Annex XVII

MEMBRANE FILTRATION FOR ENERGY-EFFICIENT SEPARATION OF LIGNOCELLULOSIC BIOMASS COMPONENTS
1. **Background**

Lignocellulosic biomass is an abundant and renewable resource which can be used for production of fuel, platform chemicals and value-added materials. However, purification and concentration of biomass components on an industrial scale puts high demands on cost and energy-efficient methods to separate the components as separation usually accounts for 60 to 80% of the process cost of most mature chemical processes\(^1\). Development of energy and cost efficient separation processes to be used in biorefineries is therefore of utmost importance.

Distillation is the unit operation that dominates the separation scheme in petroleum refineries as most compounds are volatile. In contrast to petroleum compounds, most compounds derived from biomass are non-volatile. Especially size, and to some extent charge, are the main separation characteristics of extracted biomass compounds, which make membrane processes a natural key separation technique in biorefineries.

Process streams in biorefineries are commonly relatively dilute, which means that large volumes of water needs to be removed. Guiding principles for the energy requirement for evaporation is 30-40 kWh per m\(^3\) water removed, for ultrafiltration < 5 kWh/m\(^3\) and for reverse osmosis < 10 kWh/m\(^3\). It is therefore commonly tried to reach as high dry content as possible by membrane filtration before energy-intensive drying techniques, such as evaporation and spray drying, used for final drying. Furthermore, a high volume reduction also results in a purer product. 95% to 99% are representative volume reductions when membrane processes are used to concentrate biorefinery process streams. However, the energy requirement of membrane processes increases markedly with concentration which means that great care is needed, not only when optimising the operation conditions of the membrane processes, but also to decide at which point concentration shall be terminated.

Development of new biorefinery processes is often carried out by persons with deep knowledge about biotechnology but no, or only limited, experience of membrane processes. In order to optimize energy-efficiency and fractionation ability of membrane processes instructive guidelines about how to design and operate membrane plants in biorefineries are needed.

2. **Industrial Area**

Membrane processes have been in industrial use since the 1960s. They are used in a variety of applications, such as desalination of brackish water and seawater, purification

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of oily wastewater, recovery of electrodeposition paint, and sterilization of liquids and gases. Design and operation of membrane plants to be used in biorefineries will to a large extent be based on the experience and rules of thumb obtained in established membrane applications. However, process streams in biorefineries are complex, multi-component mixtures, often with compounds that foul membranes. Purification and concentration of biomass compounds in an energy-efficient and environmental friendly way is thus a challenge.

 Flux and cleaning frequency are key parameters in membrane plants. High permeate flux and low fouling tendency can be achieved by:
- using high-shear forces
- operating below critical flux
- combining membrane filtration with adequate pretreatment methods.

 Knowledge about the influence of process stream characteristics and operating parameters on energy requirement and product quality is needed when designing the separation stages in a biomass based process. In this Annex researchers from academy and industrial partners will work together to implement the use of energy-efficient membrane processes in biorefineries.

 3. Objectives and Scope

 The objective of this IETS Annex is the development of sustainable and energy-efficient separation methods enabling utilization of renewable resources for production of chemicals, materials and energy by:

- Creation of a network of experts involved in projects with the aim of recovering value-added components in biomass.
- Bringing together and sharing information on the present state of sustainable and energy-efficient separation methods to be used in biorefineries.
- Creation of guidelines for design and optimization of membrane processes in biorefineries.
- Survey of fouling and cleaning of membranes in biorefineries.

 Dissemination of the results will take place during meetings in the Annex, seminars with industrial participation and presentations at scientific conferences. Moreover, each subtask will be presented in the format of a handbook to be used as a guideline for each treated topic.
4. **Means**

The objectives shall be achieved by performing the following subtasks:

4.1 **Subtask A. Recovery of biomass components**

Lignocellulosic biomass is composed of carbohydrate polymers (cellulose and hemicelluloses), an aromatic polymer (lignin), pectin, protein and extractives. Depending on the raw material, the composition and the content of various compounds vary. Biomass is commonly extracted in neutral, acidic or alkaline water solutions.

Extraction of biomass yields a complex, multicomponent mixture. The molecular mass of different biomass components is commonly overlapping which complicates separation. Moreover, the molecular mass distribution of different components is usually wide. Techniques used in research laboratories (e.g. size-exclusion chromatography) are excellent for producing small quantities of pure substances. However, these processes are difficult to scale-up, which limits production levels.

The objective of this subtask is to present a synthesis of methods to isolate biomass components, on a laboratory and industrial scale. Energy requirement, process cost and purity of product streams using a variety of separation configurations are studied in conjunction with subtask C. Potential fouling substances are identified in conjunction with subtask D.

4.2 **Subtask B. Sustainable and energy-efficient separation methods in biorefineries**

Membrane processes have been used in pulp and paper mills since the late 1960s treating process streams containing dissolved biomass material. The majority of applications have been aimed at the treatment of bleach plant effluent, fractionation of spent sulphite liquor and black liquor, and treatment of white water in paper mills. Replacement of fossil based raw materials with biomass will accelerate in the future, increasing the need of energy-efficient separation processes. Experience of membrane process applications in pulp and paper mills will then be a valuable knowledge basis in the development of separation processes in biorefineries of tomorrow.

The objective of this subtask is to compile a survey of membrane applications in the pulp and paper industry and in biorefineries. Influence of module design, membrane material and operation conditions on energy requirement and costs will be studied.
4.3 **Subtask C. Design and optimization of membrane processes in biorefineries**

Separation accounts for a considerable amount of the cost of chemical processes. Optimization of membrane processes in biorefineries in order to reduce investment and operating costs is thus a prerequisite for the implementation of new biobased chemicals produced from non-food renewable raw materials, such as wood and agricultural residues. Furthermore, in biorefineries we can foresee separation processes, in which several separation stages are combined, for recovery of chemicals and energy, giving maximal economical benefit while maintaining the high quality of products and fresh water. Operating parameters that need to be optimized include feed concentration, permeate flux and module hydrodynamics.

Energy requirement in membrane plants is mostly associated with electricity used for pumping. Membrane plants are equipped with a feed pump to deliver the inlet pressure of the plant, and circulation pumps to compensate for the frictional pressure losses and to maintain a certain circulation flow in the membrane modules. The energy required by the feed pump to deliver the inlet pressure usually dominates in reverse osmosis and nanofiltration plants, whereas the energy required in the circulation pumps to maintain a certain cross-flow velocity dominates in microfiltration and ultrafiltration plants. A decrease from 24 to 4 kWh/m³ achieved by reducing the cross-flow velocity in an ultrafiltration plant treating waste water in a pulp mill ² is only one example of the importance of optimization of operating parameters in membrane plants.

The fractionation of substances in biorefineries must be performed in a number of subsequent stages, using a cascade configuration including membrane, as well as other separation processes. The objective of this subtask is to demonstrate how design of processes in biorefineries influences product quality and costs.

4.4 **Subtask D. Fouling and cleaning of membranes in biorefineries**

Reduction of fouling and efficient cleaning is of great importance when a membrane process is implemented on an industrial scale. There are three main fouling mechanisms: cake layer formation, pore blocking and adsorption. Cake layer formation and pore blocking can occur if the solute molecules are large enough to be retained by the membrane. If, on the other hand, the solute molecules are small enough to enter the pores they may be adsorbed onto the pore walls of the membrane. The adsorbed molecules can then reduce the effective pore diameter resulting in an increase in the membrane resistance. The influence of different parameters on fouling is often

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application specific, and the development of cleaning procedures is usually a matter of trial-and-error.

Cleaning has a great impact on the cost of membrane plants as energy is needed for heating of the rinsing water and cleaning solution, cleaning reduces the lifetime of the membrane and shut-down for cleaning reduces the operation time. The objective of this subtask is to compile information about fouling phenomena and cleaning methods in applications where biomass is treated.

4.5 Organization of work

The participants shall establish a Technical Advisory Committee consisting of the Subtask leaders and the Annex manager. The Technical Advisory Committee shall assist the Annex manager in the co-ordination of the Annex and advice the Annex manager on the performance of the Annex.

The Annex manager will organize Annex meetings. The participants of each subtask may also decide to organize separate subtask meetings. Meeting in this context does not necessarily imply gathering participants at the same place, thus adding to greenhouse house gas emissions from transportation, but can just as well be internet meetings.

5. Results

The deliverables in the Annex will be:

1. Status reports presented to the IETS Executive Committee.
2. Newsletters presented at the IETS homepage.
3. For each of the subtasks summarize the results in the format of a handbook that can be distributed to industry and organizers.

6. Program Annex Plan

Work will be performed in all subtasks during the entire time of the Annex. However, the activity in the subtasks will vary depending on on-going activities in the participating countries. All participants will participate to a greater or less extent in all subtasks, depending on the specific basic research area of the participant.

Student exchange activities will be part of the Annex activities, thereby strengthen the membrane research network.
7. **Dissemination**

7.1 **Dissemination**

The results from the Annex will be disseminated through the following activities:

- Status reports, newsletters and handbooks from each subtask.
- Meetings to exchange information on the progress of the work in the subtasks.
- Organization of at least one industrial workshop during the length of the Annex.
- Presentation of the results at international meetings and conferences such as Euromembrane hosted by EMS (European Membrane Society) and Nordic Filtration Symposium (hosted by The Filtration Society).

7.2 **Intellectual property rights**

The publication, distribution, handling, protection and ownership of information and intellectual property, arising from this Annex, shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.

Subject only to copyright restrictions, the participants shall have the right to publish all information provided to, or arising from the Annex, except proprietary information.

The participants and the Annex manager shall take all necessary measures, in accordance with the laws of their respective countries and international law to protect proprietary information, provided to or arising from the Annex.

For the purposes of this Annex, proprietary information shall mean information of confidential nature, such as trade secrets and know-how (for example, computer programs, or design procedures and techniques), which is appropriately marked, provided such information:

- is not generally known or publicly available from other sources
- has not previously been made available by the owner to others without obligation concerning its confidentiality
- is not already in the possession of the recipient participant without obligation concerning its confidentiality.

It shall be the responsibility of each participant, supplying proprietary information to the Annex manager, or, if subtasks are formed, to a lead country, to identify the information as such and to ensure that it is appropriately marked.

The Annex manager should encourage the governments of all participating countries to make available or to identify to the Annex manager all published or otherwise freely available information relevant to the Annex.
Each participant agrees to provide to the Annex manager or, if subtasks are formed, to the Lead Country, all previously existing information, and information developed independently of the Annex, which is needed by the Annex manager or, if subtasks are formed, by the Lead Country, to carry out its function in this Annex and which is freely at the disposal of the participants and the transmission of which is not subject to any contractual or legal limitations:

- if no substantial costs are incurred by the participant in making such information available, at no charge to the Annex
- if substantial costs must be incurred by the participant to make such information available, such charges to the Annex shall be agreed between the Annex manager and the participant, with the approval of the Executive Committee.

If a participant has access to confidential information, which would be useful to the Annex manager, or if subtasks are formed, to a Lead Country, in conduction studies, assessments, analysis, or evaluations, such information may be communicated to the Annex manager or, if subtask are formed, to the Lead Country, but shall not become part of the reports, handbook or other documentation, nor be communicated to the other participants, except as may be agreed between the Annex manager and the participant, which supplies such information.

Participants shall inform the Annex manager of information that can be of value to the Annex, but which is not freely available, and the participant shall endeavor to make the information available to the Annex under reasonable conditions, in which event the Executive Committee may, acting unanimity, decide to acquire such information.

The Annex manager shall, in accordance with paragraph "Responsibilities of the participants" above, provide reports of all work, performed under the Annex and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information.

The Annex manager or, if subtasks are formed, a Lead Country, may take appropriate measures to protect copyrightable material, generated by this Annex. Copyrights obtained shall be the property of the Annex manager or Lead Country, for the benefit of the participants, provided, however, that the participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee.

Each participant will, without prejudice to any rights of authors under its national law, take necessary steps to provide the cooperation of its authors, required to carry out the provisions of this paragraph. Each participant will assume the responsibilities to pay awards or compensation required to be paid to its employees according to the law of its country.
8. **Duration of Annex**

The Annex shall enter into force on September 1, 2014, and shall remain in force for a period of 3 years until September 30, 2017.

9. **Resources**

The Annex manager and the subtask leaders will be the following:

Annex manager: Ann-Sofi Jönsson, Lund University, Sweden
Deputy manager: Frank Lipnizki, Alfa Laval Membranes, Denmark

Leader of subtask A:
Leader of subtask B:
Leader of subtask C:
Leader of subtask D:

10. **Obligations and Responsibilities of the Participants**

The Annex manager is responsible for the overall status and planning, time schedule, compilation of reports and dissemination of the Annex. The Annex manager shall:

- Prepare the detailed work plan for the Annex in consultation with the subtask leaders and the participants, and submit the Program of Work for approval to the Executive Committee.

- Be responsible for the overall management of the Annex, including overall coordination, liaisons between the subtasks and communication with the Executive Committee.

- Prepare and distribute the results of the Annex.

- Provide annual reports to the Executive Committee on the progress and the results of the work.

- Provide to the Executive Committee, within six months after completion of all work under the Annex, a final report for its approval.

- Provide the participants with the necessary guidelines for the work they carry out with minimum duplication.

- Perform such additional services and actions as may be decided by the Executive Committee, acting by unanimity.

The subtask leader shall be proposed by the Annex manager and designated by the Executive Committee acting by consensus. Changes in the subtask leaders may be
agreed by the Executive Committee, acting by consensus of the participants. The subtask leaders shall be responsible for:

- Coordinating the work performed under the subtask.
- Assisting the Annex manager in preparing the detailed work plan.
- Provide annual status reports to the Annex manager and to the other participants.
- Compile the results from the subtask in the format of a handbook when the work has been completed.
- Assist the Annex manager in editing the final report of the Annex.

Each Annex participant must make a significant contribution to at least one of the Annex subtasks. The obligations of the participants are:

- Active participation in the working meetings.
- Preparation of the working documents.
- Review of the documents and draft of the final report.

11. **Funding**

11.1 **Subtasks**

The subtasks in the Annex will be financed according to the task sharing principle meaning that each participant shall individually bear its own costs incurred in the Annex activities. This funding is expected to cover labour costs (including overhead costs) associated with the execution of activities and travelling costs for participating in at least one meeting per year during the three-year working phase of the Annex. The costs of organizing and hosting the meetings shall be borne by the host participant. Any participating country has access to the results of all subtasks. The participating country must designate at least one individual expert (normally an active researcher or scientist) for each subtask they participate in. It is expected that the same expert attends all expert meetings and acts as technical contact person regarding the national subtask contribution.

11.2 **Annex management**

The costs for the Annex manager will be born by Sweden.
12. Participants

The programme is supported by a widespread network including leading scientists in the field from universities as well as equipment manufacturers and industrial users.

The participants in the Annex at the start-up of the Annex will be:

- **Ann-Sofi Jönsson**, Lund University, Sweden
- **Frank Lipnizki**, Alfa Laval Membranes, Denmark
- **Ola Wallberg**, Lund University, Sweden

Other participants may join the Annex in the course of the work.

13. Annex management

Professor Ann-Sofi Jönsson, Lund University, will be the Annex manager for this Annex.

Professor Ann-Sofi Jönsson has more than 30 year experience from both fundamental and applied membrane research projects. The fundamental research has been performed in two main areas: (1) influence of operating parameters on mass transfer in membrane processes and (2) fouling phenomena at the surface and in the matrix of membranes. She has a wide experience of applications in chemical, mechanical, pharmaceutical, food and pulp and paper industry. She has more than 80 publications in peer-reviewed scientific journals.

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