Oil Well Performance Diagnosis System Using Fuzzy Logic Inference Models

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Abstract-This paper considers an approach to design a fuzzy logic controller to detect incipient abnormal production of wells in a reservoir. The daily operation of an oil and gas production system requires many decisions, which may affect the volumes of oil produced and the cost of production oil. These decisions are taken at different levels in the organization, but eventually they will reach the physical production system. One of the decisions may require controlling oil and gas production by changing the bean (choke) size. When a production rate is defined and if for some reasons the production is low, the management may consider the need to increase production by increasing the bean size and conversely. The fuzzy logic controller, which is a method of a rule-based decision making based on human knowledge, was developed for the oil well performance diagnosis. Simulation results demonstrate how the designed fuzzy logic controller performs well production fault detection. The purpose of this paper is to illustrate how Fuzzy logic inference system which is an automatic method of generating fuzzy rules, can predict the flow rate, as a vital parameter in determining the choke size.

Keywords: Fuzzy Logic, Oil well performance, Membership function, Linguistic variables, Fuzzy rules, Production rate

I. INTRODUCTION

In order to analyze the performance of a completed flowing well, it is important to recognize three different components which are linked together. These components are the inflow performance, the vertical lift performance and the choke performance. The inflow performance represents the flow of oil, water and gas in porous media into the bottom of the well. The vertical lift performance involves the analysis of the pressure losses in the vertical pipes carrying two-phase mixture of gas and liquid. Several models are derived for the analysis of this component such as Poettmann and Carpenter[16], Baxendel[1], Baxendell and Thomas [2], Ros{17] and Gilbert[8] The choke performance involves the study of pressure losses occurring during the flow of oil, water and gas through a flow line restriction at the surface. The factors that influence the performance of a flowing well include the following:

- Productivity index, bbl/day/psi
- Tubing depth , ft
- Bottom Hole Flowing Pressure, BHP, Psi
- Tubing Head Pressure, THP, Psi
- Gross liquid rate, bbl/day
- GLR, mcf/bbl
- Tubing size, inches
- Choke size, inches

Recently, the new group of oil production modeling methods which are based on Artificial Intelligence (AI) approaches has enormously been used by experts. Fuzzy Logic (FL), was introduced by Lotfi A. Zadeh [24], and has advantages as one of the most popular methods to model the imprecise, vague and unclear problems [5, 19]. Their related procedures areas like oil production have recently become very noticeable. It is because of its strong abilities to deal with imprecise, vague and unclear problems that made it applicable in complex operations. The determination of the most suitable model involves finding the best relationship, called fuzzy rules, between pertinent parameters such as THP, GLR, Production rate in this specific case and the target, choke size. It is therefore extremely vital, critical and crucial to search for the most compatible rules. In order to generate fuzzy rule there are 3 possible rules which are (1) Through literature Survey (2) From Human Experts (3) Automatic Rule Generation **[6]**. Furthermore, there are some techniques used to produce automatically these rules gaining from some evolutionary method like Genetic Algorithm (GA) and also, decision tree as a conventional one **[7,13, 20]**. In the present paper, an attempt is made to extract exact and useful rules out of the trained part of the gathered database. Next, these rules have been examined by testing data. Finally, the obtained results have been

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compared with the operational reports through two different figures.

II. FUZZY LOGIC OVERVIEW

Lotfi A. Zadeh was the first to published work on fuzzy sets in 1965 [25], which led to the introduction of fuzzy logic theory. The basic idea of fuzzy logic is to deal with the whole interval [0,1] as degrees of truth in addition to the values 1 and 0 corresponding to “true” and “false”. This leads to a radical extension of classical logic. The following sections will briefly discuss the general principles of fuzzy logic, definitions of fuzzy sets, membership functions, linguistic variables, fuzzy IF-THEN rules, combining fuzzy sets and fuzzy inference systems (FISs).

A. Fuzzy Sets

A fuzzy set F defined on universal set U is characterized by a function which is permitted to have any value between 0 and 1 [25]. If X is a collection of objects denoted generally by x, then a fuzzy set F in X is defined as a set of ordered pairs: $F = \{(x, \mu_F(x) \mid x \in X\}$
where $\mu_F(x)$ is called the Membership Function (MF) for the fuzzy set F. The MF maps each element of X to a membership value between 0 and 1.

B. Membership Functions

Because most fuzzy sets in use have a universe of discourse X consisting of the real line R, it is impractical to list all the pairs defining a MF. The convenient way to define an MF is by expressing it as a mathematical formula. The most commonly used MFs used in fuzzy sets are listed as follows:

1) *Triangular MF*: A triangular MF is specified by three parameters The parameters {a, b, c} (with a < b<c) determine the x co-ordinates of the three corners underlying the triangular MF.

$$\mu(x,ab,c)=\begin{cases} 0 \quad , & x \le a \\ x\text{-}a/b\text{-}a \ , & x \in (a, b) \\ c\text{-}x/c\text{-}b \ , & x \in (b, c) \\ 0 \quad , & x \ge c \end{cases}$$

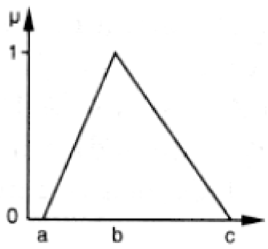

Fig 1. Triangle: [a,b,c]

2) *Trapezoidal MF*:A trapezoidal MF is specified by four parameters

The parameters '(a,b,c,d) (with a < b < c < d) determine the x coordinates of the four corners underlying the trapezoidal MF.

$$\mu(x,ab,c,d)=\begin{cases} 0 \quad , & x \le a \\ x\text{-}a/b\text{-}a \ , & a \le x \le b \\ 1 & b \le x \le c \\ d\text{-}x/d\text{-}c \ , & c \le x \le d \\ 0 & d \le x \end{cases}$$

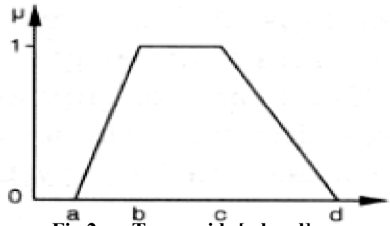

Fig 2. Trapezoid: [a,b,c,d]

3) *Gaussian MF:* A Gaussian MF is specified by two parameters (a, θ) as follows:

A Gaussian MF is determined completely by a and **θ,** where a represents the MFs center and θ determines the MF spread.

$$\textbf{Gaussian}(x,a,\theta)= e^{-\frac{1}{2}(x-a)/\theta^2}$$

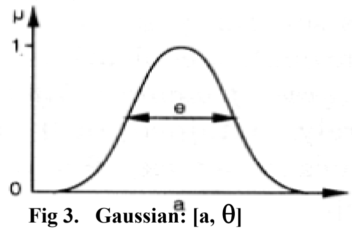

Fig 3. Gaussian: [a, θ]

C. Linguistic Variables

The concept of linguistic variables was introduced by Zadeh [24] to provide a basis for approximate reasoning. A linguistic variable is defined as a variable whose values are words or sentences. For instance, temperature can be linguistic variable if its values are linguistic rather than numerical, i.e., low, medium, high, very high, etc., rather than numerical, such as 10, 30, 89, 145^{0}C etc.

D. Fuzzy IF-THEN Rules

Fuzzy rules and fuzzy reasoning are the core components of fuzzy inference systems (FISs), which are the most important modeling tools based on the fuzzy set theory. A fuzzy IF-THEN rule (fuzzy rule, fuzzy implication or fuzzy conditional statement) is expressed as follows:
If x is A then y is B
where A and B are linguistic variables or labels defined by fuzzy sets [24,25,26,27] characterized by appropriate membership functions. The expression “x is A” is called antecedent or premise, while “y is B” is called the consequence or conclusion [24,25,26,27]. Some fuzzy IF-THEN rules are given as examples below:

- If pressure is high, then volume is small
- If speed is low AND the distance is small, then the force on the brake is small

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E. Combining Fuzzy Sets

Fuzzy sets are usually combined in the application of fuzzy reasoning. The combination of fuzzy sets can be obtained using intersection (AND), union (OR) and complement (NOT) operations. The mathematical description of the basic operations for a set X and a subset x are presented below.

1) Subset: A fuzzy set A is contained in fuzzy set B (or, equivalently, A is a subset of B, or A is smaller than or equal to B) if an only if $\mu_A(x) \le \mu_B(x)$ for all x in X. In symbols, this expression can be represented by: $A \in B \Leftrightarrow$. $\mu_A(x) \le \mu_B(x) \ \ \forall x \in X$

2}. Union: The union or "disjunction" of two fuzzy sets A and B is a fuzzy set C written as C = A U B or C = A OR B, whose MF is related to those of A and B by the following expression:

$\mu_C(x) = \max(\mu_A(x),. \mu_B(x)) = \mu_A(x) \vee \mu_B(x) \ \ \forall x \in X$

A more intuitive but equivalent definition of union is the "smallest" fuzzy set containing both A and B.

3} *Intersection:* The intersection or "conjunction" of two fuzzy sets A and B is a fuzzy set C, written as C = A ∩ B or C = A AND B, whose MF is related to those of A and B by the following expression: $\mu_C(x) = \min(\mu_A(x) , \mu_B(x)) = \mu_A(x) \cap \mu_B(x) \ \ \forall x \in X$

As in the case of union, it is obvious that the intersection of A and B is the "largest" fuzzy set which is contained in both A and B.

4) Complement: The complement or "negation" of a fuzzy set A denoted by Ă (NOT A) is defined by the following expression: $\mu_{\breve{A}}(x) = 1 - \mu_A(x)$. These fuzzy set operations perform exactly as the corresponding operations for ordinary sets, if the values of the MFs are restricted to either 0 or 1.

F. Fuzzy Inference System

Fuzzy inference systems (FISs) are also known as fuzzy-rule-based systems, fuzzy models or fuzzy controllers when used as controllers. A fuzzy inference system (FIS) is composed of five functional components, as shown in Figure4.0. The functions of the five components are as follows:

1. A *rule base* containing a number of fuzzy if-then rules.
2. A *database* which defines the membership functions (MFs) of the fuzzy sets used in the fuzzy rules.
3. A *decision-making* unit which performs the inference operation on the rules.
4. A *fuzzification* interface which transforms the crisp inputs into degrees of match with linguistic variables.
5. A *defuzzification* interface which transforms the fuzzy results of the inference into a crisp output.

In common practice, the rule base and the database in a FIS are jointly referred to as the "knowledge base", as shown in Figure 4.0. The steps of fuzzy reasoning (operations upon fuzzy IF-THEN rules) performed by FISs are:

1. Input variables are compared with the MFs on the premise part to obtain the membership values (or compatibility measures) of each linguistic label. This step is also known as "fuzzification".
2. The membership values on the premise part are combined through fuzzy set operations such as: min, max or multiplication to get firing strength (weight) of each rule.
3. The qualified consequent (either fuzzy or crisp) of each rule is generated depending on the firing strength.
4. The qualified consequents are aggregated to produce crisp output according to the defined methods such as: centroid of area, bisector of area, mean of maximum, smallest of maximum and largest of maximum etc. This step is also known as "defuzzification" [11,18,19].

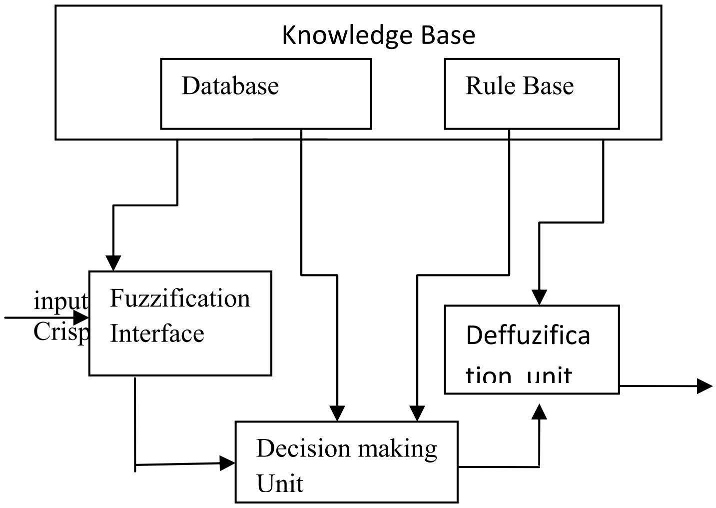

Fig 4. Flowchart of the general architecture of a FIS

Several types of fuzzy reasoning [22,23] have been proposed in literature. Depending on the types of fuzzy reasoning and fuzzy IF-THEN rules employed, FISs can be classified into three major types, which are as follows:

1) Type 1: In this type of FIS, the overall output is the weighted average of each rule's crisp output induced by the rule's firing strength (the product or minimum of the degrees of match with the premise part) and output MFs. The output membership functions used in this scheme must be monotonic functions [18,19,22].

2) Type 2: In this type of FIS, the overall fuzzy output is derived by applying the "max" operation to the qualified fuzzy outputs (each of which is equal to the minimum of firing strength and the output membership function of each rule). Various schemes have been proposed to choose the final crisp output based on the overall fuzzy output, such as the centroid of area, bisector of the area, mean of maxima, maximum criterion, etc [22,23].

3) Type 3: This type of FIS uses Takagi and Sugeno's fuzzy IF-THEN rules [18,19]. The output of each rule is a linear combination of input variables plus a constant term, and the final output is the weighted average of each rule's output.

III. FUZZY OIL WELL PERFORMANCE MODELING, FUZZY DECISION MAKING AND FUZZY CONTROL

A model simply represents relevant aspects of the behavior of a system, to help the user in obtaining a better understanding of the system, thus being able to forecast and control its behavior. If the model uses formalisms of fuzzy logic then it is called a fuzzy model. The simplest fuzzy model consists of a set of rules with an "if – then" structure: *I f* < condition 1> *and* < condition 2> *and* < condition n> *then* <conclusion > Where <condition i > is a statement of type "x*i* is L*ij*". In this statement *xi* represents the actual value of some i-th real world variable meanwhile L*ij* is a flexible predicate naming the j-th linguistic term of the corresponding i-th Linguistic Variable. L*ij* is given by a fuzzy set which represents the use of the flexible predicate on the domain of x*i*. Statements of this kind are called "antecedents". The <conclusion> is also a fuzzy set, which represents the linguistic term expressing a flexible predicate, which characterizes the output behaviour of the system if all conditions are satisfied. Notice that "if – then" rules may be used to both model the state of a system and to take a decision to control the system. Rule 1: *If* THP is low *and* GLR is Low *and* production rate is Low *then* increase the choke size. The first application at industrial level was done to control the kiln of a cement fabric [13] and possibly the most impressive results of those years was the automatic fuzzy control of the subway train in Sendai, Japan [20]. Take as example the following set of "if – then" rules constituting a fuzzy control-model for an oil well performance system:

R1: If THP is low *and* GLR is Low *and* production rate is Low *then* increase the choke size.
R4: *If* THP is Medium *and* GLR is Low *and* production rate is Medium *then* do not change the choke size.
R7: *If* THP is High *and* GLR is Low *and* production rate is High *then* reduce the choke size.

To use the rules, the meaning of "Low", "Medium" and "High" in a universe with a THP psi scale as well as that of "GLR", "Production rate" and "choke size" in a universe with a scale in $1/64^{th}$-in is needed. A schematic of fuzzy diagnosis system is shown in figure.4.0 The fuzzy fault diagnosis system is designed to monitor THP, GLR, production rate and choke size. The oil production fault diagnosis system produces the symptoms of decreased production rate for given values of THP, GLR and choke size. The fault signature is extracted on measuring the above parameters. The fuzzy model was simulated using commercially available software. The fault detection is carried out analyzing the fault signature through the fuzzy rules derived from expert's knowledge and experimental data.

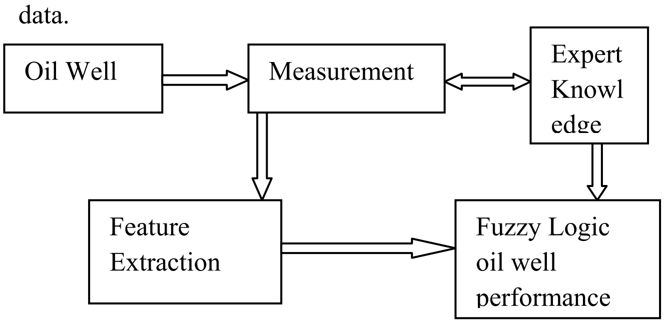

Fig.5. Fuzzy Logic oil well Performance Assessment System

IV. NUMERICAL EXPERIMENTS

Prediction performance of the resulting models depends on the size and quality of the training data. Each data record consists of input and output data. Input data are derived from production and ell data as shown inTable1.

A. Purpose of study

The objective of this study is to control well performance based on Tubing Head Pressure(THP), Gas Liquid Ratio(GLR), Production rate q bbl/day and choke size (inches).

The flow chart for Performance Assessment System is as shown in Fig 5.

B. Data Sets

The data of this study were adopted to represent different wells in a reservoir. 7 experimental samples are as shown in Table1.0.

C. Process

In this study, the measured attribute are Tubing Head Pressure (THP), Gas Liquid Ratio(GLR), Production rate q bbl/day and choke size (inches).

Table 1.Oil Well samples

Listed well of a Reservoir	THP Psi	GLR Mscf/bbl	Production rate bbl/day	Choke size (1/64inches).
1	100	0.27	600	46
2	235	0.27	210	21.5
3	170	0.4	450	44
4	400	0.8	600	46
5	100	0.8	320	27
6	300	0.2	620	46
7	200	0.2	430	45

The fuzzy model is constructed with three inputs and single output (TISO). The attributes THP (Psi), GLR, Production rate q are considered as inputs and Choke size is chosen as output for the fuzzy model. The input variables are classified into three membership functions such as low, medium and high. The output variable is classified into three membership functions such as increase choke size, No change in choke size and reduce choke size. The THP range is chosen from 70 to 500 psi, GLR range is taken from 0.1 to 30 mscf/bbl, Production rate range is taken from 60 to 900 bbl/day and choke size ranges from 5 to 64 inches The relationship between input and output variables is established through fuzzy rules as shown in table.2.

Linguistic rules describing the fuzzy system consists of two parts: an antecedent part and consequent part. It may not be necessary to evaluate every possible input combination, since some may rarely or never occur. Through the experience of the operator, few rules can be evaluated thus simplifying the processing logic.

The Linguistic variables for each attribute are as shown below:

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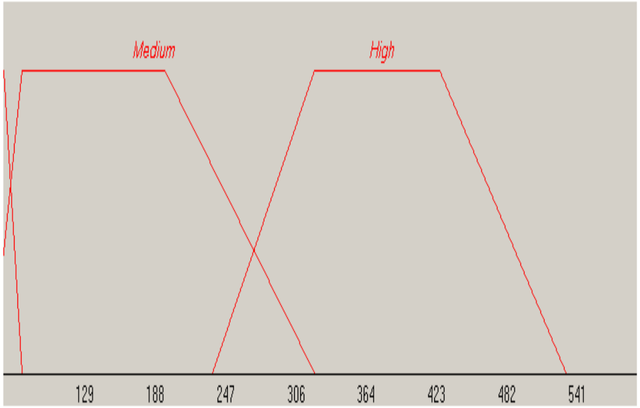

Fig 6. Tubing Head Pressure

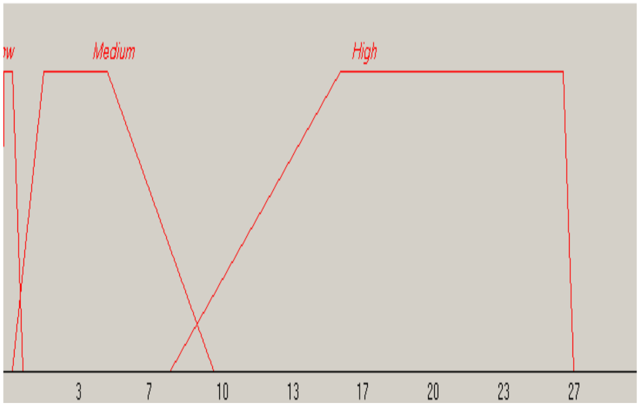

Fig 7. GLR

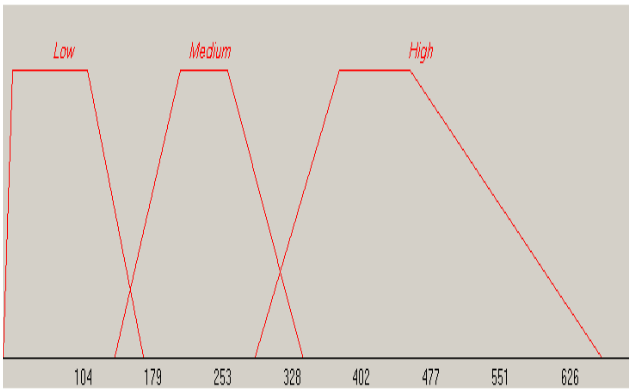

Fig 8. Production rate

Table .2. Fuzzy rules for FLFD with three membership functions

Rules	1	2	3	4	5	6	7	8	9	10
THP (Psi)	L	L	L	M	M	M	H	H	H	H
GLR mscf/bbl	L	M	H	L	M	H	L	M	H	L
Production rate (bbl/day)	L	L	L	M	M	M	H	H	H	L
Choke size (1/64-in)	IC	IC	IC	NC	NC	NC	RC	RC	RC	IC

L: Low; M: Medium; H: High IC: Increase choke size NC:No change in choke size RC: Reduce choke size

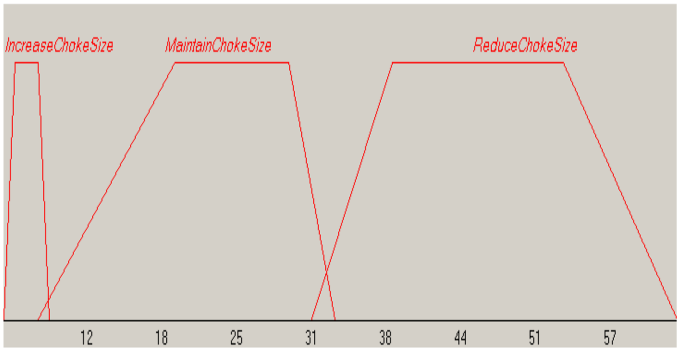

Fig 9. Choke size

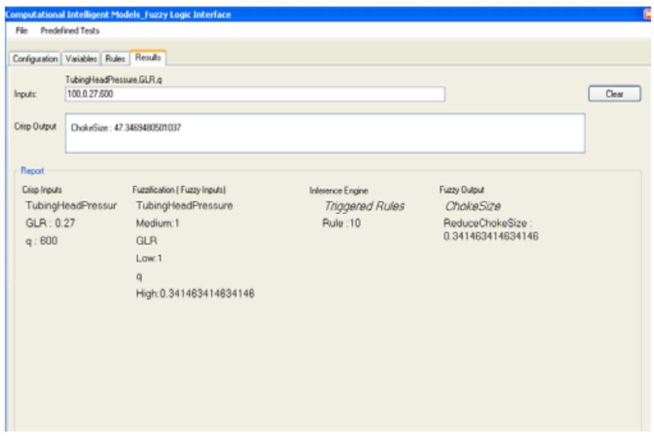

Fig 10. Production Control Results

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V. RESULTS AND DISCUSSION

The simulation study is carried out by computer program called Fuzzinator (Fuzzy Logic Controller) for the data below:

THP (Psi): 100.0, GLR(mscf/bbl): 0.27, Production rate (bbl/day):600.0
choke size of the well:46/64-in

Decision: Reduce the choke size.

The results obtained through computer simulation with three membership functions of trapezoidal shapes are as shown in figure10.0

VI. CONCLUSION

A fuzzy fault diagnosis system has been designed with three membership functions of trapezoidal shapes for an oil well production data. The performance of fuzzy fault diagnosis system is analyzed through computer simulation and sample result was presented.

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