Numerical Simulation and its Countermeasure for Leakage and Diffusion of Gas Transmission Pipeline after Earthquake

Liu Wu [1] Xu Yuan[1] Yang xinglan[1] Liu Yi[2] Chang Zhibo[2]

[1] *School of Petroleum Engineering, Southwest Petroleum University, Chengdu China*
[2] *Xi'an Changqing Technology Engineering Co. LTD, Xi'an China*
Email: wwwww65@126.com

ABSTRACT: Gas pipeline leakage and diffusion process caused by seismic disasters, the transient model for leaking gas in different diffusion links is established and the corresponding measure for numerical simulation is presented. It can delimit the areas of different disserving degree by the leaking point for center. The measures for making emergency and rush to repair on leakage accident after earthquake and establishing emergency responds system (emergency response procedure, emergency organization system and responsibility compartmentalization, emergency protection and rescue, emergency response plan, emergency state terminating) are introduced, and a assessment system of hazard for gas leaking in pipeline after the earthquake is formed. The research results provide scientific foundation for the developments of manufacture management in carrying through emergency and rush to dealing, improving ability for meeting emergency, shortening rapid repairing time, decreasing economy expense.

KEYWORDS: Gas transmission pipeline, Leakage, Diffusion, Numerical simulation, Countermeasure, Emergency responds system

1. INTRODUCTION

Earthquake doesn't only bring damage to buildings, but also arouse leakage or fracture accident of long distance gas pipeline. Once gas pipeline happens leakage, gas in the pipeline will interfuse in the air quickly, with the effect of wind, it may result fire disaster and explosion, casualty and property loss, brings incredible difficulty to emergency rescue. Gas leakage and diffusion compromises a large area nearby the leakage source. Its damage degree is related to some factors like gas flow condition, leakage duration, terrain of diffusion space, population congregated level and so on. Therefore, it is important to use computer technology for making numerical simulation and dynamic emulation on disaster formation process of gas pipeline leakage and diffusion caused by future earthquake, ensure hazard area by making gas pipeline leakage consequence assessment, establish pipeline seismic risk mitigation system.

2. CALCULATION OF GAS PIPELINE LEAKAGE CAUSED BY EARTHQUAKE

The major reason of influencing gas diffusion concentration is the intensity of leakage source, the same as leakage rate. Therefore, it is a precondition of acquiring credible gas diffusion concentration to accurately calculate the leakage rate.

2.1 Problem Description and Hypothesis

The major seismic influence for pipeline is causing formation fracture and soil liquefaction. Gas pipeline fracture caused by seismic formation dislocation, as Figure 1 shows [2] , fracture pipeline section length is l_1, subscript 1 and 2 denotes gas transmission pipeline starting point and broken point, subscript 3 denotes gas outlet section position.

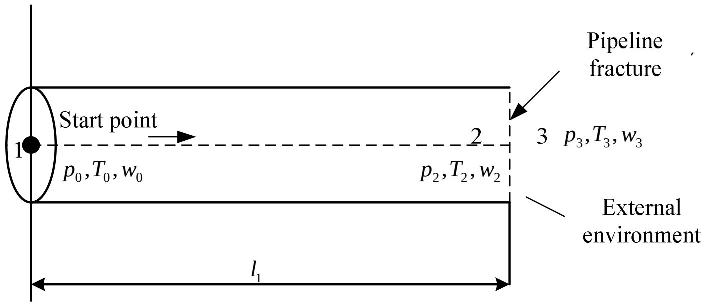

Figure 1 Schematic diagram of pipeline fracture caused by seismic disasters

Hypothesis: ① gas is isothermal flow in pipeline, and isentropic flow at leakage point; ②one-dimensional flow model; ③ fracture section shape didn't bring remarkable influence on flowing, its outflow through orifice formatted jet situation.

2.2 Establishment and Solution of Mathematical Model

Based on the gas continuity equation, momentum equation and state equation, in combination with the initial conditions and boundary conditions, gas long-distance pipeline leakage rate transient model when suffered disaster is [3-6]:

$$\frac{\partial p(x,t)}{\partial t} = \frac{c^2}{AK}\frac{\partial^2 p(x,t)}{\partial x^2} \qquad (1)$$

The boundary condition is

$$p\big|_{t=0} = \varphi(x), 0 < x < l_1,\ p\big|_{x=0} = p_0(t),\ \frac{1}{K}\frac{\partial p}{\partial x}\bigg|_{x=l_1} = -\delta(t),\ \frac{1}{K}p_x\big|_{x=0} = -Q_0(t), t > 0 \qquad (2)$$

In this formula, $\delta(t)$ is flow of leak point; $p(x,t)$ is gas pressure in pipeline; l_1 is pipeline fracture position; c is isothermal sound velocity in gas transmission pipeline; A is cross sectional area of gas transmission pipeline; K is linearized parameter; $\varphi(x)$ is gas pressure in pipeline at leakage initial time; $p_0(t)$ is gas transmission starting-point pressure; $Q_0(t)$ is gas transmission pipeline starting-point flow; $\frac{1}{K}p_x\big|_{x=0} = -Q_0(t)$, $t > 0$ is overdetermined condition.

In Model (1)～(2), we use orthogonal transform to get solution of $p(x,t)$, combined the model overdetermined condition to inverse leakage rate $\delta(t)$.

Transformed $p(x,t)$'s Orthogonal Transformation about x and the corresponding inverse transform method, we can get out:

$$\begin{aligned} p(x,t) &= \sum_{n=1}^{\infty} p_n(t)\sin\frac{(2n-1)\pi x}{2l_1}dx = \sum_{n=1}^{\infty} e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}t}\sin\frac{(2n-1)\pi x}{2l_1}\frac{2}{l_1}\int_0^{l_1}\varphi(x)\sin\frac{(2n-1)\pi x}{2l_1}dx \\ &- \sum_{n=1}^{\infty}\sin\frac{(2n-1)\pi x}{2l_1}\int_0^t\Big[\frac{2c^2}{AKl_1}(-1)^n K\delta(\tau) - \frac{2c^2}{AKl_1}\frac{(2n-1)}{2l_1}p_0\Big]e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}(t-\tau)}d\tau \end{aligned} \qquad (3)$$

From $\frac{1}{K}p_x\big|_{x=0}=-Q_0(t), t>0$, assumed as $\delta(t)=\delta_j$, $t\in[t_j, t_{j+1}]$, $j=1,\ldots,$ n, n is integral interval, by the numerical integration method, we can get out:

$$\begin{bmatrix} b_1 & & & \\ b_1 & b_2 & & \\ \cdots & \cdots & \cdots & \cdots \\ b_1 & b_2 & \cdots & b_n \end{bmatrix}\begin{bmatrix}\delta(t_1)\\ \delta(t_2)\\ \cdots \\ \delta(t_n)\end{bmatrix}=\begin{bmatrix} KQ(t_1)-c_1-a_1 \\ KQ(t_2)-c_1\cdot c_2-a_1-a_2 \\ \cdots \\ KQ(t_n)-c_1\cdot c_2\cdots c_n-a_1-a_2-\cdots a_n\end{bmatrix} \tag{4}$$

$$a_i=\sum_{n=1}^{\infty}\left\{\frac{2}{l_1}e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}t_1}\cdot e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}(t_2-t_1)}\cdots e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}(t-t_{n-1})}\right\}\frac{(2n-1)\pi}{2l_1}\int_0^{l_1}\varphi(x)\sin\frac{(2n-1)\pi x}{2l_1}dx$$

$(i=1,2,\cdots,n)$

$$b_i=\sum_{n=1}^{\infty}\frac{(2n-1)\pi c^2(t_i-t_{i-1})}{2AKl_1^2}(-1)^n Ke^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}(t-\tau)}$$

$$c_i=\sum_{n=1}^{\infty}\frac{c^2(2n-1)(t_i-t_{i-1})}{2AKl_1^2}p_0(t_i)e^{-[\frac{(2n-1)\pi}{2l_1}]^2\frac{c^2}{A\lambda}(t-\tau)}$$

Solving the above linear equations, we can get gas leakage rate in any time segment. Also, we can establish calculation model of seismic gas pipeline hole leakage which's solution method is similar to rupture leakage [7]。

3.NUMERICAL MODELING OF DIFFUSION PROCESS AFTER GAS PIPELINE LEAKAGE BY EARTHQUAKE

3.1 Diffusion Basic Control Equation

After gas leakage, gas diffused nearby the leakage source, and then formed air mass to further diffuse in the atmosphere. The essence is convection diffusion between gas and air[8]。Based on turbulent diffusion differential equations, combining the relevant initial and boundary conditions to establish the following gas convection diffusion model[9]:

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}+w\frac{\partial c}{\partial z}=\frac{\partial c}{\partial x}(D_x\frac{\partial c}{\partial x})+\frac{\partial c}{\partial y}(D_y\frac{\partial c}{\partial y})+\frac{\partial c}{\partial z}(D_z\frac{\partial c}{\partial z})+\delta(t) \tag{5}$$

In this formula, c is gas diffusion concentration; u、v、w are x、y、z direction's wind speed respectively; D_x、D_y、D_z are the diffusion coefficient in three directions; $\delta(t)$ is leakage rate; t is time.

3.2 Method on Model Solution

In formula (5), as convection term $\partial c/\partial x_i$ doesn't stand dominant function in the whole equation, each difference scheme can stimulated satisfied results; as convection term stands dominant role, existed difference schemes will bring great errors. Therefore, the key element of convection-diffusion equation numerical simulation is numerical treatment on convection term[10-12]。 Using domain decomposition method to decompose formula (5):

$$\frac{\partial c^{(1)}}{\partial t}+u\frac{\partial c^{(1)}}{\partial x}=0 \quad \text{initial condition is: } c_t^{(1)}=c_t \tag{6}$$

$$\frac{\partial c^{(2)}}{\partial t}+v\frac{\partial c^{(2)}}{\partial y}=0 \quad \text{initial condition is: } c_t^{(2)}=c_{t+\Delta t}^{(1)} \tag{7}$$

$$\frac{\partial c^{(3)}}{\partial t}+w\frac{\partial c^{(3)}}{\partial z}=0 \quad \text{initial condition is: } c_t^{(3)}=c_{t+\Delta t}^{(2)} \tag{8}$$

$$\frac{\partial c^{(4)}}{\partial t}=\frac{\partial c}{\partial x}[D_x\frac{\partial c^{(4)}}{\partial x}] \quad \text{initial condition is: } c_t^{(4)}=c_{t+\Delta t}^{(3)} \tag{9}$$

$$\frac{\partial c^{(5)}}{\partial t}=\frac{\partial c}{\partial y}[D_y\frac{\partial c^{(5)}}{\partial y}] \quad \text{initial condition is: } c_t^{(5)}=c_{t+\Delta t}^{(4)} \tag{10}$$

$$\frac{\partial c^{(6)}}{\partial t}=\frac{\partial c}{\partial z}[D_z\frac{\partial c^{(6)}}{\partial z}]+\delta(t) \quad \text{initial condition is: } c_t^{(6)}=c_{t+\Delta t}^{(5)} \tag{11}$$

Take formula （6）as example, uses Galerkin finite element method of spatial linear interpolation, omits superscript of formula （6）:

$$M_x(\frac{\partial c}{\partial t})_i+u\frac{\partial c}{\partial x}|_i=0 \tag{12}$$

In the above formula, $M_x=(\delta,1-2\delta,\delta)$ is mass operator, $\delta=1/6+\alpha^2/12$， α is coulomb. It adopts Crank-Nicolson difference:

$$M_x(\frac{c_i^{n+1}-c_i^n}{\Delta t})+\frac{u}{2}|_i(\frac{\partial c^{n+1}}{\partial x}|_i+\frac{\partial c^n}{\partial x}|_i)=0 \tag{13}$$

In formula （13）, n is time-discrete point, which discrete spatial first derivative with upwind difference scheme. When $u_i>0$, spatial first derivative uses backward difference, when $u_i<0$, spatial first derivative uses forward difference. Take $u_i>0$ as example:

$$M_x(\frac{c_i^{n+1}-c_i^n}{\Delta t})+\frac{1}{2}(\frac{u_i c_i^{n+1}-u_{i-1}c_{i-1}^{n+1}}{\Delta x}+\frac{u_i c_i^n-u_{i-1}c_{i-1}^n}{\Delta x})=0 \tag{14}$$

Formula (14) is written as matrix form

$$Ac^{n+1}=Bc^n+0.5b^n+0.5b^{n+1} \tag{15}$$

In this formula, A, B, b^n, b^{n+1} is coefficient matrix. Solving equations (15)can get gas dispersion concentrations of spatial discrete point i. The solutions of formula (7)~(11)are similar to formula (6).Based on the foundation of simulating leaking source intensity and diffusion concentration in atmosphere, according to different damage form, this paper provides foundations to accident emergency rescue by defining leakage point as center, harmful radius with various degree and making quantitative evaluation on harmful results of leakage area. Figure 2 is a concentration distribution diagram after gas pipeline leakage. 1 and 2 is concentration curves of gas concentrations 5% (lower explosive limit), 15% (upper explosive limit).

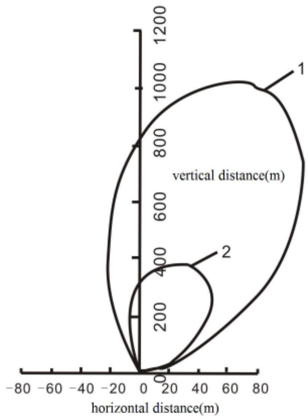

Figure 2 Gas diffusion concentration distribution diagram

4.ACCIDENT EMERGENCY RESPONSE SYSTEM OF GAS PIPELINE LEAKAGE BY EARTHQUAKE

4.1 Repair Method of Leakage Accident by Earthquake

Gas pipeline accident repair is an important measure to assure pipeline integrity after earthquake. There are some common repair methods for leakage accident of long distance gas transmission pipeline: the pipe clamping method, repair welding method, pipeline crack repair technology, cross threaded butt joint technology, metal bonds repair method, confined finite element analysis, online repairing technology and so on.

4.2 Emergency Response System

Gas pipeline leakage accident by earthquake should make effective control and treatment as soon as possible and farthest reduce and eliminate seismic loss. In order to make pipeline leakage accident emergency treatment well-organized, figure 3 provides an effective accident emergency process.

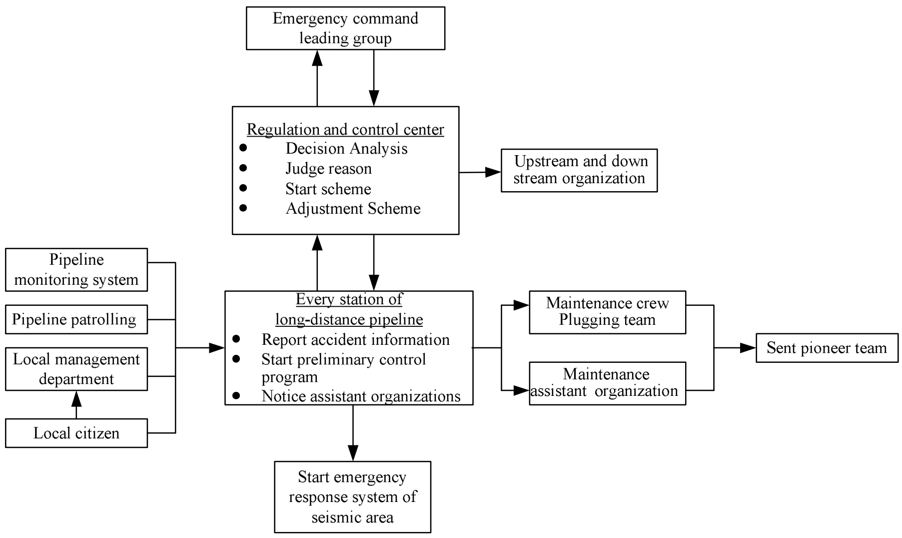

Figure 3 Emergency accident response progress of gas leakage by earthquake

4.3 Accident Emergency Organization System and Work Duty

Use accident emergency response progress as framework, we can establish emergency organization like Figure 4 shows:
Emergency headquarters: it organized by pipeline operation management apartment, local government and the department heads of environment, police, fire and health. The main duty is making sure prevention and emergency plan of gas leakage and diffusion accident.
Emergency office: it is a permanent establishment in emergency organization. It is organized by department heads of pipeline management department's production scheduling, safe operation and safety supervision and monitoring station. The main duty is making and implementing emergency plan and establishing technical reserve.
Emergency professional team: it contains police fire protection, monitoring assessment, medical rescue and engineering emergency. It provides various professional help in emergency response.

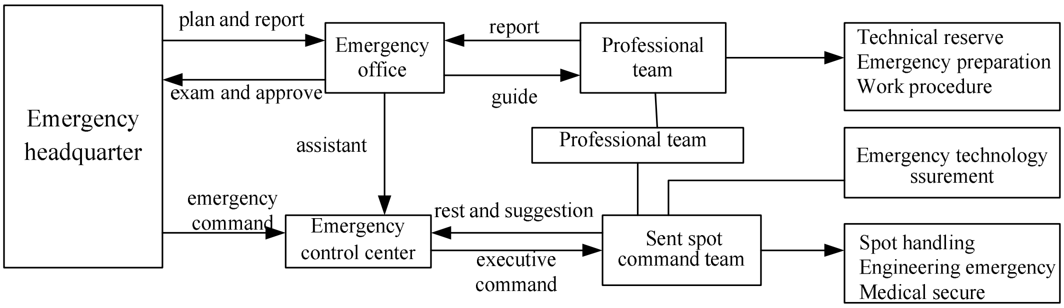

Figure 4 The relationship in emergency organization system

4.4 Emergency Communication System

Emergency communication system of gas pipeline leakage accidents contains three parts of accident alarm, emergency command and disaster information release. The requirements are ① alarm system should set up special telephone in normal time and make full use of existed rescue alarm system 110,119,120 to achieve communication unblocked. ② command system should be organized by office telephone, cell phone and interphone that are relatively secure to outside. ③ information publication system is consisted of broadcasting, TV and communication automobiles. It broadcasting accident situation and the adopted emergency measure.

4.5 Emergency Protection and Secure

When some great gas pipeline leakage accident happened, the prior duty of emergency action is control the accident leakage source and prevents important protection object injuries like population injury. According to different requirement of protection and secure, we divided gas sweep region into secure region, protection region and safe region by diffusion prediction model and set up relatively monitoring place to monitor and adjust [13] in time. The emergency protection and secure progress is shown in figure 5:

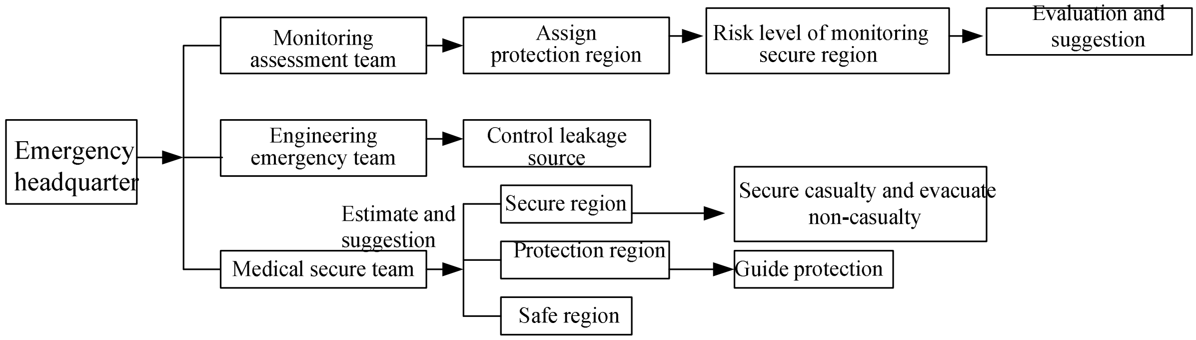

Figure 5 Emergency protection and secure procedure

4.6 Emergency Plan

The purpose of establishing gas leakage and diffusion accident emergency plan is taking precautions against possible damage. Once the earthquake caused gas pipeline leakage, we can gather preparedness information immediately and guide emergency operation workers to adopt effective emergency measures. The emergency plan contains ① emergency organization ② hazard identifying and risk assessment ③ notification procedure and alarm system ④emergency equipment and facilities ⑤ emergency evaluation ability and resource ⑥ protection measure progress ⑦ information publish and public education ⑧recovery program after accident ⑨ training and practicing ⑩ protection of emergency plan.

4.7 Termination of Emergency Situation

Gas pipeline leakage accident contains two progresses of emergency disposal and afterward disposal. After emergency disposal, we can get the following three conditions: ① according to suggestions of emergency headquarter, make sure leakage accident is under control with accident equipment is in safe status, ② relevant department has already adopted effective measures to prevent public from suffering damage, ③ relevant department is asked to establish and implement environmental recovery plan. As the accident control area and environments quality are under recovery, emergency headquarter can announce terminate emergency status and work in afterward disposal.
Afterward disposals are ①organized and implement environmental recovery plan ② continue monitoring and evaluating harmful situation and environment pollution status until basically recovered ③ evaluate damage loss, collate and harmonize compensation and other things.

CONCLUSION

(1) Regarded pipeline and leakage point as united hydrodynamic system, based on continuous equation, momentum equations and gas state equation, taking gas influence between leakage point and flowing in pipeline into consideration this paper analysis gas pipeline leakage progress by earthquake and establishes leakage transient mathematical model when pipeline suffered damage, adopts orthogonal transformation in solution, provided a approximate method of leakage rate inversion with model overdetermined condition.
(2)This paper establishes a mathematical model of diffusion in the atmosphere after gas leakage and transform multi-dimensional problem into many one-dimensional problems to get solution by limited difference and regional splitting.
(3) It explains emergency secure basic principle, duty and characters of gas pipeline leakage accident and establishes emergency response system of gas pipeline leakage accident which contains emergency response procedure, emergency organization system and emergency communication system. Using this system, we can control pipeline leakage and diffusion accident quickly and effectively to decrease loss.

REFERENCES:

[1]Zhao Zhendong, Yu Shizhou and Zhong Jiangrong. (2002). Numerical simulation and dynamic emulation of poison gas leakage and diffusion in destructive earthquake. Earthquake Engineering and Engineering Vibration **22:5**,137-142.
[2]Helenam and Juana. (1998).Mathematical modeling of accidental gas releases. Journal of Hazardous Materials **2:59**, 211-233.
[3]Joyd and Ahnbj. (2002) .Analysis of hazard is associated with high-pressure natural gas pipelines. Journal of Loss Prevention in the Process Industries **1:15**, 179-188.
[4] Tian Guansan. (1994) .Study on simulating leak of gas from pipe .Shan Dong Institute of Architecture and Engineering **4:14**, 56-60.
[5] Dong Yuhua, Zhou Jing-en, Gao Hui and so on. (2002). A mathematical model of steady state gas release flow rate in long distance pipeline. Oil-gas Storage and Transportation **21:8**, 35-41.
[6] Xiang Suping and Feng Liang. (2002).Gas pipeline leakage model. Natural Gas Industry**27:7**,100-102.
[7]Xu Yuan. (2008). Mathematical simulation and countermeasure research of gas pipeline leakage and diffusion, Southwest Petroleum University.
[8] Pan Xuhai and Jiang Juncheng.(2001).Research on discharging dispersion of chemical dangerous gases and its influence factors. Nan Jing chemical industry journal **23:1**, 19- 22.
[9] Ding Xinwei, Wang Shulan and Xu Guoqing. (1999). Overview study on combustible and toxic gas leakage and diffusion. Chemical Industry and Engineering **16:2**, 18-122.
[10]Brian J. Driessen and Je. Rey L. Dohner.(2001).A finite element boundary element method for advection diffusion problems with variable advective fields and infinite domains. International Journal of Heat and Mass Transfer**44:2**,183-2191.
[11] Wang Shoudong and Shen Yongming.(2005).Three high accuracy splitting schemes of 3-Dimension convection-diffusion equations of .applied mathematics and mechanical **26:8**, 921-926.
[12] Liu Fuxiang, Liang Xian and Tian Zhenfu.(2001) .Efficient and stable difference scheme of convection diffusion equation. Applied mathematic **14(supplement)**, 41-46.
[13] Xie Anjun. (2006).Gas pipeline emergency secure system and information technology. Gas Industry **26:5**, 115-117.