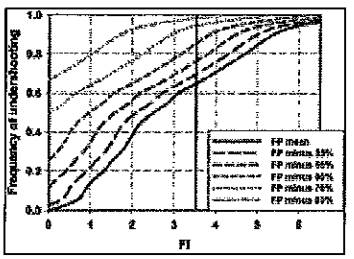
The achieved model approach allowed evaluating the effectiveness of measures to reduce the emission of foam potential in respect to foam formation on the river. It was used to calculate the frequency of undershooting for a certain *FI* considering the reduction of foam potential emission and the discharge of the river. Input data for river discharge was a long time series from 1991 to 2007, input data for foam potential was the mean foam potential observed during the monitoring, as well as, five different reduction stages of the mean value (−35%, −50%, −60%, −70% and −80%). In Fig. 9, for the emission of the mean foam potential and the five reduction stages, the frequency of undershooting of the calculated *FI* is displayed. It is obvious that an elimination of 70% of foam potential (dotted line) would assure a foam index lower 3.5 with 95% probability. Based on the current mean emission of foam potential the "not accepted degree" of foam formation is exceeded in around 60% of the cases.



Full-size image (27K)

Fig. 9. Frequency of undershooting for a foam index depending on the different reduction stages of foam potential emission at weir 4 (the line indicates the limit for the "not accepted degree of foam formation").

As the monitored tanneries operate their wastewater treatment plants with the best available technology (biological treatment with nitrification and denitrification, sludge retention time >20 days, temperature in the activated sludge tank >20 °C), foam formation on the investigated river is not the result of none compliance with legal standards. Cleaning efficiency is however not sufficient to remove the surface active compounds resulting in emission of foam potential. Analysis of tensides, as well as, qualitative screening could not identify potential foam causing substances. Thus, it was assumed that vegetable tanning agents could play a role in foam formation due to their high molecular structure and the associated poor biodegradability during the purification process. Further research is needed to gain more information on their behaviour.

As the adjustment of the production process to other chemicals is a long and complicated process in the leather industry, the implementation of end of pipe measures seemed the only fast and effective way to reduce foam formation anyway.

To evaluate proper management strategies, several end of pipe measures for the tanneries such as post treatment of tannery effluents at a municipal WWTP, precipitation and flocculation, adsorption and ozone treatment with additional biological post-treatment were tested, for which, ozonation turned out to be an appropriate way to reduce foam potential emissions. Discussion on the implementation of ozonation, as well as, other alternatives for post treatment is on going.

Measurements concerning the morphology of the river such as the removal of weirs to avoid foam formation were also part of the discussion in the beginning of the investigations. The foam potential emissions of the tanneries could be clearly linked to foam formation on the river during this study and the implementation of tertiary treatment on the tanneries' waste water treatment plants could be an effective, as well as, a politically desired measure to reduce

foaming.

5. Conclusions

Foam formation on rivers is a neglected research topic but it is becoming increasingly important due to public concern in recent days. Its occurrence generally does not need to originate from insufficient treatment of the classic wastewater compounds as it was in past decades, but as a consequence of the presence of numerous chemicals in effluents of industrial wastewater treatment plants, as well as, the intensive use of a river as receiving water for the effluents of several industries. For the investigated case no concrete statements could be made about the fate of potential foam forming chemicals during treatment, the efficiency of their removal and their behaviour in the aquatic environment.

About foam formation on rivers and foam causing substances, little literature is available and restriction of foam is difficult due to the lack of legal standards. Nevertheless, as a result of the work presented, it was possible to detect the origin of foam formation, to quantify the influence of different emitters on foam formation in the investigated river and to provide a set of tools (laboratory tests and modelling) to evaluate and compare the efficiency of measures for foam abatement.

As no clear parameter for in-stream foam formation or emission of foam exists to date, indices had to be developed during the study. The foam index is introduced as the immission parameter for foam formation. It allows a semi-quantitative differentiation between the varying foaming conditions. Description of the single foam indices is only valid for the studied river but the idea to classify different foaming conditions could be applied to other rivers. The foam potential is presented as the parameter to quantify foam emissions of a discharger. As the underlying foaming factor is clearly related to surface tension, the foam potential seems to be a valuable foam emission parameter, particularly, if the foam causing substances are unknown.

The resulting model approach provides the calculation of foam indices under varying foam potential emissions and discharge conditions. Although the model is developed for the specific local situation, via the adaption of foam index and the knowledge about the main influencing factors for foam formation, a similar model approach as the one presented in this paper could be designed for other rivers. Thus, it is a useful tool to evaluate the development and implementation of measures reducing foam. According to the model's results a foam index <3.5 (which is the "not accepted" degree of foam formation) would be assured by the elimination of 70% of the foam potential with 95% probability. Investigations concerning foam-abatement measures identified ozonation as an appropriate way to reduce foam potential emissions.

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