AN INTERACTIVE APPROACH TO THE ENERGY INTEGRATION OF THERMAL PROCESSES

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Summary

The software described here is an interactive tool to demonstrate and apply the concepts of pinch technology for the design of efficient heat exchange networks in industrial processes. It provides a mouse driven illustration of the influence of thermodynamic options or operational data on a choice of economic criteria. A computer-aided drawing module facilitates the documentation of examples of processes and the important phase of preanalysis with simplification of the flowsheet.

1 INTRODUCTION

The increasing concern for the environmental impacts of human activities has stimulated the development of new methods for the analysis of industrial processes and the implementation of energy conservation measures. One such particularly powerful method, is the so-called pinch technology for the energy integration of thermal processes, a technology which has matured during the last ten years with major contributions from B. Linnhoff (Linnhoff,1982) at the University of Manchester.

The software presented here is intended for undergraduate students in mechanical or chemical engineering, as well as postgraduate students specializing in energy. Its purpose is to facilitate the assimilation of the major concepts of this approach and to assist students and researchers working on projects. A prerequisite is a good base in thermodynamics, heat transfer and design of thermal components. The Macintosh II is the chosen platform in view of its graphical user friendliness, and the programming language is Pascal.

2 COMPUTER AIDED DRAWING AND DOCUMENTATION OF THERMAL PROCESSES: THE MODULE OPTITHERM.

The first step of the analysis of a process or of a full plant is to clearly document it with its flowsheet and the relevant thermodynamic data. A critical task is then to simplify the existing flowsheet by extracting only the basic streams to be heated (cold streams) and the basic streams which can be cooled (hot streams). It is a clearing phase during which one systematically restricts the problem to the basic requirements of the process and to the basic opportunities for energy recovery (generally from effluents). All components which are not strictly vital for the process such as heat recovery exchangers are simply disregarded at this stage.

The module OPTITHERM is a drawing tool with a data base of hardware components each having dedicated inlet and outlet points. The components appear by pulling down the menu "objects" and selecting a family of hardware like the "exchangers" in figure 1. The selected objects can then be positionned with the mouse, joined and subsequently moved with their connecting streams to reorganize the flowsheet. The pull-down menu "Fenêtres=window" allows the opening of one window for specifying the stream data and one window for listing the basic streams selected. The selection of a connection or group of connections (streams) is indicated by arrows and extracted streams are shown by dotted lines (figure 2). The student, therefore, always has a clear overview of the current status of the process of documentation and flowsheet simplification. Linking with a number of specific fluid subroutines which give, for example, the missing thermodynamic data is done by specifying the type of fluid. Data concerning the basic streams is saved in an EXCEL file for further treatment or modifications.

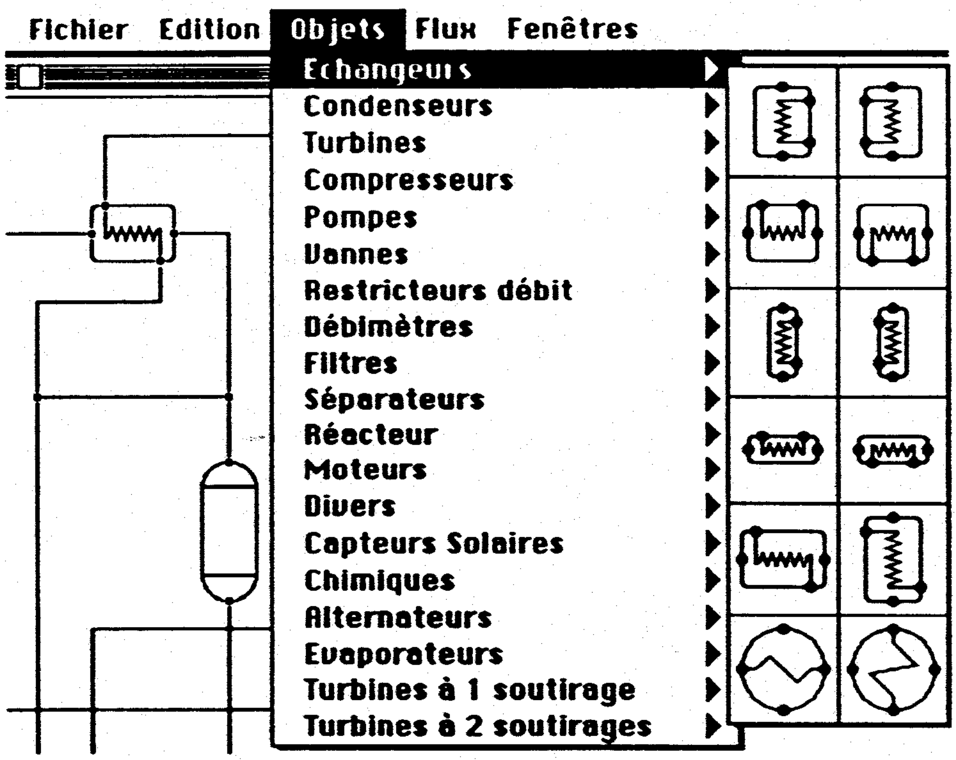

Fig. 1 : Main window of the computer assisted drawing program OPTITHERM with the database of exchangers available.

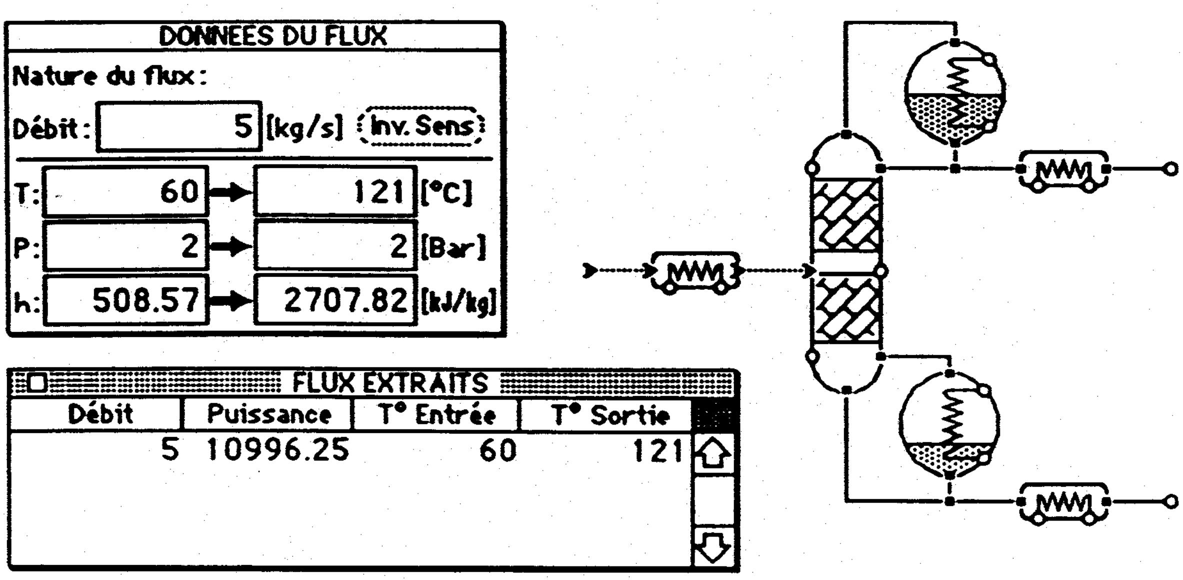

Fig. 2 : Stream data input and extraction in OPTITHERM.

3 SYNTHESIS OF NEEDS AND OPPORTUNITIES WITH PINCHY

Basic needs (cold streams) and opportunities (hot streams) can be represented as vectors or polynomial lines on a Temperature - Heat rate diagram. The accumulation of the heat rates while respecting the imposed temperature levels results in a cold composite summarizing the needs and a hot composite summarizing the opportunities for internal energy recovery at the site or process being studied (figure 3a). Using the fact that the horizontal component of each composite only represents a heat rate difference and is, therefore, not linked to a given origin of the x axis, composites can be moved horizontally with regards to each other. The student can do it by dragging the cold composite with the mouse, the hot composite remaining fixed. A single contact point normally results from the action of dragging the cold composite from right to left. It indicates the temperature level (pinch temperature) where the internal heat exchange between hot streams and cold streams is the most constrained for the process or site under consideration. It separates the site into two temperature zones: one which has a negative energy balance and is located above the pinch temperature and the other which is located below the pinch temperature and has an excess of energy but at a temperature too low to be of any use through direct heat transfer.

The black zone in figure 3a indicates the domain favorable for direct internal heat transfer between the hot and cold streams as well as the corresponding heat rate. The external supply of both heat (hot utility) or cold (cold utility) is directly apparent on both sides of the black domain. Note that when the two composites are in contact, the temperature difference (pinch) is null at this particular level which, if realised physically, would require infinite heat exchanger surfaces to permit the desired internal heat transfer. For practical considerations the cold composite should be moved to the right to provide a realistic pinch even if it increases the utility heat rates. Figure 3b illustrates the evolution of an economic criterion (minimum yearly cost, for example) as the pinch ΔT_{min} is increased. In PINCHY, this curve is precalculated in the same sequence as the composites; but a vertical indicator line follows the moves imposed on the cold composite. The student can, therefore, see at any time the correspondence between the pinch chosen and the economic criterion. He can also change through a menu the economic parameters (figure 3c) used for the cost evaluation and immediately see the influence on the optimum pinch.

The next step is to optimize the temperature level of the utilities to be chosen for the site. This is done by analysing the grand composite curve (figure 3d) which graphically represents the accumulated result of the local energy balances between the hot and cold composites. Dark zones indicate temperature domains in which the needs and opportunities are well balanced while the remaining zones must be covered by utilities. To each choice of pinch corresponds another grand composite curve. The student can also judge here of the influence of his choice of pinch on the temperature requirements for the utilities.

Having made these global design choices on the basis of the global considerations of the composites, the student is now ready to go back to the original streams and design a heat exchanger network with minimum energy consumption. He starts by pulling down the menu of PINCHY and selecting "réseau=network". The different streams then appear represented by vertical vectors intended as a reminder of the vertical temperature axis of the composites. A dotted line indicates the process pinch temperature level from which to design the network upwards for the topping zone and downwards for the bottoming zone. The requested energy need or opportunity for these zones is shown for each streams in a utility circle.

Following the symbolics proposed in (Linnhoff,1982), heat exchangers are symbolized by one circle on each of the horizontal lines, representing the streams connected with the desired heat transfer. The introduction of a heat exchanger is done by clicking on a stream, then pressing on the apple key while moving the mouse to the other stream. Both heat rate values or outlet temperature can be imposed to define the heat exchanger duties. Double clicking on a heat exchanger symbol lets a window appear which indicates the temperature profiles of each stream with regard to each other and regard to the pinch temperature (figure 4). Unfortunately, this facility tends to encourage laziness in students who forget about the relative thermal capacities of the streams and just try to see if it works, i.e., if the temperature gradients are not crossing each other and are, thus, not producing an infeasible heat exchanger.

Other features including stream splitting to improve the heat exchange capabilities or the positioning of power units like cogeneration or heat pumps are also introduced. Examples of applications for both open and closed cycle industrial heat pumps will be shown.

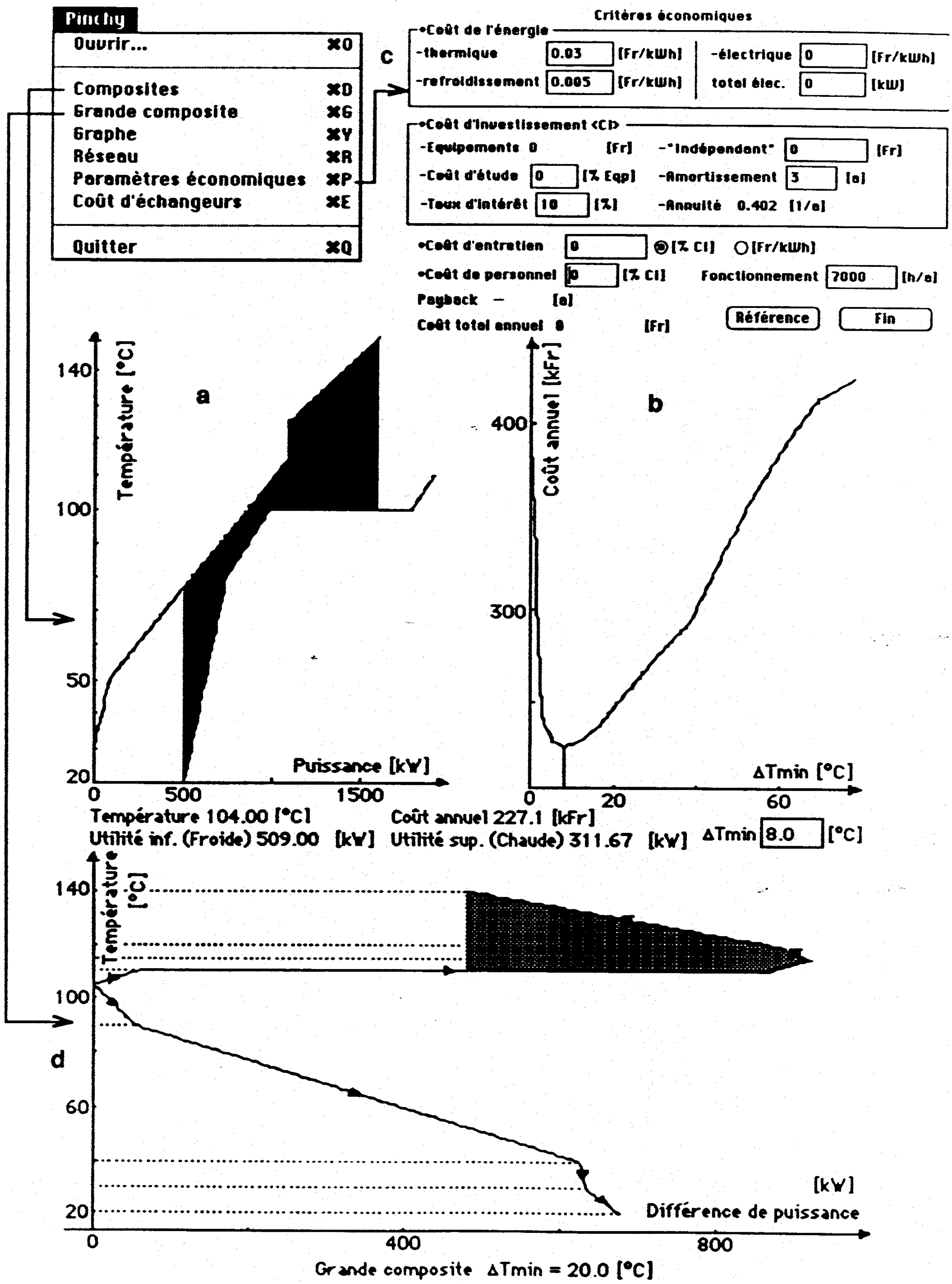

Fig. 3 : Synthesis with PINCHY of the energy data of a plant or a process with composites (a)

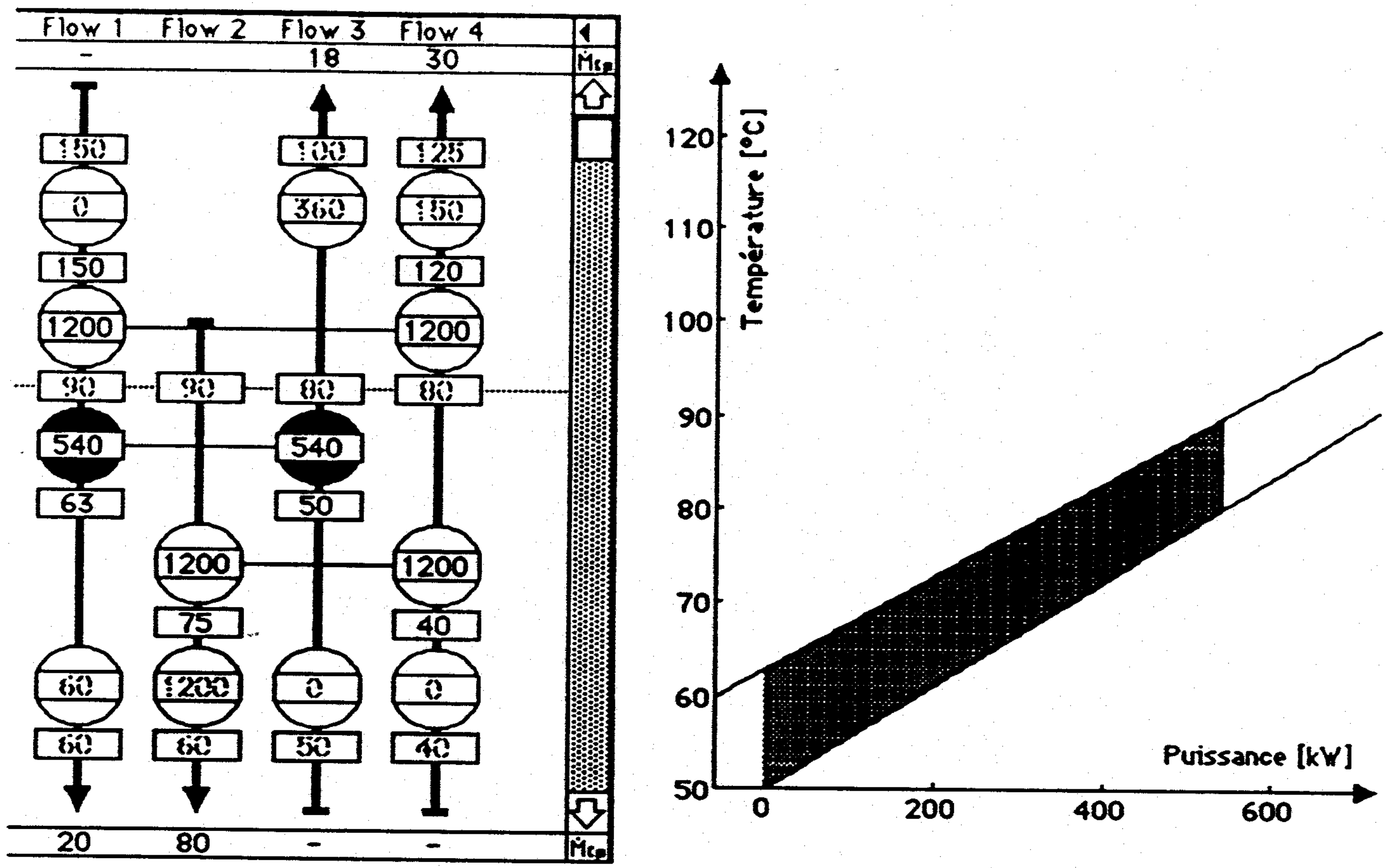

Fig. 4 : Heat exchanger network being designed with PINCHY. The window for the validation of the selected exchanger is visible on the right.

4 CONCLUSIONS

The software OPTITHERM and PINCHY are efficient teaching tools for both course work or individual projects. They have now been applied with success in a class of undergraduate and a class of postgraduate students. Results confirm a speed up in the mastering of this method which is particularly important in individual projects. Another major benefit is the possibility of increasing the sensitivity to economic parameters in order to gain a more direct insight on the results. However a too high user friendliness can also induce laziness and a lack of reflection so that some design exercises with pen and paper still have to be maintained. Future development work includes an extension to full exergy balances, an expert design system module and interface routines with a process simulation package.

5 ACKNOWLEGMENTS

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REFERENCES

Linnhoff, B.,(1982) "User guide on PROCESS INTEGRATION for the EFFICIENT USE OF ENERGY", The Institution of Chemical Engineers (U K)

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