AL, an Expert System for Selecting Artificial Lift

Lloyd R. Heinze
Texas Tech University

ABSTRACT

AL (Artificial Lift) is a software program for selecting the pumping processes best suited to an oil well. It integrates an expert system which manages the knowledge of the subject and organizes the implementation of a set of algorithmic programs for making technical assessments. This article describes in detail the expert-system part and gives an example of the use of the complete system.

INTRODUCTION

Certain problems in the petroleum industry are being analyzed by a relatively new aspect of computer systems known as artificial intelligence (AI). To illustrate the use of expert system technology, a prototype rule based expert advisor program for selecting the optimal pumping method for an oil well has been developed. This program considers the four basic methods of pumping: Gas Lift, Electric Submersible Pump, Hydraulic Pump, and Sucker Rod Pump. The program starts by prompting the user for parameters related to the candidate well. As these questions are answered, AL narrows down the choices. Additional specific questions pertaining to the remaining lift methods are asked as AL continues to narrow down the choices. Finally AL gives its EXPERT opinion of the optimal lift method. The user, whether an undergraduate petroleum engineering student or an experienced engineer, is reminded of the factors that influence the selection of the artificial lift method while answering the questions.

KNOWLEDGE BASE

Knowledge Representation

The main part of AL is the knowledge it uses for problem solving. Knowledge on methods of artificial lift is derived from experts and put into the system by a knowledge engineer. Knowledge differs from data in that data are simply raw facts whereas knowledge consists of useful, interrelated facts and heuristics. Such as those which an expert would use in reaching a specific interpretive conclusion.

AL uses a rule format to organize or represent its knowledge base. This format is simple and easily developed if the knowledge can be so represented. Rules are composed of antecedent and predicate terms in an IF-THEN construction.

Sources of Knowledge

Expert knowledge is acquired from our predecessors and contemporaries through literature. Balanced knowledge of all artificial Lift methods usually cannot be derived from the research experience of a single individual, even if such an individual with universal knowledge could be tapped. Information so obtained would be subject to legitimate criticism of more specialized experts.

In creating the rules and certainty factors for the knowledge base, we have relied on review articles and books for expertise. Our synthesis of this material has unavoidably introduced our own biases.

Refinement of the system's knowledge took place through testing. As described below, testing identified inconsistencies and gaps in the knowledge base. Other than this, specific cases were not incorporated into the knowledge base.

AL's expertise involves tracing through inferences of hundreds of IF-THEN statements. It handles its logic by probabilities. A person knowledgeable in this field can quickly develop an expert system without being an expert computer programmer or help from a programmer.

AL's knowledge base is divided into ten sections with a total of some 500 rules (figure 1). The first section defines user operators. These operators make the questions posed to the user by AL, AL's answer to user queries of WHY or OPTIONS or EXPLAIN, and the program itself be expressed in more understandable English. They consist of prefixes, infixes, and postfixes. They make the program treat a two or three or four word phrase as only one word. Initial Meta-facts the second section initializes the expert session and displays the opening screen. The third part, Intro, queries the user for instructions and if necessary provides them.

The fourth section, Rule base # 1, delineates possible and impossible methods from one another using only the criteria of depth and flow rate. Each possible method has a maximum rate and depth at which it applies. These maximum rates and depths are interrelated for many of the methods. Each manufacturer's information, recommendations and the appropriate API RP 11 have been used to generate a series of rate versus depth curves and an equation for maximum rate determined.

Rule base # 1 questions, the fifth section, delineates "legalval". That is the only answers AL will accept for a certain question. AL checks a user's response against a set of possible answers. An example from the program is:

legalvals(rate) = number(1,30000).

Meaning that rates from one to thirty thousand BFPD are allowed. This section also forms the questions posed to the user by AL and AL's answer to user queries of WHY or OPTIONS or EXPLAIN. It also helps to make the system more user friendly. When answering you may give your answers in three forms: (1) By typing the answer in full. (2) By typing enough of the answer to distinguish it from other answers. (3) By entering the number displayed (if any) before the possibility. However, before AL asks a user a question it first searches its knowledge base to see if it can find the answer itself and only as a last resort asks the user a question.

Rule base # 2 makes a preliminary evaluation of a likely method of artificial lift based on the values from rule base # 1 and further refines the solution by considering well related problems. The problems AL looks at are: sand production, paraffin, crooked hole, corrosion, casing size, scale, and ease of changing producing rate. These problems are displayed in a table and the user is prompted to select from the table any problems he feels exists. Different artificial lift methods perform better in the presence of some problems than do other methods (Table 1). The user is then asked to quantify the problems he has listed on a scale from one to five.

Rule base # 2 questions provides for rule base # 2 the same type of backup help that rule base # 1 questions provided for rule base # 1. This includes information on each of the items listed in the problems table, a short explanation of why this might be a problem and even where the user might look to determine if he should consider this problem in his well.

The eighth section of AL, Rule Base # 3, examines the more likely methods of artificial lift. If a method fails its test then another is attempted until all of the methods are exhausted or an acceptable is found. AL continues examining the remaining methods one by one in this section, asking the user questions related to the specific method that it is considering. For example:

> if the method = gas lift and
> not(gas is available)
> then gas lift is unsuccessful.

AL further keeps the user informed of which specific lift method it is considering by telling the user:

> I am now beginning my investigation of
> gas lift.

Which tells the user that the gas lift method has passed the first two rule base criteria and AL is going to ask some question specific to gas lift. AL will then proceed to ask if the user can implement gas lift.

Rule base # 3 questions provides for rule base # 3 the same type of backup help that rule base # 1 questions provided for rule base # 1. A full example set concerning only one question AL might ask a user follows:

```
automaticmenu(h2s is present).
enumeratedanswers(h2s is present).
legalvals(h2s is present) = [yes,no].
question(h2s is present) =
'Do you expect the produced fluids
to be sour? (i.e. contain hydrogen
sulfide)'.
explanation(h2s-X) =
'The presence of hydrogen sulfide
gas (H2S) tends to cause
embrittlement in some oil field
steel goods. Sucker rod lift
tends to be adversely affected by
this embrittlement. Additionally
```

the electrical cables which
connect a centrifugal pump to the
surface has copper wires in them
which can also become brittle'.

As can be seen the user friendly part of AL took a lot of time.

The last part, rule base # 4 outputs the results of the program. AL's output looks like this:

I have concluded my inquiry. I will list below what I feel are the better choices for an artificial lift method. Each method will displayed along with a rating. The methods are rated on a scale which goes from 1 to 100 with 100 representing an ideal method.

gas lift	63
hydraulic lift	32
centrifugal lift	25
sucker rod lift	21

If no method of lift has a certainty factor greater than 20, then the program will conclude: "No acceptable method is available for the data you gave. Consider changing your requirements." Additionally if any single lift method has a certainty factor less than 20 it will not be displayed as a potential choice in the answer. If the user wants to know AL's reasoning at the end of the session, he can ask "why or how." AL will list its reasons.

DEVELOPMENT

Expert-system shells offer the advantage of providing a prefabricated operating environment for the testing of expert knowledge. We examined and evaluated a shell called M1 and found it satisfactory for our purposes.

BACKGROUND

Expert systems are computer programs that use expert knowledge to attain high levels of performance in a narrow problem area. The individual human expert skills needed to interpret and assess data (decide which lift method is best in a given set of circumstances) are a result of years of formal training, rules of thumb, methods of dealing with constraints and human prejudice. In short humans have gained through experience knowledge.

AL differs from conventional programs in that knowledge is represented explicitly, as well as, data and algorithms, and that knowledge can be easily enhanced through increased exposure to a particular problem area. AL has a knowledge base, (expertise is represented in a series of IF-THEN rules), an inference engine (processes rules according to some control strategy), and a database (where facts, deductions and intermediate answers are stored). The control strategy could be data driven or goal driven, or both. In a data driven strategy, the rules are worked forward checking against the database to make further conclusions. In AL, a goal driven strategy, the system starts with a hypothesis and by using rules that establish the hypothesis, works backwards, checking their preconditions against that database.

As an expert systems AL has the following characteristics:

a) Symbolic representation of knowledge;

if temperature > TEMPERATURE and
temperature > 250
then centrifugal lift is unsuccessful.

b) Symbolic reasoning;

if A implies B and
A is true
then B is true.

c) The decision path is not predefined. AL weighs facts or assumptions depending on the users response to the questions posed. AL's artificial lift knowledge is used to guide a selective search for solutions. Each user response causes AL to select a particular decision path. When AL goes through a different session it will not necessarily ask the user the same sequence of questions

d) AL performs complex non-numerical tasks functioning in areas where there is incomplete or uncertain information. If the user is uncertain of the correct answer he can tell AL "unknown" or give AL several possible answers and even tell AL what the probability of each possible answer is. AL handles this kind of fuzzy logic with a term called certainty factor (CF).

e) AL uses artificial lift knowledge to find a solution more efficiently, if the problem is solvable, given that body of knowledge as opposed to relying on general procedures. If the problem is not solvable AL will tell you that no solution was found.

f) AL is capable of justifying its reasoning and providing explanations. The user at any time can ask AL WHY or EXPLAIN.

g) AL has a knowledge base (rules, facts, heuristics, etc.) + inference engine (rule interpreter) + database (working storage) (Figure one).

AL differentiates between knowledge base (represented as rules) from inference engine (how knowledge is used), and these two are coded separately and are kept separate. This explicit representation of knowledge has the following advantages over the conventional systems:

a) AL's knowledge base is easily understandable by experts or system developers. This facilitates the tasks of modifying the encoded knowledge and checking its consistency or completeness.

b) It is easy for AL to access specific rules for explanation by itself (for inferencing or providing justification) or by the user for explanation. Since AL was specifically intended for petroleum students use, it is important that the user should be able

to see how or why the system is producing certain conclusions. AL has a special panels mode which allows the
user to see in a set of top windows the rules it progressively searches and the temporary decisions it is holding in data as it steps through its process.

c) Prototypes can be developed rapidly due to the modularity of the AL's components. One of the advantages of separating the knowledge base from inference engine is that this facilitates changing either independently.

In a conventional program:

a) The essential meaning of knowledge is distributed in procedures, programing code, and subroutines, so that only the programmer can trace it. The programer himself has an extremely difficult time tracing the flow of the program.

b) The program cannot access this knowledge readily, for example, to provide explanations or allow interactive updating of the knowledge base.

PERFORMANCE EVALUATION

To evaluate the performance of the system, the program was given to a group of senior petroleum engineering students who had just completed a course in production applications, specifically in methods of artificial lift. Additionally, two industry expert were given copies of the program and asked to provide suggestions. Certainty factors (CF.) in the rules were adjusted after these tests to correct inconsistencies and oversights. Many questions and answers were reworded to make AL more user friendly. Additional explanations to user posed questions of WHY or EXPLAIN were added to clarify how AL made its decisions. We did not necessarily presume all comments or interpretations of experts were correct, nor did we feel that all discrepancies could be reconciled with our human experts. Thus the rule base in AL still reflects our own biases, rather than those of the experts. But as one expert in gas lift commented "We try first to see how we could possible make a gas lift system work rather than consider what method of lift is best suited to the well." We found that our expert who had Gulf Coast experience thought almost everything should be gas lifted and our West Texas expert said the same about sucker rod lift.

BENEFITS

What are the practical benefits of AL or any expert systems? The major practical benefits of expert systems can be summarized as follows.

AL increases utilization of expertise. This will allow wider access to expert knowledge. The captured expertise can be used for training. Human experts are relieved for higher level tasks. AL is a tool for assisting the experts in decision making processes.

Expert systems and expert personnel share common characteristics. They know of all the solutions available. They are capable of accurately and logically eliminating those possibilities that do not conform to any restrictions imposed. Most expert systems now use special program shells for building and managing the knowledge in the specific field of expertise. AL uses an expert shell called M1 developed by Technolowdge Inc. M1 is written in C, a very fast standard language. As a result AL is very fast and user friendly. AL handles its 500 rules on an IBM-XT class microcomputer as fast as the user can input the answer to the questions.

CONCLUSIONS

This article presents some initial results on an expert system (of research prototype grade) for artificial lift, encompassing a significant store of expert knowledge and utilizing a workable means of inference in interactive mode. Tests based on trial data cases yielded results favorably comparable to those which might be provided by an expert. Most encouraging of all, this level of performance was attained on a personal computer after a relatively short development time (the three of us only working part time had it working in 2 months). We feel the future of expert systems in petroleum engineering has a multitude of possibilities. We would recommend to anyone who wants to develop an expert system to start small. Do something that has an already well defined detailed method or procedure, make the procedure easier to use, include heuristic reasoning to make the procedure easy, faster, and consistent. Make a bunch of small expert systems instead of one big system. Each small system is a tremendous improvement in its own right. Sharing the wealth of information an old expert has with new people allows training new people in less time. With an expert system you can rapidly update your procedure.

ACKNOWLEDGMENTS

The author wishes to thank two graduate students Kevin Thornsberry and L. D. Witt for their invaluable programming and debugging help. The program started out as a learning exercise in Expert Systems for Kevin, L. D., and myself. It has developed into a useful teaching tool. AL is used in a senior production applications course after several lectures on the merits of each pumping method.

Thanks are also due my fellow University of Missouri-Rolla, faculty members A. H. Harvey, L. F. Koederitz, and D. T. Numbere without whose constant encouragement I would not have gotten this done.

REFERENCES

Heinze, L. R.; "An Expert System for Selecting the Optimal Pumping Method", ASME Production Technology Symposium, January 14-18, 1990, New Orleans, LA.

Heinze, L. R.; Thornsberry K.; Witt L. D.; "AL: An Expert System for Selecting the Optimal Pumping Method," SPE Production Operations Symposium, March 13-14, 1989., Society of Petroleum Engineers, SPE # 18872.

Waterman, D. A. ; A Guide to Expert Systems, 1986, Addison-Wesley Publishing Company, Inc.

Brown, K. E. ; Day, J. ; Byrd, J. ;
Mach, J. ; The Technology of Artificial Lift Methods Volume 2a & 2b, 1980, Petroleum Publishing Company.

Table 1
Common Problems Affecting Lift Selection

PROBLEM	ROD PUMP	HYDRAULIC	CENTRIFUGAL	GAS LIFT
	TYPE OF LIFT			
Sand	Fair	Fair	Fair	Excel
Paraffin	Fair-	Good	Good	Poor
Crooked Hole	Fair-	Good	Fair-	Good
Corrosion	Good	Good	Fair	Fair
Small Casing	Fair	Fair	Poor	Good
Production Flexibility	Fair	Excel	Poor	Good
Scale	Good	Fair	Poor	Fair
None	Fair	Fair	Fair	Fair

CURRENT CF VALUES ASSIGNED:

Poor = -95.
Poor- = -50.
Fair- = -10.
Fair = 0.
Fair+ = 10.
Good- = 40.
Good = 50.
Good+ = 60.
Excel-= 85.
Excel = 95.

USER DEFINED OPERATORS

INITIAL META-FACTS

INTRO

RULE BASE # 1

RULE BASE # 1 QUESTIONS

RULE BASE # 2

PROBLEMS TABLE
INFO OPTIONS

RULE BASE # 2 QUESTIONS

RULE BASE # 3

RULE BASE # 3 QUESTIONS

RULE BASE # 4

Figure 1 - AL's knowledge base