Executive Summary

Nanofiltration 2020, Achalm Hotel Reutlingen - *postponed twice to 26 to 30 June 2022 due to Covid*

Conference Website: https://nanofiltration2022.iamt.kit.edu/

NF2022 was a success! Not only were the scientific sessions stimulating with high quality presentations and discussions, but we all enjoyed the fun social programme – one of the highlights being the dancing (Dr Luxbacher won the best dancer award) followed by a midnight walk climbing the summit, culminating with roasting marshmallows over a warming fire. The active participation of delegates was much appreciated – everyone enjoyed seeing people again, which made for a great ambiance. While we were all together on the Achalm, the personal encounters were great, with some of the most senior scientists in the field as well as newcomers having ample opportunity to interact. The programme was intense and there was noticeable little free time!

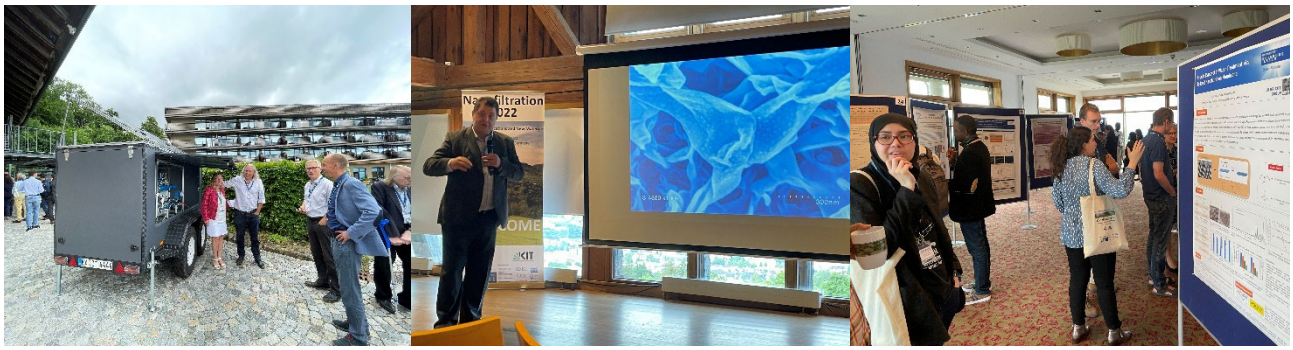


If one can somehow encapsulate – or maybe more realistically just point out some of the highlights of – this very rich programme of about 50 posters, 44 oral presentations and 13 invited/opening lectures, then this summary provides highlights and spotlights, rather than seeking to be an exhaustive record. The Nanofiltration book that was published in August 2021 with >1200 pages (a signed copy was given to participants as a conference proceeding) provides in-depth detail from fundamentals, through to applications and new materials. The NF2022 book of abstracts (to be published by *Desalination and Water Treatment*) serves as an overview of the topics presented at NF2022 – and maybe more fresh – and forthcoming is the *npj Clean Water* special issue on the topic 'Nanofiltration in the Global Water Cycle' to be edited by Dr Youssef Boussouga, Dr Rhea Verbeke, Prof Slava Freger and Prof Andrea Schäfer.


The 14 sessions within NF2022 offered an extended programme compared to what was originally foreseen. This was due to a very high number of abstracts received (and may demanding orals to come), while the originally planned IAMT laboratory opening and visit were organised online (with a virtual tour) in 2021. The numbers in terms of participant demographics are summarized in the appendix. The conference was full with the maximum number of participants of 120 reached – briefly two thirds had a PhD, one third were women, and the participation highly international (about half the participants from German institutions were again international).

The vast majority of participants stayed in the Achalm Hotel that overlooks Reutlingen. All meals were provided and the evenings were filled with an elaborate social programme, starting with a Maultaschen dinner and cocktail – the bartender was not forthcoming with a Nanofiltration cocktail so this challenge

remains open – reception (Sunday), a Swabian buffet and Nanofiltration cake (Monday), BBQ dinner, live band and Achalm nightwalk (Tuesday), followed by a visit to Lichtenstein Castle and formal dinner in the Forsthaus (Wednesday). The postconference event (Thursday) was punting of the Neckar River in Tübingen and – in case anyone missed what traditional Swabian food is – dinner at the Wurstküche restaurant. It has been an intense, heartwarming and fun event, bringing my international nanofiltration community to my home and reconnecting to the very colleagues that inspired my career many decades ago. For members of the Nanofiltration community, it was an incredible gift to meet old friends and real people (after such a long isolation period) – and, of course, make many new connections. To get academic or industry colleagues to dance is always a challenge, to witness dancing until midnight followed by a nightwalk up the Achalm (of some 30 people) was incredible.



The scientific programme was no less intense. Many abstracts were received – and a programme was designed such that the contents of sessions were coherent, which stimulated discussion. The topics were structured to first set the scene, why is nanofiltration required and seeing such a boom? Through principles and application to new materials (the topics of the book), while expanding to new areas. This scientific cocktail inspired lively discussions, ideas and engagement. For many IAMT team members (a total of 17!) this was not only the first international conference, but also the first organisational experience – and the team were very good chairs, drivers, IT managers, photographers and forever helpful contacts – and evaluated the many prizes. It was long days and many challenges!

The opening talk was given by Prof Volker Saile who, prior to retirement, played a senior role in one of Germany's most adventurous research experiments: the merger of the largest national laboratory with the Technical University of Karlsruhe (which, once upon of time, inspired the foundation for MIT) to form KIT. Water is a topic that in Germany is considered as an element of abundance, much to the frustration of some researchers, while the research at KIT focuses predominantly on energy, mobility and information (IT).

Closer to the field were the elders, namely Prof Miriam Balaban and Prof Heiner Strathmann, who many years ago (1977) hosted a membrane conference in the region – and in nearby Tübingen founded the European Membrane Society in 1982, 40 years ago. Indeed, I 'met' Prof Strathmann in 1978 at Berghof GmbH, a company that we look down to from the Achalm. Even more inspiring, Miriam Balaban – the founder of *Desalination* (now an Elsevier journal) presented her life story of what just needed doing after John F Kennedy presented his dream of making seawater potable in 1965. Whatever needs doing, Miriam just does it. "What, there is no journal on desalination – I will do it!" The rest is history. The Nanofiltration book is dedicated to her, as well as her colleague Prof Ora Kedem. These are truly inspirational women, dedicated to science and membranes. To have active women with 95 and nearly 100 years of age is incomprehensible in my Swabian culture, where even nowadays societal expectations make the life of working mothers difficult.

Session 1: The Case for Nanofiltration: From Climate Change to Micropollutants

Nanofiltration applications are exploding and this is due to i) an increasing water pollution load in a filling and ever more industrialised planet, and ii) a need for energy efficient selective separations in many fields. The invited lecture of Damià Barceló highlighted issues of water scarcity in Europe (and yes, Germany is also affected by drought), and the diversity of micropollutants from pesticides to antibiotics, along with their very complex treatment requirements (hint: nanofiltration!). But clearly, what is the impact of climate change? Another inspirational speaker was Andreas Fath. He had (and we were a little nervous about his attendance!) just completed a 2700 km Danube swim to raise awareness for water quality. We were surprised that the

wetsuit had not grown on! Andreas Fath reported that 4.2 tons of microplastics reach the Black Sea via the Danube – daily! While nanofiltration is clearly not required to separate these relatively large particles, such particles are 'vectors' for toxins and can indeed be utilized as adsorbents for micropollutants. The physical challenge and the strength of will required to complete such an endeavour is food for envy – and of course the physical fitness also.

Session 2: Nanofiltration: Opportunities and Limitations for Water & Environment

Water and environment – this session started with the chemical industries. Markus Kyburz, as one of the most prominent nanofiltration practitioners, reflected on the practical development of nanofiltration and the first full-scale plant – at the time top secret and highly innovative – in 1986. It has been a difficult chapter in the book as much of this knowledge is highly sought after and trade secrets don't publish well! However, there is so much to learn to solve our global challenges and industrial success is sometimes built on copying, where stakes are high, especially in the pharma industry. Pia Lipp took us to the water industry and highlighted that Germany has 86 nanofiltration or reverse osmosis plants. While only few are built due to micropollutant removal (most would be in honour of hardness removal), the concentration of micropollutants in concentrates, and discharge thereof, remains an ongoing challenge that affects implementation. Energy requirements are real in nanofiltration, even though pressure (hence energy) is reduced compared to reverse osmosis. Celine Jacquin presented the option of gravity-driven membrane filtration as a pretreatment to nanofiltration as well as biofilm destabilisation. It is a simple option even though the driving force – pressure – can of course always be delivered through mechanical means (pumps) or a direct head (gravity). In decentralised contexts, this may be a meaningful simplification and Bing Wu advanced this concept in decentralized wastewater treatment. Wetlands versus high pressure membrane filtration, micropollutant accumulation in plants or membrane concentrates – the problem simply does not go away. Maybe a logical continuation – and significantly more advanced – is photocatalytic degradation of micropollutants in water treatment, reuse, concentrate treatment via 'reactive membranes'. Camila Suliana Raota practised her concept for her Falling Walls Labs international competition (she recently won the nationals) with the topic of a photocatalytic membrane (porphyrin-coated PVDF) for the *in situ* degradation of steroid hormones.

Session 3: Nanofiltration Applications I: Water Treatment

Jack Gilron once again returned to issues in water treatment. Seeking to balance the tradeoffs of increased recovery, higher pressures, increased scaling and capital, as well as energy expenditure. Process design offers many option – single pass reverse osmosis versus double pass nanofiltration – with traditional finger prints of good multi- and monovalent selectivity, potential low molecular weight organic retention and high permeability. Separating scaling ions prior to reverse osmosis is key and so is mineral recovery in general. A possibly controversial idea (or as Jack put it 'a well-known secret') – that resonates perhaps with the concept of nanofiltration being considered second grade reverse osmosis – is to take end of life reverse osmosis membranes, treat with chlorine, and resell as nanofiltration membranes. Next, another practitioner, Philippe Sauvignet – who operates an exceptional training and research site in the Bretagne for water treatment – claimed that the impact of climate change on surface water is underestimated. Membrane processes such as nanofiltration are more resilient to processes such as activated carbon or coagulation in terms of changes in chemicals requirements with variable water quality, which will only become more dramatic with climate change. The trend in water treatment is the treatment of soft waters with nanofiltration membranes of high molecular weight cut-off (800-100 Da) that exhibit minimal calcium and magnesium retention, while organic retention is high. Such membranes can operate at a 95% recovery, while concentrates can be discharged into the environment. The process is patented and suitable for small rural communities in northern countries: tradename ColorX. Yoram Cohen continued at the higher-pressure end, where nanofiltration is used to enhance recovery on reverse osmosis concentrates, in a trade-off between recovery and pressure and specific energy consumption shows a clear minimum over total recovery. Tuning membrane properties is key. The term decentralised is replaced with 'autonomous distributed water treatment / desalination systems'. Mohit Chaudhary developed mixed matrix membranes to remove 'forever chemicals' from tens of nanograms per litre to below detection limits, with a reported removal of about 95%. Marcus Weyd presented experience with coated ceramic membranes for industrial laundry waters, with coatings being easier on tubes than on rotary disks.

Session 4: Nanofiltration Principles: Characterization/Fouling/Scaling

In the fouling session, Gregory Korshin presented a chemical probe that changes optical properties when binding to organic foulants. Early results with alginate indicated the suitability of *in situ* fouling detection through a strong correlation with transmembrane pressure increase due to fouling. Alessandra Imbrogno linked the interactions of micropollutants with polymeric surfaces as well as the utilisation of such 'surfaces' in the form of magnetic ion exchange resins with fouling control in nanofiltration. Stefan Panglisch introduced layer-by-layer coating on multibore membranes for both fouling control and micropollutant removal, while Vitaly Gitis introduced nano- and microbubbles for fouling control. Rodrigo Borquez used dia-nanofiltration for the removal of multivalent ions from seawater, ultimately adding to scaling reduction in seawater desalination.

Session 5: Nanofiltration Principles: Transport Mechanisms

The tandem killer section – at least for practitioners! – in transport mechanisms and nanofluidics. It proved to be the – at least for some – the most stimulating part of the conference where the communication of advances was surprisingly great. Indeed, nanofiltration is advancing towards understanding of the role of not only solute-solute, but also solute-membrane interactions in transport and hence selectivity. Whoever regards membranes as physical sieves, possibly extended by molecular scale charge interactions, notices that matters become even more complicated and models, as we knew them, are clearly limited. The well thought through presentation by Menachem Elimelech was a soft start to transport phenomena and next generation membranes. A reminder that early efforts were focused on ultrahigh flux, while current efforts focus on water-salt selectivity. Not far from this argument is then the permeability-selectivity trade-off and the pertinent question if novel membranes – based on carbon nanotubes, graphene oxide, aquaporin and alike – can actually compete with polyamide thin film composite membranes. The new frontier, perhaps much more so than the permeability-selectivity trade-off, is ion-ion selectivity. The difficulty increases from separating ions of i) opposite charge, ii) ions of different valency (the classic mono – versus multivalent) and iii) same size and same charge. A prominent example of a challenging separation is no doubt lithium and sodium separation. Biological membranes appear to master some of these separations, where the H^+ channels provide a guiding principle for ion-ion selectivity. The interaction energy of ions for a specific membrane functional group, determined by coordination chemistry, can be very different for ions and this can result in site hopping or a site occupation that hinders transport. The nanoscale spacing and ion sizes determine if pores (or transport channels) are blocked and what is transported more than the other. So much for a gentle start! Next in line is Slava Freger, who proceeded with the statement that ion association is indeed a key element in nanofiltration modelling. Mean field models are reported to smear things out, which has been improved to some extent in nanopore models even though smearing is still an issue. For ions, where potential is significant, an ion spends most of its time on the fixed charge and needs to overcome a comparatively high barrier to hop from site to site and ultimately across a membrane. Naturally, the spacing of such fixed charges is important. Considering speciation, ion pairing, adsorption of mobile ions, and charge reversal, it is not difficult to imagine that transport processes quickly become very complicated. Mobility is a totally different thing and has to be corrected for binding, while diffusivity is wrong. So that took a lot of time and next up it doesn't get any simpler: Andriy Yaroshchuk presenting on the multifaceted role of modelling in membrane science and technology. Steric exclusion and hindrance factors that encompass diffusion and convection, the superposition of steric and Donnan exclusion. Complexities that one may be able to circumvent through quantitative control of homogeneous concentration polarization. Razi Epsztein carried on with transition state theory of chemical reactions to describe transport in nanofiltration. Entropic and

enthalpic barriers reflect hydration energy and size, in form of a not well understood pre-exponential factor. Again, interactions with functional groups may lead to unstable transitions to a new bond. As such, the transport through a membrane is not a single step process, but rather a series of many interactions. Three main issues were raised, namely i) sensitivity of measurements, ii) thermal activation problem and iii) enthalpy-entropy compensation and inter-connectedness. Oded Nir ensured a return to reality in form of micropollutant concentration polarization, cake enhanced concentration polarization, fouling on spacers and high observed rejection as well as refection coefficients.

Session 6: Nanofiltration Principles: Nanofluidics

Nanofluidics was inspired by the small-but-significant nanofluidics conferences held, and attended mostly by the 2D materials community. Single pore transport methods, very purist modelling approaches and materials that are at times far from real life applications, allow unprecedented phenomenological understanding that, at times, challenges our very knowledge and understanding. It was a great honour that some speakers braved our relatively applied meeting (several cancelled last minute) and therefore enabled the bridge to span over a big gap that is still reasonably unacknowledged even at membrane-focussed Gordon Research Conferences. The IAMT was asked to compile a wishlist of speakers based on their reading. Rohit Karnik featured on that wishlist and he accepted to present. In contrast to previous speakers, he presented a more optimistic view about making a single atom thick membrane. Single layers of graphene transferred to porous supports present an experimental challenge, while such layers are then impermeable, even to helium. Such impermeable layers now need to be equipped with pores that would ideally have a narrow pore size distribution. The membrane could provide some selectivity, but also some defects, which are problematic for applications such as desalination. To overcome this challenge, several strategies to seal off such defects were presented. While the larger defects can be selectively sealed, addressing smaller defects is critical to realising functional membranes. Yoav Green took a more pragmatic view of a membrane as a solid with lots of holes in it (clearly 3D). His presentation focused on a new comprehensive analytical model to demonstrate that low-concentration conductance is the concentration conductance of nanopores. The model accounts for the interplay between surface charge regulation, advection, and slip-lengths. The predictions imply that all three phenomena are essential in all nanofluidic systems design. Alex Noy returned to 1.5 nm diameter carbon nanotube pores inserted in a lipid membrane as model nanofluidic channels. The holy grail here being precise separation of ions (anions are blocked and cations pass through), while water transport through the nanotube interior very fast and in single file manner. Soufiane Abdelghani-Idrissi presented a concept of an electroosmotic motor for water purification and desalination. Such an approach requires an electro-osmosis pump material to ensure electro-osmosis flow in composite with a selective material to provide steric exclusion. Single pore processes that can be studied in nanofluidics have the potential to provide fundamental understanding of mechanisms that occur in much more complex and heterogeneous structures that that of a nanofiltration membrane.

Session 7: Nanofiltration Applications II: Industrial & Resource Recovery

Back to applications, Hanna Kyllönen presented concepts of nitrogen recovery from wastewater, septic wastewater and mining industry. Precipitation is not a good option due to the high solubility, the Haber Bosch process is very energy intensive, where the value of nitrogen increases with energy costs. Electrodialysis reversal is set to work, while low pressure nanofiltration was prone to scale formation of calcium phosphate or lime (calcium hydroxide), especially when treating mining wastewater. Seeing the retention of nitrogen in nanofiltration is low, new process concepts are required where the role of nanofiltration may be the removal of scalants. Vlad Tarabara looks at oil droplets, that can be visualised in situ by direct observation using transparent track edged membranes. To have a transparent nanofiltration membrane Anapore membranes were used and coated with a polyelectrolyte layer. Such investigations permit the quantification of adhesion force, crossflow drag and permeation drag in fouling and determine if the reflection coefficient is concentration dependent. Thomas Wintgens took us to landfill leachates, an incredibly complex waste and very expensive to treat (15-25 €/m^3), from high scalants to per- and polyfluoroalkyl substances (PFAS). Nanofiltration may replace first generation reverse osmosis in the landfill leachate treatment sequence that typically consists of a membrane bioreactor, reverse osmosis and concentrate granular activated carbon. It is a ‘forever job’ with treatment required for 40-50 years. Benoit Teychene presented a decision tree model to evaluate and predict the treatability of the many micropollutants by nanofiltration. Ramatisa Ladeia Ramos

described the treatment of gold mining effluent with nanofiltration at some rather harsh conditions of very low pH and high temperature. Agniesszka Cuprys treated micropollutants and heavy metals with functionalised biochar nanofiltration hybrid process to solve the antibiotic resistance problem.



Session 8: Publish or Perish: Hot Topics in Publishing (Nature Publishing)

Fabio Pulizzi – outgoing editor of *Nature Nanotechnology* and incoming editor of *Nature Water* – could not have been a more suitable chair for this panel discussion session. We wanted controversy and we got it! The panel members were Lidietta Giorno, Rhea Verbeke, Oded Nir and Basma Qazi-Chaudhry. The discussion topics: open access, the cost of publishing – or why is it so expensive? Profits go up with exponential growth in papers, is this profit ethical (?) and an explanation was sought on how it can cost thousands of Euros to publish an article, with actual costs around €10k. Do we need editors and publishers, why not just publish everything – in the context of the majority of published work not being reproducible these are of course valid questions. What are career consequences, what is the state of the quality of science? Impact factor does not always mean impact, 2D materials are getting most citations and some review articles written by authors with no prior work in the field can attract thousands of citations. Should publication be reduced as a career goal post? Fake news will get high citations and propagates seven times faster. There are no easy solutions for these complex issues. It was brave for Fabio Pulizzi to shoulder the controversy as a representative for all publishers. Hopefully, *Nature* is a publisher more open to listening and debate than some of the others even more commercially oriented or possibly predatory competitors. The quality and hence the actual impact of our work is a huge responsibility, there are simply no shortcuts, while knowledge generation and communication are the core business of a researcher.



Session 9: Nanofiltration New Materials I

After a long night of partying, Mihail Barbiou had no mercy and took us on a deep dive into artificial water channels. Ideally one would want to make membranes only of such channels to maximise permeability. Selectivity of such channels was described with binding energy and perfect recognition of specific ions to achieve, for example, sodium-potassium selectivity. The mechanisms of separation are a mixture of partitioning and diffusion which is consistent with earlier presentations. Daniel Mandler is applying electrochemistry for characterization of pollutants and treatment. This is achieved with both non-conductive and conductive membranes. The 'flow by' electrode is, due to mass transfer limitations, less efficient that a flow through electrode in form of a membrane. Here, a trade-off between mesh size and costs is an issue, where stainless steel mesh is too open and lacking adsorptive properties, while carbon nanotubes are good options, with Buckey paper a cheap and readily available choice. The adsorption of micropollutants can be measured electrochemically in such a process, with applications ranging from detection, through electrochemical cleaning to removal. Mathias Ulbricht described polyelectrolytes as well as polymeric

ionomers to control membrane thickness, selectivity and permeability. This is most relevant with a view on potential utilization as a barrier layer of nanofiltration membranes. This was also discussed using the example of thin-film composite nanofiltration membranes, including synthesis and evaluation of a library of anion-exchange poly(arylene ethersulfone) multi-block copolymers as NF-selective materials. Suzana Nunes makes highly selective nanofiltration membranes by interfacial polymerization, through incorporation of macrocycles transport and selectivity can be tuned. Lei Fang discussed the preparation of aromatic porous polymer networks which are promising candidate materials for organic solvent nanofiltration membranes. Such membranes can provide molecular-sieving selectivity, high permeability, and chemical/structural stability under extreme conditions.

Session 10: Nanofiltration Applications III Desalination & Reuse

Lidietta Giorno focused her presentation on the recovery and valorisation of functional molecules, such as biophenols and oligogalacturonides, from real matrices of olive mill wastewaters and tomato leaves extracts using nanofiltration. Julia Witte presented her surprise as she discovered nanofiltration was the best solution to solve her complex separation problem with organic solvents. A three-staged process organic solvent nanofiltration combined precipitation/filtration can be a new optimised synthesis route the food and pharma sector. Hanna Rosentreter used nanofiltration for partial desalination of brackish water within the use of abstraction-desalination-recharge methodology. The cost of the required energy for desalination within a four-year remediation period was estimated per kilometre of coastline, showing a large variation. Loreen Ople Villacorte presented the application of hollow fibre nanofiltration to reduce the footprint of evaporative cooling towers, explaining that with 17-25% make-up water can be saved and 50-75% blowdown discharge can be reduced, depending on the cooling tower load and make-up water quality. Bing Wu presented a concept of nanofiltration membrane bioreactor in which high recovery (90%) in water reclamation was obtained compared to ultrafiltration membrane bioreactor (75% recovery).

Session 11: Nanoscale Imaging

When characterising nanofiltration membranes, with pores in the sub-nanometer scale, imaging reaches the limits of technical feasibility, while polymers can be challenging to image due to charging and melting of soft materials. Hans-Georg Steinrück presented an overview of common tools, focusing on advanced nanoscale x-ray microscopy. The basic principle is logical: to probe something one needs a probe of similar scale, where x ray wavelength corresponds to the length of a chemical bond or atomic structure. Atomic absorption (XANES) and scattering diffraction (XRD) being quantitative options that can be operated in scanning mode or full field with the best achievable resolutions currently limited just below 10 nm due to the availability of good lenses. This method is currently applied to fouling. Marcel Dickmann presented porosimetry of nanopores in polymer films with depth resolved positron annihilation lifetime spectroscopy (PALS) that can determine the free volume. The measurement range is 0.2 to 3 nm which is a good match for nanofiltration, while the relation from volume to pore requires special assumptions that can be a challenge, as with most models. Patrick Huber presented materials results with naonoporous silicon from the perspective of a centre for molecular science in a synchrotron facility. His group are exploring membranes with electrically switchable wettability to provide new means for nanofiltrations with stimuli-sensitive hydraulic permeability.

Session 12: Nanofiltration New Materials II

Rhea Verbeke showed her concept of epoxy membranes that exhibit strong chemical (solvent) resistance from ether bonds and can be made with highly-controlled morphological features and amine groups. The wide range of performance that is tunable for specific applications and can be used under these harsh conditions, contrary to state-of-the-art polyamide-based membranes. Joris de Grooth claimed that PFAS with a wide molecular weight range rejection could be rejected with hollow fibre polyelectrolyte nanofiltration, although the particular exclusion mechanisms were not discussed. In addition to micropollutant removal, the hollow fibre polyelectrolyte nanofiltration membranes was described as having great resistance to fouling, chlorine tolerance, and can be cleaned at a wide pH range. Klaus-Victor Peinemann entertained with a 'connecting the dots' exercise that demonstrated how many material combinations have not yet been investigated for membrane filtration, clearly publication potential for decades to come, if this is the chosen approach! Cyclodextrins for interfacial polymerization that results in either transport or adsorption selectivity determined by the shape of the macrocyclic hosts are one of the examples to design for function. Wiebe de Vos returned to multilayers with the claim that all micropollutants can be retained, with 4-6 nm thick active

layer, based on size exclusion without the salt retention of commercial membranes. This also opens up the possibility to separately tune the pore size, salt retention and surface chemistry of the membrane for a specific application. Hanna Roth presented the preparation of nanofiltration membranes with polyelectrolytes crosslinked in the phase inversion process, even though this was conceptually questioned due to the lack of a surface. The open nanofiltration (2000 Da) has a permeability of 0.4 LMH/bar highlighted room for improvement, still this is potentially an exciting development.



Session 13: Renewable Energy & International Development

Bryce Richards kicked this session off by giving an overview of renewable energy options to power membrane filtration, or specifically in nanofiltration the pumps that provide pressure. A careful evaluation and figures-of-merit highlighted the suitability of various options for direct coupling. An example – also included in the book – is the autonomous system that the Schäfer-Richards team has been working on for a couple of decades and the brand new trailer-based system on display at the conference. Mohamed Taky showed results from the field in Morocco with a similar concept, as well as a comparison of ED with NF. Laura Richards highlighted field results obtained from various nanofiltration remediation systems currently in operation in Bihar (India) for arsenic removal and other contaminants. The high dependency on source water composition (particularly iron and phosphorus) to the performance was emphasized. Youssef-Amine Boussouga focused his presentation on the application of decentralised nanofiltration systems for the removal of waterborne contaminants such as selenium, arsenic, uranium, fluoride and nitrate, which cause several health issues at µg/L and mg/L levels. Nanofiltration is a favourable solution for drinking water treatment in remote and rural areas. It can also be adopted in urban areas to reduce the stress on existing centralised water systems and reuse water locally, hence avoiding transport. The transport mechanisms or such contaminants that change characteristics with pH and interact with other contaminants is a challenging endeavour.

Session 14: The Potential of Nanofiltration for International Development

A significant effort was made to enable various participants from 'developing' countries to attend, coinciding also with a number of small collaborative research projects. The last session was created for some of these attendees that are at the forefront of implementing nanofiltration in a developing context, often with significantly less visibility. Saad Alami Younssi prepared composite nanofiltration membranes by deposition of a polypyrrole polymer layer on flat pozzolan and tubular carbone-ZrO_2 microfiltration supports for dye removal. Bourary Sawadogo presented results on a small-scale nanofiltration system in Ouagadougou (Burkina Faso), used for brackish water desalination. Likius Daniel focused his presentation on the photocatalytic degradation of dye with Ag-nanoparticles composite thin films, fabricated by molecular precursor method, with the perspective to be used for micropollutants removal.

This closing session was appropriate for some reflection about the potential impact of nanofiltration to solve global water issues. As (mostly) academics we sometimes get comfortable with research, elaborate discussions and the privilege of travel to nice conferences, like this one. However, when we reflect on what we really achieve, then maybe it is not as much as we would like to imagine. Some inspirational forefathers, like Sidney Loeb (1917–2008), contributed with membranes and modules that remain to-date hard to beat in performance. He achieved this likely with less resources, in a much smaller field, less international colleagues, and long before the creation of 'impact factor'. Perhaps we have become preoccupied with who is the first to solve a problem, rather than working together and actually solving some of the great challenges, such as the provision of safe water for all. For a great leader does not care about taking the credit, but takes joy in the work being done. According to world leading economist, Jerome Engel, innovation requires chaos,

and disruption, while the far from application research is required to fuel implementation when the market is ripe. All participants are somewhere on this s-curve and if we all brought our abilities and contacts together then all kids would have access to water.

Prizes: Six scientific cash prizes in total were given to the best oral (€500) and poster (€300) presentation. For the *STOTEN* prizes, Mohamed Taky received the best oral prize and Anett Georgi received the poster prize. For *JMS* prizes, Rhea Verbeke received the oral prize and Yaeli Oren received the poster prize. For *SPT*, Julia Witte received the oral prize and Ophir Peer Haim received the poster prize. For *Nature*, Razi Epsztein received the oral prize and Vasily Artemov received the poster prize with free subscritions. As indicated above, the most prestigious award of NF2022 was the best dancer award, presented to Dr Thomas Luxbacher (Anton Paar).

Outlook: if we had our wishes granted, we'd do it all again! It was fun and the frustrations and differences were minor, compared to the pleasures. Being "locked up" on the Achalm (with an excess amount of good food) was probably a lot better than being locked into Lichtenstein Castle. Ukrainian and Russian scientists took part and although all are 'expats', it represented a symbol of both solidarity and science over politics in incredibly challenging times. If we are to repeat, then we look forward to welcoming you to the same place, in three-years time (2025), to report on further progress in the field of nanofiltration and to also invite the many colleagues who could not travel in 2022.

Acknowledgements

First and foremost, sponsors help make great things happen. Sponsors contributed through scientific event funding, German Research Council (DFG, ST.TG 03), nanofiltration market information (BCC Research), dinner drinks (Wiley), life band Junik (DOC-Labor), a stunning nanofiltration cake (BeckaBeck), direct participant sponsorship (IFTS, Anton Paar), generous cash poster and oral prizes (Elsevier *JMS*, *STOTEN* and *SPT*), the European Membrane Society (EMS) made available 6 travel awards, DuPont (Dow and INGE) offered membrane modules for the solar powered hybrid ultra- and nanofiltration system on display, Convergence exhibited (but failed to date to pay the suggested modest contribution), while *Nature Water* and *Nature Nanotechnology* offered free *Nature* subscription prizes, and *npj Clean Water* offered the special issue with a reduced open access fees for conference participants, while the Josef Wund Stiftung promoted the new yearly Undine Award for water projects.

Invited speakers are acknowledged for foregoing the expectation that registrations are waived or reduced for invited speakers, or travel costs covered. Our bureaucratic administration and travel laws simply do not

make covering travel costs an option. We have run a model of non-profit registration fees, while many registration fees were waived for developing country participants. Student fees were not reduced, and seeing the low uptake of the EMS travel awards indicated that this was a reasonable decision. Some speakers cancelled at short notice and after some trepidation we decided to not reimburse them. Firstly, some early cancellations explicitly asked to not reimburse in order to support our still relatively high financial risk meeting, while many participants did not travel for failure getting an oral acceptance. In this context late cancellations are simply very annoying and an increasingly-common occurrence at scientific meetings. On the other hand, the bar was open all evenings, which allowed for long discussions in the lobby bar.

Photographers from the team recorded the meeting and captured the moments where Andrea was temporarily detached from her own camera: Akhil Gopalakrishnan, Camila Suliana Raota, Minh Nguyen, Nurul Himma, Zhi-Fu Lin, Phuong Trinh, Ramatisa Ladeia Ramos, Youssef-Amine Boussouga, Bryce Richards, as well as participants who shared some snapshots. The IAMT team played many roles, helping to make NF2022 happen while also learning a lot. It was a pleasure to see the professionalism that made our meeting personal, low key and scientific. Bryce Richards was steady support, fought some of the battles and thoughtfully organised the thank you's that drowned in preparations. KIT administration helped with registrations, financial management of payments and reporting, with Simon Scheuerle deserving special mention for handling this unconventional event with so much international participation. We had considered online or hybrid meeting versus postponements where his experience helped and we made the right decisions. The venue was great, as expected some background battles typically accompany such events, and while the difficulty of finding good people post-Covid was obvious, the Achalm Hotel lost a lot of income through postponements and closures and the staff that were there complimented our very unusual and interesting meeting. The place is perfect and no, we would not want to swap for a more accessible place, being "locked up" together is half the charm.

Finally, Rudi Graf was traced by a former Berghof colleague Michael Henes and convinced to come along, chauffeured by no one other than another former colleague Heiner Strathmann. This has been a very cool closing the loop of this 'homecoming' that started in the late 70's when meeting Heiner Strathmann and the late 80's when Rudi Graf (living on formaldehyde) made tubular membranes and inspired my finding membranes with a loan of the Rautenbach book. It is intriguing to reflect how our children – that were requested by Miriam Balaban to make an appearance – will remember their encounters in a few decades from now.

THANK YOU – and happy nanofiltering!

Prof Dr Ing Andrea Iris Schäfer, Dr Youssef-Amine Boussouga

Institute for Advanced Membrane Technology (IAMT), Karlsruhe Institute of Technology (KIT)
Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
Tel +49 (0)721 608 26906, Andrea.Iris.Schaefer@kit.edu, http://iamt.kit.edu/



Appendix: NF2022 in Numbers

1. Participants

Participants with/without PhD	Participant with PhD (including IAMT)	82
	Participant without PhD (including IAMT)	40
	Total participants	122
Female and male participants	Male participants	84
	Female participants	38
Posters/Oral/IL	External posters	29
	KIT posters	18
	Oral presentations	44
	Opening talks	2
	Invited lectures	11
	Panel session	2 (Nature) 1 (Elsevier)

2. Registrations

Internal and external registrations*	96	(1 registration remains non-paid)
Guest partner registrations	4	
Waiver I (Guest of Honor)	5	
Waiver II (Externals)	10	
Waiver III (IAMT helpers)	15	Off-site accommodation
Total	130	

* *This also includes cancelations that were not reimbursed (it was decided to stay with KIT 3 week cancellation policy*

3. Participant institution countries of origin *(note most Asian countries still experienced Covid Travel restrictions which has limited participation diversity significantly)*

Austria	2	Italy	4
Belgium	4	Morocco	4
Burkina Faso	3	Namibia	2
Chile	1	Netherlands	4
Czech Republic	1	Norway	3
Denmark	4	Saudi Arabia	2
Finland	1	Spain	4
France	4	Switzerland	7
Germany	46	UK	4
Iceland	1	USA	8
Israel	13		

4. **Sponsors** *(Prizes, materials, or speaker travel support paid directly to recipient direct funding DFG only)*

BCC Research	Anton Paar
DFG	EMS
Wiley	Convergence (non-paid)
IFTS	DuPont
DOC-Labor	*Nature Water*
Udine Award	*Nature Nanotechnology*
BeckABeck	*npj Clean water*
Elsevier JMS	*Elsevier SPT*
Elsevier STOTEN	