Where: v_r is the velocity in vertical tube as follow:

$$v_r = \frac{M_v}{F\rho} = \frac{4M_v}{\pi D^2 \rho} = \frac{4\gamma}{\pi D^2} \tag{10}$$

Where: γ is injection-production ratio; D is tube diameter;

Due to the rock changing, salt cavern formed irregular shape, this model is simplified as an equal volume of' equivalent spherical'; The occurrence of heat exchange with the control system and rock is taken from the $4R$ to the center of the sphere spherical; For the same temperature on the same radial position, the temperature change is in the radial direction; The differential equation for the thermal conductivity is:

$$\frac{d}{dr}(r^2 \frac{dt}{dr}) = 0 \tag{11}$$

Boundary condition is:

$$r_1 = R_r, t_1 = T$$

$$r_2 = r, t_2 = T_M \left(r > R_r\right) \tag{12}$$

Where: T_M is the average temperature of the formation; R_r is the radius of 'equivalent spherical';

The heat flow in r is:

$$\Phi = \frac{4\pi\lambda(T - T_M)}{1/R_r - 1/r} = 4\pi\lambda R_r (T - T_M) \frac{r}{r - R_r} \tag{13}$$

From (13), we can indicate the expressions of heat exchange between the control volume and surrounding rock as follow:

$$\frac{\delta Q}{dt} = \Phi_{r=4R} = \frac{16\pi\lambda R_r}{3}(T - T_M) \tag{14}$$

Thermodynamic calculation results. In the production process, known recovery ratio is $\gamma_1 (m^3/s)$, produced gas mass is $\rho\gamma_1\tau$, and the remaining part in carven is $M - \rho\gamma_1\tau$; where: M is the initial quality.

from (7), we calculate:

$$T=\left(\mathrm{T}_M+\frac{3\rho\gamma_1 v_{r1}{}^2}{32\pi\lambda R_r}\right)+C\left(M_1-\rho\gamma_1\tau\right)^{\frac{16\pi\lambda R_r}{3\rho\gamma_1 c_V}} \tag{15}$$

Initial conditions is:

$\tau=0, T=T_0$

From (15), there is:

$$T=\left(\mathrm{T}_M+\frac{3\rho\gamma_1 v_{r1}{}^2}{32\pi\lambda R_r}\right)+\left(\mathrm{T}_0-\mathrm{T}_M-\frac{3\rho\gamma_1 v_{r1}{}^2}{32\pi\lambda R_r}\right)M_1^{-\frac{16\pi\lambda R_r}{3\rho\gamma_1 c_V}}\left(M_1-\rho\gamma_1\tau\right)^{\frac{16\pi\lambda R_r}{3\rho\gamma_1 c_V}} \tag{16}$$

Assuming $a=\frac{3\rho\gamma_1 v_{r1}{}^2}{32\pi\lambda R_r}, b=\frac{16\pi\lambda R_r}{3\rho\gamma_1 c_V}$, there is:

$$T=\left(T_M+a\right)+\left[T_0-\left(T_M+a\right)\right]M_1{}^{-b}\left(M_1-\rho\gamma_1\tau\right)^b \tag{17}$$

From (17) and (9), there is:

$$P=-\rho R_r\left[T_0-\left(T_M+a\right)\right]M_1{}^{-b}\left(M_1-\rho\gamma_1\tau\right)^b+C \tag{18}$$

Initial conditions is:

$\tau=0, P=P_0$

From (18), there is:

$$P=-\rho R_r\left[T_0-\left(T_M+a\right)\right]\left[1-M_1{}^{-b}\left(M_1-\rho\gamma_1\tau\right)^b\right]+P_0 \tag{19}$$

Similarly, in the injection process, known injection ratio is $\gamma_2(m^3/s)$, produced gas mass is $\rho\gamma_2\tau$, and the remaining part in carven is $M_2-\rho\gamma_2\tau$; M_2 is the initial quality at the start of gas injection;

During the injection process, the equations of temperature and pressure are:

$$T=\left(T_M-a'\right)+\left[T_0-\left(T_M-a'\right)\right]M_2{}^{-b'}\left(M_2+\rho\gamma_2\tau\right)^{b'}$$

$$P=-\rho R_r\left[T_0-\left(T_M-a'\right)\right]\left[1-M_2{}^{-b'}\left(M_2+\rho\gamma_2\tau\right)^{b'}\right]+P_0 \tag{20}$$

Where: $a'=\frac{3\rho\gamma_2 v_{r2}{}^2}{32\pi\lambda R_r}, b'=\frac{16\pi\lambda R_r}{3\rho\gamma_2 c_V}$;

According to the GB/T11062-1998, gas density can be expressed as:

$$\rho = \left(\frac{p}{RT}\right)\sum_{i=1}^{n} x_i M_i \tag{21}$$

where: x_i is the mole percent of a component; M_i is the molar mass of a component.

From (17),(19) and(21), the P-T relationship as follow:

$$P = \frac{P_0}{1-\sum_{i=1}^{n} x_i M_i (1-\frac{T_0}{T})} \tag{22}$$

Hydraulic calculation of vertical tube. A smooth, vertical tube links the salt cavern and the ground. The gas is doing a steady flow in the tube. Because depth is large, so we can ignore the momentum change.

$$-\frac{dp}{\rho} = gdh + \lambda \frac{dh}{D}\frac{v_r^2}{2} \tag{23}$$

Integral equation is:

$$p_w = p_d - \left(\frac{\lambda v_r^2}{2D} + g\right)\rho H \tag{24}$$

where: p_w is wellhead pressure ; p_d is bottom hole pressure; H is tube length as well as depth; λ is friction coefficient, it can be used with Weymouth formula:

$$\lambda_d = \frac{0.009407}{\sqrt[3]{D}}$$

To associate the wellhead, down hole temperature, considering the high gas flow rates within the tube as approximately adiabatic process, such temperature and pressure within the tube may be determined by the law of the adiabatic:

$$\frac{p_w^{\frac{\kappa-1}{\kappa}}}{T_w} = \frac{p_d^{\frac{\kappa-1}{\kappa}}}{T_d} \tag{25}$$

Where: T_w is wellhead temperature; T_d is bottom hole temperature;

Through the above equations, we can obtain the solution temperature and pressure each time in the salt carven and the corresponding temperature and pressure in the wellhead.

VERIFICATION OF EXAMPLES

Reservoir data: equivalent radius R_r=65m , tube length $H = 1250m$, the inner diameter of the tube $D = 0.224m$, thermal conductivity of rock salt $\lambda = 4.8W/(m \cdot K)$, strata average temperature $T_M = 22 + 273K$, gas isochoric heat capacity $c_V = 1.709kg/(mol \cdot K)$; production ratio $\gamma_1 = 5\times10^5 m^3/d$;injection ratio $\gamma_2 = 4\times10^5 m^3/d$ maximum design pressure of the reservoir $P_{d\max} = 24MPa$; the reservoir minimum design pressure $P_{d\min} = 11.5MPa$;minimum allowable pressure wellhead $P_{w\min} = 8MPa$; initial temperature $T_0 = 35 + 273K$; initial pressure $P_0 = 22.1MPa$; After 12 hours of continuous production operartion, and then start to inject;

Calculation results in(fig.1) and(fig.2):

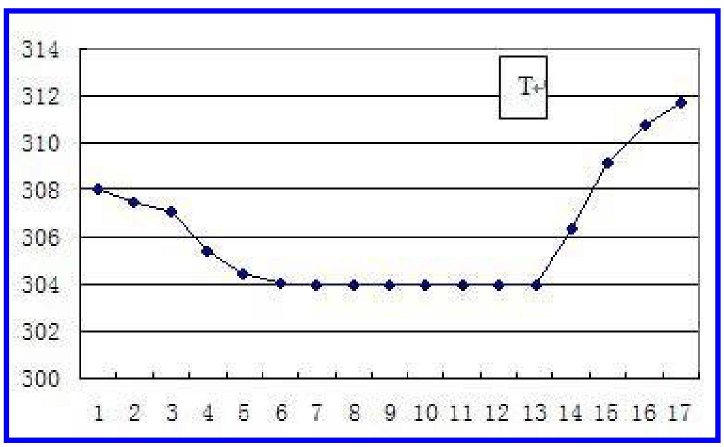

Figure 1. Salt cavern temperature and time relationships gas in injection process

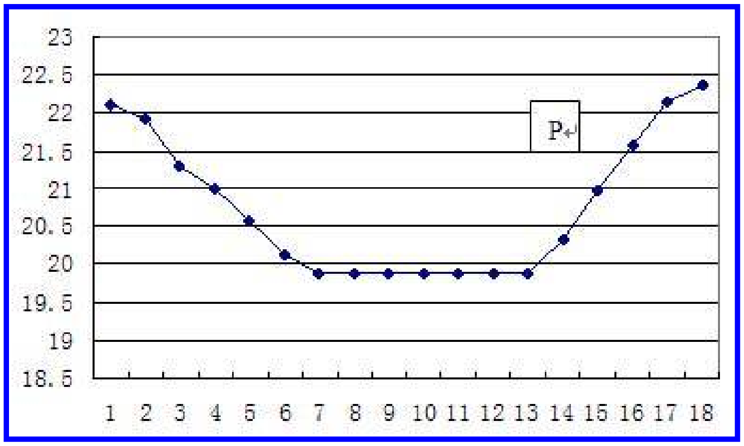

Figure 2. Salt cavern pressure and time relationships gas in injection process

Simulation results are as follows:
(1) The first few days cavern temperature drop is faster, but with the reduction of gas content, the temperature difference between the gas and the surrounding increases, and salt absorption increases, resulting in the latter part of the temperature change being gentle.
(2)Cavern pressure plummeted with the injection process, and the pressure didn't exceed safe limits.

CONCLUSION

1. A simplified mathematical model proposed to description salt cavern gas storage injection-production dynamic process, the model can predict gas pressure and temperature changes with any continuous injection-production cycle.
2. Since the gas being considered as uniform pressure and temperature fields, this model can't predict the gas temperature and pressure at each point in the salt cavern.

REFERENCES

Chen, J. W. & Yang,C.H.(2007). Study on Engineering Thermal Analysis of Gas Storage in Salt Formation During Gas Injection and Production. Chinese Journal of Rock Mechanics and Engineering. July.

GB/T11062-1998:Natural Gas-Calculation of Relative Density and Wobbe Calorific Values, Density, Index from Composition [M]: Standards Press of China, 1998;

Hagoort J. Simulation of production and injection performance of gas storage caverns in salt formations. *SPE Reservoir Engineering*,1994,9(4):278-282.

Tan, Y. F., & Lian, L.M.(2000). Dynamic Model and Its Application for Simulation of Gas Storage in Salt Formation. *Gas & Heat*: 91-94.

Tan, Y. F., & Chen, J. X.(2004). Calculation of Thermodynamic Parameter about Gas Storage Cavern in Salt Formation. OGST: 16-18.

Wu, P. Y., & Ma, Y.(1983). Thermodynamic in Variable Mass System and Its Applications [M]. Beijing: Higher Education Press.

Wang, L., Bu, C.(2001). The Pressure and Temperature of Salt Cavern Gas Estimates in the Injection - production Process. *Petroleum Planning and Design*. Dec, 32-33.

Yang, S.M. & Tao, W. S(2006). Heat Transfer [M]. Beijing: Higher Education Press.

Zhang, X(2006). Fundamental Theory of Thermodynamics and Heat Transfer [M]. Beijing: Higher Education Press.

Research on Optimal Selection of Pipeline Route Program Based on AHP

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ABSTRACT

The purpose of this article is to research the optimal selection of pipeline route program and ensure the rationality of the selected result. Combined the advantages of analytic hierarchy process (AHP), the paper analyzes the selection of the evaluation indexes and the content of the comprehensive evaluation. In consideration of the influencing factors for route selection, the evaluation index system is built and a systematic method which is suitable for the evaluation and selection of the pipeline route is proposed. At last, combined with an example in some city, the process is realized, and the results are reasonable and liable.

KEYWORDS

Pipeline route program; analytic hierarchy process; evaluation index; model analysis

INTRODUCTION

The route selection of pipeline is distinctly important for the work in the early stage of the pipeline project. Whether the selection of the pipeline route is rational or not will affect the technicality and the economical efficiency of the project. Therefore, in the initial state of the construction of the pipeline, a number of evaluations on technology, economy, environment and society need to be worked out to select a practical pipeline route program. The purpose of this paper is to analyze evaluation indexes associated with the pipeline route, to build the evaluation system, and to use the appropriate evaluation methods for studying each pipeline route program and making the right decisions.

STEPS FOR EVALUATION AND OPTIMAL SELECTION OF PIPELINE ROUTE PROGRAMS

The steps for evaluation and optimal selection of pipeline route programs are:
(1) To grasp the situation of the pipeline project. It means to grasp the design parameters, the natural conditions (such as topography, landform and climate) and the social conditions along the pipeline route.
(2) To build the evaluation indexes system on the specific circumstances of the project.
(3) To select the appropriate evaluation methods to evaluate each route program.
(4) To make a decision and select the optimal program according to the evaluation results.

BUILDING THE EVALUATION INDEXES SYSTEM FOR PIPELINE ROUTE PROGRAM

There are many factors affecting the programs of the pipeline route. In order to get an objective, comprehensive and scientific evaluation conclusion, the evaluation indexes system should be established in the following principles (Yang et al., 2006):
(1) Goal consistency. The selected indexes must have the same goal to maximize the efficiency of the program in all its aspects.
(2) Systematization. The indicator system should fully reflect the consolidation of alternatives and seize the main factors which reflecting the direct and indirect effect, then to ensure the completeness and reliability of the evaluation.
(3) Comparability. When selecting evaluation indexes, it is taken into account changes in time and space. The rational use of relative and absolute indicators will ensure comparability between programs.
(4) Emphasis Highlights. The indicators should be able to fully express the advantages and disadvantages of various aspects of the route programs, and should have a focus.
(5) Combination of quantitative method and qualitative method. In the comprehensive evaluation of the route program, some factors are easy to quantify, while some can not be quantified. But these factors have very important roles in the evaluation. So it needs to analysis with quantitative and qualitative.
According to above principles, it should take into account the following aspects when the evaluation indexes are selected:
(1) Each index is as independent as possible from each other;
(2) The number of indicators should be minimized as more as possible on the basis of reflecting pipeline system characteristics.
(3) The selected indicators can be described quantitatively as possible.

DETERMINING THE COMPREHENSIVE EVALUATION METHOD OF PIPELINE ROUTE PROGRAM

Currently, there are several common evaluation methods such as simple matrix method, principal component analysis, analytic hierarchy process and fuzzy comprehensive evaluation method.

Advantages and disadvantages for all methods. Through a comprehensive study of the various methods, their advantages and disadvantages are summarized and shown in Table 1(Lu, 2010).

Table 1. Advantages and Disadvantages for All Methods

Method	Advantage	Disadvantage	Applicability
simple matrix method	Enable the problem to be simple	It is easily affected by subjective factors	It is suitable for simple multi-level evaluation system
principal component analysis	Process is simple and practical	Some obstacles in quantification	It is suitable for qualitative evaluation
analytic hierarchy process(AHP)	Qualitative and quantitative evaluation can be combined	It is affected by subjective factors	Wide range of applications
fuzzy comprehensive evaluation method	The results are more objective	The process is tedious	It applies to the system that results required more precise

Evaluation method selected. In decision-making process, we can abstract the complex issues to mathematical models and these issues can be effectively analyzed. However, due to the complexity of the different projects, not all factors can be expressed by a mathematical model. AHP will solve this problem for its unique advantages. In the analytic hierarchy model, the decision-makers do not have to be fully quantified, but can be flexible processing according to the complexity of the problem itself (Zeng, 2009).

Evaluation of pipeline route program involves many factors, which can be quantitatively analyzed while some can not be. For some qualitative indicators, AHP provides an effective method of establishing measurement and decision-making. For the above reasons, the paper will use AHP to evaluate the pipeline route program.

Concept of AHP. Analytic Hierarchy Process (AHP) is a decision-making approach developed by Saaty in 1980(Saaty T. L., 1980). AHP is a quantitative method for ranking decision making alternatives by developing a numerical score to rank each

decision alternative based on how well ach alternative meets the decision maker's criteria(Berry,J.K.,2004).
With the help of AHP to solve the problem, it firstly classifies all the factors involved in the issues, identifies relationships, and then constructs hierarchy. All factors can be divided into the target layers, criteria layer, index layer and program layer. Then it calculates the degree of importance of each criterion to ultimate goal (i.e. weight) and analysis weights of each program to each criterion. At last, it calculates weights of each program to ultimate goal (Wang et al., 1990).

Steps of AHP. The basic calculation of AHP is to calculate the largest eigenvalue of the judgment matrix $\lambda_{\max}$ and corresponding feature vector *W*. According to AHP, general analysis procedure is as follows (Zhao et al., 1986):
(1) Defining the problem and determining the objectives to be accomplished.
(2) From the top (i.e. management objective), through an intermediate layer (i.e. criteria) to the lowest (i.e. program), forming a hierarchical structure model.
(3) Constructing a series of comparison judgment matrixes in which various factors on the lower layer relative to the criteria on the top layer.
(4) Establishing n (n-1) / 2 judgments foe the judgment matrix required in step 3.
(5) Completing all pair-wise comparisons, inputting data, calculating the maximum eigenvalue and consistency index (i.e. CR).
(6) Completing the computation of each layer following step 3, 4 and 5.
(7) Computing results of all layers are composed.
(8)If CR can not pass, some criterias need to be improved.

APPLICATION OF AHP IN THE EVALUATION OF PIPELINE ROUTE PROGRAM

In the design of the pipeline route, to get economical, route optimization is a multi-objective, multi-level and multi-criteria decision-making problem. Comparing the route programs with AHP, turning qualitative issues into quantitative analysis, the results will be more scientific and rational.

Determining the impact factors for program optimization. In route selection process, there are four main categories of factors impacting on the evaluation: technical standards, engineering factors, environmental factors and economic factors. From the above factors, we will select evaluation indexes which significantly affected on the pipeline route selection.
Technical Standards include pipeline safety spacing, region level, the areas explicitly prohibited by law, and other compulsory constraints.
Engineering factors include the pipeline length, pipe volume, crossing of rivers,