SELECTION THE BEST MODULE TYPE FOR ULTRAFILTRATION (UF) MEMBRANE IN DAIRY INDUSTRIALS BY ANALYTICAL HIERARCHY PROCESS

Mohsen Pirdashti [1]
Department of Chemical Engineering,
Razi University
Kermanshah,Iran
Pirdashti@razi.ac.ir

Keywords: Dairy, Membrane, AHP, Delphi technique, Expert choice

Summary: *Many articles have been written about applying membrane with a module type, but little has been published about the complex problem of capital equipment decision making in membrane processes. This report focus on those applications of the analytical hierarchy process is used to support and document the evolution of the management in membrane separation. It aims to demonstrate how the model can help in solving such decisions in membrane separation and it demonstrates the AHP's ability to facilitate an understanding of the underlying criteria and priorities, and to successfully support for the best selection and a good decision making. We believe that this application can be useful for managers and, because of its ease of implementation, others could benefit from this approach. In this study, case study is ultrafiltration (UF) membrane and Alternatives are four module types. In order to validate research procedure, expert's opinions have been criticized using Delphi method. Considered criteria in this study are includes: Sanitation design, Clean –in-Place, Packing Density, Resistance to fouling and shear stress, Relative cost; which has been analyzed by utilization of AHP method. Finally, Expert Choice software has been utilized to facilitate calculation.*

1. Introduction:

Dairy is an important food industry which applies membranes in several sections (Wagner, J., 2001). Membrane processes as micrpfiltration (MF), ultrafiltration (UF) and reverse osmosis (RO) have been widely applied to the dairy, food and beverage industry after the discovery of asymmetric membrane by Loeb and Souriragin in the early 1960's (Jiao,B, et al.,2004).

Those are inherently lees energy intensive compared to phase-inversion processes. With the ability to save energy up to 30-50% of the current values additionally, membrane processes are compact, modular and easily amenable automation and scale-up. These processes are fast (due to fast mass transfer through the thin membrane layer), more efficient, unique in some applications (such as hemodialysis), consume no or less additives and chemical sand applicable to very dilute solutions (such as biotechnology products) with lower capital investments. Membrane processes are carried out in low temperature. Therefore they can be used for heat-sensitive materials such as food, medical and biotechnological products. Some of the important applications of the membrane processes in various industries are as follows (Madaeni,S.S, et al.,2006).Some of the membrane applications in dairy industry are shown in the table 1 (Oak Ridge National Laboratory.,2005) :

Table 1: Some of membrane application in dairy industry.

Applications	Membrane types
Cheese whey concentration	UF-RO
Milk concentration	UF-RO
Desalting of whey	ED
Waste treatment	UF

Industrial membrane system design involves not only the selection of the proper membrane martial and module configuration, but also optimization of operating conditions (feed velocities, temperature, staging, etc.), bulk stream pretreatment (removal or stabilization of foulants), and the ability to clean membranes when necessary. Since the intrinsic performance properties that result from the material composition and morphology are seldom the controlling factors in industrial applications, it is difficult to develop membrane materials without having a specific target application. The target application can rapidly narrow the potential choice of materials (Oak Ridge National Laboratory., 2005).

In this study, case study is ultrafiltration membrane (UF).

UF is a pressure-driven membrane process widely used in dairy industry (Muthukumaran,S, et al.,2005).UF are now widely considered as economical alternatives to conventional separation processes valuable products in the pharmaceutical and dairy industry. It has become standard unit operations. Commercially available modules include spiral wound, hollow fiber, tubular and plate-and-frame modules (Schwinge, J, et al., 2004).

Module design for dairy application includes many alternatives and criteria that must be analyzed and optimized (Le-Clech, P,et al., 2006).

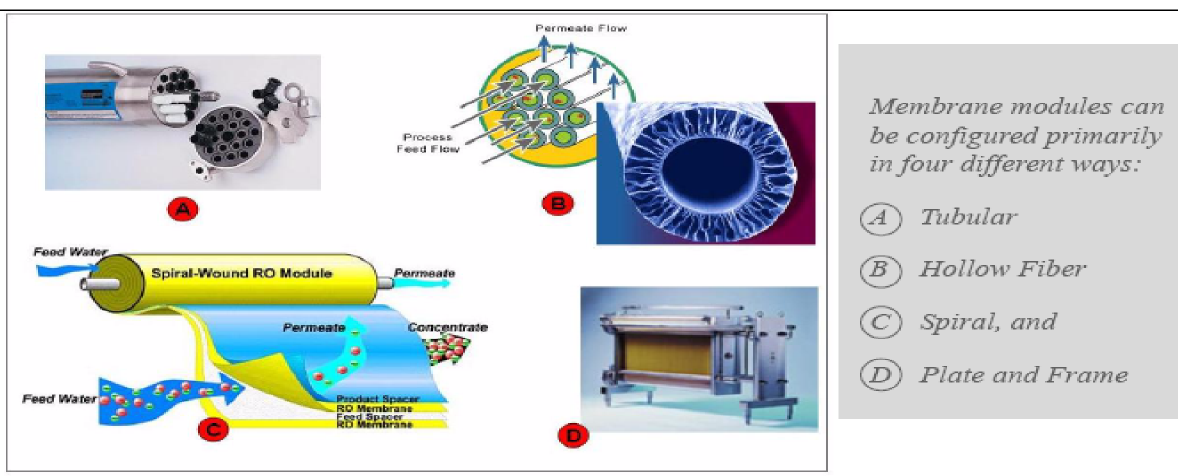
There's a remarkable demand for an appropriate management in determining the best module and also resolving the priority of other alternatives in comparison to the selected module considering various criteria, concerning the importance of the subject. Due to complicity of the problem, AHP method has been utilized for solution. Flexibility of the results achieved in this study, particularly in the sensitivity analyze stage, in which changes in priority of the alternatives considering the changes in criteria in future, also taking into account latest statistical information and methods, has made this study a distinctively extended research, which has never been done before.

2. Available modules

The term "module" is universally used, but the definition varies. Here, a module is the simplest membrane element that can be used in practice. Module design must deal with five major issues, plus a host of minor ones. First is economy of manufacture. Second, a module must provide support and seals to maintain membrane integrity against damage and leaks. Third, it must deploy the feed stream so as to make intimate contact with the membrane, provide sufficient mass transfer to keep polarization in control, and do so with a minimum waste of energy. Fourth, the module must permit easy aggress of permeate. Fifth, the module must permit the membrane to be cleaned when necessary. Many module types have been invented, quite a few were used commercially, but the winning designs as of 1996 are variations on a few simple themes (Eykamp, W., 1997). In order to membrane module is a unit assembly containing a combination of membranes and the membrane containment vessel (Oak Ridge National Laboratory., 2005).

Four suitably available modules for membrane design were assessed in this study; a general description of the different module types is presented below.

Fig 1: Membrane configurations



2.1 Plate and Frame module

The plate and frame configuration consists of membranes cut from flat sheets and bounded or clamped to a flat supporting frame is normally grooved or milled to permit flow of the permeate. The basic layout can be compared with that of a standard filter press (Eykamp, W., 1997). In Figure 1, the arrows show the upstream and Permeate paths. The upstream leaves as the retentate and is enriched in Non-permeate. Permeates is collected from channels in support plates and Leaves enriched in the most permeable component (Ali, S, et al., 1998).

2.2 Spiral-Wound module

The spiral wound membrane module consists of two flat sheet membranes wound around a central core. The membranes are oriented with the permeate site of the membranes facing. The membranes are separated by a spacer and then glued together to form an envelope. Two enveloped separated by a feed spacer are attached to the central core and wound Swiss role style around the core. The spacer on the feed side acts as a turbulence promoter and support. Once wound the ends by fixed by and anti-telescoping device. Modules are either tape bound and held in a steel housing or made as glass-reinforced modules. The feed runs axially through the unit. The permeate flows around the spiral and is removed via the central tube. This module is wrapped into a spiral and placed in a cylinder shell (Cousins, R.B., 2003-2004).

2.3 Hollow-Fiber module

Hollow fiber modules were developed in the late 1960's for use in desalination and have subsequently been adopt for ultrafiltration and microfilteration applications. A hollow fiber module consists of a bundle of self-supporting hollow fibers set inside a cylindrical shell and potted at both ends to create a shell and tube arrangement. The fibers range in size from 100 μm to 2500 μm. (Cousins, R.B., 2003-2004).

2.4 Tubular module

Tubular modules are preferred for solutions containing suspended solids and were amongst the first industrial designs. The membranes are formed as tubes and are normally cast onto a supporting porous substrate. The tubes are not self supporting and are normally inserted in a perforated tube. The tubes are typically housed in a shell and tube configuration. The membranes are normally sealed by means of elastrometric inserts at either end of the tube. The end caps determine if the flow is in series or parallel through the module. The permeate is collected in the shell side of the module (Cousins, R.B., 2003-2004).

3. Selection criteria

Five factors must be considered in selecting a UF module design; they include:

3.1 Sanitation design

Sanitation design plays an essential factor in the selection of a specific UF module. Sanitary operation is of paramount importance because the design allows for easy cleaning and sterilization.

3.2 Clean –in-Place

Easy to clean or the ability to clean membranes when necessary and replace membranes is good. This is an important factor in comparing the different UF modules types.

3.3 Packing Density

Membrane surface per membrane module volume. That low packing density is a problem in high pressure where pressure vessel costs are significant.

3.4 Resistance to fouling and shear stress: Fouling is a process resulting in loss of performance of a membrane due to the deposition of suspended or dissolved substances on its external surfaces, at its pore opening, or within its pores. It is one of the major considerations in the handling of milk products, particularly the UF of whey. However, resistance to fouling and self cleaning is very important parameters for this application.

3.5Relative cost

The membrane module must satisfy a number of economic requirements. In order to optimization of initial module costs and operating life.

4. AHP application

AHP is a decision-aiding tool for dealing with complex, unstructured, and multiple-criteria discrete decisions. Since its initial development, AHP has been applied to a wide variety of decision areas in manufacturing (Partovi,F., 2006). Saaty developed the following steps for applying the AHP:

1. Define the problem and determine its goal.

2. Structure the hierarchy from the top (the objectives from a decision-maker's viewpoint) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level which usually contains the list of alternatives.

3.Construct a set of pair-wise comparison matrices (size n×n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in table 3.The pair-wise comparisons are done in terms of which element dominates the other.

4. There are n (n-1)/2 judgments required to develop the set of matrices in step3. Reciprocals are automatically assigned in each pair-wise comparison.

5. Hierarchy synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

6. Having made all the pair-wise comparisons , the consistency is determined by using the eigenvalue , λ, to calculate the consistency index , CI as follows :CI=(λ-n)/(n-1),where n is the matrix size , judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in table 3.The CR is acceptable , if it does not exceed 0.10 . If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.

7. Steps 3-6 are performed for all levels in the hierarchy.

Table 2: pair-wise comparison scale for AHP preference.

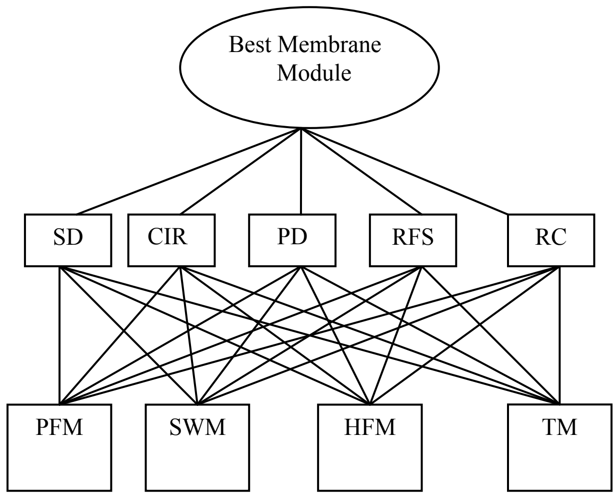
Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to Very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Table 3: Average random consistency (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Fortunately, there is no need implement the steps manually. Professional commercial software, Expert Choice, developed by Expert Choice, Inc , is available on the market which simplifies the implementation of the AHP's steps and automates many of its computations(Al-Harbi.K.M.AL-S., 2001).The software is easy to use and understand, as well as providing visual representations of overall ranking on a computer screen.

Figure 2: A hierarchal representation of problem with seven criteria and four alternatives



A schematic representation of the problem under study is shown in Fig.2 where, according to AHP design, the process is presented in three levels. Level one represents the goal which is to select the best module for membrane design in dairy industrials. The second level represents the different selection criteria, followed by the alternatives in the lower level. From the second and third levels, the best module for membrane design is selected.

The main objective of this study is to select the most suitable module for adoption in the dairy industrials. The selection process is based on different criteria with the four most important listed above.

The selection criteria are therefore as follows:

SD= Sanitation Design

CIP = Clean –In-Place

PD= Packing Density,

RFS = Resistance to Fouling and Shear stress.

RC= Relative Cost

The different module types representing the alternatives are designated as follows:

PFM = Plate and Frame Module

SWM = Spiral Wound Module

HFM = Hollow Fiber Modules

TM = Tubular Module

Ranking information representing the various degrees of importance/performance (Table 3) was used to pair-wise compare the different criteria and alternatives.

Rating ranged from equal importance to extreme importance with successively stronger preference of one criterion over the other. All comparisons were conducted in a pair-wise manner relative to their parent element in the hierarchy structure. Due to lack of sufficient quantitative information and the complex multi-objective nature of the problem, it was decided to use AHP, and for easy to work used Expert Choice software.

5. Utilized methods and techniques:

5.1 Utilizing Delphi process:

The Delphi method has proven a popular tool in information systems (IS) research. Citing a lake of a definitive method for conducting the research and a lake of statistical support for the conclusion drown," Schmidt presented a step-wise methodology for conducting such study. Building on the framework that Schmidt developed, we offer two contributions towards increasing the value of Delphi studies in investigating research questions. First, we fill in many details in the context of Schmidt's framework by proving guidelines on how to conduct a rigorous Delphi study that identifies the most important issues of interest by soliciting qualified experts. Second, we demonstrate hoe to use a Delphi survey as a research tool to serve a variety of different purposes in the theorizing process.

Increasing the rigor will increase the confidence with which researchers can use the results in subsequent studies and a managers can make decisions based on information gathered using this method. Delphi researchers employ this method primarily in cases where judgmental information in indispensable, and typically use a series of questionnaires interspersed with controlled opinion feedback. A key advantage of the approach is that it avoids direct confrontation of the experts (Okoli,Ch, et al., 2004).

In order to determine and identify parameters and criteria effective on selection of the best module for the UF membrane, in addition to appliance of the final result of the researches completed in this field, experts opinions have been taken into account in this study by means of utilizing Delphi method.

In addition to the statistical information obtained from the research author, the experts whose comments were taken into account in this research include: University Professors, Diary producers, Membrane inhibitors.

Practical application of Delphi technique in this study comprises the use of this method in determination, recognition and ranking of criteria and alternatives, with the mentioned procedure.

5.2 Application of Expert Choice software to facilitate the calculations.

Expert choice represented a significant contribution to the decision making process. It assistants a decision maker in solving complex problems involving many criteria and several courses of action. An expert choice solution to problem reflects the expertise of the decision maker, not the computer. The software is easy to use and understand, as well as providing visual representations of overall ranking on a computer screen.

Expert choice does not make a choice for you in some mysterious way, or assume that the answer is hidden in the elegance of the underlying mathematics, but helps you to make an informed choice based on your knowledge, experience, and preference.

Expert choice enables decision makers to: Support executive decision; Establish a forum for group decisions; Manage/organize complexity; Derive priorities and rank alternatives; Measure consistency of judgments; Incorporate quantitative information as well as knowledge; intuition and experience; Justify the rationale for a decision; Consider trade-offs among competing criteria; Synthesize from the goal to determine the best alternatives; Communicate the rationale for a decision to others and incorporate group judgments (http://www.Expertchoice.com).

6. Results:

In this chapter, Overall result of the experts answers has been analyzed and evaluated precisely so that the inconsistency ratio has a top of 0.06 (<0.1) which exhibits the precision of the gathered data, then it would be utilized as the primary input data for the Expert Choice software, in section one after defining the goal, the data has been input to software and the results have been shown.

Figure 4-a: Input and output of software for criteria

selection the best module for UF membrane in dairy industrial

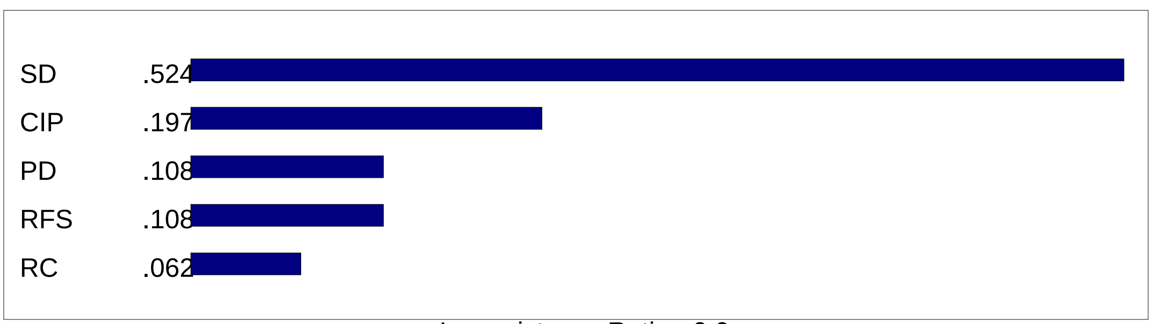
Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

	CIP	PD	RFS	RC
SD	3.0	5.0	5.0	7.0
CIP		2.0	2.0	3.0
PD			1.0	2.0
RFS				2.0

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	selection the best module for UF membrane in dairy industrial
SD	sanitation design
CIP	clean-in-place
PD	packing density
RFS	resistance to fouling and shear steress
RC	relative cost



Inconsistency Ratio =0.0

Trial Use Only

Figure 4-b: Synthesis of leaf nodes with respect to GOAL

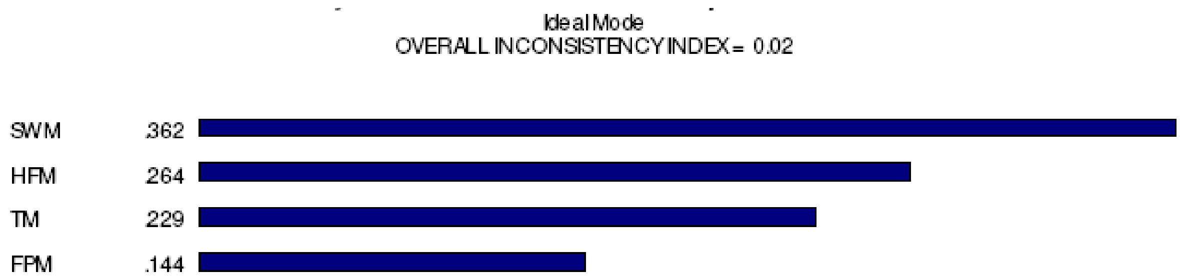


Figure 4-c: Performance sensitivity w.r.t GOAL for nodes below GOAL

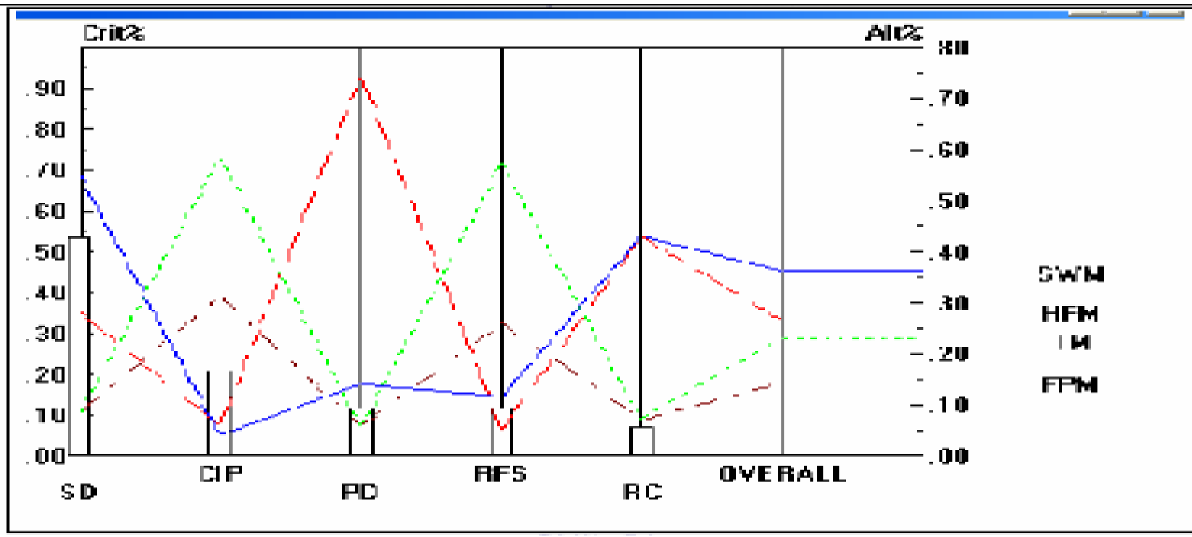
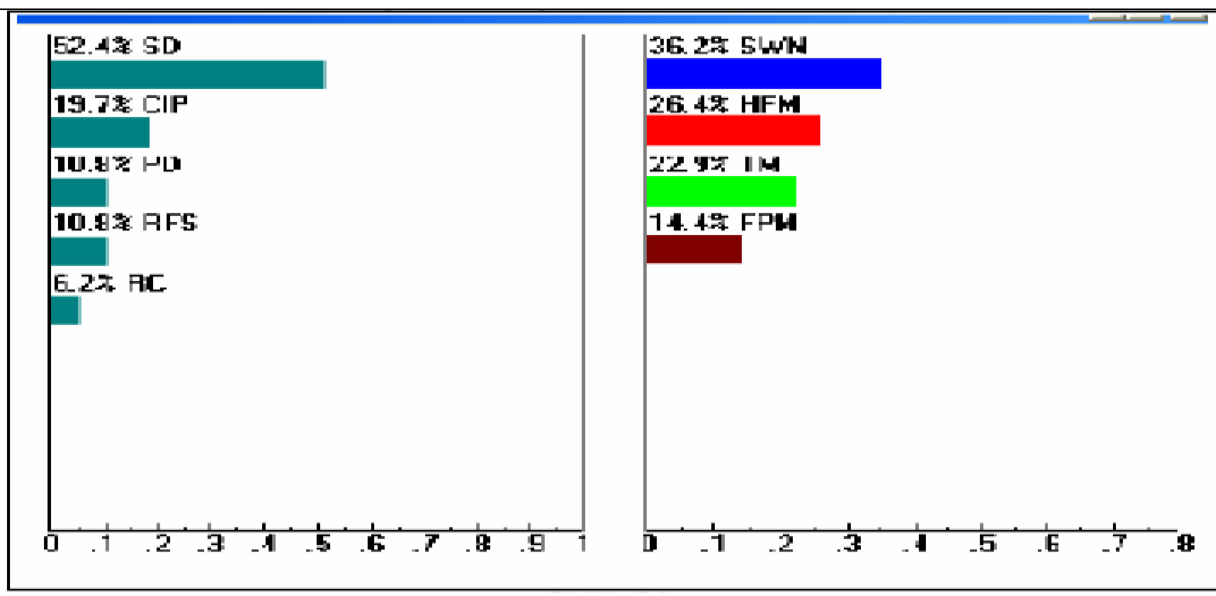


Figure 4-d: Dynamic sensitivity w.r.t GOAL for nodes below GOAL



By the end of the process, SD has been identified as the best criteria, where CIF, PD, RFS and RC have been introduced as the following ranks.

SWM has been identified as the most adequate module, where next priorities are HFM, TM and FPM.

7. Discussion:

Sensitivity analysis to obtain overall priorities Sensitivity analysis attempts to check the impact of change in the input data or the parameters of the proposed solutions. Relatively small changes in the hierarchy or judgment may lead to different outcomes. As the relative cost is not exactly predictable, it would be desirable to monitor the effects made by changes in the mentioned criteria's properties.
In order to examine the response of the overall priority of alternatives to changes in the relative importance of each criterion, two gradient sensitivity analyses are performed.

In figures below, the effects of certain changes in relative cost (low importance and high importance) has been shown.

Figure 5-a: Performance sensitivity w.r.t GOAL for nodes below GOAL

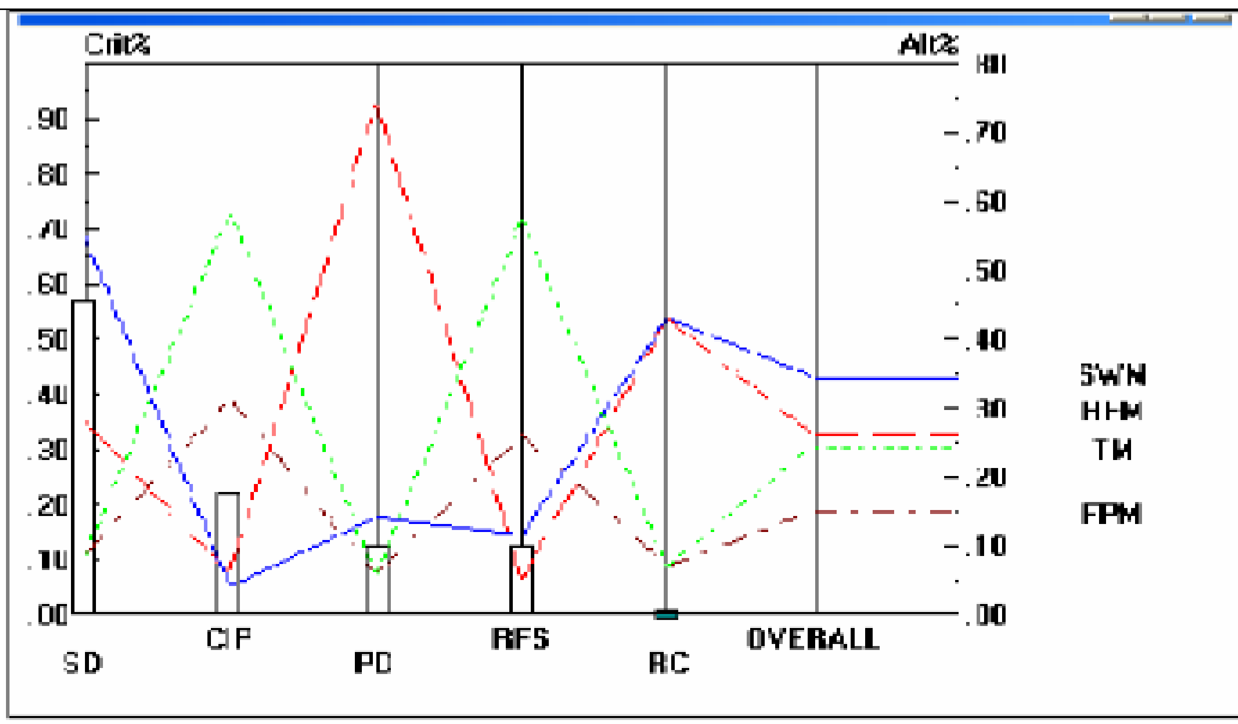


Figure 5-b: Dynamic sensitivity w.r.t GOAL for nodes below GOAL

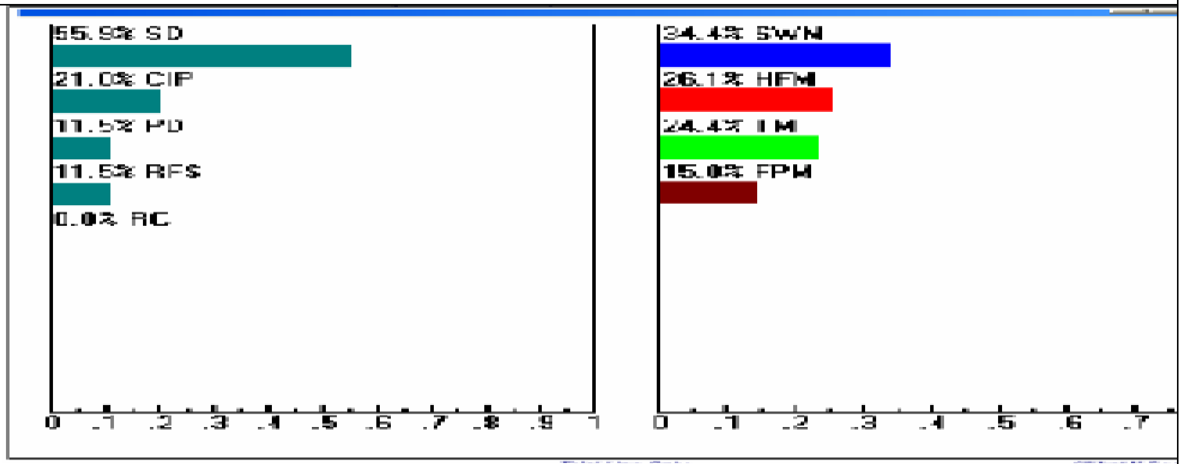


Figure 5-c: Performance sensitivity w.r.t GOAL for nodes below GOAL

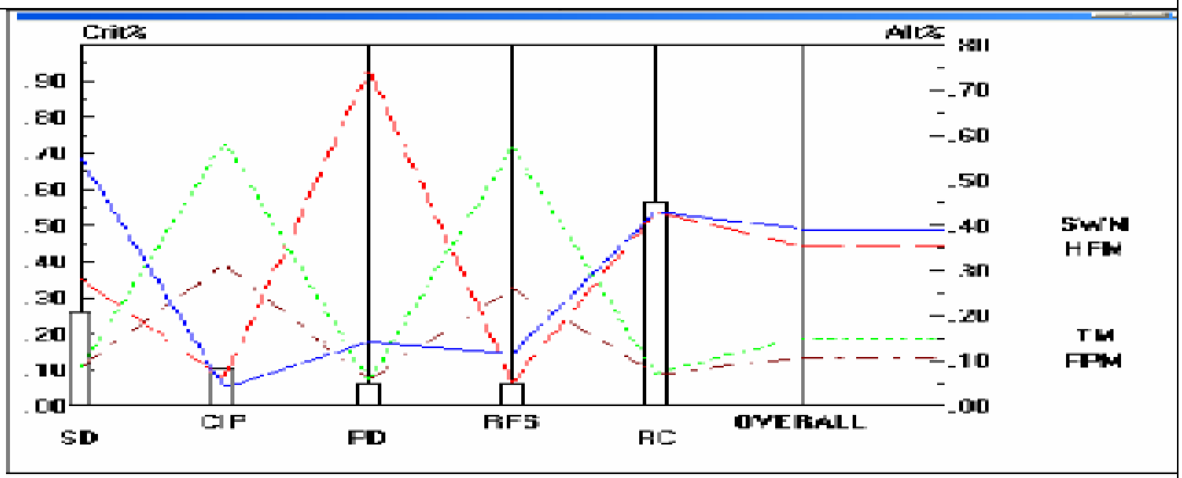
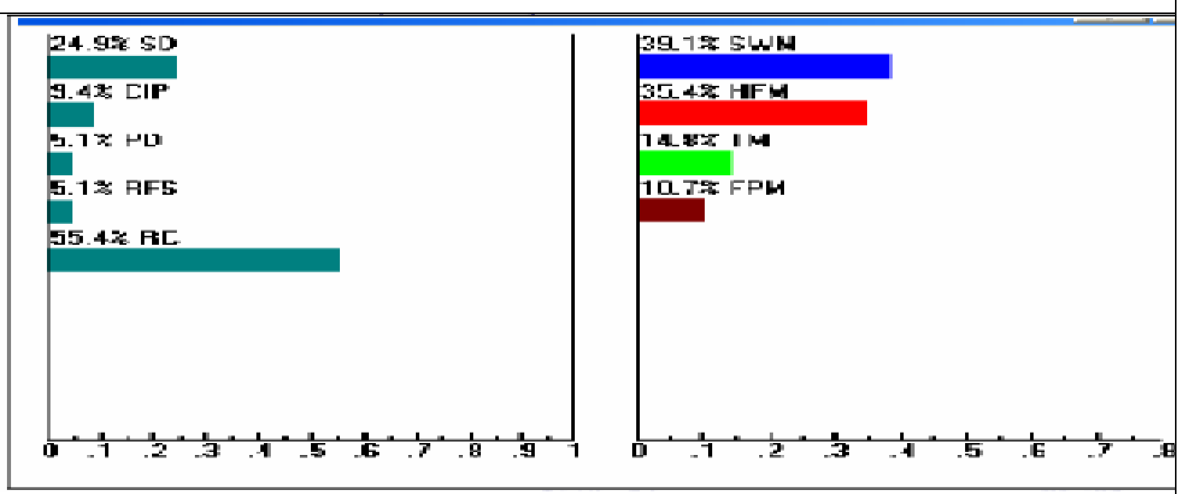


Figure 5-d: Dynamic sensitivity w.r.t GOAL for nodes below GOAL



8. Conclutions

Considering the significant value of the dairy product, lack of sufficient management information in despite of the presence of numerous dairy industry, the increasing interests for application membrane process; considerable demand for an appropriate management in terms of optimum design module membrane is sensible more than ever. Thus determining the most adequate module, along defining the priority of other alternatives is of most importance.

The main contribution of the paper is the AHP model presented in Fig. 2. This model provides a useful guideline as a structured and logical means of synthesizing judgments for evaluating appropriate module for an organization. It helps structure a difficult and often emotion-burdened decision. The second implication is the functionalities of the modules listed in the model. . Due to complicated nature of the problem and presence of various criteria, AHP method has been utilized for solving the problem. Thus, these decision-makers can examine the strengths and weaknesses of each module. Finally, with the aid of the computer tool, Expert Choice, it was shown that AHP can be easily applied to evaluate UF membrane module. The AHP methodology is particularly useful for decision-making in a multi-criteria context. After all, spiral wound module has been identified as the most adequate module for ultrafiltration membrane in dairy industrial.

References:

Wagner, J (2001)," Membrane Filtration Handbook Practical Tips and Hints," Second Edition, Revision 2.

Jiao,B., Cassano, A. and Drioli,E.(2004)," Recent Advances on Membrane Processes for the Concentration of Fruit Juices: A Review," Journal of Food Engineering ,63,303-324.

Madaeni,S.S., Zereshki,S.(2006),"Membrane Technology as a Promising Alternative for Less Energy Consumption in Food Industry," Third International Conference on Energy Research and Development (ICERD- 3).

Oak Ridge National Labratory. (2005),"Materials for Separation Technologies: Energy and Emission Reduction Opportunities," Energy Efficiency and Renewable Energy, U.S Department of Energy, Oak Ridge,TN 37830.

Muthukumaran,S., Kenitish,S.E., Ashokkumar,M. and Stevens, G.W. (2005) ”Mechanisms for the ultrasonic enhancement of dairy whey ultrafiltration”, Journal of membrane science,258,106-114.

Schwinge, J., Neal, P.R.,Wiley, S.E.,Fltcher D.F.,and.Fane A.G. (2004) ”Spiral Wound Modules and Spacers: Review and Analysis”, Journal of Membrane Science, 242,129-153.

Le-Clech, P.,Cao ,Z., Wan P.Y.,Wiley, D.E. and Fane, A.G. (2006) ”The application of constant temperature anemometry to membrane processes”, Journal of membrane science, 284416-423.

Eykamp, W., (1997),"Membrane Separation Processes in Perry's Chemical Engineers Handbook,"7^{th} ed.,Mc Graw-Hill,NY.22.39-22.41.

Ali, S., Boblak, P., Capili, E. and Milidovich, S. (1998),”Membrane Separation and Ultrafiltration”, CHE-396 Senior Design.

Cousins, R.B. (2003-2004),”Membrane Technology," Department of Chemical and Process Engineering University of Strathclyde in Glasgow.

Partovi**,** Fariborz Y. (2006)**,”** An Analytical Model of Process Choice in the Chemical Industry," International Journal of Production Economics, 105,213-227.

Al-Subhi Al-harbi, Kamal M, (2001),”Aplication of the AHP in Project Management,” International Journal of Project Management, 19. 19-27.

Okoli, Chitu Suzanne and Pawlwoski, D. (2004), “The Delphi Method as a Research Tool: An Example, Design Considerations and Applications," Journal of Information and Management, 42, 15-29.

www.Expertchoice.com