VDEh-Betriebsforschungsinstitut GmbH

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EU-RFCS-Project “Indiwater”

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1) Summary of the context and overall objectives of the project

Increasing water stress in Central Europe is a challenge for the iron and steel industry. To face it, IndiWater focused on the prediction and control of operating status of process water circuits and treatment plants under consideration of innovative online measurement techniques. Zero liquid discharge (ZLD) techniques were introduced to mitigate the water stress. The performed work in IndiWater focused on these approaches in the context of circular economy and the European Green Deal.

Following the industrial demands to ensure the water supply, the main three objectives of the project were:

I) Development of a prediction tool based on modelling, simulations and impact evaluation of different circuits using new digital monitoring and control systems;

II) Use and development of online measurement to include this in the prediction tool;

III) III.) Improve and adaptation of treatment processes to operate these with zero liquid discharge. These objectives lead to an improved water management using digitalisation and an increased internal water reuse by using new water sources as waste waters.

The progress of IndiWater beyond the state of art was focussing on: Industrial Water 4.0, Prediction tool on basis of SIMBA#, Pre-filtration with new modular ceramic flat membranes and combination of desalting technologies to achieve near ZLD. These innovative approaches and solutions were tested in two different use cases with complex wastewaters which are typical for the steel industry as an integrated steel work and a tin plate production plant.

The investigations have been performed by a well-balanced consortium of research: VDEh-Betriebsforschungsinstitut (BFI, Germany), Luxembourg Institute of Science and Technology (LIST, Luxembourg) and Instituto de Soldadura e Qualidad (ISQ, Portugal), steel industry: thyssenkrupp Rasselstein GmbH (tk-Ra, Germany), Hüttenwerke Krupp Mannesmann GmbH (HKM, Germany) and technology provider of filtration technology CERAFILTEC Germany GmbH (CFT, Germany).

A comparison of the initial situation and solutions for a reliable and sustainable water supply for iron and steel production illustrates **Figure 1**. The work distribution is shown in **Figure 2**.

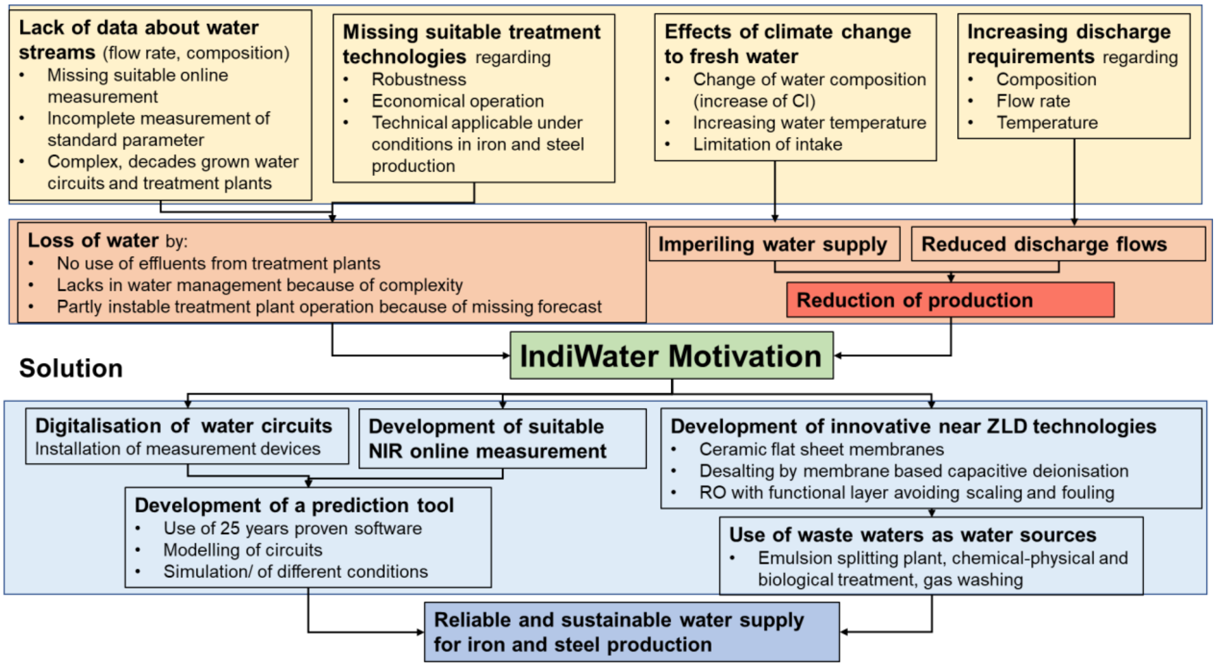

Figure 1 Situation and solution for a reliable and sustainable water supply for iron and steel production

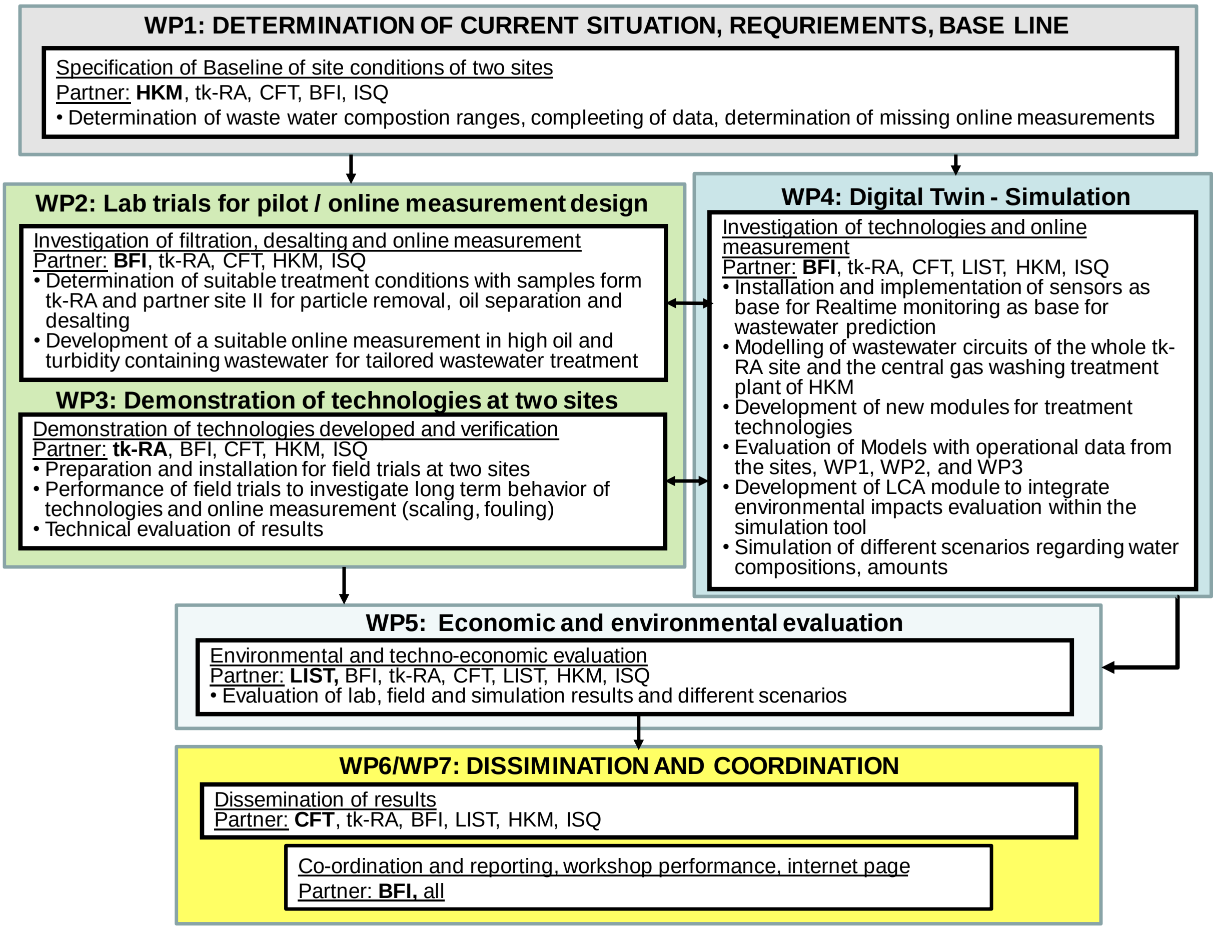

Figure 2 IndiWater project - work package structure and interactions

These aims are directly linked to the achievement of the following scientific and technical work objectives:

- Close the lack of water-related data, namely data on water consumption, stream flow rates and chemical composition, as well as information about complex water systems at the use cases that hinders an effective water management to ensure the water supply for production processes (WP1)
- Determination of optimal operating parameters and cleaning cycles for high flux ceramic flat membranes as mandatory step for removal of oil, bacteria or solids residues before desalting (WP2)
- Determination of suitable desalting technologies: e.g. membrane based capacitive deionization (MCDI), reverse osmosis (RO) using innovative three-layer thin-film composite RO membranes for reduction of scaling and fouling and the removal of critical residues e.g. innovative adsorbents (WP2)
- Development of suitable NIR online measurements for two different complex tin plate production waste waters mandatory for prediction of the operation conditions in the wastewater treatment plants (WP2)
- Operational validation of the selected technologies combination at the two use cases, e.g. gas washing water of blast furnace at an integrated steelwork of HKM and effluent of emulsion splitting plant or chemical/biological treatment plant at tin plate production of tk-Ra (WP3)
- Development of a prediction tool with the popular software system SIMBA# based on modelling and simulations of the different water circuits using new installed digital monitoring and control systems (WP4)
- Modelling and imulation of processes, validation with operational and field trial data for development of a prediction tool for wastewater occurrence and optimization of the internal water management considering technical and environmental parameters (WP4)
- Evaluation of the environmental and economic impacts of the different technologies and applications based on life cycle assessment (LCA) – coupling of LCA modules with SIMBA# to simulate environmental impacts of the different treatment technologies (WP4 and WP5)

<u>Conclusions of the actions:</u>

- Knowledge about variation of compositions of relevant streams within general factor 2 forming the base for the preselection of possible technologies for the water recovery lab trials.
- Concept for selection of technology combinations considering the wastewater composition regarding chloride, sulphate and hardness forming components, based on lab and approved field trial results, as e.g. ceramic flat sheet filtration followed by selective nanofiltration (production of sulphate-concentrate) before desalting by MCDI and production of a chloride-concentrate.

- Proof of applicability of ceramic flat sheet under pressure filtration for a reliable removal of solids, oil, grease or bacteria as mandatory step before desalting in lab and field trials with flux of up to 100 L/m²h with low energy demands of 0.003 – 0.009 kWh/m³ including suitable operational parameter and cleaning procedures.
- Membrane materials selected and successful approved for different applications - polypropylene thin-film composite membrane for separation of the feed in a mainly monovalent (chloride) based permeate and a mainly bivalent (sulphate) based concentrate as raw material for a valorisation - polyamide thin-film composite nanofiltration membrane for combined desalting and softening for chloride contents about 1000 mg/L.
- MCDI applicable for effluents as e.g. gas washing water or central treatment plants for desalting and production a mainly monovalent concentrate with water recovery rates between 60 -70%). Application of thight nanofiltration for treatment of with high chloride contents about 1000 mg/L (permeate fulfils requirements for internal reuse, but occurrence of mixed concentrate).
- Fulfilling of requirements of industrial partners similar to well water composition by treatment of effluents of operational treatment plants possible and approved.
- Internal reuse of wastewaters could open chemical saving potentials as e.g. replacing hydrochloric acid by acidic rinsing water for pH adjustment with high impact regarding Life Cycle Assessment.
- Digital mapping of the water management of an integrated steelworks and tin plate production requiring personal capacity but mandatory for required accuracy and fidelity for simulations.
- Simulation of hydraulic and chemical impact of reuse of recovered water as well impact of black water to the chemical physical treatment plant and the central treatment plant allows evaluation of different conditions and operational conditions.
- NIR online measurement in principle applicable in case of measurement in used degreasing bathes and its rinsing waters (alkaline, solid and oil containing) for a tailored chemical dosage and detection of sporadic occurring high solid and oil loaded water.
- Valorisation of during water recovery occurring concentrates as mono and bivalent concentrates as e.g. raw material for gypsum production or as brine for the electrolytical biocide production. Further, iron and zinc containing solids could be used to recover zinc as oxide by the FASTMET process (rotary furnace with reducing atmosphere).
- Return of investment calculations should consider the impact of production losses caused by a limited wate r ability beside the common costs.

2) Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Within the first reporting in WP1 a **characterization of the different water streams** at two different use cases, a tin plate production (tk-Ra) and an integrated iron and steel works (HKM) were performed, consisting of a winter and a summer campaign, to determine possible seasonal impacts. At tk-Ra 15 samplings, each at 7 different positions in a period between 3 -4 weeks have been performed. At each sampling and for all sampling positions 18 different parameter were analysed or measured, in total 1890. Similar to this, the sampling campaigns at HKM consisted of 10 samplings, each at 14 different positions in a period between 2 – 3 weeks. At each sampling and for all sampling positions 18 different parameter were analyzed or measured, in total 2520. The lower total number of samplings at HKM is related to the fact, that the variations of the water compositions could be determined already after 10 samplings, all laying in the same range. For the tin production and the integrated steel shop case, a strong variation of the wastewater compositions to the internal treatment plants between 50% and up to factor 4 were determined, depending on the current production conditions. In opposite to this, the effluent compositions vary in a limited range compared to the influents. Focus of the internal treatment plants were the removal of oil, COD or suspended solids, depending on the wastewaters. Based on the requirements for an internal reuse, defined by the industrial partners, as e.g. a low solid content, a conductivity < 1200 µS/cm or Cl-content < 80 mg/L and the compositions of the effluents the removal of suspended solids is mandatory before a desalting and/or softening by Membrane-Based Capacitive Deionization (MCDI), reverse osmosis (RO) in combination with nanofiltration (NF), if necessary. The determined data form the base for the evaluation of the current situation and of existing treatment plants and the pre-selection of theologies for the lab trials, focussing on the determination of the technology selection for the field trials. Further, the existing and required and monitoring and process control devices and parameter were defined.

In WP 2 the initial works were focused on the **determination of suitable technology combinations** for the treatment of the selected effluents for tinplate processing (chemical physical treatment plant for alkaline degreasing bath rinsing waters, biological treatment plant after the emulsion splitting plant for used cold rolling emulsions and oily waste waters, central treatment plant) in **lab trials**. Focus on the case of the integrated steelworks case was the effluent of the chemical treatment plant of the gas washing water or the effluent of sand filters for water of a vacuum treatment plant.

Independent form the desalting technology, a removal of suspended solids and organics or bacteria is mandatory to avoid scaling, fouling or clogging. As suitable technology, the use of ceramic flat sheet membranes for under pressure filtration, **Figure 3**, was determined for all effluents, allowing fluxes between 30 to 100 L/m²h. Further on, suitable cleaning conditions has been determined. While 100% of the suspended solids were removed, the removal efficiency regarding COD depends on the distribution between COD in particular form (e.g. oil, flocks, biomass) or dissolved form.

Regarding the effluent of the biological treatment plant of tk-Ra and the effluent of the continuous sand filters for the water from the vacuum treatment plant, the requirements for an internal reuse were fulfilled (e.g for chloride, sulphate and hardness) already after the filtration with ceramic flat sheet membranes. No further desalting was necessary.

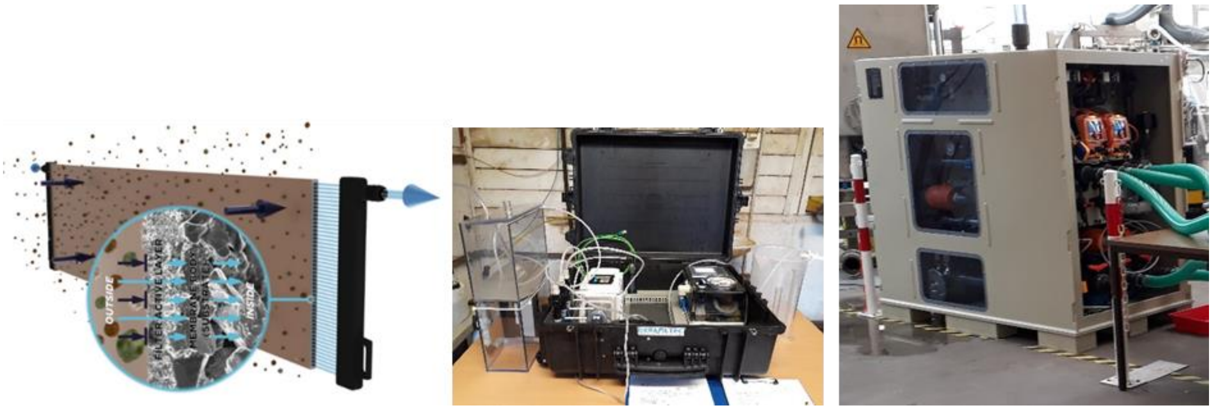

Figure 3 Ceramic flat sheet module (left) - lab MCDI (middle) - field trial MCDI (right)

Further on, the determined contents for chloride, sulphate and hardness formers had to be decreased for fulfilling the requirements for an internal reuse to avoid corrosion or scaling caused by precipitation products.

Further, the production of mono-concentrate by separation of the occurring desalting concentrates in a mainly monovalent and a mainly bivalent containing stream for at later potential valorisation was investigated. Focus of the application of the **nanofiltration** (NF), **Figure 4**, in the IndiWater project is the selective removal bivalent ions as Ca^{2+}, Mg^{2+}, sulphate, in a concentrate, while monovalent ions, especially chloride, will pass. In the work, two different approaches have been investigated: the use of NF as the pre-treatment of high sulphate and calcium loaded effluents to achieve higher water recoveries during desalting by MCDI and the production of the chloride-rich mono concentrate or the treatment for mixed concentrates occurring desalting of average or low loaded effluents to produce a sulphate rich concentrate or chloride rich permeate for a valuations as raw material in e.g. other industries or internally for the electrolytic biocide production (NaOCl). In the first step, a screening with 5 NF thin film composite membranes with different active layers and materials as Polyester, Polypropylene, Polyamide has been performed with a synthetic effluent, consisting of 2 g NaCl/L and 2 g $MgSO_4$/L, using the BFI-Lab test cell. All membrane showed high SO_4-recoveries between 98.1 – 99.8% with a neglectable influence of pressure with similar fluxes between 25 L/mh² up to 140 L/mh². Significant differences in the Cl-retention were determined, in minimum between 15 -20% up to 85 - 90%. For the further trials with the operational samples focussing on the selective removal of bivalent ions, a polyamide NF membrane was selected. Due to need of a sufficient amount of permeate for operating the MCDI, BFI performed trials with the above-mentioned effluent, using the BFI nanofiltration pilot plant. The operational conditions of the cross-flow filtration with modules in industrial size (membrane surface: 2.6 m²), were a pressure of 30 bar with a flow rate of 1,500 – 2,000 L/h. During the trial, the flux decreased and stabilized at about 110 L/m²h, which is in the range of the lab trial with about 92 L/m²h.

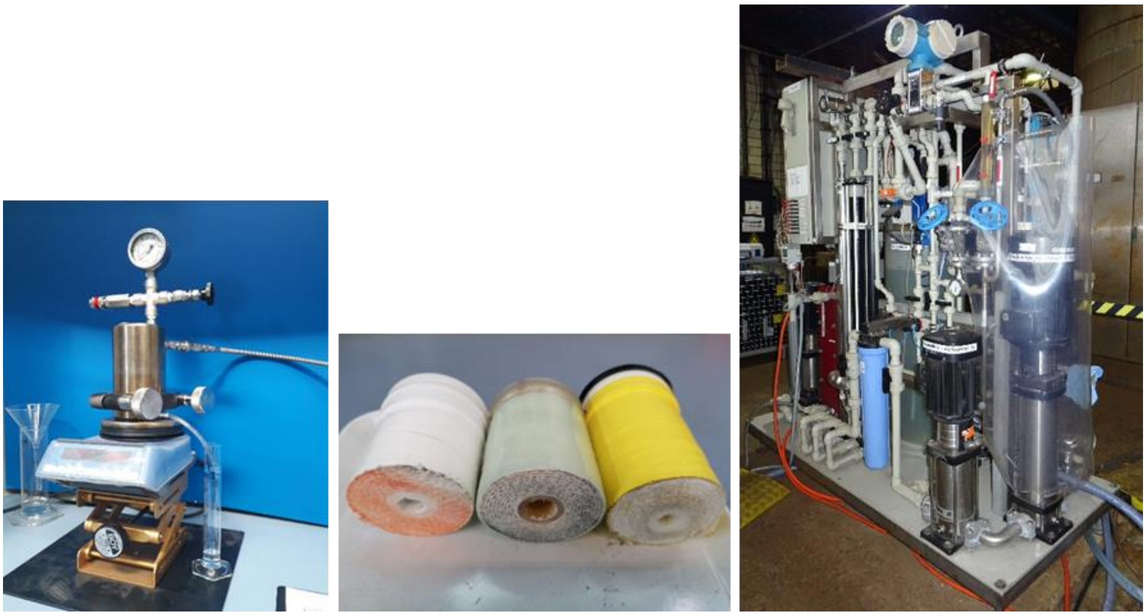

Figure 4 BFI-Lab test cell (left), exemplary membranes (mid), BFI technical scale nanofiltration unit (right)

For the case of the effluent of the chemical physical treatment plant, with chloride contents up to 1000 mg/L, a polypropylene based NF membrane was chosen, due to the not applicability of the MCDI with sufficient water recovery rates. The crossflow filtration trials showed a good accordance with the dead-end filtration trials. The permeate fulfilled the requirements for an internal, while the concentrate, consisting of a mixture of mono and bivalent ions required a further treatment to produce mono-concentrates.

For desalting, Membrane based Capacitive Deionization (MCDI, Figure 5) was used, a comparable new technology for removing of ions from water by electrostatic adsorption on two opposed charged electrodes, covered by ion exchange membranes, by a low-voltage electromagnetic field. During the desalting period, ions are separated from the feed water stream and selective collected at the electrodes behind the anion or cation Exchange. After loading the electrodes, the current is reversed, and the collected ions are released in a so-called concentrate stream. Due to the low maximum voltage of 1.2 V, there is no formation of hydrogen like in other electrochemical processes and no special safety measures are necessary. The used current is directly related to the achieved water quality, meaning the water composition regarding e.g. conductivity or chloride content can be adjusted to fulfil the requirements of the operator.

For the case of the effluent of the chemical physical treatment plant at tk-Ra, with a chloride content of 350 mg/L and a sulphate content of 340 mg/L together with a calcium content of 104 mg/L, different pre-treatment technologies have been investigated. The softening with ion exchange to decrease of the calcium content led to chloride contents of 242 mg/L or 140 mg/L in the pure water of the MDI, missing the operational requirement of 80 mg/L. Due to this, the effluent of the CTP was pre-treated with a selective nanofiltration before MCDI treatment, After adaption of the MCDI parameters, the tk-Ra requirement was fulfilled with a conductivity of 375 µS/cm and a recovery rate of 62%. The energy consumption was about 0.4 kWh/m³ feed.

For the case of the integrated steelworks, the effluent of the chemical treatment plant after the central gas washing water treatment, a combination of ceramic flat sheet filtration, selective NF and desalting by MCDI was determined as suitable technology combination due to the parallel presence of comparable high contents of chloride (370 mg/L), sulphate (240 mg/L) and especially calcium with 190 mg/L.

Considering previous described results, a pattern for technology selection based on the water composition, especially considering conductivity, chloride, sulphate and hardness contents, was developed.

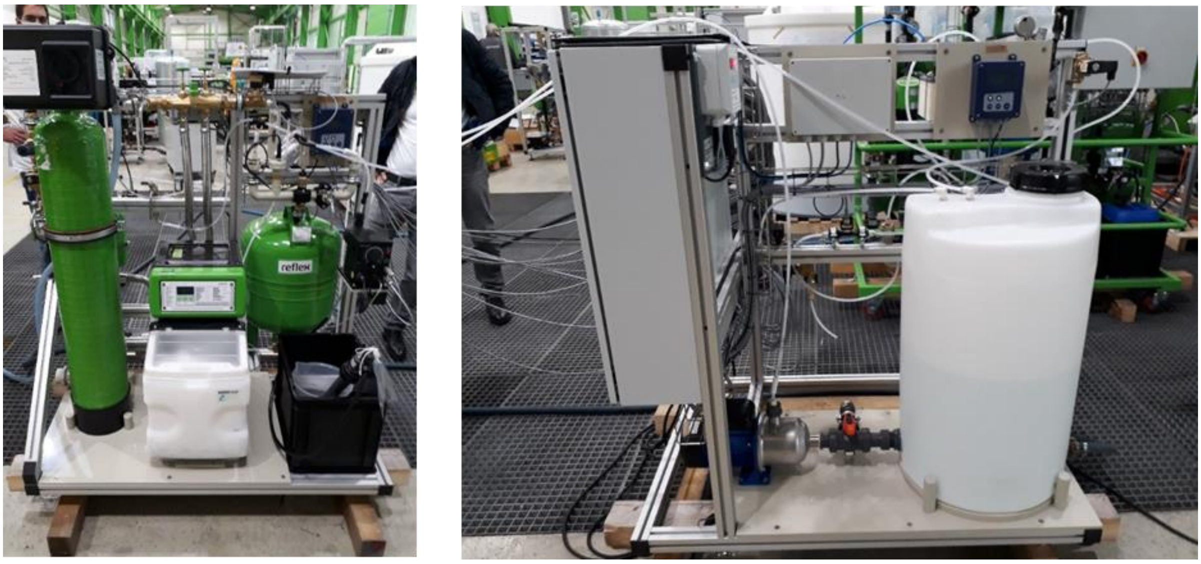

Figure 5 Pre-Treatment unit (left) and MCDI plant (right) at BFI

Beside this, a device for **online measurement in acidic, oily and solid containing effluents** was developed and tested in laboratory with the effluents of the chemical physical treatment plant and the emulsion splitting plant. Background is, that a recovery of water from the effluents of the previous named operational treatment plants required a reliable removal of free oil, grease and solids for an efficient operation. Both influents showed varying flow rates and compositions, due to changes in the production and cleaning processes. This leads to sporadic unstable operation conditions in the treatment plants causing an insufficient oil water separation correlated to additional efforts as manual treatment. A correlation between production conditions and effects to the treatment is not known. In the first step, different light sources with different wavelength have been tested with operational samples, showing that in the spectrum of UV and VIS light no evaluable differences in the spectral range of 750 nm and 1050 nm were visible, but in the range of NIR. The developed NIR sensor was tested with samples of inlet during common operation and a high loaded sample, with a composition out of the determined common range. The measurement of this sample showed a curve and peak, differing from the previous samples. In deeper chemical analyses, increased values for sodium and potassium were determined. Based on the results, two measurement devices were built and installed at the operational plant of tk-Ra.

For the treatment of the tk-Ra effluents from degreasing (degreasing bathes and rinsing waters) and cold rolling (emulsions) a stable and reliable operation of the emulsion splitting and chemical treatment plant removal of oil and fat is mandatory for a reuse after further treatment. Considering this, the effects using acidic sulphur containing wastewaters or alternative acids as H_2SO_4 instead of fresh acid (HCl) to lower the pH-value in the oily wastewater treatment plants was investigated. The achieved COD and oil removal rates over 60% or 90% were in range of the average values of chemical physical treatment plant, if acidic wastewater or H_2SO_4 is used as alternative chemicals for adaption of the pH-value. Further, an accelerated phase separation and water clarification was noticed.

In field trials, the in lab trials determined suitable technology combinations (**Figure 6**, **Figure 7**) were demonstrated at the industrial partners tk-Ra (tin plate production, **Figure 8**) and HKM (integrated steelworks, **Figure 9**) in a period of 7 month for the following effluents.

- Chemical physical treatment (CPT, tk-Ra): ceramic flat sheet filtration, tight NF
- Biological treatment (BTP, tk-Ra): ceramic flat sheet filtration, MCDI (optional for production of demineralized like water)
- Central treatment plant (CTP, tk-Ra): ceramic flat sheet filtration, selective NF, MCDI
- Gas washing treatment (HKM): ceramic flat sheet filtration, selective NF, MCDI

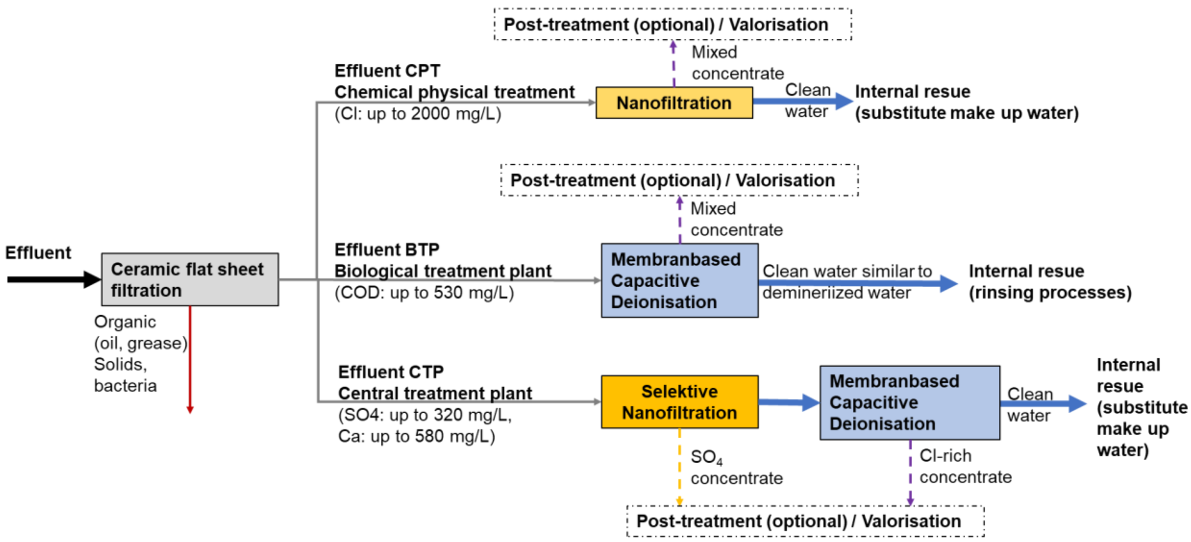

Figure 6 Pattern of wastewater treatment technology selection for tin plate production

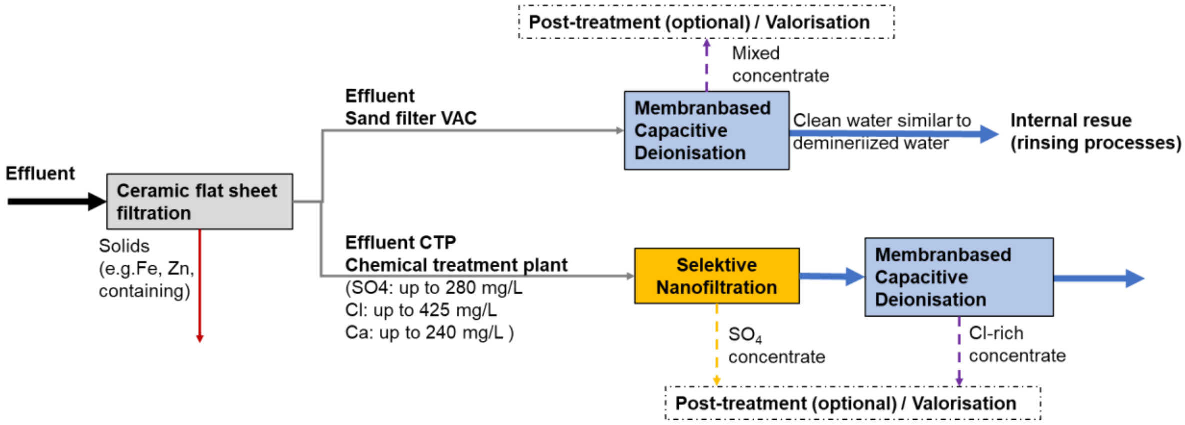

Figure 7 Pattern wastewater treatment technology selection for integrated steel shop

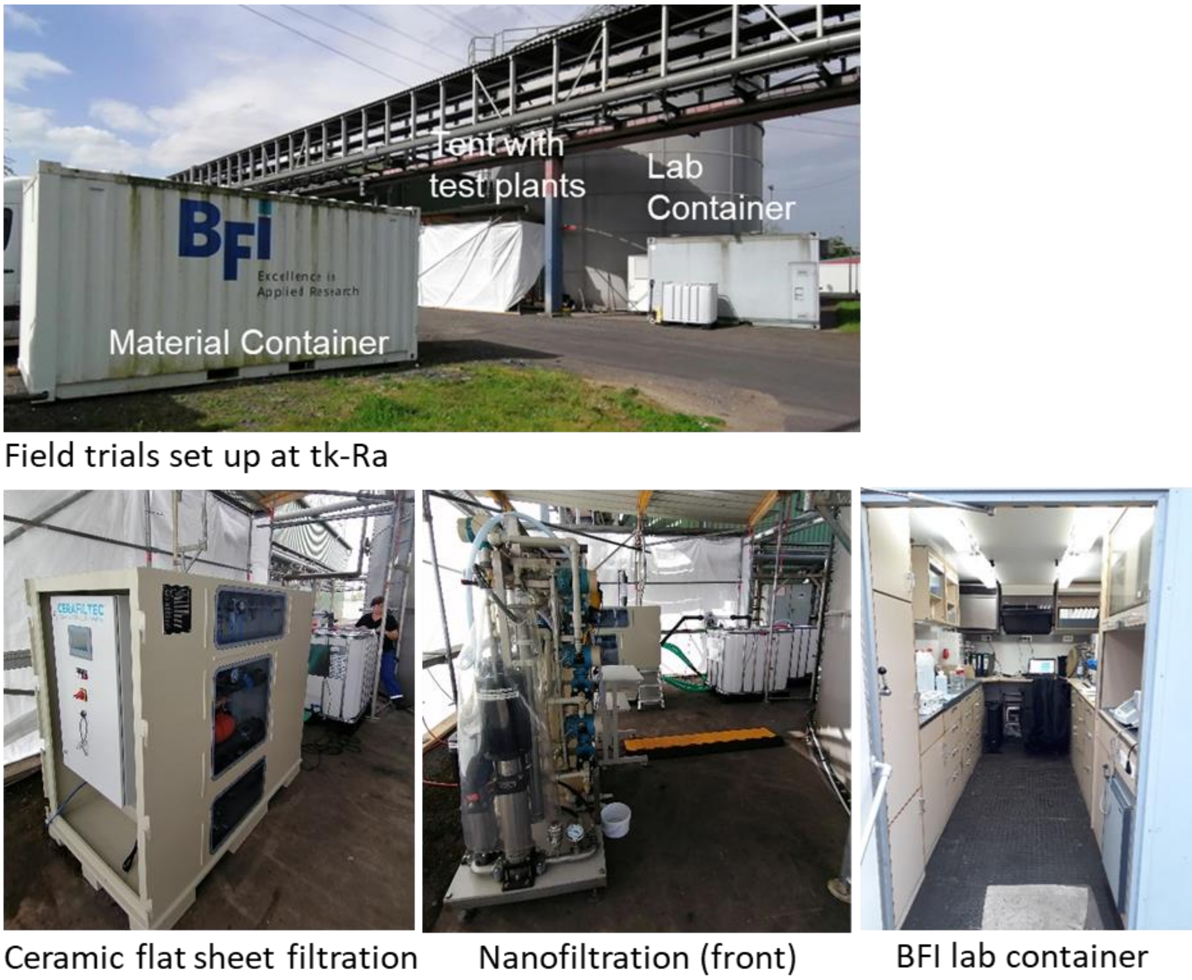

Figure 8 Field trial set-up for the effluent of the chemical physical treatment plant at tk-Ra

Figure 9 Field trial at effluent of the chemical treatment plant (CTP) of HKM (CTP (left), buffer and filtrate tanks in front of CTP (centre), ceramic flat sheet filtration at HKM (right)

For all applications of the **field trials (WP3)** the produced waters fulfilled the requirements of for an internal reuse, which are similar to well water compositions. Further, the field trial results showed a good accordance with the lab trial results. In all case, the ceramic flat sheet filtration achieved a complete removal of solids and particular compounds. operating stable with water recovery of 99%, with flux in up to 125 L/m²h in combination with water recovery rates of 99% and energy demands between 0.003 – 0.009 kWh/m³. Due to the presence of organic, a periodical chemical cleaning with sodium hypochlorite is necessary for all cases of **tk-Ra**, and an additional acidic cleaning in the case of the central treatment plant. The aimed water recoveries for the effluents (chemical physical treatment plant: 60%, biological treatment plant: 75%, central treatment plant: 50%) of tk-Ra have been achieved with the technology combinations. In the **case of the integrated steel work (HKM),** the effluent for the field trials was changed from the effluent of the continuous sand filters of the vacuum treatment plant to the effluent of the chemical treatment plant after the gas washing water treatment plant. Background is, that after the change of the sand of all filters, the zinc content of the effluent decreased from sporadic zinc contents over 2 mg/l down to continuous below 0.5 mg/L, due to removal of accumulated zinc in the sand. During operation of the ceramic flat sheet filtration, a cleaning effect of the H_2O_2, dosed in the operational chemical treatment plant, was observed, leading to a decrease of the required trans membrane pressure and a chemical free operation with a stable flux of 125 L/m²h and an energy demand of 0.0035 kW/h. The water recovery rates were 99% for the ceramic flat sheet filtration, 75% for the selective nanofiltration for removal of bivalent ions and 69% for the membrane based capacitive deionisation for producing a monovalent concentrate, both concentrates for further valorisation.

The applicability of the NIR online measurement was demonstrated in field trials in WP3 (**Figure 10**) for the case of the strong alkaline, organic and solid loaded wastewater of the chemical physical treatment plant. A correlation of the NIR signal intensity with the splitting agent ($FeCl_3$) dosage was determined, as well as a correlation of inlet conductivity and the dosage of HCl for pH-adjustment (neutralisation). For the case of the emulsion splitting plant influent, the measured NIR signal was only in the range of the random noise, due to the low load of the wastewater, consisting of used cold rolling emulsions and oily wastewater from cleaning processes. Due to this, correlations were determined between already measured parameters in the emulsion splitting plant. After the installation at the inlets of the chemical physical treatment plant (CPT) or of the emulsion splitting plant (ESP) and three months of operation, leakages occurred, causing damages at the electrical and mechanical parts of the measurement devices. The design of the NIR online measurement devices was reworked, realized and the field trials continued. During the rework, it could be seen, that there were no impurities or layers on the optical measurement part, indicating a sufficient work of the mechanical cleaning after each measurement.

Figure 10 NIR-Measurement device set-up and operational installation at ESP emulsion feed

In WP4 digital twins of selected water circuits within the defined system boundaries – tk-Ra: complete wastewater treatment including ESP, CPT, biological treatment plant (BTP) and central treatment plant CTP as well as HKM: central gas washing water treatment system including VAC plant – were developed. **Figure 11** illustrates the concept for digital twin development and operational application in the steel industry. **Figure 12** shows exemplarily the main view of the developed digital twin for HKM gas washing treatment system.

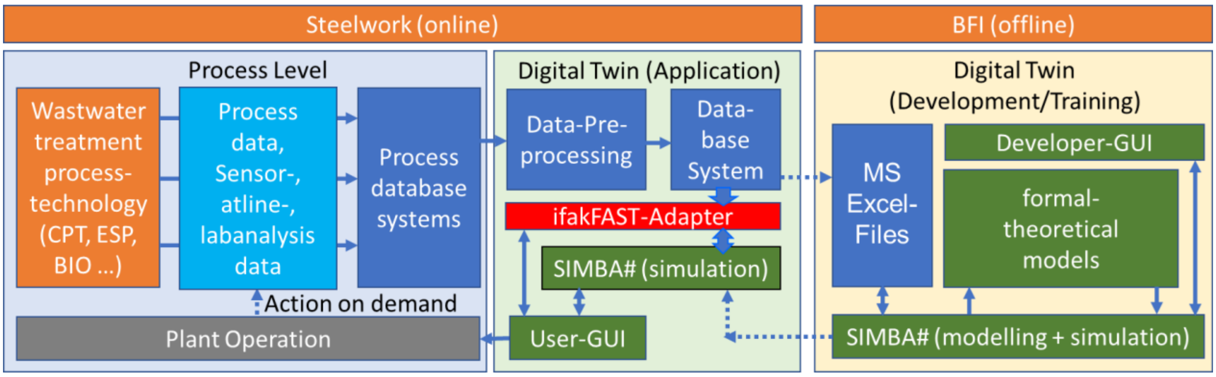

Figure 11 Application-concept of digital tools to model operational water and wastewater management in the steel industry

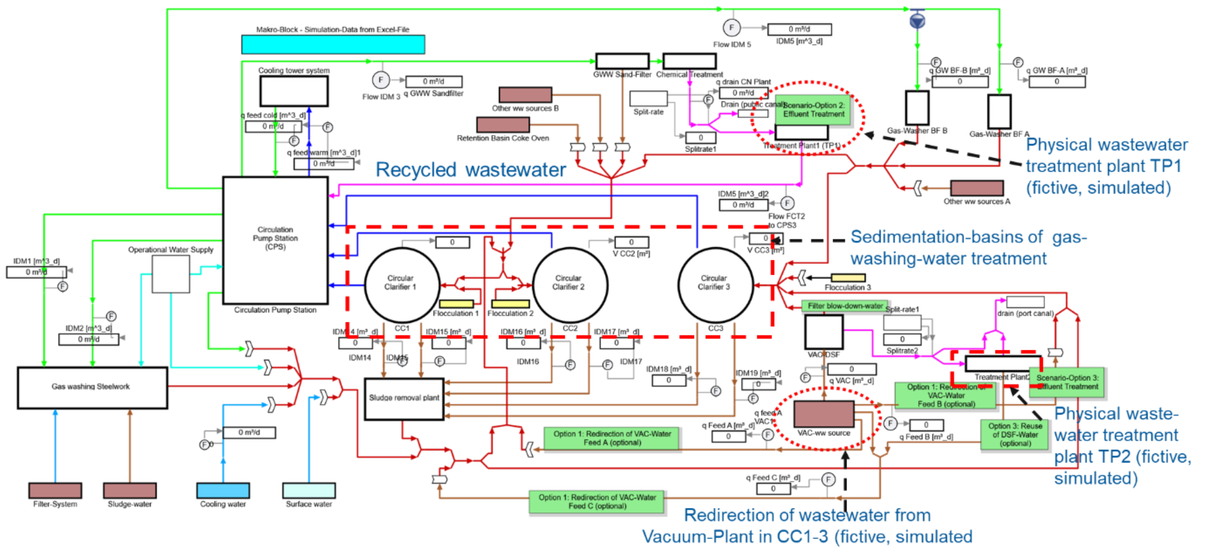

Figure 12 Digital mapping of the gas washing water treatment network of the integrated steelworks

During the reporting period, the different scenarios have been simulated in SIMBA# (WP4), focusing on the impact of the reuse of recovered water to the composition, the occurrence of high solid and oil load black water or as the hydraulic capacities in the gas washing water treatment basins for the case of using water from the vacuum treatment as fresh water substitute in presence of different varying intake flows. An online-Version of the HKM SIMBA#-model was connected to the operational process database system successfully.

Further on, the SIMBA# models have been combined with tool for performing life cycle assessment for the different selected technology combinations and effluents (see scheme of data compilation from SIMBA# models in **Figure 13**). The LCA showed, that highest impact could be achieved by decreasing the chemical use, e.g. replacing HCl by acidic wastewater for pH adjustment in the chemical physical treatment plant. Further, the treatment of the effluents is decreasing the impacts regarding climate change, freshwater eutrophication or e.g. fossil depletion.

The cost evaluation of (WP5) showed that capital costs have a share of about 40 -50% of operational costs. For the technology combination of ceramic flat sheet filtration, selective NF followed by MCDI applied for effluents of the central treatment plant (tin plate production, tk-Ra) and the chemical treatment plant (integrated steelworks, HKM), the total treatment costs are 1.05 €/m³ or 0.88 €/m³. About 24 – 29% of the costs are related to the energy consumption of the selective NF, due to the required operational pressures, while lowest energy costs occur for the ceramic flat sheet filtration (0.012 – 0.030 €/m³). The energy costs for the MCDI are between 0.025-0.064 €/m³. The determined return of investments (ROI), without considering vouchers for concentrates or costs for disposal, are between 10 to 22 years. For a final evaluation of the ROI, the case of a limited water outtake e.g. in summer over three weeks and causing a decrease of the production of 10%, would lead to a loss of about 24.000 t of steel (production site capacity: 4 mio. t/a) with a financial impact of about 24 mio. €.

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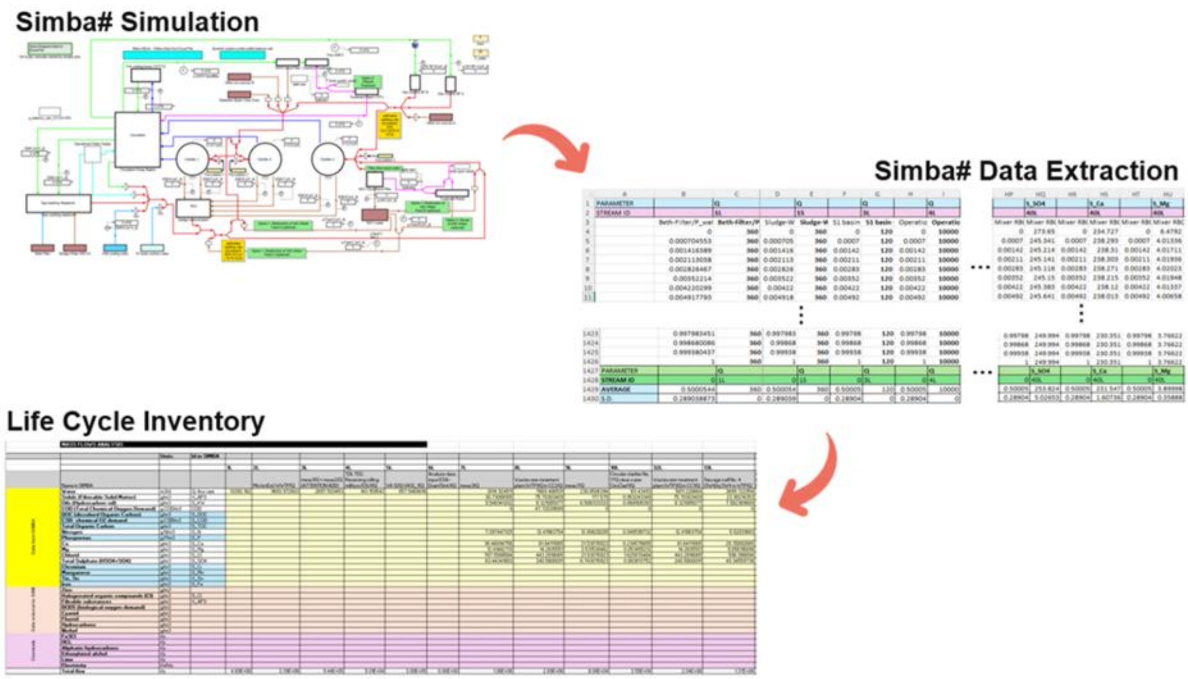

Figure 13 Scheme of data compilation from SIMBA# models - simulation data export to the creation of the Life Cycle Inventory

Possible valorisation ways (WP3/5) for the mono and bivalent concentrates from the water recovery processes are e.g the use as raw material for gypsum or as brine for the electrolytical biocide production. Further, iron and zinc containing solids could be used to recover zinc as oxide by the FASTMET process (rotary furnace with reducing atmosphere). The methodology used during this task is represented in **Figure 14**.

The results of the lab and field trials at tk-Ra and HKM form the base for the life cycle assessment, focussing on the environmental impact of the investigated technology combinations and approaches. The methodology is standardized under ISO 14040 and 14044, ensuring consistency and credibility in its application. The most impacting source of environmental loads in the initial situation were the addition of chemicals as polymers and coagulants for water treatment, but especially the dosage of HCl for pH-adjustment. For the different technologies, cleaning chemicals as NaClO has an environmental impact, depending on the dosage and the required frequency. Lowest environmental impact has the treatment of the effluent of the chemical physical treatment plant followed by the treatment of the effluent of the central treatment plant and final of the biological treatment plant. In the case of the integrated steelworks, the treatment of the effluent of the chemical treatment plant and the reuse of the water has a noticeable positive impact.

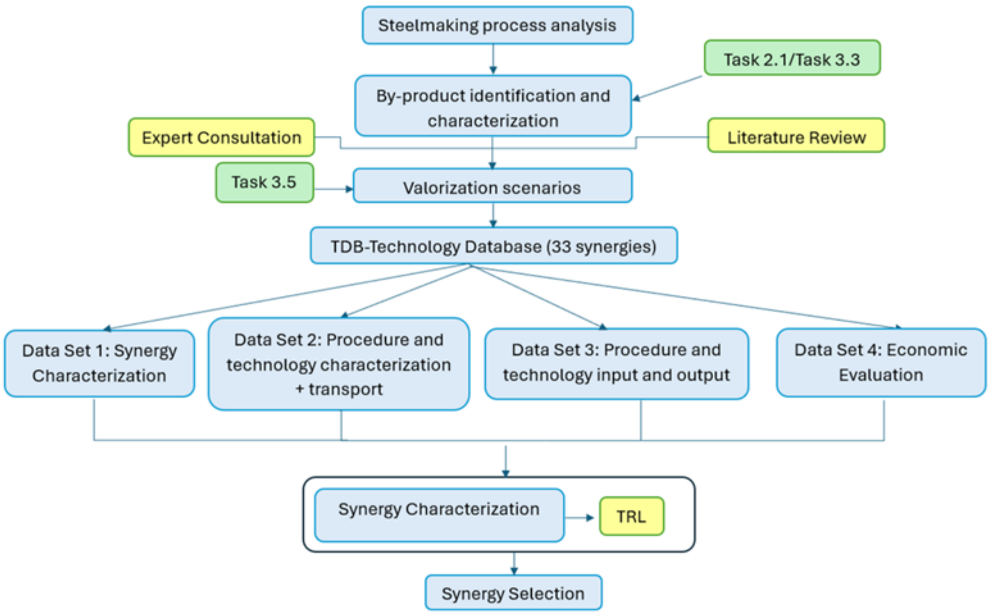

Figure 14 Methodology used within identification of valorisation scenarios for waste water treatment plant concentrates

Further on, the prognosed results of SIMBA# were combined with the ecoinvent dataset to predict the environmental impact. “Indiwater” tool is a graphical user interface developed in Python software to run LCA simulations. This tool reads the simulation outputs from SIMBA#, including water flows, composition, consumption of energy and chemicals as well as outputs/co-products flows. This data is linked with ecoinvent database to model upstream and downstream process and calculate relevant environmental indicators such as climate change or water use. The tool developed offers significant advantages for decision-makers, researchers, engineers, and consultancy companies involved in wastewater management. By linking software simulations directly to the environmental footprint of wastewater systems, it provides a clear and data-driven foundation for making informed choices. Decision-makers can use it to identify optimal strategies that balance operational efficiency with sustainability, ensuring smarter and more impactful investments. This combination of technical and environmental insight empowers various stakeholders to create sustainable, efficient, and forward-looking wastewater management solutions.

In the project, **dissemination** activities as publications or presentations and a youtube video were performed for a transfer of the project. This included the presentation at the participants homepages and conferences, publication of articles in journals and visit of 11 European and international fairs by Cerafiltec, using the project flyer. Further examples for the dissemination activities are the presentation at the ESTEP Spring Event in March 2023 or regular technical discussions with the developer and manufacturer of the membrane based capacitive deionisation (MCDI), company Grünbeck AG. Beside this, an article was published focussing on potential Industrial Synergies in the Steelmaking and Metal-Processing Industry (DOI: 10.3390/su152115323). Further on, LIST produced a public promotion youtube video related to the IndiWater project (https://www.youtube.com/watch?v=9gMmooJC3_k) on the LIST youtube channel with 1760 followers. Further on, a workshop with 34 participants from 7 different industrial areas, mainly from iron and steel industry, but even plant manufactures for iron and steel industry or chemical industry and mineral producer as supplier of iron and steel industry, was performed.

3) Progress beyond the state of the art, expected results until the end of the project and potential impacts

The progress of the IndiWater project beyond the state of art, are the following key technologies and solutions as pre-filtration with new modular ceramic flat membranes and combination of desalting technologies to achieve near ZLD. Further, IndiWater placed digitisation and automation at the centre of the approach exemplary for two use cases (integrated steelworks, tin plate production) for resource-efficient, flexible and competitive water management by assessment of monitoring needs to deliver a holistic approach and the development of digital process twins and simulation-based prediction tools (e.g. using commercially available software SIMBA#) for an improved water management by optimum usage of water. Both have been developed.

- Zero Liquid Discharge (ZLD) – In IndiWater several new and established (new to application field or combination) treatment technologies for near-zero/zero liquid discharge were developed and validated. An important added value is the near-zero water discharge in the industry through the maximization of the process interrelationships between primary and secondary production. In this regard a recommendation system will be created, which is able to offer strategic decision making focused on advising the industrial stakeholders about efficient configuration strategies over current systems, addressing investment cost and/or advising about new technology investment into the industry to improve water reuse and recycling.
- Prediction tool on basis of SIMBA# - first time a prediction of the occurring wastewater amount and composition was developed. Because of the independency of the commercial software SIMBA# there are no risks regarding the basic functions of the software and the interface compared to software platforms as Modelica used in EU RFCS project WHAM. In addition to temperature (enthalpies) and volume flows (hydraulic), dissolved components (e.g. Cl, SO_4), undissolved components as particles can be considered in the simulation.
- Pre-filtration with new modular ceramic flat membranes for solid removal before suitable desalting technologies was performed. Main advantage compared to conventional pressure filters is the low energy demand with high fluxes up to 1000 L/m^2h in combination with high chemical resistance. Advantage of innovative ceramic flat sheet UF module solution compared to polymeric hollow fibre membranes are a higher withstand (temperature, pH) combined with higher fluxes and lower back wash frequencies in combination with lower energy consumption being operated under 0.3 bar pressure.
- Application of NF-filtration in combination with MCDI for desalting of complex wastewater. NF was used in combination with MCDI for lab testing on waste waters. The added values are the selective removal of divalent ions (Ca^{2+}, Mg^{2+}, sulphate) for production of a mainly chloride containing feed for further deionization. The Cl- enriched stream will be up concentrated in a desalting unit

and will be used as base for the electrolytic biocide production (NaOCl). A further added value is the application of a tight NF for production of a permeate fulfilling the requirements for an internal reuse but without the corrosive properties of demineralized water from reverse osmosis.

- Near-infrared spectroscopy (NIR) for oily, solid containing and partly alkaline has been developed for a real-time detection of the occurrence of problematic waste waters, disturbing the treatment plant operation. This is a mandatory based for the development of the prediction tool for stable water treatment plant operation.

The results of the IndiWater project are a contribution to a sustainable steel production by water recovery from wastewaters leading to a decrease of the freshwater demand and discharge amounts as well as a contribution to environmental conservation. This is in a line with EU goals focussing on Zero Discharge, Zero Waste (circular economy) or good water quality in surface waters (EU water directive, European Green Deal).

Exemplary in detail, regarding the tin plate production case of tk-Ra, the in lab trials determined and in field trial conditions approved technologies open up potential water savings by water recovery of water from the effluents of different internal wastewater treatment plants which are currently discharged. The aimed water recovery has been achieved for the applied cases, e.g. allowing water recovery of 75% or 110 m³/h of water in the case of the chemical-physical treatment plant for the treatment of alkaline degreasing process waters from surface treatment, meaning an annual potential water savings of 884,000 m³. Further cases were the effluent of the biological treatment plant after emulsion splitting from rolling mill process waters and the central treatment plant for treatment acidic rinsing process waters from surface treatment before discharge.

Due to the holistic approach of IndiWater, possibilities for reuse of materials or the possible valorisation ways of occurring concentrates during the water recovery have been considered. A material recovery could be achieved by replacing hydrochloric acid by operational occurring acidic wastewaters for the adjustment of the pH-value in the chemical-physical-treatment plant. Further impacts are a decrease of the lime demand at the neutralisation plant, because the acid wastewater is already neutralized, and a significant decrease of the chloride intake leading to a decreased chloride discharge to the river.

Further, the produced monovalent and bivalent concentrates could be used as substitutes for raw materials for the electrochemical production of biocide or to produce gypsum, in principle. Beside this, oil and organic containing sludges from filtration could be used a substitute fuel in the case of a thermal valorisation to produce energy, heat and steam.

In general, the water demand for iron and steel production varies strongly, e.g. for raw iron production in blast furnaces between 8.8 to 23 m³ of water are used per ton of raw iron due to different local conditions. The values for the water demand consider for gas washing, furnace cooling and material (slag) conditioning. Considering a European crude steel production of approximately 130 million tons in 2024 in about 70 blast furnaces, a freshwater demand of about 2,000 million m³ of fresh water per year. Assuming a water recovery of 10%, the water saving potential is about 200 million m³/y.

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