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AN AUTOMATED CONTROL SYSTEM OF OIL AND GAS FIELDS EXPLOITATION FOR THE FOUNTAIN EXTRACTION METHOD

1. INTRODUCTION

The goal of any oil producing and processing enterprise is optimal production which is controlled at real-time. Oil and gas industry is constantly evolving and constant search for the most effective ways of solving the problems have been conducted by leading oil-and-gas enterprises and companies. Productive formations, wells, pipelines, and the trunk lines are part of the large complex dynamic system. Any few changes in their parameters can affect to the overall behavior of the system and consequently cause a huge challenge for the experts and operators. Traditionally, the operators have to process and control of downhole and surface sensors at run-time to regulate the valve and obtain the desired flow rate. The downhole sensors give a large amount of data of the monitored well such as temperature, pressure, flow rate data and other parameters which have to be analyzed by the system and as result it produces much more information according to the correspondent profile [1].

Meantime, lack of precise data scanned from the well may issue even harder obstacles during decision making process. In other words, poor or insufficient information together with complex geological conditions can lead to inaccurate solutions such as disappointingly low initial production rates, especially for the new oil fields evaluated primarily by seismic data analysis and exploration of several wells. Sometimes a significant difference in an oil extraction forecasted and real data make the engineers to revise the initial estimate of recoverable reserves towards decrease.

Essentially, advanced software and hardware tools are one of the main components to automate control, monitoring and analysis of the real-time data. “Smart fields” and “smart

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wells" can significantly increase an overall profit of an oil company and win in global competition [2–5]. The main components of the smart well technology are well valves controlled by a dispatcher at the operation center. Basically, those valves are used to control flow from individual zones and laterals while a permanent downhole temperature and pressure sensors allow managing of the reservoir exploitation. Smart well technology has a number of advantages over its traditional competitors:

– The information obtained in real time allow responding quickly to the behavior of the reservoir and making operational decisions to maximize well productivity, while ensuring the highest efficiency of extraction product formation.
– The use of permanent deep sensors that provides deep scan of the productive zone allows reacting quickly to changes in reservoir parameters. The data from these systems can also be used for continuous optimization and updating of the production models, forecasting of sand and water inflow and measuring the volume of production and water cut.
– A wise division of several productive zones and applying a sequential extraction scheme of intelligent completions, and meantime, providing remote opening and closing of each zone increase an efficiency of oil extraction and improvement of an overall production profiles due to the exclusion of extra downhole operations.
– At the injection wells when several areas separated by impermeable barriers are flooded, control valves serve as inductors providing adequate pressure at each point of injection, employing only one pump.

There are many types of valves such as ball, needle, plug and others [6] (Fig. 1). Some of them also are equipped by an automatic temperature control valves.

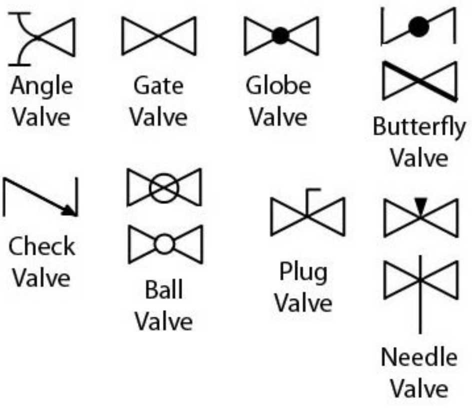

Fig. 1. Types of valve

Figure 2 shows a typical structure of valve produced by Schlumberger company, namely, "The Odin* flow control valve and The TRFC-HB dual-line on-off flow control valve".

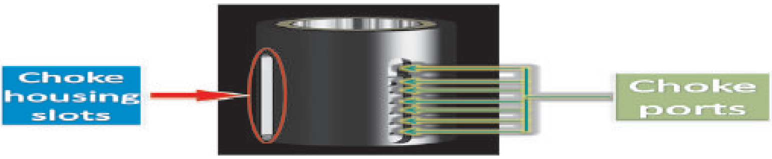

Fig. 2. The Odin* flow control valve structure

The TRFC-HB dual-line on-off flow control valve used for intelligent completion and provides surface-actuated downhole control of the reservoir flow in dual-zone or multi-lateral wells. It supports high-scale environment and a scale usually builds up at areas of pressure drop and it occurs at the choke ports.

In general, the principal of working of any type of valves is based on D.Bernoulli's equation, that as a liquid flow through some orifice (in our case, it is a choke) the square of the fluid velocity depends on the pressure differential ΔP across the orifice and specific gravity (G) of the liquid. Therefore, the volume flow rate of the liquid can be calculated by multiplying the fluid velocity times the flow area and a basic liquid sizing equation can be written as follows [7]:

$$Q = C_v \sqrt{\Delta P / G} \tag{1}$$

Where Q is a capacity in gallons per minute; C_v is a valve sizing coefficient determined experimentally for each type and size of valve; ΔP is a pressure differential in psi; G is a specific gravity of fluid. In order to calculate the expected Cv for a valve controlling liquid that behave like water we re-write (1):

$$C_v = \frac{Q}{\sqrt{\Delta P / G}} \tag{2}$$

(1) and (2) derive correspondently formulas to predict flow rate (Q_{pred}) using a required liquid sizing coefficient (C_{vreq}) and an additional viscosity correction factor (F_v):

$$Q_{pred} = \frac{C_{vreq}\sqrt{\Delta P / G}}{F_v} \tag{3}$$

where $C_{vreq} = C_v \cdot F_v$ should be calculated as a viscosity can lead to the sizing errors due a simplification as C_v values are taken from tests made over the water.

In addition, it is necessary to define predicted pressure drop (ΔP_{pred}) as it helps to determine flashing and cavitation effects [8]:

$$\Delta P_{pred} = G \cdot \left(\frac{Q}{C_{vreq}} \right)^2 \tag{4}$$

Typically, uncontrolled regulating of pressure via valves might lead to Venturu effect which forms choked flow as follows: at the given pressure and temperature a liquid passes through a valve of the well into a lower pressure the fluid velocity increases. The cavitation effect cause sufficient damage to valves, pipes and associated equipment.

In this paper we employ common approach to calculate predicted flow rate and pressure drop in a system of well by introducing a system of automatic controlled valves equipped on the appropriate wells of the reservoir. Next section considers an automated control system of oil and gas field exploitation that can be also applied for the fountain method of oil extraction.

2. AN AUTOMATED VALVE CONTROL SYSTEM USING INTELLECTUAL CONTROLLERS

This work proposes smart hardware and software components of the automated control and monitoring information self-adaptive system for the fountain exploitation mode based on adjusting the valve according to the change of values of the pressure sensors, flow rate, temperature and other parameters. The primary component of self-adaptable system of our work is the principle of AMS (Automated management system) which uses predictive logic to improve access and performance of production assets, in particular, mechanical equipment monitoring wells and sensors. This approach allows equipment to identify problems before they occur.

We present a general scheme of intelligent control of oil well control based on self-adaptive system and a wireless self-organized network. An overall scheme of the model to automatically control (AC) valves together with sensors that measure temperature, pressure, flow rate and other parameters is shown on Figure 3.

Our system is designed on the platform for a more proactive approach to the management of such elements as sensors and intellectual controller devices which interact via wireless self-organized network can ultimately lead to a more flexible data routing, precise analysis and prediction and finally increase oil production rate.

In this paper we propose a new multi-component model based on mobile wireless networks with the optimal routing of data obtained from the system of wells in real time, temperature, pressure, flow meter. This model is the link automation of the process of oil production in the entire life cycle process, from data collection, analysis, and, finally, finalize the optimum operation of the well. The entire life cycle is realized in the developed world information system capable of accepting and processing inconsistent and sometimes incomplete and fuzzy data obtained from different wells, and then synthesize them into a single information field, providing a more efficient development of oil or gas field. Most of these processes, except for the server data, computationally intensive, automated built-in logic-based optimal routing of the developed intelligent controller.

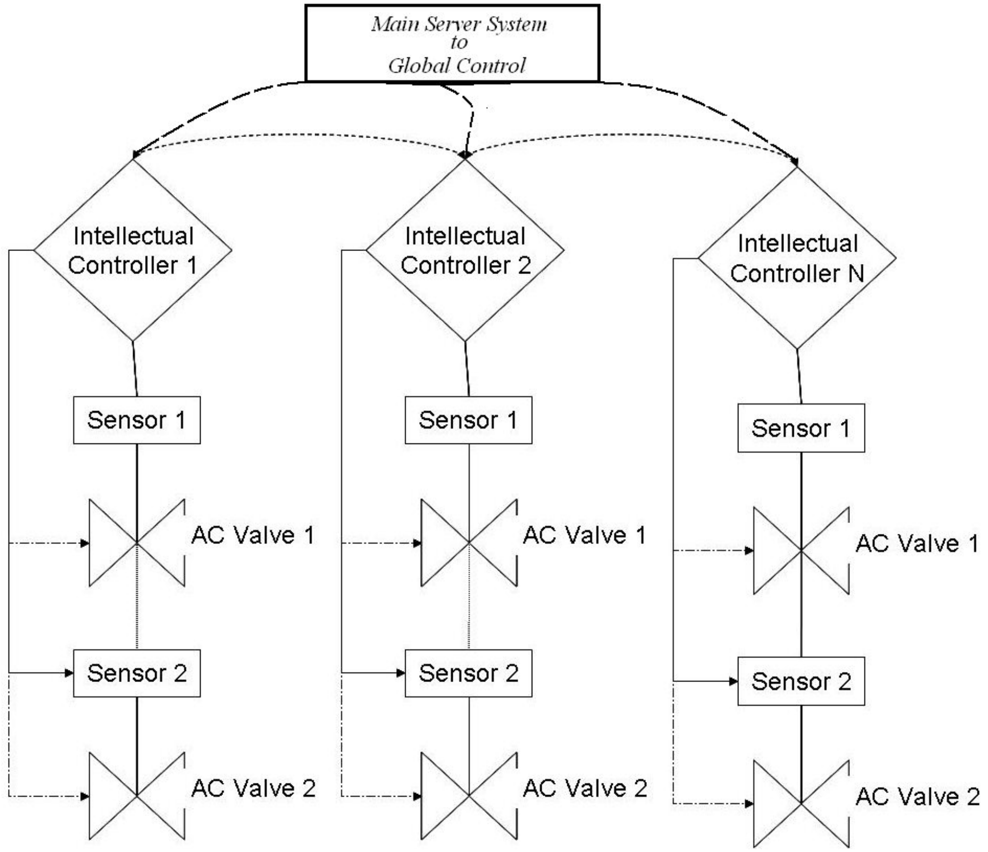

Fig. 3. A model of system of automatically controlled valves via intellectual controllers

All data measures are transferring from sensors to smart controller „Smart device" which is developed by our team [9]. "Smart device" is a device that can work with any type of sensors. It also has an additional element of storage-memory cards to ensure the safety of the measured data. Built-in LAN port enables the transmission of data through radio modem or any other transmission network equipment with RS-485 connector. Using „Smart device" at each well of the oil deposit for preliminary data proceeding greatly facilitates monitoring of all parts of deposit and increases reliability of the system and allows making precise predictions of oil extracting process. All data obtained from sensors then subsequently are forwarding to the access point. An access point is a device with high capacity (WiMAX) communicates via an interface to the gateway. This approach provides the entry point and exit point for transfer to and from the field device.

There are two basic concepts of data routing in ad hoc networks: source routing (DSR) [10], and distance-vector routing, (AODV) [11]. To find a new route to the destination node by the method of source routing probe packets are used to determine the path from source to destination node, this information is stored in each packet. On the other hand, in a distance-vector routing, each node in the network uses the routing table, which stores information about call forwarding to the appropriate node. Overwhelm the network routing tables with test packets. Some modifications of these methods increase the reliability of routing data have been proposed in [3]. In this paper the principle of self-organizing systems [4], which can organize new routes on the basis of fuzzy and incomplete information, and the number of test packets from the network is minimal. At each node of the program involved „agent" that constructs the route dynamically to meet future network downloads. Intelligent controller is a key element in the transmission of data from the wells, which provides data collection, the best routing of the data for processing, select the best mode of the well by means of automatic control valves, thus, in general, to optimize the cost of managing the process of oil production.

3. FUZZY CONTROLLER IN OIL WELLS MANAGEMENT SYSTEM

Classical fuzzy controllers have been of the rule-based type, where the rules in the controller attempt to model the response of an operator to a particular process situation. Based on the ability of fuzzy systems to approximate any nonlinear mapping, the nonlinear well is represented by a fuzzy model and it is analytically inverted for designing a fuzzy controller. In order to minimize the steady-state-error due to model-well mismatch, an internal model control (IMC) will be considered. The proposed fuzzy controller is applied to control the oil extraction and is shown to be capable of providing good overall system performance [11].

Design of a fuzzy controller requires more design decisions than usual, for example regarding rule base, inference engine, defuzzification, and data pre- and post processing.

The main idea is to use a Takagi-Sugeno Type Controller, optimize its structure under usage conditions of oil wells management system.

Structure of a Fuzzy Controller

There are specific components characteristic of a fuzzy controller to support a design procedure. In the block diagram (Fig. 4), the controller is between a preprocessing block and a post processing block [12].

Preprocessing

The inputs are most often hard to crisp measurements from some measuring equipment, rather than linguistic. A preprocessor contains any conditions, measurements before they enter the controller [12].

Examples of preprocessing are:

– Averaging to obtain long term or short term tendencies.
– A combination of several measurements to obtain key indicators.
– Normalization or scaling onto a particular range.

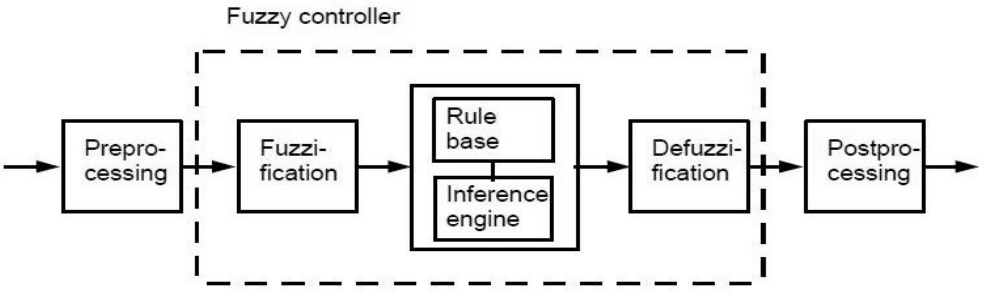

Fig. 4. Blocks of a fuzzy controller

Fuzzification

The first block inside the controller degrees of membership by a lookup in one or several membership functions. The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. There is a degree of membership for each linguistic term that applies to that input variable [12].

Rule base

The rules may use several variables both in the condition and the conclusion of the rules. The controllers can therefore be applied to both multi-input-multi-output (MIMO) problems and single-input-single-output (SISO) problems. The typical SISO problem is to regulate a control signal based on an error signal. The controller may actually need both the "ERROR", the "CHANGE IN ERROR", and the "ACCUMULATED ERROR" as inputs, all three are formed from the error measurement. To simplify, this section assumes that the control objective is to regulate some process output around a prescribed setpoint or reference. The presentation is thus limited to single-loop control.

The names Zero, Pos, Neg are labels of fuzzy sets (Fig. 5).

The same set of rules could be presented in a relational format, a more compact representation [12].

Error	Change in error	Output
Neg	Pos	Zero
Neg	Zero	NM
Neg	Neg	NB
Zero	Pos	PM
Zero	Zero	Zero
Zero	Neg	NM
Pos	Pos	PB
Pos	Zero	PM
Pos	Neg	Zero

Fig. 5. Labels of fuzzy sets

Inference Engine

The rules reflect the strategy that the control signal should be a combination of the reference error and the change in error, a fuzzy proportional-derivative controller.

The instances of the "ERROR" and the "CHANGE IN ERROR", are indicated by the vertical lines on the first and second columns of the chart. For each rule, the inference engine looks up the membership values in the condition of the rule [13].

Deffuzzification

The resulting fuzzy set must be converted to a number that can be sent to the process as a control signal. This operation is called deffuzzification. The resulting fuzzy set is thus defuzzified into a crisp control signal [13].

Post processing

Output scaling is also relevant. In case the output is defined on a standard universe this must be scaled to engineering units, for instance, volts, meters, or tons per hour. The post processing block often contains an output gain that can be tuned, and sometimes also an integrator.

Implementing example rule according to Takagi- Sugeno Type Controller

The general Takagi- Sugeno rule is:

$$\text{if } f(e_1 \text{ is } A_1, e_2 \text{ is } A_2, ..., e_k \text{ is } A_k) \text{ then } y = g(e_1, e_2....)$$

Here "F" is a logical function that connects the sentences forming the condition, y is the output signals that will be reconfigured in graphs and monitored by the oil well administrator for helping in decision making process for example in changing latch position in a specific oil well, according to real time information that administrator could review with the help of fuzzy logic controller.

And "g" is a function of input information that should be delivered from oil well sensors or "Smart devices"[13].

- *If error is Zero and change in error is Zero then output "y = c" where c is a crisp constant. This is "zero – order" model, and it is identical to singleton output rules.*
- *If error is Zero and change in error is Zero then output*
  $y = a * \text{error} + b * (\text{change in error}) + c$

where *a*, *b* and *c* are all constants. This is a first-order model.

Inference with several rules proceeds as usual, with a firing strength associated with each rule, but each output is linearly dependent on the inputs. The output from each rule is a moving singleton, and the defuzzified output is the weighted average of the contributions from each rule. The controller interpolates between linear controllers; each controller is dominated by a rule, but there is a weighting depending on the overlap of the input membership functions. This is useful in a nonlinear control system, where each controller operates in a subspace of the operating envelope. One can say that the rules interpolate smoothly between the linear gains. Higher order models are also possible [12].

4. CONCLUSION

We have presented an automated control and monitoring information self-adaptive system for the fountain exploitation mode to control valves according to the change of values of the pressure sensors, flow rate, temperature and other parameters. The primary component of the self-adaptive system is the developed intellectual controller device based on the principle of fuzzy logic to improve production assets. A model of the fuzzy controller to wisely control valves has been developed to help the intellectual device "Smart device" automatically make decision for better control of flows. This approach considerably facilitates process of monitoring of oil deposit and raises level of reliability of the whole information system. Takagi- Sugeno Type Controller used in our work guarantees a higher level of reliability and performance of the fuzzy controller.

REFERENCES

[1] Stuart McAleese Operational Aspects of oil and gas well testing. Published by Elsevier B.V., vol. 1, 2000, pp. 1–321.

[2] Gao C., Rajeswaran T., Nakagawa E.: *A Literature Review on Smart Well Technology*. Paper SPE 106011, presented at the SPE Production and Operations Symposium, Oklahoma City, Oklahoma, USA, March 31–April 3, 2007.

[3] Konopczynski M., Nielsen V.J.: *Intelligent Completions: A Decade of Innovation Revolutionizes the Industry*. World Oil 228, no. 5, May 1, 2007, pp. 55–56.

[4] Glandt C.A.: *Reservoir Aspects of Smart Wells*. Paper SPE 81107, presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Port-of--Spain, Trinidad and Tobago, April 27–30, 2003.

[5] Arashi A., Konopczynski M., Nielson V.J., Giuliani C.: *Defining and Implementing Functional Requirements of an Intelligent-Well Completion System*. Paper SPE 107829, presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Buenos Aires, April 15–18, 2007.

[6] Waite A.W., Eng P.: *Controllers, Final Control Elements and Regulators*. In: Green D.W., Perry R.H. eds. Perry's Chemical Engineers Handbook, 8th edition. McGrow, NewYork 2008, pp. 871–896.

[7] Hullender D.A., Woods R.L.: *Modeling of Fluid Control Components*. Proceedings of the First Conference on Fluid Control and Measurement, FLUCOME '85, Pergamon Press, Tokio, London 1985.

[8] Moholkar, Vijayanand S., Pandit, Aniruddha B.: *Bubble behavior in hydrodynamic cavitation: Effect of turbulence // AIChE Journal, V.43 (6)*. American Institute of Chemical Engineers, 1997, 1641–1648.

[9] Akzhalova A., Baymirov K.M., Zhunusov Ch.T., *Myltykbekov M.J Smart device to process signals from the sensor well gas and oil fields*. Journal «Search», Almaty, Kazakhstan 2011, pp. 262–276.

[10] Johnson D.B.: *Routing in ad hoc networks of mobile hosts*. In Proc.of the Workshop on Mobile Computing Systems and Applications, Santa Cruz, CA, December 1994, pp. 158–163.

[11] Perkins C., Royer E.: *Ad hoc on-demand distance vector routing*. In 2nd IEEE Workshop on Mobile Computing System and Applications, New Orleans, LA, Feb. 1999.

[12] Angelov, Plamen (2009) Evolving Fuzzy Systems. In: Encyclopedia of Complexity and System Science. Springer, Berlin/Heidelberg. ISBN 978-0-387-75888-6

[13] Design Of Fuzzy Controllers Jan Jantzen Technical University of Denmark, Department of Automation, Bldg 326, DK-2800 Lyngby, DENMARK. Tech.