Proceedings of the 3rd IASME/WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING AND ENVIRONMENT, Corfu, Greece, August 20-22, 2005 (pp55-60)

The Study on Axial Temperature Drop Calculation Method for Oil-gas-water Mixture Transferring Buried Pipeline

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Abstract: The oil well producing mixture is oil-gas-water. The mixture flowing along the gathering and transporting pipeline belongs to multiphase flow. Temperature drop calculation for oil-gas-water buried pipeline is important, which influents the safety and economy of crud oil gathering and transporting system. Many oversea scholars have done research in the axial temperature drop in oil-gas-water transportation pipeline. But up to now, the influence that the annual periodicity change of soil temperature and time delay bring to axial temperature drop calculation hasn't been considered. In this article, the axial temperature distributing calculation expressions for oil-gas-water mixture gathering and transferring buried pipeline is educed, which Tom-Joules effect, potential energy, the annual periodicity change of soil temperature and time delay is taken into account. By contrasting to testing and calculating data, we concluded that the temperature drop method which was given in this paper is fit for the slug flow temperature drop calculation of oil-gas-water with super high water-cut.

Key-Words: Oil-gas-water; Mixture Transportation; Highly-watery; Buried Pipeline; Temperature; Periodicity Change; Model

1 Introduction

The output of oil well is mixture of oil, gas and water. The mixture flow along gathering and transporting pipeline belongs to multiphase flow. Temperature drop calculation in multiphase mixture transferring pipeline is obviously different from single-phase gas or liquid. Not only heat is transferred to environment by pipeline wall, nut also there is mass and energy exchange between gas and liquid. So the multiphase flow pipeline temperature calculation is very complicated. Because the pipeline is buried in soil, the soil temperature periodicity change which is evocable by atmosphere temperature periodicity change affects the pipe temperature drop. Especially in severe cold region, the difference in annual atmosphere temperature is higher than 70℃, the soil nature temperature field in different depth changes largely all the year around correspondingly. So the annual periodicity change of soil temperature field is one of the major factors that influence the temperature drop in buried pipeline [1].

Both domestic and oversea scholars have already studied on multiphase flow heat transfer calculation. Schorre[2]considered heat transfer between pipeline and environment, supposed that Tom-Joules effect increased linearly along the pipeline and put forward the temperature calculation equation in horizontal pipeline; Coulter &Bardon ameliorated Schorre arithmetic, educed and provided famous Coulter-Bardon equation that the non-linearity variety along pipeline of Tom-Joules was cosidered[3]. The expression could do the calculation of single-phase or two-phase flow temperature drop in horizontal pipeline, the calculation results and testing data were adjacent. But they didn't consider the liquid potential energy losing and supposed the environment temperature is a constant; Alves[4,5] presented the method which could calculate the single-phase or two-phase flow temperature drop in pipeline with different slope, unified the Coulter-Bardon formula and Ramey formula. It was used abroad. It was applicable for both component model and black-oil model. Alves advanced a model for calculating the Tom-Joules coefficient in black-oil model; Yu Xicong, Feng Shuchu educed the temperature drop expression of multiphase flow[6], the equation was the same as Culter-Bardon equation basically; Yu Xicong[7] had done systemic research in the application of black-oil model in concreting and separatng out oil-gas transportation pipeline design, summed up theory and equation of black-oil model that used in multiphase flow; Liu Wu, Chen Cailin etc[8]bring forward expression for calculating multiphase flow temperature drop, which the temperature drop by Tom-Joules effect, temperature ascendant by liquid friction, the temperature distribution by the hypsography and gas/liquid velocity variety were considered in mixture transportation [8]. Wang Shuli, Zhao Zhiyong etc [9] presented the mathematics model that the gas ratio and Tom-Joules were considered. The pressure drop calculation adopted Baker pressure drop associating formula according to different flow pattern. The pressure drop relates with flow pattern, so temperature drop curve does.

Temperature drop calculation for oil-gas-water multiphase transportation pipeline is a difficult problem. Although some method has already been presented in inside and outside countries and several calculating software have been made into commodities [10~14], there is no temperature drop calculation method that consider the annual periodicity change of natural soil temperature field and time delay in buried transportation pipeline. In this paper Tom-Joules effect, potential energy, the annual periodicity change of soil temperature and time delay were taken, educes the temperature drop calculating expression of buried oil-gas-water pipeline and contrasts and analyzes with the testing data.

2 The educing of multiphase flow temperature drop calculation equation in inclined pipeline

Oil-gas-water mixture transferring pipeline that buried in soil is showed in Fig.1

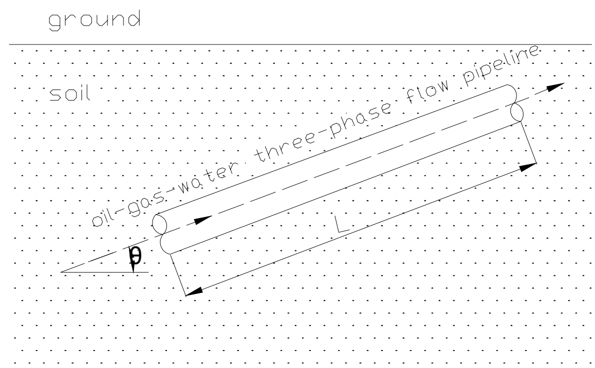

Fig.1 The sketch map of oil-gas-water buried pipelines

Annotation: L—length of buried pipeline，m;

θ—angle between liquid flow and level ,rad。

Making use of acknowledge in engineering thermodynamics, heat transfer, hydrodynamics and gas-liquid two-phase flow [15~20], considering Tom-Joules effect, potential energy, the annual periodicity change of soil temperature and time delay, we educe the temperature drop calculating expression of buried oil-gas-water pipeline and contrasts and analyzes with the testing data.

2.1 Some assumption during educing expression

(1) Suppose oil and water mixed uniformly, oil-gas-water three-phase flow predigests into gas-liquid two-phase flow;

(2) The section area of pipeline is constant;

(3) Takes no accountant of loss in accelerating tiny section and liquid;

(4) Takes no accountant of phase changing heat in tiny section;

(5) The oil-gas-water flow in pipeline belongs to one dimension stable flow;

(6) Environment temperature obeys annual periodicity change;

(7) The soil heat conduction predigests into half-infinity object one dimension periodic under the third boundary term, the soil physical characters are constants[15,16].

2.2 The basic equations

$$d(\rho vu)+d(\rho v\frac{1}{2}v^2)+d(\rho vgz)+d(pv)+\frac{q\pi d.\,dL}{A_p}=0 \quad (1)$$

$$d(\rho v)=0 \quad (2)$$

$$dh=c_p dT - \eta c_p dp \quad (3)$$

$$q=k(T-T_0) \quad (4)$$

$$\frac{dh}{dL}=\frac{w_l}{w}\frac{dh_l}{dL}+\frac{w_g}{w}\frac{dh_g}{dL} \quad (5)$$

$$\frac{dh_l}{dL}=-\eta_l.c_{pl}\frac{dp}{dL}+c_{pl}\frac{dT}{dL} \quad (6)$$

$$\frac{dh_g}{dL}=-\eta_g.c_{pg}\frac{dp}{dL}+c_{pg}\frac{dT}{dL} \quad (7)$$

$$\eta_l = -\frac{1}{c_{pl}\rho_l} \quad (8)$$

$$\eta_g = \frac{1}{c_{pg}}[T(\frac{\partial v_g}{\partial T})_P - v_g] \quad (9)$$

$$\frac{\partial T_0(x,\tau)}{\partial \tau}=\alpha_t\frac{\partial^2 T_0(x,\tau)}{\partial x^2} \quad (10)$$

$$t_\tau = t_{am}+(t_{a\max}-t_{am})\cos\left(\frac{2\pi\tau}{\tau_0}\right) \quad (11)$$

Eq. (1) is conversation of energy equation, the first item is inner energy, the second item is kinetic energy, the third item is potential energy, the forth item is impetus energy, the fifth item is the energy exchanged between pipeline and environment; Eq. (2) is continuity equation; Eq. (3) is liquid ratio enthalpy calculation expression; Eq. (4) is the heat transfer from pipeline to environment; Eq. (5) is gas-liquid two-phase flow ratio enthalpy calculation expression; Eq. (6) and (7) are the equation for calculating liquid and gas ratio enthalpy; Ea. (8) and (9) are the equation for calculating liquid and gas Tom-Joules coefficients. Eq. (10) is half-infinity object one dimension heat conduction differential equation; Eq. (11) is environment temperature annual periodicity change expression.

Where ρ —oil-gas-water three-phase density，kg/m^3； u —Ratio inner energy of oil-gas-water three-phase flow，J/kg；v—oil-gas-water three-phase flow mixture velocity，m/s； z —The height of liquid，m； q —The heat flow density that transfer from pipeline to soil，W/m^2；dL—Tiny section length of pipeline，m；A_p —Cross section area of liquid，m^2；d—Inner diameter of buried pipeline, m； η —Tom-Joules coefficients of fluid，□/Pa； Cp、Cpl、Cpg — Specific heat of oil-gas-water three-phase flow、Specific heat of oil-water two-phase flow and Specific heat of gas，J/(kg·□)；T—fluid temperature in any locate in pipeline ，□；p—fluid pressure in any locate in pipeline，Pa；k—Heat conduction coefficient between pipeline and environment ，$W/(m^2 \cdot K)$；T_o —Natural soil temperature in the depth of buried pipeline，□； h、h_l、h_g—Ratio enthalpy of oil-gas-water, liquid and gas，kJ/kg；w、w_l、w_g—The mass velocity of oil-gas-water, liquid and gas ，kg/s;；a_t—Soil thermal diffusivity，m^2/s； τ —Time away from hottest atmosphere temperature ，s；x—Depth in soil，m； τ_0 —Time of annual periodicity，s； t_τ —Environment temperature at τ，□；t_{am}—Annual mean atmosphere temperature，□；t_{amax}—Annual highest atmosphere temperature，□。

2.3 Equation of axial temperature distribution of

oil-gas-water buried pipeline

Base on the twelve equations and basic assumption, educe temperature calculation expression of oil-gas-water three phase buried pipeline with annual periodicity change of soil environment temperature.

$$T = t_{am} + (t_{a\max} - t_{am}) \cdot \phi \cdot \exp\left(-\sqrt{\frac{\pi}{a_t \cdot \tau_0}} \cdot x\right) \cdot \cos\left(\frac{2\pi\tau}{\tau_0} - \sqrt{\frac{\pi}{a_t \cdot \tau_0}} \cdot x - \psi\right) - B$$

$$+ (T_i - t_{am} - (t_{a\max} - t_{am}) \cdot \phi \cdot \exp\left(-\sqrt{\frac{\pi}{a_t \cdot \tau_0}} \cdot x\right) \cdot \cos\left(\frac{2\pi\tau}{\tau_0} - \sqrt{\frac{\pi}{a_t \cdot \tau_0}} \cdot x - \psi\right) + B)\exp(-L/A)$$

$$+ \overline{\eta}.A[1 - \exp(-L/A)]\frac{\Delta P}{L} \qquad (12)$$

Where: $\phi = \left(\langle 1 + 2\frac{\lambda_t}{\alpha_2} \cdot \sqrt{\frac{\pi}{a_t \cdot \tau_0}} + 2\left(\frac{\lambda_t}{\alpha_2}\sqrt{\frac{\pi}{a_t \cdot \tau_0}}\right)^2\right)^{-0.5}$, $\psi = tg^{-1}\left(\frac{1}{1 + \frac{\alpha_2}{\lambda_t}\sqrt{\frac{a_t \tau_0}{\pi}}}\right)$ （13）

$$B = \frac{A.g\sin\theta}{\overline{c_p}}, \quad A = \frac{w\overline{c_p}}{k\pi d}, \quad \overline{c_p} = \frac{w_l}{w}c_{pl} + \frac{w_g}{w}c_{pg}, \quad \overline{\eta} = \frac{x_{wg}c_{pg}}{\overline{c_p}}\eta_g - \frac{x_{wl}}{\rho_l.\overline{c_p}} \qquad (14)$$

Where T — Liquid temperature in oil-gas-water three-phase flow buried pipeline anywhere，□； T_i —Inlet liquid temperature of oil-gas-water three-phase flow buried pipeline，□；L—Pipeline length，m； θ—Pipeline inclined angle，rad；g—Acceleration of gravity，m/s^2； ΔP —Three-phase flow pressure drop from inlet to calculating locate，Pa；L—Length from inlet to calculating locate，m；H—Depth at buried pipeline ，m； λ_t —Soil thermal conductivity，W/(m·K) α_2 —Heat exchange complex coefficient between earth's surface and environment，W/(m^2·K) 。$\overline{c_p}$ —Converted specific heat of oil-gas-water three-phase flow，J/(kg· K)； $\overline{\eta}$ — Tom-Joules coefficient of three-phase ，□/Pa ； x_{wg}、x_{wl} —mass ratio of gas、mass ratio of liquid,%.

3 The calculating wellhead temperature contrasts and analyzes with testing

To check the validity of this method, we have tested the liquid output, gas output, water-cut, temperature drop, and pressure drop etc on the 4 pipelines in certain measuring space of Daqing oilfield. Making use of the Eq. (13) and tested temperature returning-workspace to calculate the outlet temperature at wellhead (that is inlet temperature in pipeline), The pressure drop calculation adopted slow flow model [17], the results contrasting are showed in Fig. 2~5.

For 217 well, liquid production is 78.55m^3/d, gas production is1353.28m^3/d, water-cut is 93.2%. The relative error of calculating output temperature and testing is between -6.4% to +6.4%.

For 313 well, liquid production is 36.13m^3/d, gas production is171.43m^3/d, gas and oil ratio is 26m^3/t, water-cut is 92.3%. The relative error of calculating output temperature and testing is between -20% to +20%.

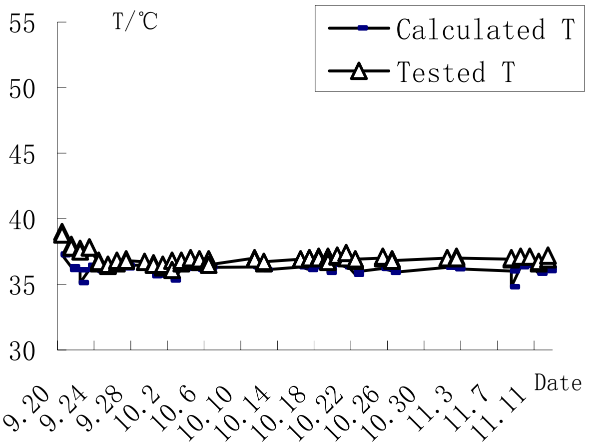

Fig.2 The comparison chart between experimental and computable well head temperature of 217

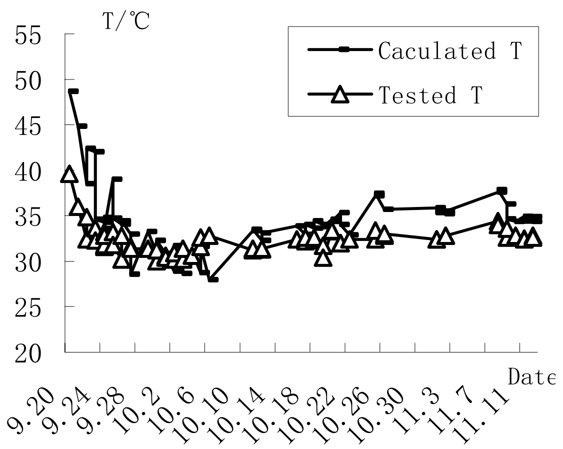

Fig.3 The comparison chart between experimental and computable well head temperature of 313

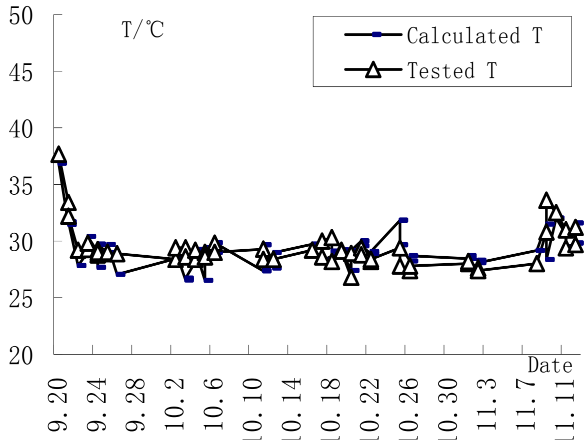

Fig.5 The comparison chart between experimental and computable well head temperature of 617

For 41-617 well, liquid production is 24.41m^3/d, gas production is104.72m^3/d, gas and oil ratio is 40m^3/t, water-cut is86.6%. The relative error of calculating output temperature and testing is between -10.8% to +10.8%.

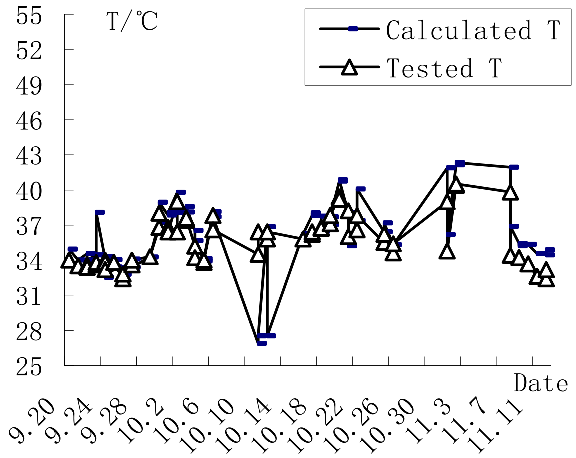

Fig.6 The comparison chart between experiment and computable well head temperature of 616

For 616 well, liquid production is 71.91m^3/d, gas production is329.00m^3/d, gas and oil ratio is 94m^3/t, water-cut is88.3%. The relative error of calculating output temperature and testing is between -11.2% to +11.2%.

Thus it can be seen that all the testing well water-cuts are higher than 85%, belonging to super highly-watery. The relative error of calculating output temperature and testing is between -20% and +20%. So the temperature drop calculating equations provided are fit for the oil-gas-water slug flow during super high water-cut.

4 Conclusion

(1) The temperature distribution calculation expression of multiphase flow pipeline under annual periodicity change of soil environment natural temperature field has been educed;

(2) The calculating results are compared with the 364 groups data tested and analyzed, and the relative error is between -20% and +20%. So the temperature drop calculating equation provided is fit for the oil-gas-water slug flow during super high water-cut.

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