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To cite this article: Hangyu Shi et al 2021 J. Phys.: Conf. Ser. 1732 012068

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Combine the AGA and L-M algorithms to predict the oil-water flow profile of production wells

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Abstract. Production logging is the main means of dynamic monitoring of oil wells at present. The interpretation method of production logging fluid profiles is the key to the dynamic evaluation of oil wells and is of great significance. A joint optimization technique of a AGA and L-M is proposed to deal with the profile data of oil-water two-phase flow. The method is based on the energy conservation of the fluid in the production unit space. According to the nonlinear weighted least squares principle and the error theory, the objective function of the minimum value is established by the difference between the theoretical fluid temperature and the measured value of the thermometer. According to the fluid volume conversion, the flow rate of each phase in the well and the flow log value at the bottom of the control body are constrained. In order to improve the interpretation accuracy, the global search method (AGA) of genetic algorithm and the direct local search method of L-M algorithm are combined to solve the optimal solution. Firstly, the adaptive genetic algorithm is used for heuristic global search, and then as a result of the initial parameters, the L-M method is applied to approach the optimal solution. The interpretation results from the joint inversion are stable and reliable. This method is not only suitable for vertical wells but also for inclined wells.

1. Introduction

Production logging is the primary tool for evaluating fluid flow characteristics in oil wells and reservoirs. The success or failure of production logging interpretation depends to a large extent on whether the choice of interpretation model and parameters is correct^[1]. At present, the slip model and the drift model are mainly used in China. The difficulty of the slip model and the drift model is the determination of the slip speed and the drift speed. The determination of slip speed and drift speed are based on empirical formulas based on certain simulation tests^[2]. And the traditional multiphase flow production logging interpretation method is also related to fluid property parameters such as fluid interface tension, gravity acceleration, and fluid density of each phase. The errors in these calculated parameters will be passed into the flow profile interpretation results. In order to reduce the model error and maximize the comprehensive utilization of various production logging and other useful information, the author mainly discusses the energy conservation of the fluid in the production interval of the oil-water two-phase production, and proposes the AGA-in combination with the optimization method mathematical method. The LM algorithm jointly predicts the method of producing the oil-water flow profile of the oil well. It does not need to estimate the oil-water slippage speed,



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eliminates the error caused by determining the slip-off speed, and makes a new exploration for the production logging data interpretation technology.

2. Theoretical model

When fluid flows from the formation into the wellbore, it is accompanied by the transfer of energy; The control body is established with the top of the production layer as the upper boundary and the wellbore as the side boundary. Figure 1 is a schematic diagram showing the conservation of energy of a fluid at a production interval in a two-phase production of oil and water.

In Figure 1, Z represents the log depth value, m; Z0 represents the top depth of the control unit, m; ZT represents the depth of the instrument, m; v_{f1} , v_{f2} respectively The velocity of oil and water flowing from the reservoir into the wellbore, m/s; D represents the vertical depth of the lowest layer, m; q1,q2 respectively represent the delivery of oil and water, m3/s; Tw is the corresponding depth Z the

temperature of the fluid, °C; T_0 is the temperature of the top fluid of the control unit, °C; θ is the inclination of the wellbore, rad; T_{g0} is the surface temperature (Z = 0), °C; shadow the part represents the control unit volume and is used to study the energy conservation problem. First, according to the metering device such as surface flow rate, the flow rate of the two-phase fluid is obtained, assuming the flow rates of the oil and water phases at the top of the downhole control unit are q_{10} and q_{20} respectively, and the flow rates of the downhole phases are equal to the product of the flow rates of the ground phases and the volume coefficients of the respective formations^[3]. which is

$$q_{i0} = B_i \times q_{i_{surface}} \tag{1}$$



Figure 1. Schematic diagram of control space of two-phase flow production interval.

Where q_{i0} is the flow rate of the i-phase fluid at the topmost position; B_i is the formation volume factor of the i-phase fluid; $q_{isurface}$ is the flow of the i-phase fluid on the ground. Formula (1) shows that the flow rate of each phase fluid on the ground and the accuracy of the formation volume coefficient of each phase fluid directly affect the flow of each phase of the oil and water at the top of the downhole control body.

In the process of calculating the spatial energy conservation of the two-phase flow production layer, for the convenience of analysis, the author assumes that the heat transfer, kinetic energy and potential energy change are so small that they can be ignored. As shown in Figure 1, after converting the surface flow rate to the downhole, it is assumed that the total oil flow at the top of the downhole control body is q_0 , which is equal to the sum of the flow rates of the oil and water phases, is $q_{10} + q_{20}$, and the total flow of oil at the bottom of the control body is q_T , the flow rate of oil and water phase is q_1 and q_2 , the velocity of oil and water flowing from the formation into the wellbore is v_{f1} and v_{f2} respectively, and the energy carried by the fluid flowing from the formation into the control space is:

$$2\pi r_{w} \int_{Z_{0}}^{z_{\tau}} (\rho_{1} v_{f1} H_{1} + \rho_{2} v_{f2} H_{2}) dZ$$
⁽²⁾

(where, r_w represents the borehole radius, m; ρ_1 , ρ_2 represent the density of oil and water, respectively, kg/m³; H₁ and H₂ represent the unit mass enthalpy of oil and water, respectively, J/kg).

The energy carried by the fluid flowing from the bottom boundary of the control volume is:

1732 (2021) 012068 doi:10.1088/1742-6596/1732/1/012068

$$\rho_1(q_1 + \pi r_w^2 Y_1 V_T) H_1 + \rho_2(q_2 + \pi r_w^2 Y_2 V_T) H_2$$
(3)

(where Y_1 , Y_2 represents the oil and water holding ratio, respectively; V_T represents the speed of the instrument, m/s).

The energy flowing out from the bottom boundary of the cell space is:

$$\rho_1 q_{10} H_1 + \rho_2 q_{20} H_2 \tag{4}$$

In the space of the control unit, the rate of change of energy with time t is:

$$\frac{\partial}{\partial t} \left(\pi T_{w}^{2} \int_{Z_{0}}^{Z_{T}} (\rho_{1} Y_{1} U_{1} + \rho_{2} Y_{2} U_{2}) dZ \right)$$
(5)

(where U_1 and U_2 represent the unit mass internal energy^[4] of oil and water, J/kg).

For the control unit body shown in Figure 1, the conservation of energy is:

$$(q_1M_1 + q_2M_2)T_w = (q_{10}M_1 + q_{20}M_2)T_0 - 2\pi r_w \int_{Z_0}^{Z_1} (M_{1Vf1} + M_{2Vf2})T_f dZ$$
(6)
here $M_1 = 0.C$, is the volumetric heat capacity, $kI/(m^3, °C)$, $i = 1, 2; C$, is the mass heat capacity

where $M_i = \rho_i C_{pi}$ is the volumetric heat capacity, $kJ/(m^3 \cdot {}^\circ C)$, i = 1, 2; C_{pi} is the mass heat capacity, $kJ / (kg \cdot {}^\circ C)$.

For the control unit body, according to the conservation of mass, the flow of each phase has the following relationship:

$$q_1 = q_{10} - 2\pi r_w \int_{Z_0}^{Z_T} v_{f1} dZ \qquad q_2 = q_{20} - 2\pi r_w \int_{Z_0}^{Z_T} v_{f2} dZ$$
(7)

Substituting formula (7) into formula (6) yields:

$$T_{w}(Z) = \frac{(q_{10}M_{1} + q_{20}M_{2})T_{0} - 2\pi r_{w} \int_{Z_{0}}^{Z_{T}} (M_{1}v_{f1} + M_{2}v_{f2})T_{f}dZ}{(q_{10}M_{1} + q_{20}M_{2}) - 2\pi r_{w} \int_{Z_{0}}^{Z_{T}} (M_{1}v_{f1} + M_{2}v_{f2})dZ}$$
(8)

Introduce the ground temperature calculation formula here:

$$T_{f} = T_{bot} - g_{T}(D - Z_{T}) = T_{g0} + g_{T}Z_{T}\cos\theta$$
⁽⁹⁾

Where T_{bot} is the ground temperature of its corresponding depth, °C; g_T is the geothermal gradient value, °C/m.

Substituting formula (9) into formula (8) to obtain the theoretical fluid temperature value at the location of the instrument:

$$T_w(Z) = \frac{(q_{10}M_1 + q_{20}M_2)T_0 - 2\pi r_w \int_{Z_0}^{Z_T} (M_1 v_{f1} + M_2 v_{f2})(T_{g0} + g_T Z \cos\theta) dZ}{(q_{10}M_1 + q_{20}M_2) - 2\pi r_w \int_{Z_0}^{Z_T} (M_1 v_{f1} + M_2 v_{f2}) dZ}$$
(10)

From the above analysis of the conservation of energy in the control unit, it can be known that the Darcy velocity and the open area of each phase fluid in the formation (both the integral is the flow rate of each phase) is an important contribution of the fluid temperature in the wellbore, and formula (10) is the theoretical equation between them. When the Darcy velocity and the open area of each phase fluid are known, the theoretical temperature value^[5] of the fluid in the well can be obtained by the calculation of formula (10).

3. Solution Procedure

The study uses a top-down interpretation method, that is, based on the ground data, the flow rate q_{10} and q_{20} of the oil and water at the top of the first control body can be obtained, and the percolation velocity of each phase fluid is the independent variable X (v_{f1} , v_{f2}), the theoretical response equation of the wellbore fluid temperature is established according to formula (10), and then the difference between the theoretical fluid temperature T'_w and the thermometer measured value Tw is established according to the nonlinear weighted least squares principle and the error theory. To find the objective function of the minimum value, the flow meter at the bottom of the control body obtains the sum of the flow rates of the phases as a constraint. which is:

$$\begin{cases} \min F(v_{f1}, v_{f2}) = \min \frac{(T_w - T'_w)^2}{\sigma^2 + \tau^2} \\ \text{s.t.} \quad g(X) \ge 0 \quad h(X) = 0 \end{cases}$$
(11)

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where σ is the measurement error of the actual temperature log, °C; τ is the temperature theoretical error, °C; $F(v_{f1}, v_{f2})$ is the objective function of the optimal interpretation; g(X) is the inequality constraint on X ;h(X) is an equality constraint on X^[6].

The optimization technique is used to continuously adjust the unknown fluid parameter X so that the calculated theoretical fluid temperature value T'_w of each control body continuously approaches the corresponding actual fluid temperature log value T_w . Once the two are sufficiently close, that is, the objective function value reaches a minimum value, then the independent variable X (v_{f1} , v_{f2}) used to calculate the theoretical fluid temperature value T'_w of each control body is the most Fully reflect the oil and gas production of each control body of the actual oil well v_{f1} , v_{f2} , that is, the output of each production layer is:

$$Q_1 = 2\pi r_w \int_{Z_0}^{Z_T} v_{f1} dZ \qquad Q_2 = 2\pi r_w \int_{Z_0}^{Z_T} v_{f2} dZ$$
(12)

The flow rate of each phase at the top of the previous control body minus the output of each phase in the middle of the control body is the flow rate of each phase at the top of the next control body, using the same the method can gradually calculate the production of each control unit. Optimization process shown in Figure 2.

4. Combine the AGA and L-M algorithms to predict the output of production formation

In order to explore an accurate and effective optimization method, assuming a theoretical model, the seepage velocity of the production layer fluid is $v_{f1}=0.122$ m/min, and $v_{f2}=0.244$ m/min does not vary with depth in the production interval; the borehole radius $r_w = 0.0634$ m; the volumetric heat capacity of oil and water is M₁=1336.7kJ/(m³·°C), M₂=1336.7kJ / (m³·°C); the production interval is vertical, the depth is 3.05m; the oil well space in the production interval is the control body, the fluid temperature at the top of the control body is T0 =251.6 °C; the top formation temperature Tg0 of the control body =238.1°C; geothermal gradient gT=0.0885 °C / m; total flow from the ground to the top of the control body according to equation (7) Tw=267.138 °C, the total flow at the bottom of the control body is qT=420.48m³/d. Using the above optimization interpretation method, the seepage velocity of the production layer fluid is inversion, that is, the production of contributing zone.



Figure 2. Flow chart of optimization method for production liquid profile based on energy conservation.

4.1 Search performance of genetic algorithm (GA) in seepage velocity inversion

In order to understand the genetic algorithm (GA) to search for the optimal solution in the inversion of seepage velocity, the theoretical fluid temperature is built as the measured temperature. The objective function is searched by genetic algorithm in the set parameter interval, and the optimal solution found is the Darcy velocity of each phase of the formation. The objective function f is a binary multimodal function whose function image is shown in Figure 3. In the GA space, the initial population is randomly selected, and genetic operations such as selection, crossover, and mutation are implemented to obtain new populations. The fitness of each individual in the new population is evaluated. This is an iterative process of the genetic algorithm. When the number of iterations is 51, the best fitness is 3.4175×10 -6, as shown in Figure 4.



 Figure 3. Theoretical model objective function
 Figure 4. Genetic algorithm inversion theory model diagram.

 diagram.
 fitness change diagram.



Figure 5. Analysis of genetic algorithm inversion results.

Figure 5 is an analysis of the results of six GA inversions of the optimized model (12). It can be seen that under a limited number of iterations, the inversion results for the same model are different, with a probability distribution around the optimal solution. The maximum deviation between the seepage velocity of the formation and the given parameters of the model is 18%.

The model calculation results show that the local search performance of the genetic algorithm is relatively poor, and the results have scattered characteristics.

4.2. Reprocessing of inversion results of genetic algorithms using L-M algorithm

The L-M algorithm belongs to the local optimization method. The objective function has a local solution in the case of strong nonlinearity. The inversion result is affected by the initial model and is sensitive to the initial value^[6,7]. To this end, in order to improve the inversion accuracy, a global search method (AGA) of genetic algorithm is combined with a direct local search method such as the L-M

algorithm: a heuristic global search is first performed, and then the result is directly used as an initial parameter. Again the L-M method is processed to approximate the optimal solution. An iterative search phase using the L-M algorithm is inserted between the crossover and the sudden variation in the genetic algorithm calculation flow. If there is an individual in the new population generated after the intersection that exceeds the predetermined fitness threshold, use it as the initial amount for L-M search. If the fitness value of the search result exceeds another predetermined threshold, the inversion is considered to have reached the goal, and the inversion process is ended. Otherwise, if the search reaches a certain local solution, it returns to the genetic algorithm process and continues to abruptly mutate. The formation Darcy velocity from the joint inversion is consistent with the given parameters of the model, and the calculation results are stable.

5. Example

Well A is a multi-layer production well with production levels of ZJ1VI, ZJ1VII \pm , ZJ2 I \pm , and ZJ2I \mp .In the longitudinal direction, the oil groups are not connected to each other, showing the characteristics of the oil field with multiple oil-water systems. The oil field is a uniform temperature system with a geothermal gradient of 5.4 °C/100m. By calculating the ground production: oil is 144.4 m³/d, water is 375. 6m³/d, gas is 825. 9m³/d, ground water content 72.2%, well radius r_w =0.062m. The results of joint inversion interpretation using energy conservation-based AGA and L-M algorithms are shown in Table 1. From the interpretation results (Table 1),the main production layer is the ZJ1VI oil group, the output is mainly water, the underground production accounts for 77.1% of the total underground production, and the ground water content is 87.1%; The upper layer is the ZJ1VII \pm oiling group, the output is mainly oil, the underground production accounts for 17.0% of the total underground production, the ground water content is 24.7%, The oil production of ZJ2L \pm and ZJ2I \mp is less, and oil production is the main one.

Oil group	Perforating section (m)	Oil production (m ³ /d)	Water production (m ³ /d)	Downhole total (m ³ /d)
ZJ_1VI	1210.5-1221.7	55.5	360.3	415.8
ZJ_1VII_{upper}	1244.2-1248.3		21.9	91.4
	1258.3-1261.8	69.5		
	1265.2-1276.4			
ZJ ₂ I _{upper}	1296.5-1308.8	14.0	1.6	15.6
$ZJ_2 I_{lower}$	1319.1-1320.4			
	1322.2-1324.3	14.3	1.7	16.0
	1326.6-1328.7			
total		153.3	385.5	538.8

 Table 1. A well interpretation results table

6. Conclusions

The traditional production logging flow profile interpretation method mainly relies on the holdup to calculate the flow rate of each phase. However, the acquisition of the holdup logging value is different due to the different logging instruments used, which will inevitably bring relative accuracy to result. The energy-conservation-based oil-water two-phase production profile optimization interpretation method avoids the requirement of holding rate logging value, and uses temperature logging value and flow logging value and ground phase flow value to process the flow section of each well. This method has the following characteristics:

doi:10.1088/1742-6596/1732/1/012068

1) Applying energy conservation and optimization calculation method to production logging is one of the effective methods to deal with oil-water two-phase liquid production profile data. It has the characteristics of high interpretation precision, simple logging data, and global optimal results. It is suitable for vertical wells. Also suitable for inclined wells.

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- 2) Using the theory of conservation of energy to solve the production of oil and water production layers, and citing the production data of the various phases of the ground, make interpretation results are more harmonious reason.
- 3) Applying the AGA and L-M algorithms to solve the flow profile jointly, overcoming the blindness of artificially setting the initial value, improving the computational precision degree.
- 4) Since the method relies mainly on calculating the conservation of thermal energy from the formation to the wellbore of the production layer fluid, the temperature log response and the geothermal gradient is sensitive, not applicable to gas-producing wells, and has high interpretation accuracy for medium and high-yield production layers.

7. Acknowledgments

The research is supported by Educational Commission of Hubei Province of China (D20141302) and National Natural Science Foundation of China (41474115).

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