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ATOMIC ENERGY OF CANADA LIMITED

ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

SHELL-AND-TUBE HEAT EXCHANGER SELECTION AID

SYSTÈME POUR AIDER À LA SÉLECTION DES ÉCHANGEURS DE CHALEUR MULTITUBULAIRES

L.R. LUPTON and R.A.J. BASSO

Presented at: International Symposium for
Demonstration of Expert System Applications to the Power Industry,
Montreal, Quebec, 1989 May 7-12

Chalk River Nuclear Laboratories

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RÉSUMÉ

On a mis au point un prototype pour étudier la possibilité d'utiliser des systèmes experts pour aider les concepteurs subalternes de systèmes industriels à la sélection d'éléments d'échangeurs de chaleur multitubulaires. Les critères de sélection pour la conception des échangeurs de chaleur sont fonction des contraintes industrielles, écologiques et administratives. On a mis au point ce système à l'aide d'EXSYS; il comporte à peu près 140 règles. Dans cette communication, on décrit le processus de mise au point et les leçons tirées.

Présentée au Symposium international sur la démonstration des applications des systèmes experts à l'industrie électrique, à Montréal, Québec 1989 mai 7-12.

Instrumentation en contrôle
*Projet CANDU avancé
Laboratoires nucléaires de Chalk River
Chalk River, Ontario, Canada ROE 1L0
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ABSTRACT

A prototype has been developed to investigate the feasibility of using expert systems to aid junior process system designers with the selection of components for shell-and-tube heat exchangers. The selection criteria for heat exchanger design were based on process, environmental and administrative constraints. The system was developed using EXSYS and consists of approximately 140 rules. This paper describes the development process and the lessons learned.

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1. INTRODUCTION

Recent developments in expert systems technology offer a vehicle to enhance the design of process systems by assisting in the decision making process. A prototype expert system was constructed, for the Heat Transfer and Fluid Flow Service, to aid junior designers with the proper selection of components for shell-and-tube heat exchangers

Heat Transfer and Fluid Flow Service (HTFS) is an international organization of 200 members in over 20 different countries. It is a co-operative venture funded by industry and government to improve heat transfer and fluid flow technology. Atomic Energy of Canada Limited (AECL) is a member of HTFS and has been designated as the support group for North American HTFS members.

This prototype allowed HTFS to evaluate the benefits of expert systems for the process industry and it was hoped that the benefits for a junior designer would include:

- confidence of design,
- improved operating reliability,
- reduced equipment costs,
- energy savings, and
- on-line access to expert knowledge.

This paper summarizes background information related to the application, specific details of the implementation of the expert system and lessons learned.

2. OVERVIEW

The shell-and-tube heat exchanger is one of the most common types of exchangers in use today. It consists of three major components: a front head, a shell (filled with tubes), and a rear head (see Figure 1). This equipment exchanges heat between the process fluid and the service fluid. The designer must select between various combinations of heads and shells as well as determine on what side of the exchanger to place the process and service fluids - shell side or tube side. These design decisions depend upon the properties of the two fluids (i.e., corrosive, dirty, etc).

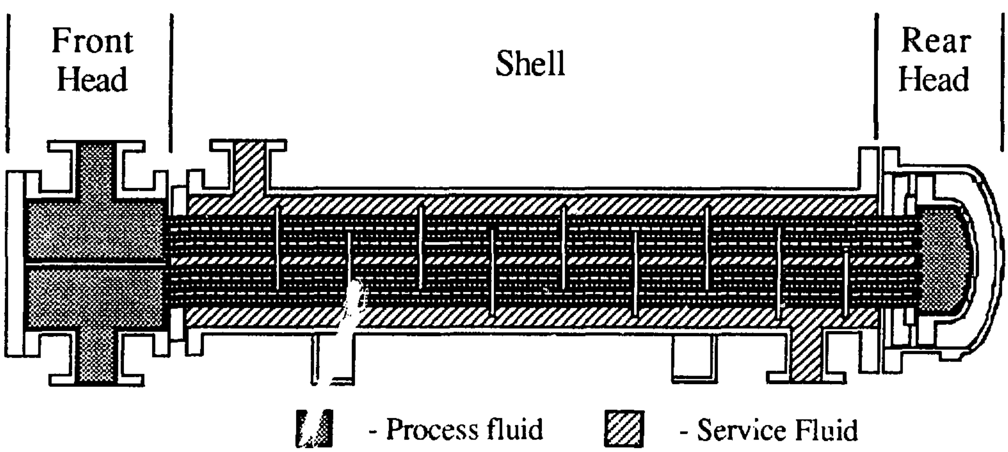

Figure 1: Cross-section of a Typical Shell-and-Tube Heat Exchanger

This prototype expert system focuses on a small cross-section of literature selected by HTFS personnel [1 -3]. Development of the prototype consisted of scanning the design literature to extract the basic rules for the design of shell-and-tube exchangers, and encoding the pertinent information into an expert system shell for evaluation.

3. OBJECTIVES

The functional objective behind the development of this prototype was to evaluate the merits of using expert system technology to assist junior engineers with the design of shell-and-tube heat exchangers. Specifically, we were investigating if sufficient information (knowledge) could be encoded into an expert system to enable it to produce valid recommendations. Also, it was required that the recommendations made by the system be verifiable through the inclusion of references to the literature.

Hardware and software selected for this system had to satisfy the following constraints:

1. Hardware selected had to be IBM XT / AT compatible. This condition was imposed as the existing HTFS software packages are IBM-based. The delivery version of this expert system had to be capable of integrating into this environment.

2. To expedite prototyping, the expert system development environment had to be an expert system shell. Five man-weeks of effort were allotted to the development of the prototype including one man-week of a local expert's time.

3. The cost of the expert system shell software had to be low as the development was designated as a "prototype".

4. The user interface to the prototype had to be simple, so that junior designers could quickly learn to use it.

4. IMPLEMENTATION

The heat exchanger expert system was implemented using EXSYS, a low-cost expert system shell [4]. It was hoped that this expert system would be capable of executing on an IBM XT or a clone, but as the number of rules became large (> 100), delays of up to 2 -3 minutes were experienced. A Toshiba T3100/20 (AT compatible) was then selected as the development platform to improve the response time. This computer also offered the advantage of portability.

EXSYS follows the traditional "IF-THEN-ELSE" style of rules (see Figure 2) which made the development of the application straightforward. We used the simple, built-in rule editor to enter the information into the system. As rules were created, probabilities (or confidence factors) were also assigned to the outcome, if appropriate. For this development, backward chaining was used where the expert system attempts to satisfy the IF condition of a rule from information derived from other rules contained elsewhere in the knowledge base.

To verify the operation of the expert system, a local expert was consulted frequently. Three versions of the prototype were eventually constructed before the expert felt that sufficient knowledge had been encoded correctly. After a 5 man-week development effort, the third version of prototype, consisting of approximately 140 rules, was delivered to the HTFS group for evaluation.

When running the application, the designer is presented with a series of screens each containing a qualifier statement and a series of values that can be used to describe the qualifier statement (see Figure 3). The designer is allowed to select one or more of these values to complete the statement. The expert system then evaluates each completed statement with its rules - attempting to arrive at a conclusion. If all the IF conditions of a rule are true then the information contained in the THEN portion of the rule is added to the list of knowledge. In the situation where the IF condition cannot be proven, the ELSE portion of the rule (if present) is added to what is known to be true. The expert system only poses sufficient questions to arrive at a conclusion. After the system has evaluated the rule base, it automatically generates a list of possible choices ranking them according to probability (see Figure 4).

At the completion of the analysis, the expert system automatically produces a summary list of all the designer's inputs (see Figure 5). The designer has the option of changing one or more of the original entries and re-running the analysis. The designer can then compare these new results with the original results.

```
RULE NUMBER: 47
IF:

      (1)    process stream on tubeside > 5/10
and   (2)    The PROCESS stream is NOT hazardous
and   (3)    The PROCESS stream is dirty or fouling

THEN:

             'A' Type Front Head (channel and removable cover) -
             Probability=9/10

NOTE: The B-type head is not recommended for exchangers which require frequent
      tubeside cleaning since the entire head must be removed. A-type heads
      are preferred for dirty fluid on the tubeside.

REFERENCE:   Preliminary Selection and Design of Shell & Tube Heat Exchangers -
             Section 2.4.3, 2.4.8, 2.5.1

CHANGE: IF<I>, Then <T>, Else <E>, Note <N>, Reference <R>,Done <ENTER>
↑ for previous rule, ↓ for next rule
```

Figure 2: Typical Developer Screen

```
The PROCESS stream is
    1  high temperature (> 400 F)
    2  high pressure (> 300 psig)
    3  corrosive
    4  dirty or fouling
    5  high volumetric flow (> 1000 igpm)
    6  hazardous
    7  expensive
    8  in contact with expensive materials
    9  NONE of the above
1,3,4

Enter number(s) of values, (?) for more details, Quit to save data entered
or <H> for help
```

Figure 3: Typical Input Screen Used by a Designer

```
      Values based on 0 - 10 system                                   VALUE

1   'A' Type Front Head (channel and removable cover)                   9
2   odd tubepass exchanger                                              9
3   'L' Type Rear Head (fixed tubesheet - channel and removable
    cover                                                               8
4   process stream on tubeside                                          7
5   service stream on shellside                                         7
6   all welded construction or double tubesheet                         7
7   'E' type: one pass shell                                            6
8   fixed tubesheet exchanger                                           6
9   outside diameter of tube (inches) 0.75
10  tube layout = TRIANGULAR OR ROTATED TRIANGULAR
11  Note: low fin tubing should be considered for this application.

All choices <A>, only if value>6, Print <P>, Change and rerun <C>,
rules used <line number, Quit/save <Q>, Help <H>, Done <D>:
```

Figure 4: Results of Expert System Evaluation

```
1   The PROCESS stream is high temperature (>400 F) and corrosive and dirty
    or fouling
2   The specification for the PROCESS stream is not specified (program selects
    the best location)
3   Specifications indicate that leakage between the process and service
    streams CANNOT be tolerated
4   The SERVICE stream is NONE of the above
5   Specifications indicate the the allowable pressure drop for the SERVICE
    stream is high
6   Specifications indicate that the heat exchanger required is NOT specified
    (program selects best exchanger type)
7   The current company operating practice indicates that ALL 'shell' and
    'head' types are to be considered
8   Specifications indicate that the heat transfer process involves no phase
    change to the process stream
9   Specifications indicate that the temperature difference between the shell
    and tube metal is <125 degrees (F)

Enter number of line to change, <O> for original data, <R> to run the data
<H> for help or any other key to redisplay data:
```

Figure 5: Summary of Designer Information Entered for Expert System Evaluation

5. LESSONS LEARNED

Several lessons regarding the development of expert system applications have been learned. These include:

1) During the development of the prototypes, access to an expert was critical to the success of the project.

2) Low-cost expert system shells are excellent tools to rapidly develop proof-of-principle systems. The expert was impressed by how quickly knowledge could be entered into the system and manipulated into a usable form.

3) One surprising feature of the expert system was that it occasionally made an unexpected recommendation that was subsequently verified to be correct.

4) While this low-cost system was easy to use, facilities were not available to track large rule bases. This expert system development package claimed it could support 4000 rules (a memory limitation) but after 100 rules it became awkward to handle. A rule network diagram would have enabled the knowledge engineer to understand what was in the system and how it was connected.

5) A full screen rule editor would have made development easier. The simple line editor provided was cumbersome to use.

6) A "find" feature - as used in word processing - would have made searching the rule base much simpler. Currently, the rule base must be interrogated rule by rule.

7) Table entry of data was preferred by the expert instead of the single line entry offered by this package.

8) A graphic interface would help designers visualize heat exchanger component information.

9) The "Change and Rerun" facility within EXSYS was useful rerunning original data with only some minor modifications. This feature was felt to be very powerful for debugging the knowledge base and allowing junior designers to run "what-if" scenarios.

6. CONCLUSIONS

A shell-and-tube heat exchanger expert system was designed with the intent of evaluating the capability of such systems to aid junior designers. After 5 man-weeks of effort, 3 prototype systems were developed using a low-cost expert system shell. This style of shell was well suited to rapid development of "proof-of-principle" systems. The final version of the heat exchanger prototype consisted of 140 rules and encompassed much of the low-level knowledge required to support junior designers.

Although "proof of principle" conditions were satisfied, the use of this type of shell to develop a delivery system for this style of application would not be practical. Better rule management tools and rule editors are required by developers if the knowledge base extends beyond more than 100 rules. Graphics capabilities and table entry are considered important by designers for a delivery system.

Currently, the HTFS group is investigating the feasibility of developing an expanded form of this heat exchanger selection aid with the intent of producing a delivery system.

7. REFERENCES

[1] C.J. Norman, "HTFS Design Report, Heat Exchanger Selection, Part 2: Selection and Preliminary Design of Shell and Tube Heat Exchangers", Atomic Energy Research Establishment, AERE - R12202, HTFS DR18, 1986 May. (Proprietary to HTFS members).

[2] J.C. Rose, "Heat Exchanger Selection with Specific Reference to Shell and Tube Heat Exchangers", Heat-Transfer and Fluid Flow Service, Atomic Energy Research Establishment, Harwell, HL 72/4770, 1972 November. (Proprietary to HTFS members).

[3] J. Robbins, "The Selection of Heat Transfer Equipment, Heat-Transfer and Fluid Flow Service", Atomic Energy Research Establishment, Harwell, HL 71/3820, 1971 August. (Proprietary to HTFS members).

[4] EXSYS Expert System Development Package, EXSYS Inc, P.O. Box 75158, Contr. Station 14, Albuquerque, NM 87194.

ISSN 0067-0367

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