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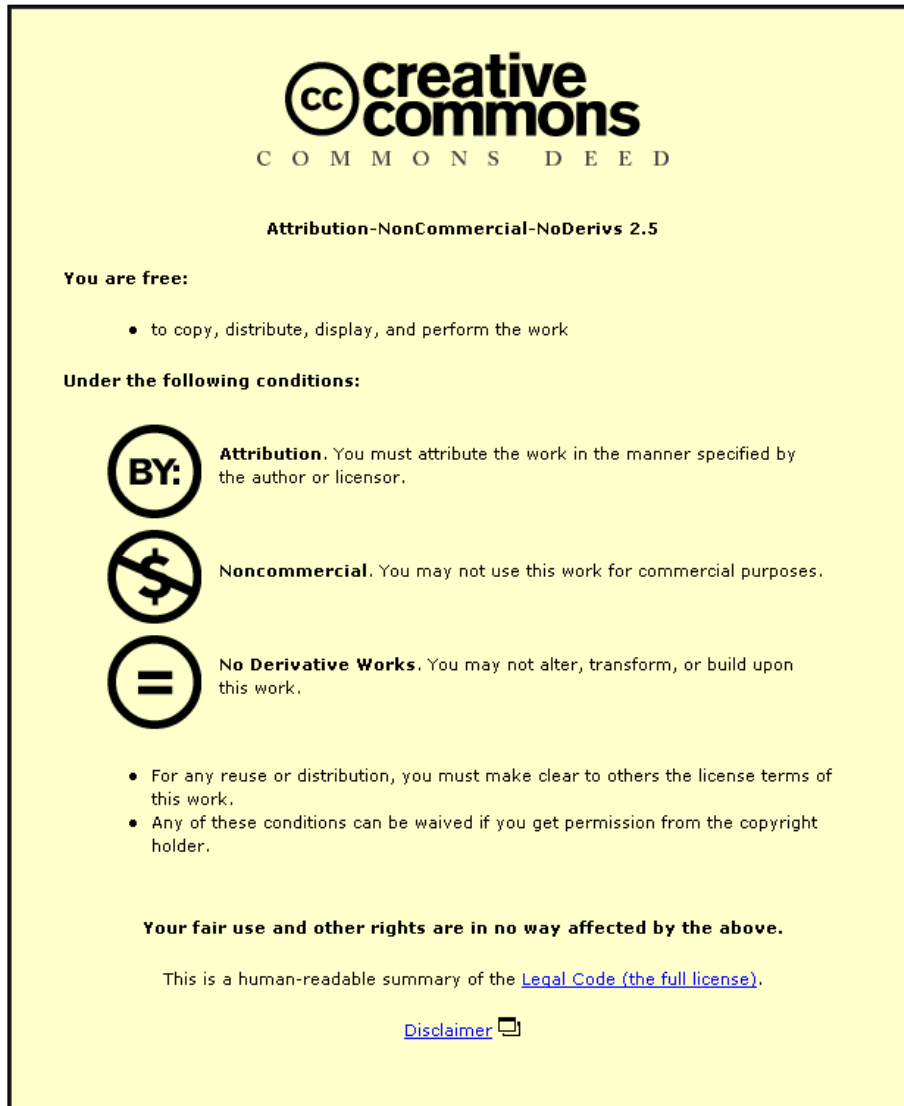
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## EXPERT SYSTEM FOR SOLID/LIQUID SEPARATION EQUIPMENT SELECTION

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### ABSTRACT

Commercially available expert systems on their own are inadequate for solid/liquid separation equipment design and selection. Software which utilises a well-chosen mix of algorithm, graphics, expert system, and interactive input from the engineer is more effective. An example of the application of the combined approach to equipment selection is given to demonstrate that efficient software can save time and enable decisions to be made rapidly. Equipment selection using the p<sup>C</sup>-SELECT software is shown.

### INTRODUCTION

Artificial intelligence has achieved considerable success in the development of expert systems which can now be found in many areas of technical endeavour<sup>1-7</sup>. The area of expert systems uses techniques such as rapid prototyping, backward and forward chaining and knowledge representation through production rules, semantic networks and frames to construct man-machine systems with specialised problem solving expertise. Figure 1 illustrates in a general sense the components of an expert system; the knowledge base contains the factual and empirical knowledge of experts in the subject, the inference mechanism simulates the problem-solving strategy of a human expert and the explanatory interface determines how the expert system interacts with the user.

Expertise comprises knowledge about a particular topic, understanding of the problems in the topic, and skill at solving some of these problems. Knowledge in this sense is usually of two sorts, public and private. Public knowledge includes published definitions, facts and theories of which textbooks are typically composed. But expertise in a technical area usually involves rather more than just this public knowledge; human experts generally possess private knowledge that has not found its way into the published literature. Private knowledge may consist of unpublished techniques or approaches, or it may take the form of rules of thumb that have come to be called heuristics. Heuristics enable the human expert to make educated guesses when formalised or algorithmic solutions are difficult or impossible to determine, to recognise promising approaches to problems and to deal in the best practicable way with errors or incomplete data.

Filtration and separation technology contains numerous heuristics, which can be evidenced by consulting industrial reference books such as *Solid/Liquid Separation Equipment Scale-Up*<sup>8</sup>. A majority of industrial process engineers need to possess wide ranging knowledge covering many unit operations and different types of plant, and rarely have the opportunity to gain in-depth specialist knowledge of filtration and separation technology. Consequently the large number of heuristics that have evolved in the technology must be confusing and probably presents to the non-expert a picture of a technology in disarray. This is compounded by published textbooks which are frequently remarkably similar to previous ones in their technical content and generally convey the impression that developments in the understanding and formulation of more rational and reliable approaches to such factors as equipment selection and design have stagnated since about 1930. It is also the case that better design methods exist in published literature, but all too often there is the problem that book authors have not assimilated what is available and they may not have a good enough grasp of either fundamental or of heuristic knowledge to advance the technology through the written medium.

Solid/liquid separation technology, whether it be in areas of selection or design, is best dealt with by software designed to run interactively, so that the engineer can input data and receive a result rapidly. The expert system can be used to ensure the correctness of input data as far as this is possible, and it can utilise interactive graphics facilities to show effects of changes in variables or to allow the engineer access to calculations to make value judgements where these are peripheral to the expert system. To be most effective the software must be a well-chosen mix of algorithms, expert system and input information from the engineer<sup>9</sup>.

## SELECTION CHARTS AND THEIR USE IN P<sup>C</sup>-SELECT

There exist a number of charts<sup>10,11</sup> which can serve as a guide to the initial approach to equipment selection, the better ones of which consider a variety of possible eventualities and indicate where decisions must be made. These charts generally have been devised by experts to be fairly comprehensive and are of value to the solid/liquid separation expert.

They also illustrate the near-impossibility of combining comprehensiveness with useability when so much interacting is presented in the written form. Purchas<sup>8</sup> introduced a general guide for the non-specialist, which is a valuable aid to one confronted with this confusing and complex area. The basis of this guide is adopted, suitably extended and adapted, for use in the software p<sup>C</sup>-SELECT<sup>12</sup> which incorporates features of the type discussed in this paper to produce an expert system.

The essential steps in solid/liquid separation were clearly identified and laid out by Purchas<sup>8</sup> and are shown in a simplified form in Figure 2. There are three principal sets of data which characterise the problem. The first set describes the requirements of the separation in the process environment, the second set concerns the data obtained from leaf and/or jar tests to characterise the filtration and/or sedimentation behaviour of the slurry, and the third set constitutes a data bank which holds information about available solid/liquid separation equipment.

Information associated with more than fifty categories of equipment is held in the p<sup>C</sup>-SELECT data bank. These data are analysed by p<sup>C</sup>-SELECT using public knowledge, heuristics and decision making techniques such as production rules.

Results from the analyses are data sheets which detail both experimental and calculated results from tests, and a list of recommended equipment which satisfies the process requirements and slurry characteristics. The list may be sorted and ranked according to various relative operational performance criteria or product quality demands. Any other screens displayed during the analysis also may be printed for inclusion in reports.

## EQUIPMENT SELECTION BY P<sup>C</sup>-SELECT

The following is a hypothetical problem illustrative of the type which the process engineer may face in the selection of solid/liquid separation equipment. As part of the production cycle a plant needs to recover the solids constituent in a washed form at the rate of 0.3 t h<sup>-1</sup> from an aqueous feed suspension carrying a solids mass fraction of 0.05%. The nature of the plant indicates that a continuous type operation will be required; identify a preliminary list of equipment which may be suitable for this separation. Leaf and jar data have been measured.

p<sup>C</sup>-SELECT allows entry into its rule based selection procedures at various levels, the level of entry being determined by the amount and type of information available. In terms of the amount and type of information available there are two important entry points. The first is the ability to enter for an initial list of equipment without any form of test data, but with a knowledge of the process. Here a list can be produced, but against each item in the list will be one or more warning messages indicating the need to additional data of a particular type. The second important entry point is after

the analysis of leaf and/or jar test data, the results from which will enable a more reliable and shorter list to be drawn up than was possible at the previous entry level.

Entry into the expert system with the low level of data specified above (excluding any test data) will lead to a long list of equipment which might be capable of achieving the separation (Figure 3). The list is divided into three parts. The top part is a summary of the information fed into the selection procedure. The second part is a list of the selected equipment (in order of an overall performance rating in this instance) that indicates for each item, through selection warnings, what further action should be taken to check the equipment suitability and what limitations the equipment may possess.

The suitability of the equipment is also related to typical particle size ranges and feed concentrations. Although the latter information has been used in the selection, the values have been implied through the use of composite data and it is at this point the engineer can check the equipment information against values from the process. The third part of Figure 3 is the equipment listed together with relative performance criteria. These are based on a scale from 0 to 9, with larger numbers indicating better performance and showing whether the solid is generally discharged in cake (C) or slurry (S) form. The technical expert will recognise that some items in Figure 3 are not realistic alternatives. The selection warnings marked against each item in the list reflect this and clearly it would not be acceptable to rely on Figure 3 for anything other than first impressions.

Analysis of the leaf and jar test data, using  $p^C$ -SELECT, provides additional data which the selection procedure can utilise. The previous list of 20 items is reduced to the 6 listed in Figure 4, which also shows that inclusion of the additional data has removed most of the selection warnings.

A full analysis using  $p^C$ -SELECT uses algorithm and graphics software with interactive input from the engineer to analyse test data followed by expert system software, again with engineer input. A selection and a report if desired, are completed within minutes and 'what-if?' queries are easily investigated.

It is not the purpose of the example to demonstrate all the facilities of  $p^C$ -SELECT, but to illustrate the general method of approach to equipment selection using computers. It is interesting to note that avoidance of 'pure' expert system tools has been recommended<sup>12</sup> in circumstances that arise in evaporation process design where the need for an interface between heuristic based selection and detailed calculation is similar to that required for solid/liquid separation equipment selection.

The procedures outlined above enable the non-expert to come to rational decisions based on expert knowledge, without the need to consult an expert in the earlier stages of solving his problem. This is important in solid/liquid separation, as the expert is often a representative of an equipment manufacturing company whose job it is to sell a particular type of separator. Taking filters as an example, many types usually will be capable of carrying out a particular filtration, but probably only a few general types will be most suited to the task. It is wise to have an insight into which types these are before consulting an expert.

Software such as  $p^C$ -SELECT enables the rapid analysis of data and exploration of alternatives, it puts the engineer in a position to ask more penetrating questions of whichever expert he or she may consult, and reduces expenditure on unwarranted pilot scale testwork. These advantages are gained without the need for extensive computer knowledge or high speed/capacity computers.

## CONCLUDING REMARKS

The widespread use of heuristics, the lack of standard approaches to most aspects of design and the limited information available to the design engineer in texts gives rise to several requirements in solid/liquid separation. There is a need to

- standardise small scale tests
- rationalise the analysis of the data which come from the tests
- formalise the approaches to process design and scale-up of equipment.

Manufacturers of different equipment types tend to use different heuristic approaches to equipment sizing, making it very difficult for a user engineer to check that the correct equipment is being specified for the separation and that the size of the equipment is appropriate.

Computer software could be of considerable assistance not only in the areas identified above, but also in design and scale-up<sup>14</sup>. Design procedures and know-how in many other branches of engineering, for example in heat transfer, are documented widely and simulation and model equations are freely available and well developed.

This is not the case in solid/liquid separation where design codes and other useful information are effectively non-existent. Starting from the present overall position of the technology and the current state of design procedures it would be unrealistic to expect to formalise all aspects of design or scale-up, not least because of the wealth of rule-of-thumb knowledge which is not available to the technologists. The main problem is that this information is available to a limited number of technology experts, but to few others.

The use of an integrated software approach utilising a well-chosen mix of algorithm, graphics, expert system and input information from the engineer could overcome the problem that probably stems from deficiencies of communication between experts and non-experts, and between academics and industrialists. To bring all of the technology up to such a level that it is equally available to everyone that wishes to use it would be an enormous task, but perhaps it is a goal we should aim to achieve.

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## TABLES AND FIGURES

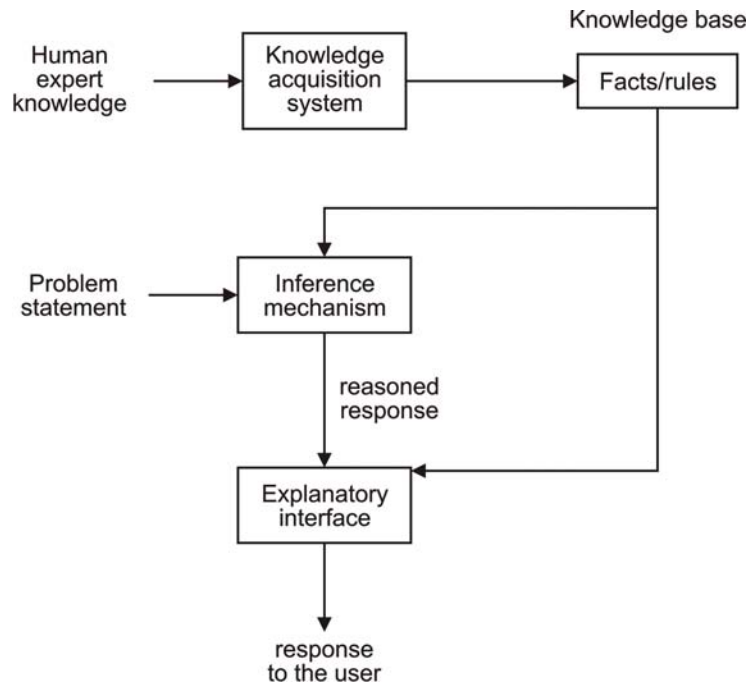


Figure 1: The basic elements of an expert system.

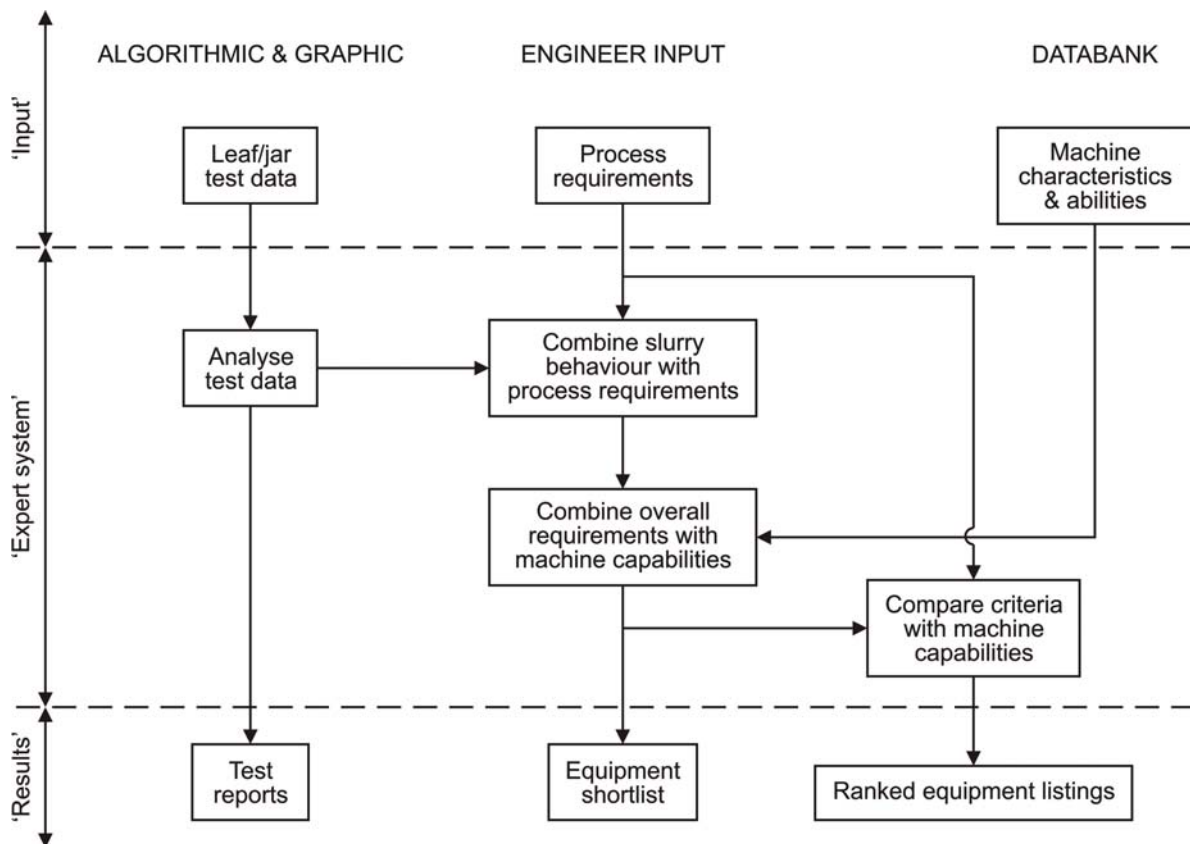


Figure 2: The steps involved in the selection of separation equipment.

Solid/Liquid Separation Equipment Simulation & Design, P<sup>C</sup>-SELECT

## DATA SHEET FOR EQUIPMENT SELECTION

## Specifications

Duty            Scale:- medium (1 m<sup>3</sup>/hr)  
 Operation:- continuous  
 Objective:- washed solids recovery

Settling        Rate:- not specified  
 Overflow clarity:- not specified  
 Sludge proportion:- not specified

Filtration     Cake growth rate:- not specified

Selected equipment description	Selection warnings	Particle size (µm)	Feed conc. (% v/v)
Horizontal belt, pan or table filter	2,3	20-80,000	3-40
Bottom fed drum filter, knife dis.	2,3	1-200	3-30
Bottom fed drum filter, roll dis.	2,3	1-50	3-30
Bottom fed drum filter, string dis.	2,3	1-70	3-30
Continuous pressure filter	2,3	1-100	0.01-30
Variable volume filter	1h,2,3	1-200	0.1-25
Top fed drum filter			
Screen or sieve bend classifier			
Low shear crossflow microfilter			
Gravity thickener			
Drum, grid or belt magnetic filter			
High shear crossflow filter			
High gradient magnetic filter			
Scroll (decanter) centrifuge			
Hydraulic classifier			
Mechanical classifier			
Low shear crossflow microfilter	1h,2,3		<10

Selected equipment description	F3: index	F4: index	F5: index	F6: index	F7: index
Horizontal belt, pan or table filter	7C	7	9	8	31
Bottom fed drum filter, knife dis.	6C	7	7	8	28
Bottom fed drum filter, roll dis.	6C	7	7	8	28
Bottom fed drum filter, string dis.	6C	7	7	8	28
Continuous pressure filter	6C	7	6	7	26
Variable volume filter	8C	7	4	7	26
Top fed drum filter					22
Screen or sieve bend classifier					18
Low shear crossflow microfilter					18
Gravity thickener					17
Drum, grid or belt magnetic filter					17
High shear crossflow filter					16
High gradient magnetic filter					15
Scroll (decanter) centrifuge					14

Hydraulic classifier					14
Mechanical classifier					13
Low shear crossflow microfilter	1S	9	2	0	12

F3 index:- Solid product dryness

F4 index:- Liquid product clarity

F5 index:- Washing performance

F6 index:- Crystal breakage

F7 index:- Overall performance

Equipment listed in order of overall performance rating

Figure 3: Equipment selection with a low level of data.

Solid/Liquid Separation Equipment Simulation & Design, P<sup>C</sup>-SELECT

## DATA SHEET FOR EQUIPMENT SELECTION

## Specifications

Duty	Scale:- medium (1 m <sup>3</sup> /hr) Operation:- continuous Objective:- washed solids recovery
Settling	Rate:- (0.1-5 cm/s) Overflow clarity:- good Sludge proportion:- medium (2-20% vol)
Filtration	Cake growth rate:- fast (greater than 1 cm/min)

Selected equipment description	Selection warnings	Particle size (μm)	Feed conc. (% v/v)
Horizontal belt, pan or table filter	2,3	20-80,000	3-40
Screen or sieve bend classifier	1cBG	45-100,000	20-40
Gravity thickener			
Scroll (decanter) centrifuge			
Hydraulic classifier	None	50-2,000	4-40
Mechanical classifier	1h	100-3,000	4-40

Selected equipment description	F3: index	F4: index	F5: index	F6: index	F7: index
Horizontal belt, pan or table filter	7C	7	9	8	31
Screen or sieve bend classifier	5C	5	4	4	18
Gravity thickener					
Scroll (decanter) centrifuge					
Hydraulic classifier	3C	3	3	5	14
Mechanical classifier	4C	3	2	4	13

F3 index:- Solid product dryness  
 F4 index:- Liquid product clarity  
 F5 index:- Washing performance  
 F6 index:- Crystal breakage  
 F7 index:- Overall performance

Equipment listed in order of overall performance rating

Figure 4: Equipment selection with a high level of data.