海上油田矢量井网研究初探

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摘要:海上油田开发中井的类型和布井方式均比陆上油田更为复杂。为了优化井网结构,实现经济技术开采最优化,引入了矢量井网的概念,将影响井网布置的地质、开发及经济因素视为该向量空间的一组向量。一方面通过模糊评判技术确定适合布井的目标区域,另一方面通过对典型油藏单井及井网开发指标计算方法的研究,建立各个向量之间的定量联系;以此为基础,应用随机模拟和模糊优化技术实现多向量的井网整体优化。该技术在埕岛油田一区馆上段油藏进行了有限区域、有限层数和有限影响因素的探索性应用,初步证明了该方法的可行性,为今后的井网整体优化奠定了基础。

关键词:矢量井网;模糊评判;随机模拟;模糊优化
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1 矢量井网概念的引入

井网布置是油气田开发的关键问题之一,一直倍受关注[1-3]。井网问题能否处理好,直接关系到油气田能否长期稳定生产和油气田企业能否获得较好的经济效益[1]。而海上油田开发与陆上油田相比,需要投入巨额的资金,而且具有更大的风险性,因此,在海上油田开发中,为了取得较好的经济效益,须综合油藏工程、海上建筑、生产设施及储运工程等方面,以实现全局最优为目标,选取合理布井方案及平台位置。基于上述考虑,笔者引入了矢量井网的概念,即基于多向量优化技术、与油藏类型相适应、与油藏非均质性相匹配,能够对油藏达到合理高效立体开发,且技术、经济指标双优的三维井网系统。它将包含井网系统的整个油藏视为一个多维的向量空间,将影响井网系统开发效果的地质、开发及经济因素视为该向量空间的一组向量,以便于引入数学方法对井网进行整体优化。

2 总体技术思路

在矢量井网的研究过程中,首先应用矢量化技术将各种地质图件中的油藏要素转化为多维向量空间 (整个油藏系统)中的向量;然后一方面通过模糊评判技术确定适合布井的目标区域,另一方面通过对典型油藏单井及井网开发指标计算方法的研究,建立各个向量之间的定量联系;最后在上述两方面研究的基础上应用随机模拟和模糊优化技术实现多向量的井网整体优化。具体的技术路线和所涉及的关键技术如图 1所示。

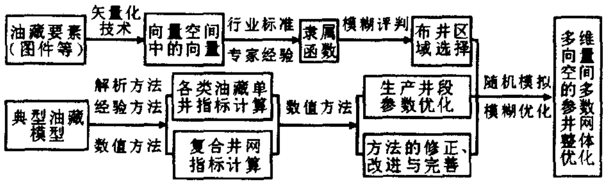

图 1 矢量井网研究的技术路线

3 布井目标区域的优选

3.1 影响井网布置的主要参数

从地质因素、技术因素和经济因素考虑,影响海上油田井网部署的主要油藏参数包括:孔隙度、含油饱和度、小层有效厚度、地层流体粘度、层内非均质性、渗透率、海水深度、油藏埋藏深度和油藏的展布形状、面积及油水界面位置等。其中,油藏的孔隙度、含油饱和度和小层有效厚度直接影响油藏的储量丰度;地层流体粘度、层内非均质性和渗透率影响油藏的采收率;海水深度和油藏埋藏深度与海上平台及钻井的费用直接相关,影响油藏的经济效

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益;而其余几项参数与井网的形式、井数、注水的部位、注水方式、海上平台的数量及位置直接相关。

3.2　布井区域优选的基本原理

在海上油田这个复杂的系统中,要做出综合的布井区域决策必须考虑与之有关联的各个因素的影响。因各种影响因素中既有确定量又有模糊量,所以对布井目标区域的优选采用模糊综合评判方法。模糊评判[4]的基本思路如下。

设模糊评判集合 (代表等级分类的集合) $U = (u_1, u_2, \cdots, u_m)$,共 m 个等级。模糊因素集合 $V = (v_1, v_2, \cdots, v_n)$,共 n个因素。

设第 i个因素的单因素评判为 $R_i = (r_{i1}, r_{i2}, \cdots, r_{ik})$,它可以看作是集合 R上的一个模糊子集,其中 r_{ik}表示第 i个因素的评判对第 k个等级的隶属度。

U与 V之间存在模糊关系,可表示为

$$R = (r_{ij})_{m \times n} \tag{1}$$

式中:R为模糊评判矩阵; r_{ij}为从第 i个因素作出第 j种可能的评价程度; m 为评判等级个数,亦为矩阵 R的行数; n为影响因素的个数,亦为矩阵 R的列数。

U中各评判等级对综合评判结果的影响程度可用向量 A表示, $A = \{a_1, a_2, \cdots, a_m\}$,即权重分配。权重向量 A满足归一化条件,即

$$\sum_{i=1}^{m} a_i = 1 \tag{2}$$

式中: i为集合 U中因素的次序号; a_i 为集合 U中第 i个因素的权重。

给定 A和 R之后,即可进行综合评判,评判结果为 A与 R之积。

一般而言,模糊因素集的选取应尽可能利用最有效的信息,同时各种信息的获取应较为方便。模糊评判集的选取应考虑与井网部署结果相对应。考虑到研究区的具体特点同时便于分析和判别,一般不宜选择过多因素。

3.3　隶属函数的确定及目标区域优选

假设用于海上井网部署的特征参数为 M 个,已知海上油田有 L 个网格数。在每一个网格内,某一特征值应有一定的范围,对于 L个网格,就有 L个这样的范围;然后取用于井网部署的某特征参数的某一特征值,统计含该量值的范围频率 (N_n),则第 m个特征参数的隶属度可由 N_n表示,由此可求得相应离散的隶属度函数。对于连续的隶属函数可通过模糊分布函数拟合散点求得。隶属函数确定后,便可按模糊评判的思路对布井区域进行综合评判,在评判结果中得分最高的区域即为最优的布井区域。

4　复杂结构井及其与直井组合井网的开发指标计算

水平井、分支井等复杂结构井具有接触更大油藏面积的能力,可控制更大的泄油面积,其生产压差小于垂直井的压差,可以减少气顶和底水锥进效应,提高油藏的产量和采收率。矢量井网的典型特征便是充分利用复杂结构井对油藏进行三维立体开发,因此有必要对复杂结构井及其与直井组合井网的开发指标计算方法进行研究。

对任意形状的复杂结构井,为正确反映油藏内三维流动的特点,可将生产井段沿长度方向分成若干小段,由于每段长度较短,可假定流体从油藏流入每一小段的流量沿该小段长度方向均匀分布,但流量并不一定相等。以普通油藏中的一般定向井为例,将一定长度的井段分割成 N段,根据镜像反映原理,油藏上下边界之间的有限区域和其中的井段反映成无界空间中的无穷井排,根据势的叠加原理即可得到各井段在油藏中任意点产生的势[5],随后将 N个井段在该点产生的势进行叠加,即得到全井在此点产生的势。若对于多井组成的井网系统,则还须再进行一次各井之间的叠加,便可得到多井同时工作时在任意点产生的势。此时给定油水井的压力便可求解产量。

对于复合井网的其他开发指标的计算可根据具体的井网形式采用解析方法、经验方法、数值方法和统计方法相结合的策略,首先利用解析和经验方法导出计算公式,再应用数值方法进行对比和校正,最后应用统计方法获得相应的校正公式[6-8]。

5　井网优化的随机模拟方法

5.1　基本思路

矢量井网设计的核心是提高储量控制程度和油藏开发效果。在一定的井网系统条件下,影响油藏开发效果的基本参数包括:油水井的类型、油水井间的距离、油水井间的配置关系及油水井自身参数。给定井排方向、注水方式和油水井类型等井网系统参数,用随机抽样来模拟油水井的长度、方向、井距以及油水井在油藏中的空间位置,对于每一次抽样都计算其技术及经济指标,以其指标最优者作为该

类井网系统的待选井网。改变井网系统和井的类型,再按上述步骤对油水井的长度、方向、井距及油水井在油藏中的空间位置进行随机优化,从而得到各类井网系统的待选井网。最后在各类井网系统的待选井网中选取指标最优者,作为推荐方案。

5.2 模拟步骤

用随机模拟法进行井网优化的步骤如下:①依据实际资料确定油井参数的范围。根据油藏面积、层数、厚度及井网类型,确定油水井数量、井距、油水井位置、水平井长度、油水井的方向和分支数等井网参数的范围。②混合同余法产生伪随机数[9],对井的参数随机抽样。为避免随机数发生器不稳定影响抽样结果,在随机抽样时,随机数的产生采取了混合同余法,利用产生的随机数对油井参数进行随机抽样。③各随机井网指标的计算及优化。应用前述各种井及井网的开发指标计算方法,计算每一随机井网的技术指标,优选出指标最优者为该类井网系统的待选井网,实现在同一类井网(如五点井网)内的井网参数优化。其他面积井网的处理方法相似。最后在进行各类井网中待选井网间的横向对比,选取其技术经济指标最优者为推荐方案。

6 井网整体模糊优化方法

6.1 数学模型的建立

以净现值最大为目标,建立的目标函数为

$$\max \sum_{i=1}^{n_w} \sum_{j=1}^{n_p} \alpha_{ij} \Big\{ \sum_{t=1}^{T} P(t) Q(t) T_{ot} W_i f_1(l_i)(1+R_1)^{-t} - C_v [(x_i-x_j)^2+(y_i-y_j)^2+z_i^2]^{1/2} - C_H f_2(l_i) \Big\} \quad (3)$$

式中:n_w为总井数,口;j为平台次序号;n_p为平台总数;α_{ij}表示第i口井是否钻在平台j上,若“是”取1,若“否”取0;t为油田投产开始的时间,a;T为开发年限,a;$P(t)$为油价,元/t;$Q(t)$为水平井产量递减规律函数,t/a;T_{ot}为年生产时率;W_i为筛选靶点位置的权重;$f_1(l_i)$为水平井产能变化倍数,是水平段长度的函数;l_i为第i口井的水平段长度,m;R_1为贴现率;C_v为油水井垂直段的费用系数(假设垂直段的总费用与水平位移成线形关系),元/m;x_i,y_i和z_i为第i口井的位置坐标,m;x_j,y_j和z_j为第j个平台的位置坐标(以平台所在平面为基准则$z_j=0$),m;C_H为油水井水平段的费用系数;$f_2(l_i)$为水平段钻井费用,是水平段长度的函数,元。

该目标函数的约束条件如下。

平台与井的关系约束式为

$$\sum_{j=1}^{n_p} \alpha_{ij} = 1 \qquad (i=1,2,\cdots,n_w) \quad (4)$$

整数条件约束式为

$$\alpha_{ij} = 0, 1 \quad (5)$$

平台钻井能力约束式为

$$\sum_{i=1}^{n_w} \alpha_{ij} - N_j < 0 \qquad (j=1,2,\cdots,n_p) \quad (6)$$

式中:N_j为平台j的最大钻井能力,口。

水平段的长度约束式为

$$l_{min} \le l_i \le l_{max} \quad (7)$$

式中:l_{min}为水平井优于直井的最低长度界限,由经济分析确定,m;l_{max}为水平井最大长度界限,由油藏条件及钻井工艺水平确定,m。

采油速度约束式[10]为

$$\sum_{i=1}^{n_w} Q(t) T_{ot} f_1(l_i) \ge N v_o \quad (8)$$

式中:N为石油地质储量,t;v_o为采油速度。

投资条件约束式为

$$\sum_{i=1}^{n_w} \Big\{ C_v [(x_i-x_j)^2+(y_i-y_j)^2+z_i^2]^{1/2} + C_H f_2(l_i) \Big\} \le C_{max} \quad (9)$$

式中:C_{max}为财政允许的最大投资,元。

最大钻井半径约束式为

$$[(x_i-x_j)^2+(y_i-y_j)^2+z_i^2]^{1/2} \le r_{max} \quad (10)$$

式中:r_{max}为目前技术与设备条件下的最大钻井区域半径,m。

最大水平位移约束式为

$$(x_i-x_j)^2+(y_i-y_j)^2 \le h_{max} \quad (11)$$

式中:h_{max}为目前技术与设备条件下所能达到的最大水平位移,m。

在以上数学模型中,平台位置、平台数、井的位置、油水井井数及水平井水平段长度均为待定量,所以以上问题可归结为一复杂的混合整数规划模型。

6.2 模型的求解

从初始位置开始采用交替分配算法变更平台的位置进行优化。在某一个平台位置布局方式下,要使目标函数取得极值,必须满足下列方程

$$\frac{\partial NPV}{\partial x_i} = 0 \quad (12)$$

$$\frac{\partial NPV}{\partial y_i} = 0 \quad (13)$$

$$\frac{\partial NPV}{\partial z_i} = 0 \quad (14)$$

$$\frac{\partial NPV}{\partial l_i} = 0 \qquad (15)$$

式中:NPV为净现值,元。

在 (x_i, y_i, z_i)的取值范围和相应约束条件下,求解上述 $4n_w$ 个方程构成的方程组并不容易,尤其是当平台数和井数较多时。考虑到 (x_i, y_i, z_i)的数值已经离散化,并且也可将水平段的长度分解成离散的数值,采用遗传算法进行求解。首先根据不同井网设计,初步计算出井数和平台数;再将水平井靶点位置、水平井长度及平台的位置作为决策变量,其中每个染色体都由决策变量构成,利用模糊模拟检验染色体的可行性和计算染色体的目标值。采用遗传算法将最好的染色体作为最优解。

7 应用实例

应用模糊评判技术从海上埕岛油田一区馆上段油藏中选出一小块适合布井的区域为研究对象 (图 2),进行矢量井网的探索性研究,选择其中的 2个层作为布井目标层,目标区域面积为 4.0 km^2,石油地质储量为 1 040.9 ×10^4 t,开发年限为 15 a。

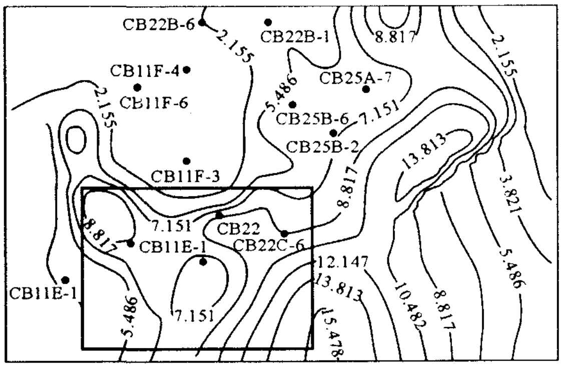

图 2 埕岛油田一区馆上段研究区域与最优布井区域

采用上述方法,对目标区域进行井网优化研究,得到叠式分支井三点井网 (3 - 1)、叠式复合分支井五点井网 (5 - 6)、叠式分支井反七点井网 (7 - 2)和叠式分支井反九点井网 (9 - 2) 4种不同形式的最优井网布置 (图 3)。由表 1中数据可知,采用叠式分支井反九点井网的累积产油量和净现值均高于其他井网,即其开发的技术指标和经济指标均最优,所以

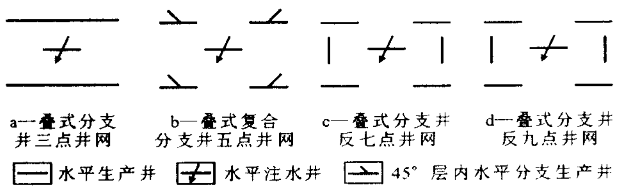

图 3 各类井网中最优井网示意

选择叠式分支井反九点井网为最终的推荐井网。

表 1 各类井网中最优井网参数及经济技术指标

井网方式	模型号	油水井数/口	排距/m	井间距/m	油/水井长度/m	分支数/个	累积产油量/10^4 t	净现值/10^{4}元
三点法	3 - 1	3	650	500	1 450/1 050		495.58	194 552
五点法	5 - 6	5	600	450	500/200	2	508.55	242 897
七点法	7 - 2	7	550	300	400/200		559.71	278 247
九点法	9 - 2	9	550	300	350/150		640.39	338 465

8 结论

矢量井网的技术思路建立在油藏参数矢量化的基础上,将影响井网的诸多因素视为该空间的向量,用向量组合的形式描述各个关键指标,并采用逐步优化的策略实现井网的整体优化。

由于海上油田平台及其他设施均受到开发年限的限制,故采用可获得较高产量的叠式分支井反九点井网的经济效益最佳。

实例中的研究区域、开发层数及影响因素均较为有限,考虑更大区域、更多层数和更多影响因素的井网整体优化方法尚待进一步完善。

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nology, it can reflect frequency spectrum property of time variant signal efficiently and has such features as high resolution and focus energy and track instantaneous frequency. Based on the feature of time variant signal, the authors introduce a basic method truth of quadratic form time – frequency analysis technology and verify its validation by using forward model analysis. The technology is used to identify the source orientation and classify sedimentary facies belt and predict structure and relative thickness of reservoir, there is good effect in all of use.

Key words: time – frequency analysis, seismic signal, exploration activity, reservoir prediction

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Cheng Langhong. Synthetic reservoir prediction of multiple seismic attributes in the west of Lungu area, Tarim Basin. *PGRE*, 2007, 14(3): 70 ~ 72

The performance of reservoirs and its oil and gas productivity are mainly controlled by the types of reservoirs in the west of Lungu area, so the main aim of reservoir prediction is to find out the favorable reservoir. The quality of seismic data can be improved by seismic processing which focus on the interested time window. This procedure provide excellent database for reservoir prediction. The author selects average reflection strength, RMS amplitude, average energy, the slope of half energy attenuation time and coherent attribute to execute reservoir prediction by seismic attributes sensitivity analysis. With the technique of self – organizing fuzzy neural network, distribution of reservoir was predicted. Cavernous reservoir and fractured – cavernous reservoir are distributed mainly over northwest of region of interest, southeast of Lungu 41well and Lungu 40 well.

Key words: carbonatite, reservoir prediction, seismic properties, neural network

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Li Weizhong. Near surface model and static correction in complex surface areas. *PGRE*, 2007, 14(3): 73 ~ 76

It is the key of static correction to build a proper near surface model and static correction treatment scheme and exactly eliminate influence of static correction. Research content and relevant technologies of near surface model in complex surface areas are introduced in the paper. Based on the geological, technical and economical basis and utilizing all available data of the area, by means of proper techniques and methods, building a proper near surface model and characterizing the geological structure of weathering layers and low velocity layers are very important for the static correction flow building and correct static calculation. It can decrease the static impact on the seismic data processing, enhance the data processing quality, ensure the correct imaging of the deep layer structure and the precision of the time to depth reversion.

Key words: complex surface, near surface model, static correction, integration model building

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Li Chuanliang. Deliberation on the paper "New computing method for radius of investigation based on flow rate". *PGRE*, 2007, 14(3): 77 ~ 79

Investigation radius of oil wells must be determined accurately for providing design parameters for oilfield development. Based on the basic theory of fluid seepage mechanics in porous medium, the calculation of the investigation radius of the oil wells is researched, and all the formulae of the investigation radius are analyzed. The conventional formula of the investigation radius is defined by the peak time of pressure wave, which is mainly on theory. The formula proposed by the author of this paper is defined by the out edge of approximate solution of the formation pressure, which is more practical. Moreover, the new formula conforms to the formula calculating distance of fault to testing wells.

Key words: oil well, investigation radius, formula, flow in porous media, pressure, well test

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Lü Aimin, Yao Jun, Fan Haijun et al. A preliminary study of vector well patterns in offshore oilfield. *PGRE*, 2007, 14(3): 80 ~ 83

In the development of offshore oilfield, the well type and well pattern will be more complicated than that of onshore oilfield. In order to optimize well pattern structure and optimize the development process economically and technically, the conception of vector well pattern is introduced. All of the geological, developed and economic factors, which influence the well pattern, are taken as variables in vector space. On one hand, the optimal drilling target areas are determined by fuzzy evaluation method; on the other hand, the relationship among those vectors is built by studying the calculation method of development index in single well and well patterns of the typical oil reservoirs. Based on the above two studies, the overall optimization of vector well patterns is realized by applying stochastic simulation and fuzzy optimization methods. The method is applied in upper Guantao Formation, No. 1 area, Chengdao Oilfield with limited areas, limited layers

and limited influencing factors. It proved the feasibility of this method and set up the foundation for the overall well pattern optimization in larger areas, more layers and more influencing factors.

Key words: vector well pattern, fuzzy evaluation, stochastic simulation, fuzzy optimization

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Wang Guangfu, Liao Rongfeng, Li Jianglong et al. The development situation and future of low permeability oil reservoirs of SINOPEC. *PGRE*, 2007, 14(3): 84 ~ 89

After analyzing the characteristics of 286 developed low permeability oil reservoirs belong to SINOPEC, three indices, including permeability, formation pressure and burial depths, are selected to classify the low permeability oil reservoirs into six types, which are deep – high pressure – extra low permeability oil reservoirs, mid – depth – normal pressure – extra – low permeability oil reservoirs, shallow – low pressure – extra low permeability oil reservoirs, deep – high pressure – low permeability reservoirs, mid – depth – normal pressure – low permeability reservoirs and shallow – normal pressure – low permeability oil reservoirs. The production characteristics are different for different types of oil reservoirs. The ideas of improving development condition of the low permeability oil reservoirs are proposed, such as strengthening the research of low permeability reservoirs and flow mechanism, reasonable infilling the well patterns, implementing fine water flooding, integrated fracturing and shaft hoisting, implementing pilot tests of the carbon dioxide drive and natural gas drive, etc. It points out that horizontal wells and multilateral wells should be applied to exploit all types of low permeability oil reservoirs in the future in order to enhance economic effects and bring about a bright future for all low permeability oil reservoirs of SINOPEC or even whole China.

Key words: low permeability oil reservoirs, sophisticated category, production characteristics, development effects, development future

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Zhang Yigen. Influencing factors of production decline in fault block oil reservoirs in Shengli Oilfield. *PGRE*, 2007, 14(3): 90 ~ 93

Since "tenth – five", in the fault block oil reservoirs in Shengli Oilfield, the decline rate is larger than that in other types of oil reservoirs and how to control the decline rate in later high water cut stage must be studied. The methods of reservoir engineering and field statistics are used to analyze the theoretical and actual field factors influencing the production decline. The main influencing factors of the production decline in the fault block oil reservoirs include production rate, development stage, production structure, etc. The measures of slowing down the production decline are proposed in this paper.

Key words: fault block oil reservoir, production decline, influencing factor, liquid production velocity, oil production rate of recoverable reserves, Shengli Oilfield

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Yang Erlong, Zhang Jianguo, Chen Caiyun et al. A study on numerical simulation of deformable low permeability gas reservoir. *PGRE*, 2007, 14(3): 94 ~ 96

Based on the lab study of variation of porosity changing rate and permeability changing rate with effective pressure, a numerical simulation model of deformable low permeability gas reservoir is established and is solved using IMPES method. The simulation result shows that both the duration of plateau production period and the gas recovery factor during this period decrease as the productivity in the period increases; but the deformation of the porous medium has great influence on the simulation results. The flowing bottomhole pressure decreases more quickly, the period of plateau production is shortened and the gas recovery factor obtained when the plateau production period ends is lower while media deformation is considered. The production proration of the gas wells should not be too large in deformable low permeability reservoir, otherwise the gas recovery factor obtained during the plateau production period would decrease greatly.

Key words: low permeability gas reservoir, deformable media, numerical simulation, finite difference

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Hou Jianfeng, Jiang Ruizhong, Wang Haijiang et al. Streamline method of quantitatively characterizing injection – production relationship of single sand body. *PGRE*, 2007, 14(3): 97 ~ 100

Streamline method of quantitatively characterizing injection – production relationship of single sand body is proposed based on dynamic production model of the single sand body. The characterization principle is discussed systematically. The method is used in the well group G76 – 30 of fault block Guan104 in Dagang Oilfield. Response factors of four producing wells and distribution coefficient of water injection rate in the water injector G76