conclusion, the new Jp^{SP} is set from t = 40 min to a value equal to 19.30 l h m^{-2}. In Figure 4, a zoom of the servo control to contrast the α* value change is reported.

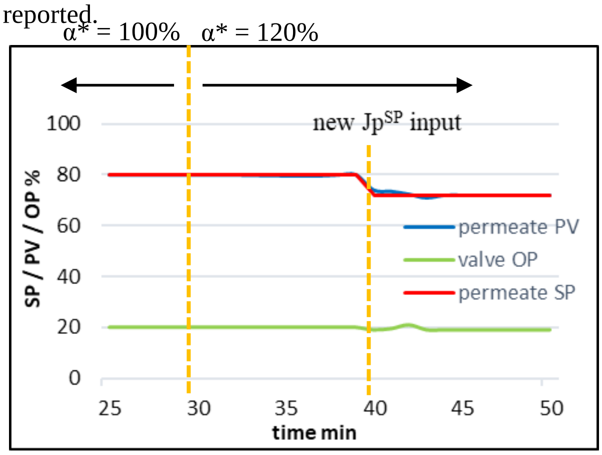

Figure 4. Servo control of the membrane process at a 20% step increase of the alpha value

4. Conclusions

The application of membrane technologies for the purification of tannery wastewater streams appears to be very promising. A legal discharge to municipal sewer system in Italy of 90% of the initial wastewater stream volume and the production of a recyclable chromium-rich concentrate is possible, allowing cost savings of 40%. In order to maintain on the long run these advantages, an advanced control system was developed. The control system is able to track down the actual process conditions, evaluate optimized operating conditions and target the technical-economical requirements. This permits to guarantee the desired service for a long period of time.

References

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