Research on Partial Pressure of Oilfield Water Injection Pipeline Network System Based on Fuzzy Logic

Zhang Ruijie¹*, Wu Zhenming¹, Wang Mengxiao¹, Guo Yaping¹ and Mao Guoan¹

¹Mechanical science and engineering college of northeast petroleum institute DaQing 163318 China

Corresponding author:*hefujun@nepu.edu.cn

Abstract. Aiming at the middle and late stages of oilfield development, the retirement of water injection wells in old areas of the water injection system, the increase of water injection wells in new areas, and the incorporation of tertiary injection wells into the subsequent water flooding have caused great changes in the layout of the water injection pipeline network, causing the mixed injection of high and low pressure wells, a fuzzy logic method is proposed to divide the pressure of the water injection pipeline network, establishing a partial pressure reasoning model, setting the fuzzy domain and reasoning rules, and finally realize the division of high and low pressure areas of a large number of water injection wells. Taking an oilfield water injection pipe network system as an example, the effectiveness of the method is proved through Matlab simulation and application research.

1. Introduction
In the middle and late stages of oilfield development, with the continuous increase of water injection, the scale of the water injection system has also been continuously expanded. The abandonment of water injection wells in the old area, the increase of water injection wells in the new area, and the incorporation of three production injection wells into the subsequent water flooding have caused great changes in the layout of the water injection pipeline network, resulting in mixed injection of high and low pressure wells. In order to meet the pressure requirements of high and low pressure wells, the principle of "high, not low" is adopted. The entire system is operating at a higher pressure, and energy consumption is increased; low pressure wells are adjusted through the throttling of the water distribution valve to reduce the pressure, and the throttling loss of the well pipe pressure difference increases, resulting in a large amount of wasteful energy. In this case, analyzing the pressure distribution characteristics and laws of water injection wells, dividing the water injection pipe network as necessary, separating the high pressure area from the low pressure area, and performing partial pressure water injection is a significant method for the water injection system to reduce energy consumption[1,2].

Since the water injection system is composed of a large number of water injection wells, each injection well has different injection pressures. When the pressure is divided, not only the pressure level of the water injection well must be considered, but also the overall structure of the pipe network and the operability of the divided pipe network. Many factors cannot be reasonably divided based on human experience. To solve this problem, a fuzzy logic theory is proposed to determine the dividing point of the pipe network.
2. The concept of fuzzy logic

Fuzzy logic is a method to accurately solve imprecise and incomplete information. It is a method and tool to express and analyze uncertain and imprecise information by imitating people's way of thinking. It does not depend on the model, uses language to express variables, uses rules to carry out fuzzy reasoning, and processes things. We admit the intermediate transition between true and false, and think that things are the same in form and category[3,4]. The fuzzy logic inference system is shown in figure 1.

![Fuzzy logic inference system](image)

**Figure 1.** Fuzzy logic inference system

3. Prior knowledge of fuzzy reasoning

For the partial pressure design of the water injection system, it is necessary to separate the high-pressure water injection area from the low-pressure water injection area according to the pressure of the water injection well. At the boundary of the two areas, there should be sufficient separation conditions.

Principles for the division of high and low pressure areas:

- Regarding the level of single well pressure as a judgment principle, the high pressure may be classified into the high pressure zone.
- The pressure difference between two adjacent wells on the same pipeline is used as the judgment principle to realize the separation between high and low pressure wells. There is a certain pressure difference between the wells in the high and low pressure zones. If the pressure difference between the two wells is relatively high, they may belong to two pressure zones. Of course, the wells in the same pressure zone may also have a large pressure difference, which must be judged by fuzzy logic based on the pressure of a single well.
- Take the operability of the water injection well as the judgment principle. Operability refers to whether there is a shut-off valve on the pipeline around a well, whether the shut-off valve is near the road, and it can be easily shut down. After the water supply pipeline is cut off at this well, the impact on the water supply capacity of other wells around it is judged as not affecting the normal water supply of other wells, and it is considered that its operability is high.
- For example, several adjacent low-pressure wells in the high-pressure zone also need to be classified into the high-pressure zone. That is, several low-pressure wells are surrounded by the high-pressure zone and are also considered high-pressure wells.
- For the situation where there are several high-pressure wells in the low-pressure zone, or the situation where there are several low-pressure wells in the high-pressure zone, there is no need to delineate them. If several low-pressure wells in these high-pressure areas can be cut off with the surrounding wells through valves to form an independent low-pressure area, it is also necessary to judge whether the water supply pipelines of these wells are all cut off. Significance. If the isolated low-pressure area is small and has no practical meaning, there is no need to optimize it. In this case, it should be merged into the surrounding high-pressure area.

The division of high and low pressure areas should be divided into two steps. First, the high and low pressure areas are divided by fuzzy logic. At this time, low pressure areas may be scattered in the high pressure area, and then according to the size of these areas and the presence or absence of water supply
pumps. Station, or the size of the water supply capacity to decide whether to merge these wells. For example, fuzzy logic is also used for the second judgment; if the block is relatively large and the water supply capacity is relatively strong, then it is likely to be classified as an independent low-pressure area. The water supply capacity here refers to this independent block.

4. Establish a fuzzy inference system model
In the fuzzy reasoning model for dividing the high pressure zone of water injection wells, the input variables are the pressure PS of the water injection well, the pressure difference PD between adjacent water injection wells on the same pipeline, and the operability of the water injection well OA. The output variable is the possibility HPP that the water injection well belongs to the high pressure zone.

The fuzzy sets and domains of pressure PS, differential pressure PD, operability OA, and high-pressure HPP are defined as follows:
- The fuzzy set of PS is \{Low, Middle, High\}, and the domain is \([8,15]\); for different oil fields or different oil production blocks, the domain value will change.
- The fuzzy set of PD is \{Low, Middle, High\}, and the domain is \([0, 7]\); for different oil fields or different oil production blocks, the domain value will change.
- The fuzzy set of OA is \{Low, Middle, High\}, and its domain is \([0, 10]\);
- The fuzzy set of HPP is \{Low, Lower, Middle, Higher, High\}, and the domain is \([0, 10]\); if the fuzzy set of HPP is above Higher, it can be classified into the high pressure zone.

The membership function of each language variable is represented by a linear function, as shown in figure 2.

5. Fuzzy reasoning rule design
When designing fuzzy rules, considering that the division of water injection wells into high-pressure and low-pressure areas is not absolute, the high-pressure area may also contain a small number of low-pressure wells. The low-pressure wells in the high-pressure pipe network use valves to control the injection pressure. Therefore, fuzzy inference can distinguish the high and low pressure conditions of wells in a wide range to a certain extent, and then carry out further integration processing in the follow-up.

5.1 Fuzzy reasoning rules based on well pressure
Firstly, it is distinguished by the level of well pressure. For a certain block, after preliminary analysis, the pressure range is set and the high pressure is clearly defined. The high pressure must belong to the high pressure zone, but because the high pressure zone may also contain low pressure wells, the low pressure wells may not be in the high pressure zone, and the judgment should be based on conditions such as operability.
5.2. Fuzzy reasoning rules based on pressure difference

According to the judgment of the pressure difference between adjacent wells, if the pressure difference is high, it means that the boundary point should be set here, but it also depends on whether there are operating conditions for setting the boundary point; if the pressure difference is low, the pressure of the well is still The higher ones should be classified as high-pressure areas.

5.3. Fuzzy reasoning rules based on operability

If there is no pipeline valve around the well, it cannot be used as a demarcation point; even if there is a valve, the closing of this position will affect the injection volume of other wells, and it cannot be demarcated here.

Based on the above considerations, the establishment of fuzzy logic rules is shown in the following table1. The fuzzy system adopts the Mamdani reasoning method, in which the logical relationship between the input variables is "and".

Use Matlab's fuzzy logic toolbox [5] to simulate the fuzzy inference system to check the feasibility of fuzzy inference. In the GUI system of fuzzy logic, by changing the value of each input variable, the expected output value can be achieved according to the inference rules. The fuzzy regular surface is shown in figure 3.

| Rule number | PS  | PD  | OA  | HPP | Rule number | PS  | PD  | OA  | HPP |
|-------------|-----|-----|-----|-----|-------------|-----|-----|-----|-----|
| 1           | Low | Low | Low | Low | 15          | Middle | Middle | High | Higher |
| 2           | Low | Low | Middle | Low | 16          | Middle | High | Low | Lower |
| 3           | Low | Low | High | Low | 17          | Middle | High | Middle | Higher |
| 4           | Low | Middle | Low | Low | 18          | Middle | High | High | Higher |
| 5           | Low | Middle | Middle | Lower | 19          | High | Low | Low | High |
| 6           | Low | Middle | High | Lower | 20          | High | Low | Middle | High |
| 7           | Low | High | Low | Lower | 21          | High | Low | High | High |
| 8           | Low | High | Middle | Lower | 22          | High | Middle | Low | High |
| 9           | Low | High | High | Middle | 23          | High | Middle | Middle | Higher |
| 10          | Middle | Low | Low | Middle | 24          | High | Middle | High | Middle |
| 11          | Middle | Low | Middle | Middle | 25          | High | High | Low | Higher |
| 12          | Middle | Low | High | Higher | 26          | High | High | Middle | High |
| 13          | Middle | Middle | Low | Middle | 27          | High | High | High | High |
| 14          | Middle | Middle | Middle | Middle |             |      |      |      |      |

![Figure 2. Membership function for input and output variables](image)
Fuzzy logic is used to judge the possibility of each well being classified into the high-pressure zone, and the probability inference value greater than 7 can be classified into the high-pressure zone. This can better distinguish the high-pressure wells in the water injection pipeline network. In addition, according to the needs of optimized operation of the pipeline network, it is not appropriate to divide the overall water injection pipeline network into more high and low pressure areas. Therefore, the small-scale high-pressure wells contained in the low-pressure zone can be reclassified into the low-pressure zone, and the small-scale low-pressure well blocks in the high-pressure zone should also be classified into the high-pressure zone.

6. Case analysis
An oilfield water injection system currently has 10 water injection stations, 72 water distribution rooms, 14 injection stations and 2,257 water injection wells. The number of wells opened per day is between 1,800 and 1,900. 29 water injection pumps, 13-14 pumps are on everyday. The water injection volume is between $9 \times 10^4 \sim 10 \times 10^4$ m$^3$, The average unit consumption of water injection is about 5.80 kWh/m$^3$. The distribution of injection pressure of wells is shown in figure 4, the color index of the pressure distribution of injection wells is shown in figure 5.
It can be seen from figure 3 that only a part of the northeast corner and some water injection wells in the transition zone between east and west have relatively high pressures, which are basically between 12.0 MPa and 13.5 MPa, and a few wells have pressures between 13.5 MPa and 15.0 MPa; The pressures of water injection wells in other areas are relatively low, all below 12.0 MPa, or even lower than 10 MPa. As shown in Figure 5, the average pump pressure of the water injection pump is as high as 16.6 MPa. The average main line pressure of the water injection well is 15.4 MPa, and the average oil pressure of the water injection well is only 11.8 MPa, so the difference between main line pressure and oil pressure is 3.6 MPa. The energy loss of the wellhead water distribution valve is the main reason of the high energy consumption of the water injection system. Therefore, through the above analysis, the necessary partial pressure of the pipe network is a prerequisite for energy saving and consumption reduction of the water injection system. Figure 6 shows the high and low pressure blocks divided by the water injection pipeline network system using fuzzy logic theory. The entire pipeline network is divided into two parts: high pressure area and low pressure area. The larger area on the left is the low pressure area, and the upper right corner has a smaller area and is the high pressure area.

| Pressure range | Color index | Number of Injection Wells | Proportion(%) |
|----------------|-------------|---------------------------|---------------|
| >15.0          | Purple      | 0                         | 0.0           |
| 14.5-15.0      | Red         | 31                        | 1.4           |
| 14.0-14.5      | Dark red    | 256                       | 11.3          |
| 13.5-14.0      | Yellow      | 234                       | 10.3          |
| 13.0-13.5      | Light green | 216                       | 9.5           |
| 12.5-13.0      | Green       | 279                       | 12.3          |
| 12.0-12.5      | Blue        | 277                       | 12.2          |
| 11.5-12.0      | Dark blue   | 364                       | 16.0          |
| 11.0-11.5      | Medium blue | 138                       | 6.1           |
| 10.5-11.0      | Light blue  | 32                        | 1.4           |
| 10.0-10.5      | Blue green  | 1                         | 0.0           |
| <10.0          | Black       | 446                       | 19.6          |

**Figure 5.** Color index of pressure distribution of water injection wells

**Figure 6.** Diagram of partial pressure of water injection system

### 7. Conclusion
Due to the large number of water injection wells in the oilfield, it is difficult to realize the division and pressure distribution artificially. Based on the fuzzy logic theory, a partial pressure reasoning model is established, which takes the pressure of a single well, the pressure difference of adjacent wells and the...
operability of partial pressure as variables. The fuzzy universe and reasoning rules are set. Through the research on the pressure distribution law of water injection wells in an oilfield, the fuzzy logic idea, field production conditions and artificial experience are closely combined to realize the high and low area of water injection wells, which has a certain guiding significance.

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