The ultrasonic cleaning performance in dependence on the driving power

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Introduction and Setup

This article puts focus on peculiar observations about the cleaning performance in dependence on the acoustical driving power. For the influence from other parameters, such as the frequency, see [1].

In the experiments, a polymer membrane stack (Microdyn-Nadir UPS-150) is to be cleaned periodically by ultrasound-enhanced backflushing with aeration (see [2]) in a laboratory test plant (see Fig. 1). The ultrasound (US) is applied by two transducers from Elma, Germany (surface: $\approx 41 \times 32 \, \mathrm{cm}^2$, frequency $130 \, \mathrm{kHz}$, overall power from $100 \, \mathrm{W}$ ($5\,\%$) to $2000 \, \mathrm{W}$ ($100\,\%$), corresponding to $75 \, \mathrm{mW/cm}^2$ to $1.5 \, \mathrm{W/cm}^2$). The sound field is measured with a hydrophone (Reson TC 4038) in planes parallel to the membrane surfaces as indicated in Fig. 1.

The laboratory test plant performs the final step in drinking water purification, as widely done commercially. This final step consists mainly in the filtration of pretreated raw water. In this experiment, the raw water is prepared from tap water with soft clay, a coagulant ($FeCl_3$) and some biologic contaminations. For a sufficiently fast filtration, the raw water is sucked through the membrane by a pump creating a transmembrane pressure (TMP). The TMP is controlled and significantly affects the properties of the cake layer that gets attached to the membrane. The cake layer consists of the contaminants remaining in the retentate tank and of a film of extracellular polymer substances from microorganisms settling on the outer membrane surfaces. In the results reported here, TMPs of $-200 \, \mathrm{mbar}$ (filtration) and $100 \, \mathrm{mbar}$ (backflushing) were used. The permeability of the membrane gets severely affected by the presence of the cake layer until the membrane is completely stucked and must be replaced. The permeate flow is measured and gives (after temperature normalization and at constant TMP) the membrane permeability which is a measure for the degree of membrane fouling and cake layer

presence. The change in permeability, or permeate flow, after one cycle of filtration and backflushing is considered as the cleaning performance. A particle counter and a turbiditymeter in the permeate circuitry analyse the permeate to give more information about the cake layer and to check the membrane integrity. Note that even though the membrane filtrates in dead-end-mode the contamination level in the retentate tank remains constant as the permeate is piped back to the retentate tank.
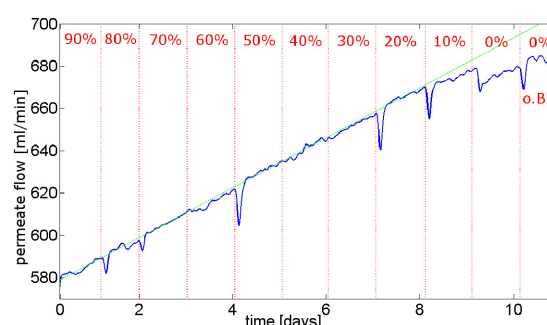
Figure 2: Permeate flow (blue) and cleaning performance (slope of the green line) at different US-powers (smoothened).
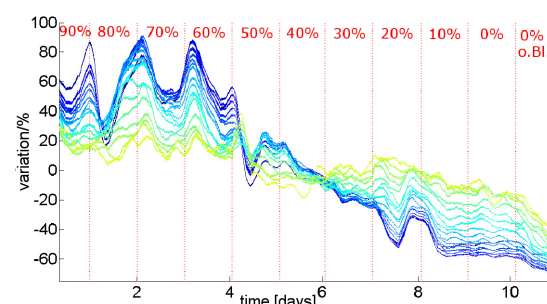
Figure 3: Variation of particle concentrations in the permeate for different particle sizes (color coded, see text). The smoothened variation from each average is shown. Data from the same test run as in Fig. 2.
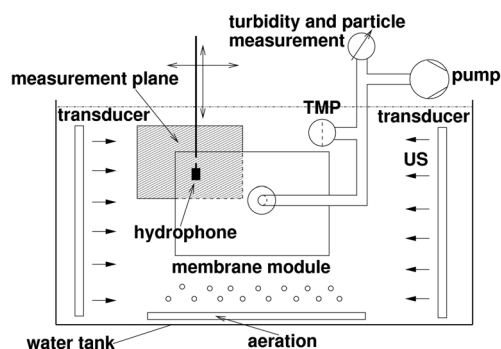
Results

In the test run presented here, a membrane stack was fouled for several days by using it in the test plant described above, but without the use of ultrasound in the backflush cycle, until the permeate permeability decreased to a medium level (permeate flow of $580 \, \mathrm{ml/min}$). Then, the same fouled membrane stack was run in the test plant but with the application of ultrasound. The ultrasound power started at $90\,\%$ and was reduced by ten percentage points per day down to zero. The permeate flow, being a measure for the permeability, is shown in Fig. 2. The green line fits the permeate flow linearly for up to a US power of $20\,\%$ and its slope can be considered

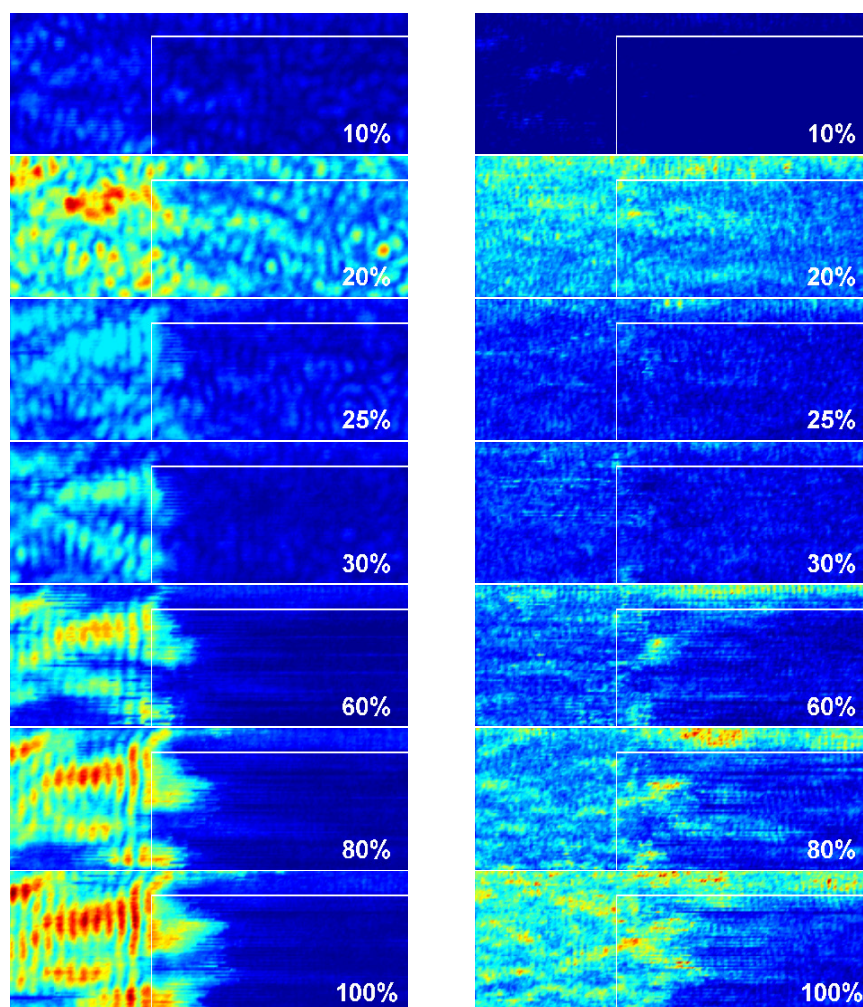**Figure 1:** Sketch of filtration plant in sideview.

Figure 4: Evolution of the pressure field with raising driving power: red indicates high, blue low pressures (the left and right columns are shown in different color scales). The membrane is located in the lower right corner (white line), the closer transducer radiates horizontally from the left side. One image size covers $\approx 6 \times 14 \, \text{cm}^2$. **Left:** Maximum peak to peak pressure (max $\approx 3.2 \, \text{bar}$) **Right:** Same measurement as left column, but only second harmonic frequency interval shown. Standing wave fields for λ (left) and $\lambda/2$ (right) are clearly visible, mainly between transducer and membrane.

as the cleaning performance down to 20 %. Note that the flow without further US application would fall again down to zero. The five to seven minima shortly after a US-power change are artefacts due to stirring sediments by refilling evaporation losses in the retentate tank. Figure 2 shows the existence of two thresholds for the cleaning performance: One between 20 % and 10 % US power and one between 10 % and 0 %. Estonishingly, from the permeability measurement no difference in cleaning performance can be observed from 100 % to 20 %. The reason for this can be deduced from the graphics of Fig. 3 and Fig. 4: Figure 3 shows the change in the particle concentration in the permeate from the same test run as in Fig. 2. The particle sizes are color-coded from dark blue (smallest: $0.9 \, \mu\text{m}$-$1.2 \, \mu\text{m}$) to light green (biggest: $8.0 \, \mu\text{m}$-$9.0 \, \mu\text{m}$). It demonstrates that at high US powers ($> 40 \%$) the concentration of small particles is high - this is because of cake layer fragments getting emulgated by the surplus in acoustic power. The emulgated fragments get easily stuck again on the membrane. Primarily it can be observed that the cleaning performance does not raise because the acoustic power does not get delivered

to the membrane surfaces at high powers due to sound shadowing bubble structures that evolve between membrane stack and transducer (see Fig. 4). These structures are closely connected to second harmonic generation (see Fig. 4) and will be examined in more detail in a further publication. Note that the qualitative change in the sound field configuration appears around the same power level ($\approx 20 \%$) as the cleaning performance change (compare Fig. 2 and Fig. 4).

References

[1] F. Reuter, R. Mettin, W. Lauterborn: Pressure fields and their effects in membrane cleaning application. Proc. Acoustics '08 Paris, Soç. Franc. d'Acoustique (ed.), Paris 2008, pp. 579-584

[2] S. Lauterborn, W. Urban: Ultrasonic cleaning of submerged membranes for drinking water applications. Proc. Acoustics '08 Paris, Soç. Franc. d'Acoustique (ed.), Paris 2008, pp. 2603-2608