WATER PINCH:
SIMULTANEOUS ENERGY AND WATER MINIMISATION
SEWUM

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Contract JOE_3-CT950036

PUBLISHABLE FINAL REPORT

1 January 1996 to 31 December 1997

Research funded in part by
THE EUROPEAN COMMISSION
in the frame of the
Non Nuclear Energy Programme
JOULE III

Abstract

A novel Water Pinch methodology was developed by UMIST to decrease the number of heat transfer units based on separate system generation and non-isothermal stream mixing. Also, a new tool to design a system for simultaneous water and energy minimisation was developed - Two-dimensional Grid Diagram. A new method of dealing with interactions between energy and water minimisation and the subsequent trade-offs was introduced. Issues of design of a water system for maximum energy recovery and minimum number of heat transfer units have also been addressed. Two different energy recovery systems have been analysed: direct and indirect, and three different schemes been compared: no mixing water streams for heat transfer, isothermal stream mixing and non-isothermal stream mixing. Isothermal stream mixing gives the opportunity to reduce the complexity of stream distribution, and realise better structure and size for HEN without any penalty in energy consumption.

UMIST developed in close collaboration with the project partners the prototype software. New techniques were implemented in order to combine the two existing methodologies in software, and provide a flexible and imaginative user interface. The software was structured and highly interactive, and provides results in an easy, unambiguous, methodological form. Practical refinement of the how the technology is exposed in a re-usable format through generic software implementation is critical to project application.

LM have reviewed the prototype software as it has been developed and provided valuable feedback related to user friendly exposure of some of the detailed technical features of the concepts. As part of the review an industrial case study in the food industry was undertaken. The savings identified were substantial with hot utility requirements reduced by 80%. In parallel with this LM have undertaken a review of the industrial sectors where the technology is marketable to identify industrial sector specific set procedures and problem areas for the practical exposure of the technology.

UPC has extended the basic concepts of UMIST development for energy and water use minimisation from continuous to time dependent processes. UPC has developed novel methodologies and techniques that contemplate the time dependence of the different process variables. The methodology is based on the use of storage tanks for spent water leading to minimum water use by means of reuse. The heat integration problem has been addressed by means of an operations timing methodology that enhances hot and cold process streams simultaneously and makes possible heat integration between them. UPC has developed a supporting software prototype, which combines both methodologies and is provided with a user-friendly interface. The methodologies proposed by UPC have been applied to industrial cases of the beverage and food industrial sectors. Specific case studies have been realised in the DAMM brewery as well as in the fruit juice manufacturing plant INDUL. In both cases considerable water and energy use reductions have been obtained.

The Finnish partners LUT and VTT in close collaboration with ENSO have studied the possibilities of applying the methods developed by UMIST on the Pulp and Paper processes. A combination of simulation with the pinch-based methods has been chosen as a feasible solution for the main design work including especially the allocation of water flows, ie the water circulation arrangements in the mill considering also the water purification and energy aspects of the system. Software has been developed for the combined, iterative problem of simulation and pinch design eg for a combination of different basic software packages. Three case studies have been made as a test of the methods. These cases show the possible benefits of new designs in different cases, and they indicate the possibility of almost complete closure of the paper mill as well as substantial savings in energy consumption.

1. Partnership including names and addresses of co-ordinating institutions and one contact person per partner

Co-ordinator:
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2. Objectives

The objective of the project is to develop new design methods, supported by appropriate software, for energy and water management with the purpose of minimising energy consumption, fresh water use, waste water generation and the cost effective disposal of any waste generated. Both continuous and batch / semicontinuous processes are addressed.

Water is used extensively in the process industries for processing, sterilisation washing operations and as a carrier liquid. The water used for such operations is often used hot. Industries such as speciality chemicals, pharmaceuticals, pulp and paper, textiles, food and beverage, brewing, distilling and dairies, make extensive use of hot water. In these industries it is most effective if energy and water management are considered together.

Pinch analysis is now the established method for studying heat recovery in the process industries. The methodology first identifies sources for heat (termed hot streams) and sinks for heat (termed cold streams). Sources for heat can be combined together to construct the composite hot stream and sinks for heat can be combined together to construct the composite cold stream. Plotting the composite curves together, Fig 1, allows targets to be set for maximum heat recovery, minimum hot and cold utilities. Design methods then allow these targets to be achieved in practice.

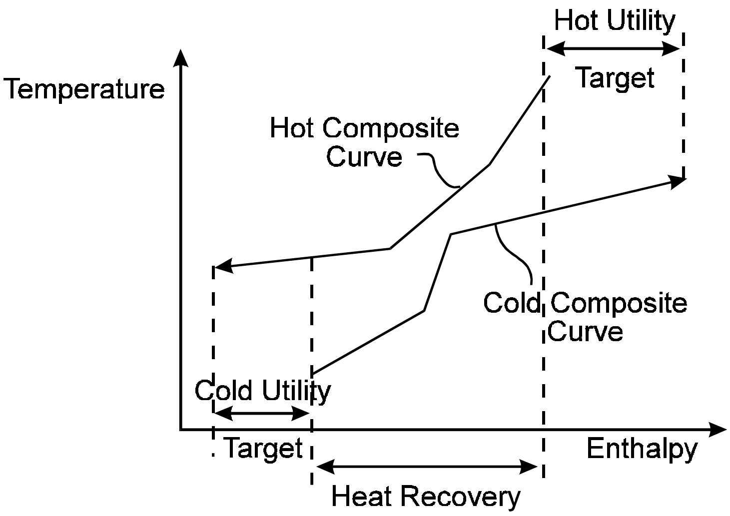


Fig 1 The Composite Curves for heat integration allows targets for hot and cold utilities to be set.

The methods of pinch analysis have now been extended to the problem of water and wastewater minimisation. Water can be minimised by re-use or by regeneration followed by either re-use or recycling. The methodology first sets concentration limits for contaminants for each water-using operation. Knowing the flowrate of water to each operation allows a concentration composite curve to be plotted, Fig 2. Matching a water supply line against the concentration composite curve allows the target for maximum water re-use to be set, Fig 2. Fig 3 illustrates how the construction is modified to target for regeneration. Design methods allow the targets for minimum water use to be set in practice.

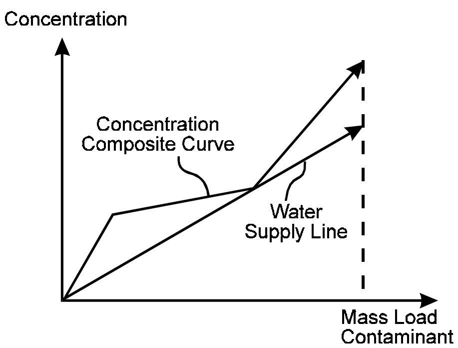


Fig 2 The concentration composite curve allows minimum water target to be set.

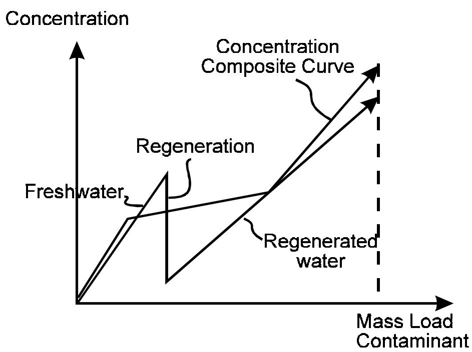


Fig 3 Regeneration targets can also be set.

Many uses of water in the process industries require the water to be heated. If water is re-used this recovers heat directly. This requires that the re-use of water should simultaneously consider both the level of contamination and temperature. The recovery of heat can be both direct by re-use or indirect using heat exchangers. To analyse this problem requires the two methodologies for energy and water minimisation to be merged into a new methodology which considers them simultaneously.

New methods for combined minimisation of energy and water consumption based on this novel concept is being extended for use in the Pulp and Paper Industry. Energy is saved and possible surplus energy used to diminish the use of fresh water by purifying and recycling process waste waters, quite possibly up to 100% recycle. The Pulp and Paper Plant of the future will require full waste water recirculation. However, in order to achieve this goal, it is likely that the energy consumption of the plant will increase. Consequently, to make the plant economically viable, major energy efficiency improvements are needed. Another aim of this research is to decrease the energy consumption in the future pulp and paper plants by a minimum of 20%.

Semicontinuous and batch processes (e.g. speciality chemicals, brewing and food industries) are characterised by a wide variety of reaction steps, solvents or separation methods for the recovery and purification of the products. As a result, a wide variety of aqueous effluents are generated. In such processes, water streams characteristics are time-dependent. Any systematic effort must be based on a realistic water management scheme based on economic appraisal of different options, and processing scheme optimisation guided by minimum pollution. This concept departs from conventional approaches as it focuses on process integration techniques.

A key objective has been to extend the methodology to contemplate simultaneous energy and water minimisation from continuous to time-dependent processes. It should be taken into account that, in time dependent processes, not only the plant design but also the way in which the production is planned determines the energy and water saving opportunities. The products sequence and the production tasks timing defines the characteristics of water streams, such as existing time, concentration upper-bound, flowrate and temperature. The Gantt-chart of a defined production plan leads to its corresponding stream chart, where the water streams can be easily identified (Fig. 3). A methodology that enables a systematic study of the opportunities for energy and water use minimisation is a tool of great interest for the daily operation of the plant and, also, for plant retrofitting decisions in order to reduce the consumption of water and energy.

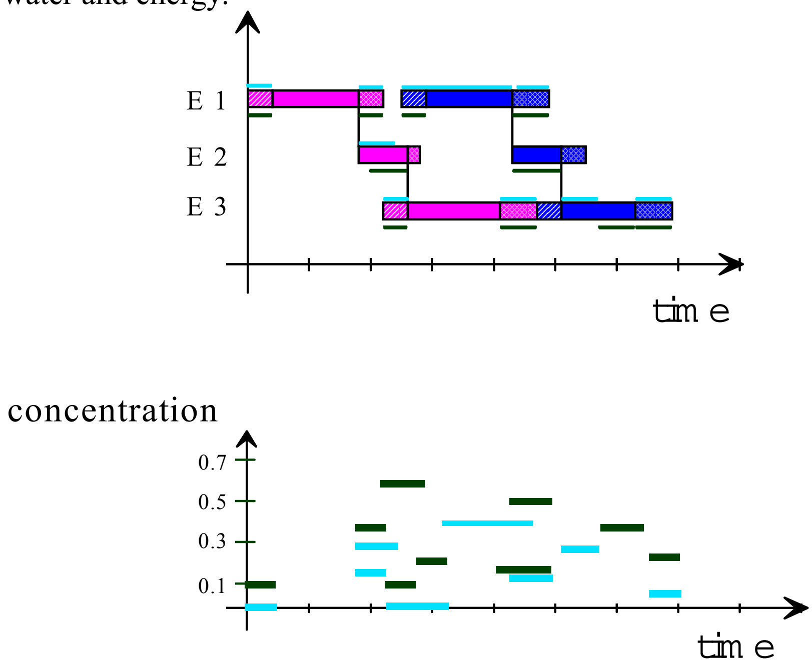


Fig 3: Gantt chart - stream chart

The food and beverage industry has a great potential for reduction in the energy and water consumption (between 10-40% depending on the kind of industry and its present situation). Two different industries, a brewing and a fruit juice manufacturing industry, have provided an excellent test-bed for the analysis and validation of the novel methodology and tools developed during the project. Saving energy and water usage and addressing environmental aspects on European scale. The methodology that is being developed in this project is generic and will bring substantial gains and achievements across a wide range of the process industries.

The pulp and paper processes are characterised by large amounts of water circulating in different ways as a carrier and processing medium. The pulp produced from wood is contacted with water (mixed and separated) in many stages for different processing purposes. In principle 1 ton of fibre needs to be contacted with 200-300 m^3 of water in the production process. Due to the circulation of water the actual need of fresh water may be some 15-25 m^3. The process has also a large energy demand; electrical energy mainly for pulp production and pumping, and thermal energy for final drying of the paper. Different parts of the process work at different temperatures. Heat recovery can be used to decrease the demand of fresh thermal energy. This also includes the possibility to burn bark and other process wastes and by-products in boilers to generate electricity and process steam.

The objectives of this study was to develop novel methods to be used in the design of new paper mills and in the upgrading of old mills with minimised use of fresh water and energy. The methods are based on combining process simulation with pinch-based methods to give an improvement to these design problems. It was shown that by combining new paper drying techniques with internal water treatment based on multiple-effect evaporation it is possible to design almost closed processes with no increase in energy consumption when compared to present day situation. The additional capital investment required will, however, be significant and it is not yet clear whether it can be balanced out by corresponding capital savings in waste water and fresh water treatment.

The LM contribution has been the development of a computer program that encapsulates the methodologies developed by UMIST into an industrially usable form. The program was tested and further developed through a case study.

3. Technical description

WP 1 Development of novel Water Pinch methodology (UMIST, LUT, VTT, UPC)

A novel Water Pinch methodology (WP 1) was developed by UMIST to decrease the number of heat transfer units based on separate system generation and non-isothermal stream mixing. Also, a new tool to design a system for simultaneous water and energy minimisation was developed - Two-dimensional Grid Diagram. A new method of dealing with interactions between energy and water minimisation and the subsequent trade-offs was introduced.

Issues of design of a water system for maximum energy recovery and minimum number of heat transfer units have also been addressed by UMIST (WP 1). Two different energy recovery systems have been analysed: direct and indirect, and three different schemes been compared: no mixing water streams for heat transfer, isothermal stream mixing and non-isothermal stream mixing. Isothermal stream mixing gives the opportunity to reduce the complexity of stream distribution, and realise better structure and size for HEN without any penalty in energy consumption.

LUT and VTT have collaborated on this WP 1 with UMIST by developing water pinch methodology for the paper industry and by testing the software developed. Water pinch software has been applied by LUT and VTT to pulp and paper processes. The main result has been that the problem formulation used in the present program version is not very well suited for pulp and paper type problems. A typical feature for paper making processes is that water is not primarily used for washing operations, but is extensively used as a processing medium, for transportation of the fibre material and for consistency control. Contaminant mass transfer depends on concentrations and flows. The main unit operations are dilution and water removal stages. In both unit operations there is normally a consistency constraint that specifies the flowrate of water. The removal rates for contaminants can be calculated from simulated values.

A basic processing unit (BPU) able to represent the most important processing steps in the paper manufacturing process has been proposed by LUT and VTT. The unit is based on the idea of contacting a process pulp stream with a water stream possibly in connection with other processing operations (refining, bleaching, thickening). The addition of the water stream may be seen as a washing or impurity reduction step based on first diluting the pulp stream with the water stream and then separating the water stream with most of the impurities through thickening.

The mathematical model of the BPU developed by LUT and VTT includes parameters from the simulation and the constraints created by the simulation or by the process specifications. Similar relations apply for all impurities and can possibly be modified to apply also for temperatures. The current definition of BPU is for an operation with one water inlet and one water outlet - inlet and outlet water streams are composed of summarised flows with mean contaminant concentrations. One possible development could be a BPU with many separate inlets and outlets.

UPC collaboration in this task consisted mainly of the discussion of the concepts involved and technology transfer of these basic concepts using electronic mail and during several visits from UPC team members to UMIST.

WP 2 Extension of methodology to pulp and paper industry (VTT, LUT, UMIST, ENSO).

VTT, LUT and ENSO supported by UMIST, Valmet, Ahlstrom Machinery have developed simulation models for pulp and paper processes. A complete paper producing line based on TMP can be simulated. LUT has focused on fibre line processes (debarking, grinding and refining, bleaching and stock preparation) and VTT on the paper machine itself including heat recovery, energy production processes and processes used to treat process effluent for reuse.

The simulation models created have been verified using process data from ENSO Kotka Mills in collaboration with Valmet and Ahlstrom Machinery. Process data for the ENSO Kotka mill case was collected and given to VTT and LUT. The information comprised comprehensive data of the water streams of the mill and data from waste heat evaporation, membrane separation and flotation/filtration processes obtained in pilot studies and from mill scale demonstration plants in Kotka. Additional detailed information was obtained from several simulation studies of the mill and its water purification equipment. A block diagram as introductory definition of the problem of the mill case was presented at the First Progress meeting by ENSO.

WP 3 Extension of methodology to time dependent processes (UPC, INDUL, DAMM)

The concepts developed for continuous processes in the fields of energy integration and water reuse are not suitable for non-continuous processes. Therefore, UPC has extended these basic concepts and created a novel methodology to handle as well the problems associated to time-dependent processes. DAMM and INDUL have collaborated validating and testing the methods and software developed. The water use minimisation methodology is based on the use of storage tanks for spent water allowing its further reuse. The heat integration problem has been addressed by means of an operation timing methodology that enhances hot and cold process streams simultaneity and makes possible heat integration between them.

The water use minimisation methodology requires the identification of all the water streams that exist in the process. These streams will not be characterised only by their flow rate, temperature, and composition, but also by the time they start and finish to operate. The sequence in which the products are processed and the timing of the operations will influence the characteristics of these streams. All the water streams are represented in a stream chart, where the timing and purity requirements of each one can be easily identified.

The use of storage tanks for spent water partially overrides the problem that represents the limited existence in time of the water streams. Driving the wastewater streams to storage tanks allows its reuse at any future time, if in the future an operation exists that can use water with a quality equal or lower than that of the water stored in the tank. The presence of more than one tank permits having water of different qualities in each tank, thus covering a wider range of operations that can be supplied by spent water. The decision on which streams are driven to each tank and the streams that are supplied by water stored in them will determine the potential water savings to be obtained by water reuse. It is possible to split a stream and drive it to more than one tank or to supply one operation unit with water from more than one tank. A procedure that combines heuristics and rigorous mathematical optimisation determines the stream-tank assignments leading to reduced water demand.

The mathematical model takes into consideration constraints related to streams purity requirements, tanks capacity limitations, contaminants mass balances and streams start and finish times. The model is solved using an NLP-solver. When trying to solve large industrial cases, severe problems emerge for the NLP-solver to find a first feasible solution. Thus, an initial solution is obtained using a heuristic procedure. This initial solution is provided to the solver which improves it until a local optimum is reached. Due to the non-linear character of the model, the globality of the optimum cannot be guaranteed. The solution obtained by this procedure can be also considered as a pre-design of the water reuse network.

In relation to the energy integration, a methodology has been developed that takes into consideration the time constraints imposed by the time dependence of the energy streams which, in addition to the energy constraints, define the energy integration opportunities of the process for a given production schedule. Then, rescheduling techniques are applied with the objective of increasing these opportunities.

The use of storage tanks for spent water partially decouples the water reuse opportunities from the production plan. Because of this, the water and the energy methodologies have a low interference if they are simultaneously applied. Furthermore, the temperature can be used as an additional criterion for the decision of which water streams are driven to each tank and which tank supplies each stream. This increases the energy integration opportunities, because the tanks are additionally used as heat storage, while keeping the water reuse opportunities unaltered.

WP 4 Software development (UMIST, LUT, VTT, UPC, INDUL, DAMM, LM, ENSO)

UMIST has developed the prototype software (WP 4.1). New techniques were to be implemented in order to combine the two existing methodologies in software, and provide a flexible and imaginative graphical user interface. The software has prepared and presented deliverables *"Design tool - computer prototype software for simultaneous energy and water minimisation based on methodology developed in WP 1"*.

The new software developed by LM is a full Windows 95 implementation of the UMIST methodology. The program has been planned to have the look and 'feel' of established commercial process integration software. The design has been structured to allow for further anticipated technology advances and operational feed back during the commercialisation phase. The program has been thoroughly tested using all accessible test data to prove that we have an accurate implementation of their research results. Naturally UMIST have been kept fully involved in the software developments through regular meetings. They have also had the opportunity to review the current version of the product.

The objective of UPC (WP4.4) was to develop a prototype software for simultaneous energy and water minimisation in time-dependent processes. On the one hand, the existing open modelling framework that allows the integration of the developed methodologies has been adapted. The definition and implementation of a data base has been also realised enabling the input of the necessary data to obtain a production schedule and the characterisation of water and heat streams.

On the other hand, the methodologies themselves have been implemented. These methodologies are structured in independent modules. Water and energy methodologies considering water and non-water streams can be applied sequentially, while water and energy associated to water streams can also be applied simultaneously. The solution procedure consists of two basic steps: an heuristic procedure that provides an initial solution with a certain degree of water reuse followed by a rigorous optimisation of the mathematical model using GAMS.

The software created by UPC has a graphical user interface, which allows an easy input of the data and a graphical analysis and navigation through the results obtained. The access to data base allows the storage of the results at the end of a working session for further evaluation under different scenarios. The software-prototype runs under Windows NT or Windows 95 environment and offers decision support in an easy interactive way.

WP 5 Case studies (LM, LUT, VTT, ENSO, UPC, INDUL, DAMM)

The partners carried out industrial case studies using the new methodology. The test cases served several important objectives:

- To test developed methodology in an industrial environment.
- To identify any shortcomings in the methodology and thus provide feedback to UMIST on important areas for further research and development.
- To carry out beta testing of the prototype software and to define areas for improvement in the software.
- To establish target values for specific energy and water consumption.

UPC and INDUL realised a case study for semicontinuous process in the fruit juice industry. The case study included two main aspects. First, the process modelling and simulation with water and energy streams identification for the planned products sequence was carried out. Second, novel methodologies were applied to reduce water and energy demand using the software developed by UPC and analysing the results obtained. The process water streams can be identified in Fig 4. The results obtained considering set-up, process and cleaning water streams are summarised in Fig 5 and presented in the deliverable WP 5.3 *"Report describing the semicontinuous case study in the fruit juice industry"*.

UPC and DAMM applied the methodology to a batch case study in the brewing process. First, the correct modelling of the process and the water and energy streams identification for a given production plan was carried out. Then, the developed methodologies were applied using the software developed by UPC. The results and their implementation possibilities were analysed and discussed. Relating to water and energy consumption, the critical area of the process lay on the bottling section because it represents an important part of the global demand. In addition, water requirements and effluents happen in a wide range of contamination and temperature levels (Fig. 6). The main identified reuse opportunities are represented in Figure 7. The results of this case study are presented in the deliverable WP 5.4 *"Report describing the batch case study in the brewing process industry"*.

VTT and LUT in co-operation with ENSO have applied the combined simulation/pinch method to the design of some test cases. The base case is a generalised integrated paper mill with TMP as the pulping method similar to the Kotka Paper Mill. Simulation combined with pinch methods for water allocation and heat integration has been used to make feasible designs for the new case mills.

The cases studied were

1. A typical integrated TMP-paper mill
2. Green field mill with closed water circulation
3. Paper mill of year 2010, including novel paper drying method

The results, presented in Deliverable No 9: *"Case studies for the pulp and paper industry (Final report for Working Package 5.2)"* show that with new technology and the developed methods, substantial savings can be achieved both in water and energy consumption.

By separating the water circulations of pulp production and paper machine using a press (standard technique in modern paper mills) and by applying the counter current principle in water allocation, it was possible to reduce the consumption of fresh water by 30%, from 13 to

9 m^3/ton. In addition to that it was possible to realise an additional saving of 2 m^3/ton by using the software developed to match the available water sources and consumers of water in an optimal way. The analysis also showed that in Case 2 the TMP-based pulping process produced so much heat that it was possible to completely close the water circulations by applying waste-heat operated multiple effect evaporating for water treatment.

LM have produced a case study based on the application of the simultaneous energy and water minimisation technology to a food processing operation where there is significant water use, some of which is hot. As part of the case study, LM identified areas of the technology and software where further work and improvement was necessary. This is normal when introducing a new technology and is expected to be an ongoing process during the early years of industrial application. Throughout the case study continuous feedback to UMIST was provided, identifying problems with the technology and improvements to the software where necessary. During the case study, Linnhoff March also assisted in the development and improvement of the software and incorporated new ideas/developments to make the software as user friendly and easy to use as possible,

The results from the case study were compared with the more traditional approach of separate energy and water analysis in order to identify the benefits and improvements from this new technology. The case study was based on a animal product processing plant. The process site is relatively large consuming about 80t/h of fresh water, some of which is treated on site before being passed to effluent.

Final Results

	Existing	New	Saving	
Fresh Water (kg/s)	22.1	16.1	6	**27.1 %**
Hot Utility Requirement (kW)	1,791	350	1,441	**80.5 %**

4. Results and Conclusions

There were 12 deliverables resulting from the project research.

UMIST was a co-ordinator and a leading partner in development of the new methodology (WP 1). A new strategy was developed to decrease the number of heat transfer units based on separate system generation and non-isothermal stream mixing. Also, a new tool to design a system for simultaneous water and energy minimisation was developed - Two-dimensional Grid Diagram. A new method of dealing with interactions between energy and water minimisation and the subsequent trade-offs was introduced.

Issues of design of a water system for maximum energy recovery and minimum number of heat transfer units were also addressed by UMIST. Two different energy recovery systems were analysed: direct and indirect, and three different schemes compared: no mixing water streams for heat transfer, isothermal stream mixing and non-isothermal stream mixing. Isothermal stream mixing gives the opportunity to reduce the complexity of stream distribution, and realise better structure and size for HEN without any penalty in energy consumption.

Seq. Numb.	Work Pack. No	TITLE	Due Date	Nat*	Av
1	WP1	Report describing the theoretical background and a basic methodology for Combined Energy and Water minimisation. The methodology will be generic and will concentrate on industries where hot water is used for washing operations and sterilisation. Such industries include pulp and paper, food and drinks, chemicals.	TO+12	R	P
2	WP2	Report on simulation models of pulp and paper mills required for simultaneous energy and water minimisation. It will include fibre line processes, models of paper machines energy related processes and process effluent treatment.	TO+12	R	P
3	WP3	Report on novel combined water and energy optimisation methodology for time-dependent processes. This model will serve as the bases for the economic assessment and optimum energy savings in batch and semi-continuous industries.	TO+12	R	P
4	WP 4.1	Design tool - computer prototype software for simultaneous energy and water minimisation based on methodology developed in WP 1.	TO+15	S	P
5	WP 4.2	Enhanced software for the combined energy and water minimisation, developed in WP 4.1, to enable effective use on industrial cases. This includes data and procedures testing and validation, verification of all possible logical trees, development of more detailed industrial models.	TO+16	S	P
6	WP 4.3	Design tool and data base - computer software for combined energy and water minimisation in the pulp and paper industry. This will also supply and transfer pulp and paper related data to software developed in WP 4.1 and 4.2.	TO+17	S D	P
7	WP 4.4	Design tool and data base - Prototype software based on WP 3 for time-dependent processes in brewing and beverage industry (soft drinks and juices) addressing minimum energy and water consumption.	TO+19	S D	P
8	WP 5.1	Report describing the continuos food processing industrial case study (e.g. dairy), testing and further developing the methodology and software from WP 1 and 4.3. Any shortcomings will be identified and provide feedback for further development of the methodology.	TO+22	R	P
9	WP 5.2	Report describing three case studies (typical integrated paper mill, green field mill with closed water circulation, paper mill of year 2010 - a target mill with both closed cycle energy and water usage) in the pulp and paper industry.	TO+22	R	P
10	WP 5.3	Report describing the semicontinuous case study in the fruit juice industry that is a typical representative of beverage industry. The results will lead up to 20% combined energy and water savings.	TO+22	R	P
11	WP 5.4	Report describing the batch case study in the brewing process that will lead up to 25% combined energy and water savings. The brewing process represents a typical batch industrial problem consuming substantial amount of both energy and water. This process has many different features from continuos ones.	TO+22	R	P
12	WP 4.5	Final version of comprehensive software developed in WP 4.1, 4.2, 4.3, 4.4, taking into consideration feedback from all case studies results of WP 5.1, 5.2, 5.3, 5.4. This software will provide a tool for solving combined energy and water minimisation problem in industries where hot water is used for washing operations and sterilisation namely pulp and paper, food and drinks, chemicals.	TO+24	S	P

* R = Report, S = Software, D = Database

The existing water pinch software has been applied by VTT to simplified pulp and paper processes together with LUT. The main result has been that the problem formulation used in the present program version is not very well suited for pulp and paper type problems. A typical feature for paper making processes is that water is not primarily used for washing operations but as a carrier for the fibre material. The main unit operations are dilution and water removal stages. In both unit operations there is normally a consistency constraint that specifies the flow rate of water. It is also quite difficult to specify a removal rate for contaminants in any water removal or dilution operation. A more natural constraint is the concentration of contaminants in a process (water) stream.

This WP 1 resulted into Deliverables No 1 *"Report describing the theoretical background and a basic methodology for Combined Energy and Water minimisation. The methodology will be generic and will concentrate on industries where hot water is used for washing operations and sterilisation. Such industries include pulp and paper, food and drinks, chemicals*". The report was submitted by the end of December 1996. Deliverables No 1 also covered the Milestone of this project *"Development of novel methodology for simultaneous energy and water minimisation and subsequent technology transfer (Report describing the Novel Methodology - Month 12).*

UMIST completed the development of the prototype software. New techniques were implemented in order to combine the two existing methodologies in software, and provide a flexible and imaginative user interface. The attention was focused to develop the concepts, the insides of a combinatorial analysis of two major parts of the industrial consumables: energy and water. Following the principles of Energy Pinch as well as Water Pinch a new technique for solving simultaneous a problem of energy and water minimisation was developed and presented.

The targeting stage is based on the thermodynamic principle. For a set of water-using operation data, the water targets can be establish as minimum flowrate of fresh water and minimum wastewater, and also energy targets as maximum energy recovery, minimum utility consumption and minimum number of heat transfer units. In the design procedure of a simultaneously minimisation of energy and water consumption problem, the Two-Dimensional Grid Diagram is used as a new tool that incorporates the energy aspects into the water network design. The method for designing the heat exchanger network with minimum number of units is based on the generation of the maximum number of separate systems. The aims of the research were:
1. To illustrate the effects of the relaxation of some of the assumptions.
2. To present an automatic procedure solving the problem of simultaneous energy and water minimisation.

The software has prepared and presented deliverables *"Design tool - computer prototype software for simultaneous energy and water minimisation based on methodology developed in WP 1"*.

UPC was responsible for the development of the novel methodology for the combined water and energy optimisation use in time dependent processes (WP 3). The results are presented in the Deliverable No. 3 "Report describing the theoretical background and a methodology for energy and water minimisation in time-dependent processes". The report was prepared and submitted by the end of December 1996.

LUT and VTT were responsible for data collection and development of methodology for process design in the Pulp and Paper industry. The methods includes the definition of a Basic Processing Unit (BPU) for the paper process as well as its use for a combined iterative simulation and pinch solution for this complex process. Results are reported in deliverables No 2 and No 6.

The new software developed by LM is a full Windows 95 implementation of the UMIST methodology. The program has been planned to have the look and 'feel' of established commercial process integration software. The design has been structured to allow for ongoing improvement as experience is gained in its commercial application. The program has been thoroughly tested using all accessible test data to prove that we have an accurate implementation of the research results. Naturally UMIST have been kept fully involved in the software developments through regular meetings. They have also had the opportunity to review the current version of the product.

There have been close collaboration and contacts with the other project partners. VTT and LUT researchers visited UMIST in April 1997 and worked together with UMIST on water and energy minimisation in the pulp and paper industry. LUT and VTT collaborated on WP 4.3 by developing a data base and design tools for the pulp and paper industry. The design tools developed can be used to transfer pulp and paper related data to the software packages developed in WP 4.1 and WP 4.2. The interface software is based on Excel spreadsheet package. The software can exchange data with simulation packages like WinGEMS or BALAS and to modify the input files of the pinch software packages as needed.

The pinch methodology developed by UMIST was extended by LUT and VTT to include the unit operations and processing conditions encountered in the pulp and paper industry. A mathematical model (BPU, Basic Processing Unit) was developed as a basic water using unit. Process data is taken from the simulation models developed in WP 2. An iterative water pinch method including iterations between a simulator, a spreadsheet-based interface software and the pinch software, was developed and data transfer between the simulation packages and the pinch package was demonstrated. The results of WP 4.3 were presented in *"Report on deliverables No 6: Design tools and data base - computer software for combined energy and water minimisation in the pulp and paper industry“.*

UPC, together with INDUL and DAMM, have developed a prototype software for simultaneous energy and water minimisation in time-dependent processes based on the methodologies developed in WP 3. The software has a graphical user interface and integrates a modelling framework and database management tools for batch/semicontinuous processes and allows the implementation of the methodologies for water and energy use minimisation.

The software developed in WP 4.4 allows the user to generate a production schedule and to apply the methodologies on this schedule. Modifications in the production schedule will lead to modifications in the target energy and water use consumption. So, it is possible to use the energy and water consumption as optimisation criteria for the production-scheduling problem. The results of WP 4.4 was presented in deliverable No. 7 “*Design tool and data base - prototype software based on WP 3 for time-dependent processes in brewing and beverage industry (soft drinks and juices) addressing minimum energy and water consumption*”.

5. Exploitation plans and anticipated benefits

5.1 Functional analysis of the project to identify all potential direct and indirect applications

The production of paper in the European Union is currently about 40 Mt/year. The consumption of energy in a typical modern mill is roughly 5 GJ/t of paper. The consumption of water varies between 15 and 25 m^3/t of paper, depending on the product. The first demonstration case study where an existing mill was analysed give an idea of the existing energy and water savings potential in the European paper making industry.

The replacing of fresh water intake by re-used treated water ensures that constraints on water supply do not affect production and the quality of the product as the disturbances caused by the variation of the quality of the fresh water are eliminated. This increases the productivity of the process and decreases the specific energy consumption of the production.

The project has aroused interest among the Finnish pulp and paper community and has also triggered additional research to identify critical contaminants in process waters and to find acceptable contaminant levels. The chemistry of papermaking is very complicated and the relationship between contaminant levels and quality and runnability is still poorly known.

The developed methodology and tools for energy and water minimisation in time-dependent processes is also generic and relevant to a variety of industrial sectors from petrochemicals to fine chemicals and specialities in chemical processing industries and also to all discrete manufacturing facilities.

Beer manufacturing constitutes a large industrial sector which has an important social, cultural and economical impact in Europe. It is well represented in the EU and the other European countries, which produce beer in large quantities of the order of 421 10^6 Hl / year. Spain is the fourth largest producer with 26,106 Hl / year. The production in the single site contemplated in this project is over 200 Ml / year of beer. This modern factory has an energy average consumption of 246 10^6 GJ over the year just in gas and fuel. A typical figure of energy consumption in gas and fuel per product unit is 120 MJ / Hl of beer produced, and an additional 12 kWh / Hl of beer produced is spent in electricity consumption. Water consumption varies between 6 and 10 Hl / Hl of beer produced, depending on the kind of factory considered.

Beverage production represents about 20% of the Spanish food sector. The incidence of the water costs in the global production costs varies between 1-4%. In the fruit juice industry, the main consumption of water is distributed in the following operations: cooling, fruit transport, fruit cleaning, steam production and cleaning of facilities and equipment units. The water requirement of the fruit juice industry is between 6 and 9 m^3 / m^3 of final product. The incidence of the water costs in the global production costs may represent between 1 and 4%. The energy consumption varies around 0.5 MWh/ m^3 of final product depending on the kind of industry and on the implemented technology.

Both beer and fruit juice are representative of complex processes involving batch-wise manipulation. Thus, the case studies realised provide experience to be exported to other processes involving complex time-dependent operation mode. Potential savings are very important in these type of industries. Estimates indicate reductions of as much as 40% in water and 60% in energy which will have a direct implication in making environmentally more benign processes.

The European process industries are facing increasing freshwater costs due to supply problems. The quality of water supplied in many areas of Europe is decreasing as a result of over-extraction. At the same time, increasingly strict discharge regulations mean that there is a considerable investment in effluent treatment systems. Such investment brings no return on investment. Minimising water usage will bring reductions in both freshwater costs and effluent treatment costs. If hot water is used then minimising water usage will also reduce energy costs. Taken together, these effects could have a major influence on the economic viability of the European process industries. Moreover, water shortage in the future will be a major constraint on the expansion of the European process industries.

The project has been developing special methods to minimise the use of energy and water in paper manufacturing. It will develop software suitable for applying these methods and then use the methods for evaluating the saving potential in existing plants and in new green field plants. The methods will provide the potential for very significant savings by industry in most European countries.

The figures given above indicate quantitative aspects of the social and economical impact expected. The rationalisation and reuse of cleaning water in the bottling section of a brewery will considerably reduce the environmental impact. The use of distributed effluent treatment, i.e. removal of waste from aqueous stream at the point of generation will be of special importance in the concentrate juice manufacturing. Here again the use of combined energy and water pinch will help to make energy savings at the same time.

5.2 Market study to identify the potentialities (real and potential market)

Simultaneous energy and water minimisation will increase the economic incentive to reduce both energy and water costs over and above the incentive for energy and water savings taken above.

Total recycle of water in a paper mill will considerably decrease the environmental impact of the mill. A mill with closed water circulation can also be located more freely. Today the mills are usually close to rivers and lakes, often in areas that are also of high recreation value. A zero discharge mill can be located where the raw-material is or where the consumers are. An example could be a newsprint mill located near a city area using the recycled paper as raw material and selling the products to the printing houses in the same area. In this concept, further substantial savings should also be achieved in transportation.

The application of combined energy and water pinch on pulp and paper manufacturing addresses an industry, which uses very large amounts of electrical energy (100-150 MW for a big mill) and for paper drying large amounts of thermal energy. The processing also depends on large flows of water.

The potential users of the combined energy and water use minimisation methodology developed by UPC are all time-dependent process industries, including batch and semicontinuous mode of operation. The results of this project should provide an optimum water use and energy recovery. This will enhance productivity with lower environmental impact. Both cases, brewing and fruit juice production, present substantial potential savings. Both are well represented in most European countries. Moreover, the results obtained and experience gained will be exported to other manufacturing systems thanks to the general methodologies and tools developed.

5.3 Protection of results

The basic information regarding the novel methodology will be made publicly available. The design tools however are going to be protected. At this preliminary stage it is still being assessed which protection measures are the most appropriate.

The same situation occurs in the case of time dependent processes. The fundamental concepts of the new methodologies developed will be made available through adequate channels (publications, reports, presentations to meetings, etc.). Design tools and software development should be appropriately protected. Steps are taken in this direction.

5.4 Exploitation strategy, including plan of actions and resources necessary

Exploitation plans are based on the project results benefits, its economic and social impact. As the leading partners have an excellent record in technology transfer, they will use their well proven structures. It has been envisaged that a THERMIE-JOULE demonstration project would be the most helpful step for the exploitation.

UMIST will use its industrial and academic contacts to transfer novel technology and design tools into European practice. UMIST will target other areas of European industry not directly covered by the project partners, which would benefit from the novel methodology and design tools, e.g. speciality chemicals, pharmaceuticals, textiles, distilleries, diaries and other using significant amount of both energy and water.

LUT and VTT will cover the pulp and paper industry not only in Finland but through Europe. The first step in exploitation is to further develop the software tool into a form that it can be released to industry for β-testing.

The testing will be done by companies, consultants and research organisations taking part in the Cactus research programme (Water Management in Papermaking 1996-1999) co-ordinated by VTT and funded by TEKES (Technology Development Centre Finland) and the industry. The European dimension for the exploitation will be provided by the industrial partners most of which have production plants in several European countries.

Based on the feedback from the initial testing the software tool will be further developed within the framework of the Cactus programme. The dissemination to wider public will be done in form of technical papers in scientific and trade journals and as presentations and demonstrations in conferences and seminars. The eventual commercialisation of the software will be done by Finntech Finnish Technology Ltd. Finntech is a technology transfer company with main function to commercialise the research results of its owner institutions (VTT, Helsinki University of Technology and SITRA).

Eventual exploitation will be made through the University Technology Transfer Centre (CTT) which offers UPC products to potential clients: industrial firms, engineering services and software houses. UPC exploitation in this case has two aspects: software licensing and specific application implementation and engineering. There are also two complementary actions: consultancy and hot line services. UPC policy is to keep low cost license rights to make the products also accessible to small SME's.

The partners intend to disseminate the project results through the common channels as technical paper in scientific journals, trade journals, demonstrations and presentations of software at conferences, workshops ad seminars. The information about software will be also disseminated in the frame of European Conferences on Computer Aided Process Engineering (ESCAPE series).

Exploitation of the expected results will be made through the Universities Technology Transfer Centre and Research Consortia which will provide vehicles for disseminating R & D results to the industrial environment by:

- Organising seminars.

Adequate technology transfer will be made, specifically in this case, by making use of the proven structures.

- Contacting potential end-users.

Feasibility studies are undertaken under contract. They will normally range from 3-6 months in duration, with the aim of demonstrating the applicability of the software to specific problems and establishing the likely benefits. It is envisaged that such case studies will usually be a prelude of the granting of software license for direct use by the company.

- Software licensing to end-users

This will involve the granting of non-exclusive licenses to individual operating companies. The licenses will cover limited use within each company as specified by the relevant contract.

- Software Applications

This will involve study an d development of specific applications to interested companies. This will be realised directly by the project partners or through software engineering houses specialising in the marketing and support of process engineering software. In all cases the project partners co-ordinates and controls those activities.

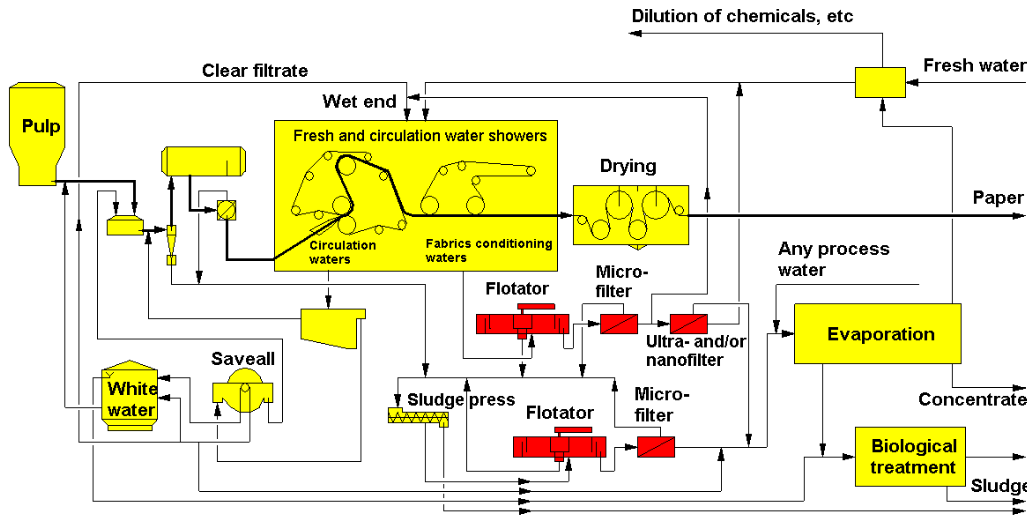
- Public Training Courses

Short courses will be given in public venues to train practising engineers and academics to become familiar with the techniques developed.

6. Photograph, diagram or figure to illustrate potential applications of the project

Figure 4 shows one possible process concept for a City Mill. In this concept power generation, paper drying and waste water treatment have all been integrated together. The steam circulating in the steam drier is superheated using gas turbine exhaust gases. Surplus steam from the drier is used to drive the evaporation plant. Fig 5 shows hot and cold composite curves for a case where the evaporation plant produces enough water to cover the fresh water need of the process (7 m^3/ton_{paper}).

In the hot composite curve it has been assumed that, if necessary, the gas turbine exhaust can be cooled down to ambient temperature. For simplicity the superheating of the drying steam and the flow of back pressure steam to the de-inking plant have been omitted from the curves.



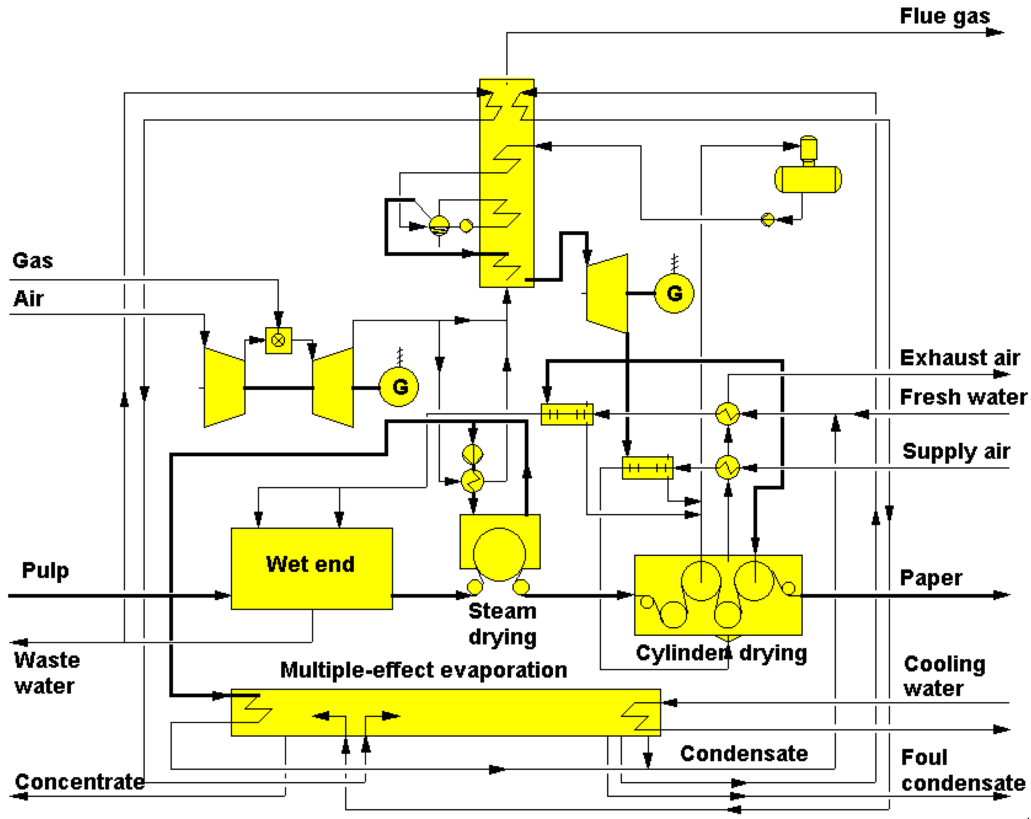


Fig. 4 Superheated steam drying integrated with waste-water evaporation.

The pinch curves in Fig 5 show that the closing of water circulations using evaporation can be done ”free-of-charge”, without any energy penalty. Understandably, ”free-of-charge” is a relative measure. There may be other uses for the waste heat outside the process, like district heating, that are more profitable.

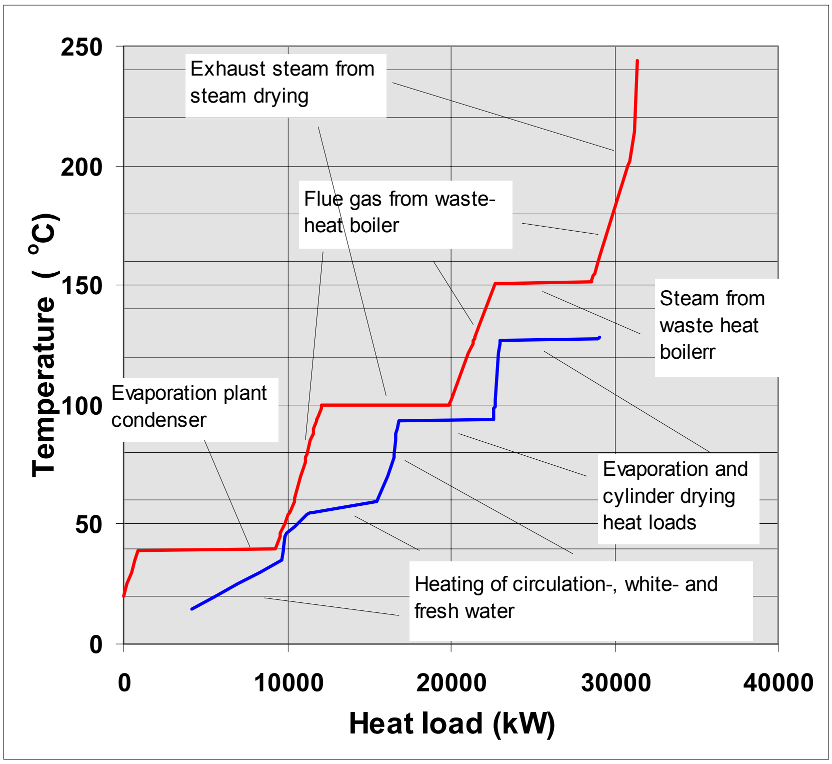


Fig 5. Hot and cold composite curves for City Mill concept

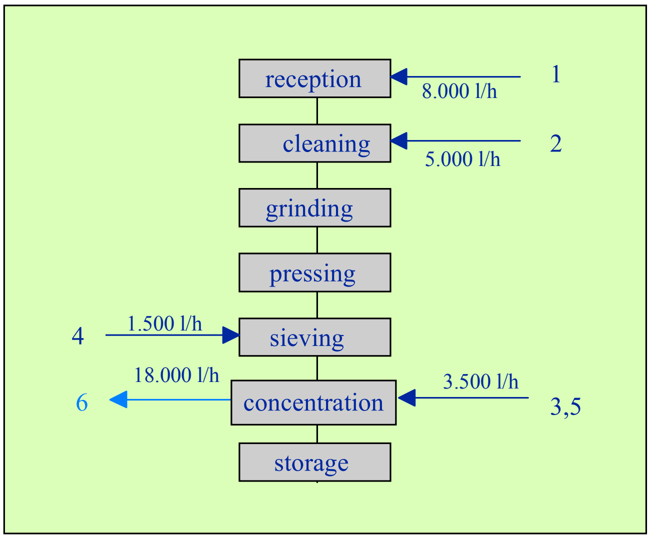


Fig 6: Fruit juice concentrate flowsheet (process water streams)

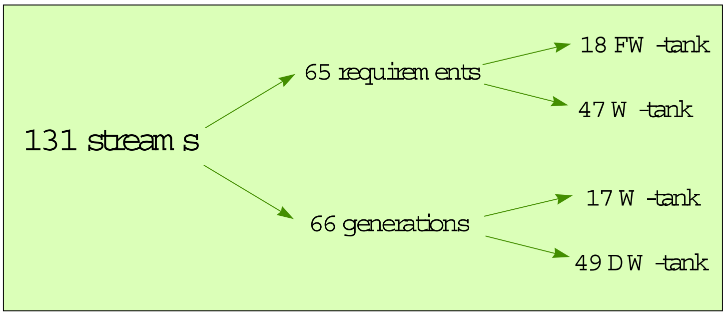
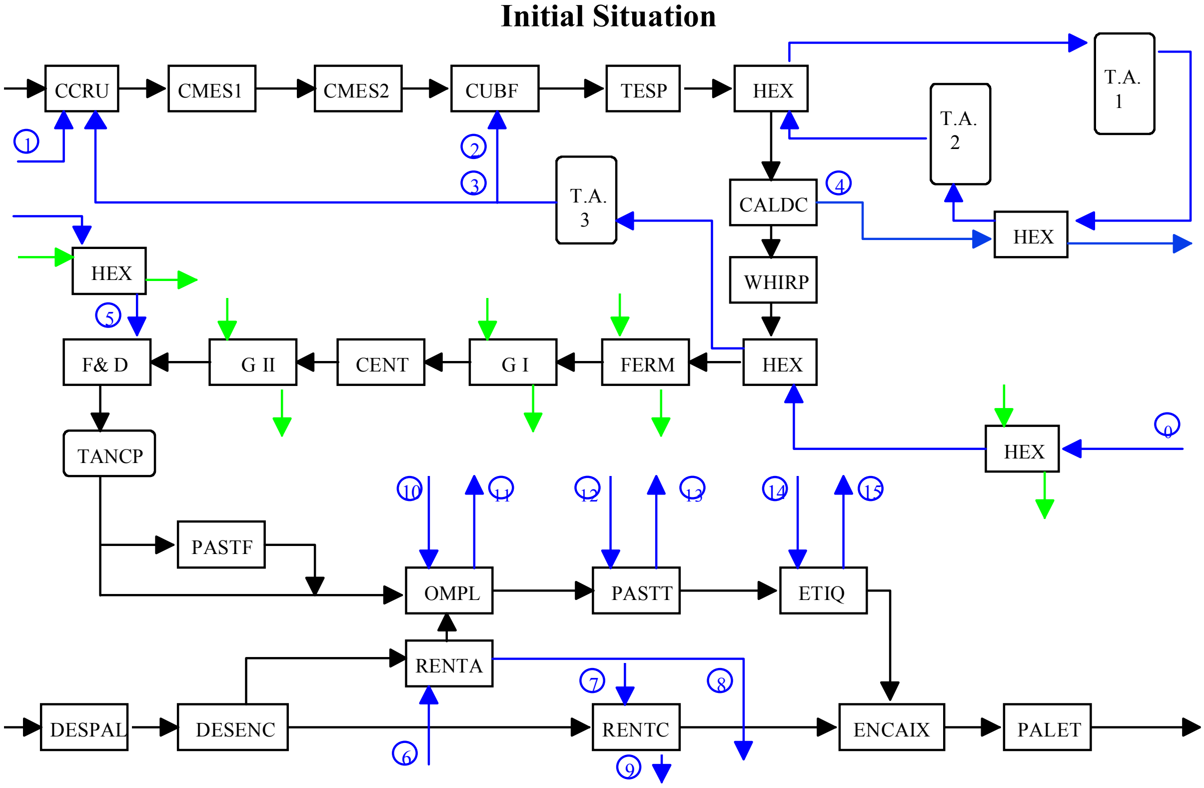


Fig 7: Water reuse network obtained after the methodology application (set-up, process and cleaning water streams).

Fig 8: Brewing process novel methodology application

Initial Situation



Proposed water reuse arrangement