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The Integral Optimization Method of Oilfield Production System

LU Yufeng[a],[b],*

[a]Institutes of Science and Development, CAS, Songyuan, China.
[b]Fuyu Oil Production Plant of PetroChina Jilin Oilfield Company, Changchun, China.
*Corresponding author.

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Abstract

Based on the study of the various flow patterns of the oilfield production system, the oilfield production system is divided into five relatively independent subsystems by node analysis. The nodes are the connection points of two adjacent sub systems, the dynamic parameters of flow and pressure are passed. According to the principle of balanced offtake, the energy loss in each subsystem is determined, and the theoretical model of the energy management of the ground pipe network of the production system was established. An example of energy consumption analysis in Daqing Xinghelian area, the integral optimization method is presented. The results show that the energy consumption of the production system in the region can be well represented by the established energy consumption model. The seepage of the reservoir is the largest in the whole production system, which is 40.2%. The reservoir can improve its seepage capacity by means of fracturing, better grading of sewage treatment process, improve the level of oil and water wells.

Key words: Oilfield development; Production system; Node analysis; Energy consumption; Integral optimization

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INTRODUCTION

In the current oilfield development work, the reservoir engineering, ground engineering and oil production block management, the three closely linked inseparable. As a result of a variety of complex technology, economic problems, systems engineering methods in the past did not get a good application, which led to the oil field after the development of forced to undergo uninterrupted adjustment and transformation, not only affect the normal production of oil fields, but also caused a great waste of people's property. China's large-scale system modeling technology in the field of oil and gas field development is mainly concentrated in the ground water injection system optimization[1-3] and ground, underground integration optimization[4-5] and so on. The solution is mainly genetic algorithm, network topology, etc. While the oil field production system to optimize the integral, taking into account the reservoir and oil wells and ground facilities, the theoretical method is still relatively little. The oilfield production system is a complete pressure system, but there are several different flow patterns in this system, and the node analysis technique analyzes the whole system by selecting a point within the analysis system, so it can be combined in different flow rules set the node. The author uses the node analysis method, the oil production of the entire production process as a whole study[6], can make the analysis and design to achieve local optimization, but also to maintain the overall coordination.

1. GENERALIZED NODE SETTINGS

According to the principle of decomposition coordination, the oil field production system is divided into 5 subsystems: the ground water injection pipe network system, the water injection system, the reservoir system, the oil well lifting system and the surface oil and gas water treatment gathering and transportation system. Analysis of generalized node of oil production system is shown in Figure. As can be seen from Figure 1, in each subsystem, the fluid flow is restricted by many factors, which makes the system in a dynamic state of coordination;

according to the different structural characteristics of each subsystem, the two subsystems can be further subdivided, and then the node analysis method is introduced, The five subsystems of the oil field production system are connected by means of four nodes, each node divides the two adjacent systems into upstream and downstream systems, the node is not only the outlet of the upstream system but also the entrance of the downstream system; at node, two systems make fluid transfer, the corresponding dynamic index is rate of flow and pressure.

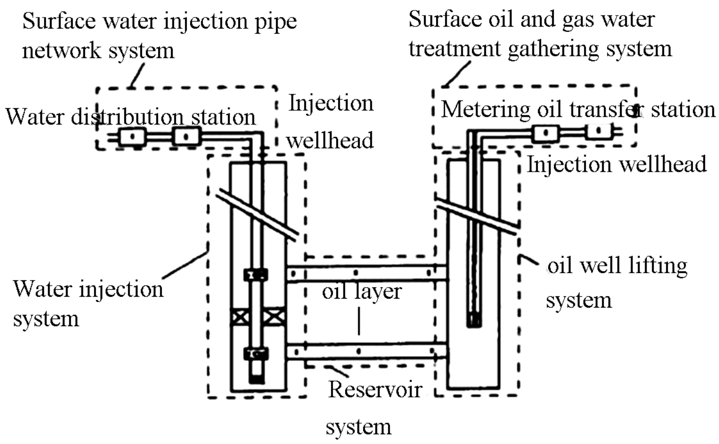

Figure 1
Generalized Node Analysis of Oilfield Production System

2. ESTABLISHMENT OF ENERGY CONSUMPTION MODEL

Flow injection production system with vertical pipe ground level pipeline pipe flow, wellbore flow in oil wells, the water faucet mouth flow and fluid in the reservoir seepage.

2.1 Surface Water Injection Pipe Network System

The oilfield water injection pipe network system belongs to the branch pipe system, longer pipeline between nodes, generally can not be included in the local head loss, and calculated by long pipe[7]. The whole pipe network is composed of a series of connected pipes (pipe element), many pipe elements are connected to a certain number of nodes. Constant flowing in the pipe, whether single or connected with the pipe network pipe element, by the algebraic equation of mass conservation and energy conservation are quantitatively described.

The energy equation of pipe element:

$$\Delta H^i = H_k - H_j . \tag{1}$$

In formula: ΔH^i-total head loss of pipe element I; H_k-total head of pipe element k,H_j- total head of pipe element j,water flowing from K to j, $H_k>H_j$.

Continuity equation of pipe element:

$$Q^i = A^i v^i = \text{常数}. \tag{2}$$

In formula: Q^i- rate of flow of pipe element, A^i- cross section of pipe element, v^i-velocity of pipe element

The energy consumption model of the derived pipe element is derived from the Formulas (1-2).

$$\Delta p^i = R^i \times Q^i, \tag{3}$$

$$R^i = 100877.181 \times \frac{(n^i)^2 \times l^i}{(D^i)^{5.333}} \times Q^i \ . \tag{4}$$

In formula: Δp^i-Pressure difference between two ends of pipe element, D^i-pipe diameter l^i-Element Length, Q^i- rate of flow of pipe element, R^i-Flow resistance n^i-Hydraulic friction factor.

The hydraulic diagram of the surface injection system branch pipe network is shown in Figure 2. The triangular symbols stand for injection wells, $p^1_{1,}$ $p^1_{2,}$ $p^1_{3,}$ p^1_4 are respectively for different wellhead pressures of injection wells, Q_1,Q_2 are respectively for different injected water volume. The thicker water pipes are main injection pipes, while the thinner pipe which connects to injection wells is the pipeline from main pipes to injection wells, and the direction of the arrow is the flow direction of the injected water.

According to the similarity principle of water and electricity, we can make the corresponding electric power of Figure 2, and the results are shown in Figure 3. Figure 3 is analyzed by means of electrodynamics ,and we can get the matrix of the Formula (5) after a series of derivation.

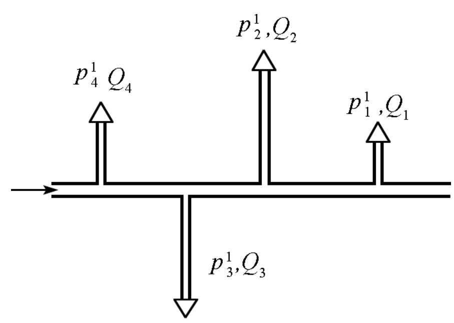

Figure 2
Hydraulic Schematic of Ground Water Injection Pipe Network

Injection pipeline network can be transformed into a matrix in the form of $A \cdot X= B$. $A_{(2n-1)\times(2n-1)}$ is the matrix consisting of frictional drag R, and in the case of known diameter and length of the pipe element, it can be transformed into a matrix with flow mouth. X_{2n-1} is the matrix consisting of flow Q and pressure p_i^0. B_{2n-1} is the matrix of pressure p_i^1. And the means of initial value iteration is proposed in the solving process.

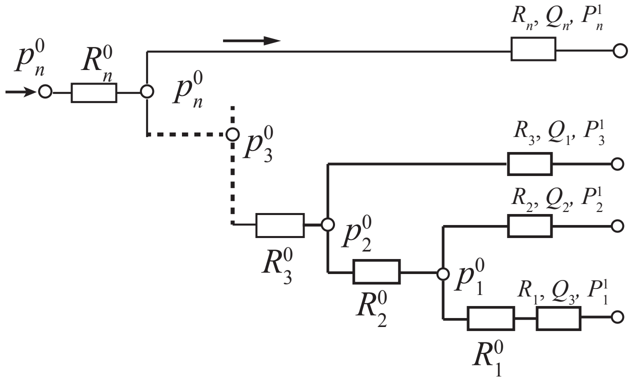

Figure 3
Schematic Diagram of Surface Water Injection Pipe Network

$$\begin{bmatrix}
R_1^0+R_1 & -1 \\
R_2^0 & 1 & R_2^0 & -1 \\
 & -1 & R_2 \\
R_3^0 & & R_3^0 & 1 & R_3^0 & -1 \\
 & & & -1 & R_3 \\
R_4^0 & & R_4^0 & & R_4^0 & 1 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots \\
R_{n-1}^0 & & R_{n-1}^0 & & R_{n-1}^0 & & \cdots & 1 & R_{n-1}^0 & -1 \\
 & & & & & & & -1 & R_{n-1} \\
R_n^0 & & R_n^0 & & R_n^0 & & \cdots & & R_n^0 & 1 & R_n^0 \\
 & & & & & & & & & -1 & R_n
\end{bmatrix} \cdot \begin{bmatrix} Q_1 \\ p_1^0 \\ Q_2 \\ p_2^0 \\ Q_3 \\ p_3^0 \\ \vdots \\ p_2^0 \\ Q_3 \\ p_2^0 \\ Q_3 \end{bmatrix} = \begin{bmatrix} -p_1^1 \\ 0 \\ -p_2^1 \\ 0 \\ -p_3^1 \\ 0 \\ \vdots \\ 0 \\ -p_{n-1}^1 \\ -p_n^0 \\ -p_n^1 \end{bmatrix} \tag{5}$$

2.2 Injection System

2.2.1 Energy Loss From Wellhead to Bottom of Injection Well

$$H_{2-3} + \frac{p_2}{\gamma_w} = \frac{p_3}{\gamma_w} + h_{2\text{-}}, \tag{6}$$

$$H_{2-3} = \frac{2\lambda_{2-3} H_{2-3} Q_3^2}{\pi g D^3}. \tag{7}$$

Where Q_3 is bottom flow of inject well, p_2 is wellhead pressure of inject well, p_3 is bottom pressure of inject well, $\lambda_{2\text{-}3}$ is the Lateral resistance factor of inject wellhead to the bottom of injection well, $H_{2\text{-}3}$ is the length of the wellhead to the bottom, r_w is the density of injected water, $h_{2\text{-}3}$ is the loss of the head along the path from the wellhead to the bottom of the well, D is the inner diameter of injection well tubing, g is the acceleration of gravity.

2.2.2 Nozzle Pressure Loss

In order to achieve better effect of water flooding, prevent the injection water monolayer breakthrough, install different diameter distributing nozzle according to the actual needs of each oil layer, achieving stratified and quantitative water injection. The injection pressure loss of water through the water outlet is

$$\Delta p = \frac{\rho}{2}\left[\frac{Q}{\phi A}\right]^2. \tag{8}$$

Where Δp is the pressure difference before and after the water faucet, Q is the flow through the water outlet, A is the cross-sectional area of the water outlet, ϕ is the flow factor, the value is set to 0.82.

2.3 Reservoir System

The pressure loss of fluid in reservoir can be obtained by IPR curve, Can also be obtained by numerical simulation method; However, the IPR curve method has more restrictive conditions, The IPR curves of different types of oil reservoirs and oil layers at different stages are different, the numerical simulation method is seriously affected by human and the workload is very large. Therefore, it is feasible to calculate the pressure loss by using the reservoir pressure distribution and the layered dynamic parameter prediction model at the well point. Pressure at any point in the reservoir (x, y) is p_m

$$p_m = p_e + \frac{\mu}{2\pi Kh}\left[\sum_{i=1}^{M} q_i \ln\frac{r \times f(x,y)}{r_e} + q_w \ln\frac{r}{r_e}\right], \tag{9}$$

$$f(x,y) = \sqrt{\frac{(x-x_i)^2+(y-y_i)^2}{(x-x_i')^2+(y-y_i')^2}}. \tag{10}$$

Equation (9-10) is: p_e is supply edge pressure; μ is fluid viscosity; h is effective thickness of formation; r is the distance from point (x,y) to well point; r_e is supply radius; x_i, y_i and x_i', y_i' is the location coordinates and their conjugate coordinates respectively; q_i is the injection volume of thickness per meter; q_w is the injection volume of central injection well.

2.4 Oil Well Lifting System

2.4.1 Flow in Oil Pumping

Pressure drop through pump valve is:

$$\Delta p_i = \frac{(SN)^2\gamma_f}{28630}\left[\frac{D_p}{D_o}\right]. \tag{11}$$

In the equation: Δp_i is the pump valve pressure drop; D_p is plunger diameter; D_o is the valve pore diameter; γ_f is liquid density; S, N is the pumping stroke and pumping speed.

2.4.2 Before the Nozzle Flow From The Pump Outlet to the Wellhead

The vertical pipe flow theory of oil gas water mixture is calculated:

$$\frac{\mathrm{d}p}{\mathrm{d}l} = \rho_m g + \rho_m v_m + f_m \frac{\rho_m}{D}\frac{v_m^{\ 2}}{2}. \tag{12}$$

In the equation: l is length of tubing string; ρ_m is density of multiphase mixtures; V_m is flow rate of multiphase mixture; f_m is friction factor for multiphase mixture flow.

2.4.3 Calculation of Nozzle Flow

Pressure drop for multiphase flow nozzle is:

$$q = \frac{p_{wh} d_{ch}^{\ m}}{c R_{go}^{\ n}}. \tag{13}$$

In the equation: q is nozzle flow; p_{wh} is wellhead pressure; R_{go} is GOR; d_{ch} is nozzle diameter; c, m, n are both factors, according to the data of oil field and the variables in the formula which depends on the unit.

2.5 Surface Oil, Gas and Water Treatment Gathering System

The calculation method of two-phase pipeline in our country is from the Soviet Union textbooks in 1950s, it is derived from the energy conservation equation based on the homogeneous flow model and hydraulic calculation formula of gas liquid two phase pipeline is:

$$p_q^2 - p_z^2 = KG_1^{2-n}L, \tag{14}$$

$$K = \frac{4^{2-n}C\mu^n\eta(1+\eta)^{1-n}ZR_aT}{\pi^{2-n}d^{5-n}\Delta_g}. \tag{15}$$

Where in Frmulas (14-15), p_q,p_z is pipeline start and end pressure; K is coefficient; Z is gas compressibility factor; T is average pipe temperature; G_1 is liquid mass flow rate; η is gas-liquid mass flow ratio; R_a is characteristic constant of air; L,d is pipeline length and diameter respectively; Δg is relative density of pipeline gas with air in engineering standard state; C, n is the coefficient and exponent of flow.

3. ENERGY CONSUMPTION ANALYSIS AND OPTIMIZATION

Taking the oil and water wells in the area of Daqing apricot six as an example, the injection pressure and water injection rate are determined in injection wells and bottomhole pressure is determined in production wells so as to fitting the pressure and flow parameters at each node. By using the remaining oil distribution of single sand body and the prediction method of dynamic index and calculation of oil production by reservoir system. When injection pressure and water injection quantity of the injection well have changed, the station and pipe network of the ground water injection system will change accordingly; at the same time, the production capacity and the oil production of oil wells should be changed accordingly, and the change of production capacity and oil production will lead to the change of oil and gas water treatment system. Based on the actual production data and test data of the apricot six block in Daqing oil production plant, the energy consumption of the system was analyzed

3.1 Node Fitting

Table 1 is the fitting result of ground water injection system in Daqing six area. From Table 1: the maximum relative error of water injection at each node is 9.38%, the average relative error is 4.9%. Table 2 is the fitting result of the ground gathering and transportation system in Daqing apricot area of six. From Table 2: The maximum relative error is 17.8% and the average relative error is about 6.9% about the pressure of selected node; the maximum relative error is 22.6%, and the average relative error is 9.1%.

3.2 Energy Consumption Analysis and Optimization

Because of the technical process of water injection and gathering, the depth of oil and water well, the property of oil and gas, and the physical property of formation are very different, so the energy consumption of different blocks is very different. Analysis of energy consumption in the study area using the energy consumption model of each system, findings: The energy consumption of reservoir system and lifting system is the main part of the total energy consumption, accounted for 40.2% and 31.1%, respectively, oil gas gathering and transportation system accounts for 17.6%, the other 2 systems have the least energy consumption, accounting for 11.1%. It can be seen from the test data, the energy loss near the well bottom is very serious, It can reduce the energy consumption of the system by reducing the seepage resistance. So, On the one hand, measures should be taken to change the physical property of the reservoir and improve the seepage capacity; on the other hand, it is necessary to improve the quality of the well, improving the quality of injected water and preventing the pollution of the reservoir:

Table 1
Fitting Results of Surface Water Injection System in Daqing Xingliulian Plot

Well No.	Injection flow rate/($m^3 \cdot d^{-1}$)			
	Calculate value	Actual value	Absolute error	Relative error/%
X1-2-DW37	65.12	64	1.12	1.75
X1-D2-W136	51.13	52	-0.87	1.67
X1-D2-W139	137.98	127	10.98	8.64
X1-D2-W142	121.62	128	-6.38	4.98
X1-D3-W148	110.3	114	-3.70	3.25
X1-20-642	14.22	13	1.22	9.38
X1-1-641	8.42	9	-0.58	6.39
X1-20-640	41.22	42	-0.78	1.86
X1-D2-440	109.26	120	-10.74	8.95
X1-1-639	30.35	29	1.35	4.66
X1-30-639	43.61	42	1.61	3.83
X1-D2-438	113.8	110	3.80	3.45

Table 2
Fitting Results of Ground Gathering System in Daqing Xingliulian Plot

Well No.	Flowing pressure/Mpa			Daily fluid production rate/t		
	Calculate value	Actual value	Relative error/%	Calculate value	Actual value	Relative error/%
X1-1-35	4.89	5.12	4.7	27	30.2	11.9
X1-1-36	2.67	2.72	1.9	37	34.1	7.8
X1-2-33	4.44	4.31	2.9	14	15	7.1
X1-2-35	3.98	3.60	9.5	105	101	3.8
X1-4-35	6.76	7.64	13	68	66.8	1.8
X2-1-35	6.77	6.08	10.2	36	39.5	9.7
X2-2-35	8.72	8.35	4.2	77	68.7	10.8
X2-3-47	7.28	5.98	17.8	45	40.3	10.4
X1-1-D33	2.22	2.27	2.2	22	24	9.1
X1-2-235	6.72	6.24	7.1	17	18.2	7.1
X1-2-D35	2.03	2.16	6.4	7	8.6	22.6

Table 3
Preferred Results of Ground Gathering System in Daqing Xingliulian Plot

Well No.	Formation name No.	Permeability/ $10^{-3}\mu m^2$	Effective thickness/m	S_o / %	Reservoir pressure/MPa	Score	Scheme
X1 -3 -146	P23	3.00	12.00	0.48	9.75	65.71	The best
X1 -4 -644	P151	50.00	14.00	0.50	10.03	63.32	The best
X1 -30 -638	P21	57.00	3.00	0.46	9.59	60.34	The best
X1 -31 -640	G14+5	10.00	0.01	0.63	11.30	57.76	The best
X1-D3 -339	P291	12.18	22.00	0.60	11.02	54.37	The best

To be continued

Continued

Well No.	Formation name No.	Permeability/ $10^{-3}\mu m^2$	Effective thickness/m	S_o / %	Reservoir pressure/MPa	Score	Scheme
X1 -1 -636	P23	4.00	2.00	0.52	10.18	52.98	The best
X1 -20 -639	G11	30.00	2.00	0.59	10.86	46.52	The best
X1 -40 -642	P291	5.00	4.00	0.61	11.14	42.27	The best
X1 -20 -639	P281	29.00	19.00	0.45	9.51	41.28	The best
X1 -30 -638	G121	21.00	3.00	0.61	11.08	40.13	The best
X1 -30 -642	P25	6.00	3.00	0.61	11.15	39.78	The best
X1 -1 -636	P271	7.00	2.00	0.62	11.23	38.24	Better
X1 -1 -640	G121	11.50	4.00	0.63	11.29	38.11	Better
X1 -40 -636	P291	19.33	20.00	0.50	10.00	37.74	Better

(a) Based on the establishment of the energy consumption theory model, combining with the prediction method of remaining oil distribution[9], optimization measures of fractured wells in Daqing Xingliulian plot oil wells. The preferred results of ground gathering system in Daqing Xingliulian plot are shown in Table 3. The optimization of fracturing of X1-3-146 well in P23 layer and some wells is fracturing wells firstly in order to improve these properties of reservoir and reduce the energy consumption of fluid flow in the formation.

(b) The primary degreasing and the primary gravity filtration, this two stage process, are used in oil sewage treatment station, which can not meet the requirements of water treatment, water quality seriously exceed the standard. According to the current development situation of oilfield wastewater treatment process and the actual application, the transformation process of two stations should be selected as the two levels of gravity in addition, the oil level pressure filtration process. This process has a strong ability to adapt to the variation of oil content in sewage and the fluctuation of incoming water, especially have the good purification effect on sewage containing polymer. The specific process is: incoming water → natural degreasing → coagulation and oil removal → cushion → boosting → filtering → cushion → transporting → water injection station.

In addition, due to the longer pipeline, the ground pipe network energy consumption is not negligible. According to the analysis of the ground pipe network system, that apricot Xingliulian of the ground facilities corrosion aging is relatively heavy, energy consumption is relatively large; so we must take measures to transform the pipeline and reduce energy consumption.

CONCLUSION

(a) Fitting the water injection volume of the ground water injection system and the flow pressure and the daily production volume of the gathering and transportation system, the relative error is not significant, show that the energy consumption of the production system in the apricot Xingliulian can be expressed very well by the method established by the article.

(b) The seepage of the reservoir is the largest in the whole production system, which is 40.2%. The reservoir can improve its seepage capacity by means of fracturing, better grading of sewage treatment process, improve the level of oil and water wells.

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