

低温原油管道中压力传递速度的计算

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摘要 原油管道中的压力传递速度是管道运行管理过程中需要掌握的重要参数。加热原油管道停输后, 管内油品不仅会出现降温收缩, 而且当温度降到一定程度后会出现屈服值; 因此, 热油管道停输后初始再启动的压力传递不同于一般流体中的压力传递, 这时的压力传递速度除了与原油物性、管道状况有关之外, 还与降温幅度、再启动时施加的压力大小和传递距离有关。应用质量守恒和动量守恒原理, 推导出了既有温降收缩又有屈服值的原油管道再启动时的压力传递速度公式。

关键词 原油管道 管道输送 屈服值 压力传递速度

原油管道中的压力传递速度是管道(尤其是密闭运行的管道)运行管理过程中必须掌握的重要参数。热油管道的停输(包括因事故停输和计划停输)是不可避免的。对一个从事管道设计或管理的工作者来说, 欲保证管道安全运行, 必须掌握管理中压力传递速度的计算方法, 以确定清除管路凝油所需的时间。停输后既有温降收缩又有屈服值的原油管道, 再启动时其压力传递不同于一般流体中的压力波传递。热油管道停输后, 油品降温收缩, 管内出现蒸汽空间, 从而使管道再启动时出现启动充装过程^[1]; 此外, 油品出现屈服值, 会使压力在传递过程中衰减, 降低传递速度。

1 模型的提出

实验管路示意如图1, 整个装置放在恒温水槽中。截面积为 A 的管路中充满密度为 ρ 的原油, 当原油达到某一温度 t_1 时, 再在密闭流程状态下静置降温至 t_2 , 此时实验管路内原油的屈服值为 τ_0 , 压力为 p_2 。打开阀门2, 向装置内充气至压力达到 p_1 为止。然后, 瞬间打开阀门3, 假设此时原油以速度 u 流入实验管段, 经过 dt 时间, 压力传播了 dL 距离。

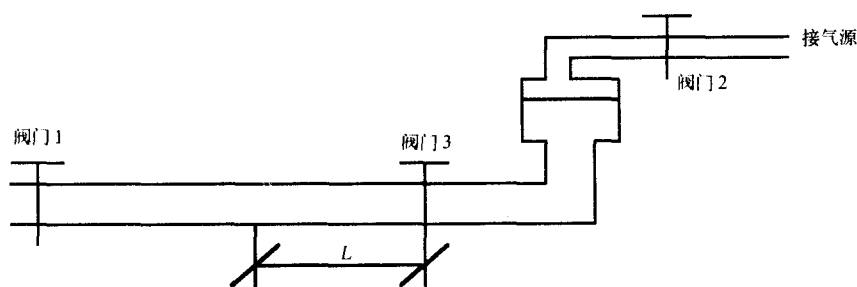


图1 实验管路示意图

dL 管段在启动压力作用下, 管内液体质量的增加量可分为3部分: (1) 管道受压膨胀后增加管容量所需的液体量; (2) 流体受压后密度变化增加的液体量; (3) 填充温降收缩所需的液体量。应用质量守恒定律计算式(忽略高阶无穷小)

$$\rho A u \frac{dL}{v} = \rho dL \Delta A + A dL \Delta \rho + \rho A dL \beta_t \Delta t \quad (1)$$

式中: $\Delta t = t_1 - t_2$, $^{\circ}\text{C}$; β_t 为原油的膨胀性系数; v 为压力传播速度, $\text{m}\cdot\text{s}^{-1}$ 。对 dt 时刻受启动压力影响的管段, 应用动量守恒定律, 有

$$\left(\Delta p - \frac{4L\tau_0}{D}\right)A - \pi D dL\tau_0 = \frac{\rho A dL(u-0)}{dt} \quad (2)$$

式中: $\Delta p = p_1 - p_2$, Pa ; D 为管径, mm 。

2 温降收缩后有屈服值的流体内压力传递速度求解

将式(1)两边同除以 $\rho A dL$, 得

$$\frac{u}{v} = \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho} + \beta_t \Delta t \quad (3)$$

整理式(2), 得

$$\Delta p = \frac{1}{1 - \frac{4L\tau_0}{\Delta p D}} \rho v u \quad (4)$$

式中 $v = \frac{dL}{dt}$ 。

原油的弹性系数

$$K = \frac{\Delta p}{\frac{\Delta \rho}{\rho}} \quad (5)$$

将式(4)、(5)代入式(3)整理可得

$$v^2 = \left(1 - \frac{4L\tau_0}{\Delta p D}\right) \frac{\frac{K}{\rho}}{1 + \frac{K\Delta A}{A\Delta p} + \frac{K\beta_t \Delta t}{\Delta p}} \quad (6)$$

根据弹性力学的薄壳理论, 当管道 $D/\delta > 25$ 时, 有

$$\frac{\Delta A}{\Delta p A} = \frac{D}{E\delta} C \quad (7)$$

式中: E 为管道的弹性系数, Pa ; δ 为管道壁厚, mm ; C 为管道的约束系数。

将式(7)代入式(6), 得

$$v = \sqrt{\left(1 - \frac{4L\tau_0}{\Delta p D}\right) \frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta} C + \frac{K\beta_t \Delta t}{\Delta p}}} \quad (8)$$

式(8)即为既有温降收缩又有屈服值的原油压力传递速度公式。

由 $K = \frac{\Delta p}{\frac{\Delta \rho}{\rho}}$ 和 $\beta_t = \frac{\frac{\Delta \rho}{\rho}}{\Delta t}$ 可得

$$\beta_t \Delta t K = \Delta p_d \quad (9)$$

式中: Δt 表示温度降低的幅度; Δp_d 为一当量压力, 它引起的液体收缩量与温降 Δt 引起的收缩量相等。

另外, 有

$$\tau = \frac{\Delta p D}{4L} \quad (10)$$

式中 τ 表示压力波前锋管壁处液体所受的切应力。

将式(9)和式(10)代入式(8), 可得

$$v = \sqrt{\left(1 - \frac{\tau_0}{\tau}\right) \frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C + \frac{\Delta p_d}{\Delta p}}} \quad (11)$$

式(11)和式(8)都可以用来计算既有温降收缩又有屈服值的液体压力传递速度。

3 公式的讨论

当 $\tau_0 = 0$ 时,式(8)变为

$$v = \sqrt{\frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C + \frac{K\beta_t \Delta t}{\Delta p}}} \quad (12)$$

或

$$v = \sqrt{\frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C + \frac{\Delta p_d}{\Delta p}}} \quad (13)$$

式(12)和式(13)为有温降收缩而无屈服值情况下的停输后初始再启动压力传递速度计算公式,该公式已在工业管道上得到了验证^[2]。

若 $\Delta t = 0$ 或者温降收缩得到充分补充,且 $\tau_0 > 0$,则式(8)变为

$$v = \sqrt{\left(1 - \frac{4L\tau_0}{\Delta p D}\right) \frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C}}$$

或

$$v = \sqrt{\left(1 - \frac{\tau_0}{\tau}\right) \frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C}}$$

当 $\tau_0 = 0$,且无温降收缩需要补充时,式(8)变为

$$v = \sqrt{\frac{\frac{K}{\rho}}{1 + \frac{KD}{E\delta}C}} \quad (14)$$

式(14)即为一般流体在通常情况下的压力波波速表达式,与文献[1]中相同。

4 温降收缩后有屈服值的流体内压力传递速度的影响因素

将以上各个公式无因次化,设温降幅度为0、屈服值也为0时的压力传递速度为 v_0 ,无因次剪应力 τ^* 、无因次压力 p^* 和无因次压力波速 v^* 分别为:

$$\tau^* = \frac{\tau_0}{\tau}, \quad p^* = \frac{\Delta p_d}{\Delta p}$$

$$v^* = \frac{v}{v_0} = \frac{\sqrt{1 - \tau^*}}{\sqrt{1 + \frac{p^*}{1 + \frac{KD}{E\delta}C}}}$$

当无温降收缩需要补充,即 $p^* = 0$ 时,有

$$v^* = \sqrt{1 - \tau^*}$$

当液体的屈服值为0,即 $\tau^* = 0$ 时,有

$$v^* = \left[1 + \frac{p^*}{1 + \frac{KD}{E\delta}C} \right]^{-1/2}$$

当启动压力很大,即 $p^* \rightarrow 0, \tau^* \rightarrow 0$ 时,有

$$v^* = 1$$

因此,原油管道停输后,原油既有温降收缩又有屈服值,再启动后的压力传递速度除了与原油物性和管道状况有关外,还与管壁处的无因次剪应力和无因次压力有关。在理论上,当启动压力很大时,压力波速与原油物性和管道状况有关。

5 算 例

某热油长输管道外径为711 mm,壁厚为8 mm,弹性模量为 2.07×10^{11} Pa;输油密度为 $895 \text{ kg} \cdot \text{m}^{-3}$,弹性模量为 1.75×10^9 Pa,停输后再启动时的压力波传递情况如图2所示。

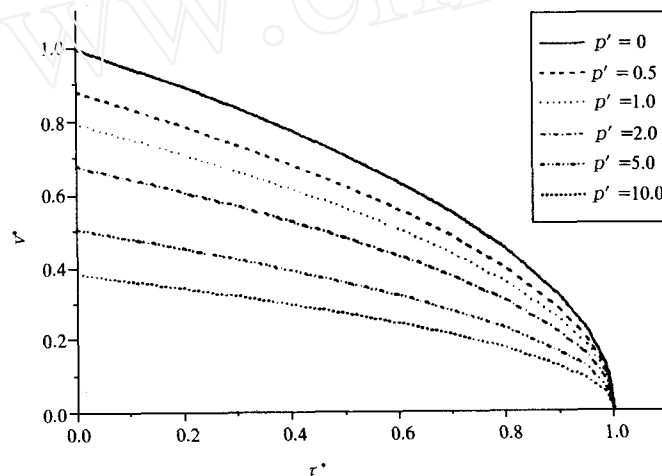


图2 无因次压力波速 V^* 与无因次剪应力 τ^* 和无因次压力 p' 的关系

6 结 论

热油管道停输后初始再启动的压力波不同于一般流体中压力波的传播;这时的压力传递速度除了与原油物性、管道状况有关之外,还与降温幅度、再启动时施加的压力和传递的距离有关。随着压力传递距离的增大,压力差减小,管壁处的剪应力减小,因而压力传递速度下降。提高启动压力,增加压力波速,可以减少凝油的顶挤时间,恢复正常的原油输送量,提高安全性。

7 参考文献

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Key Words: Liaodong Bay, cluster well, high quality and high speed drilling, drilling technology, management

Development of New Activity Agent of Barite and Its Assessment in Sea Water Drilling Fluid

..... *Li Yinsu, Zhang Jufen, Mo Chengxiao, Pan Huifang* (20)

Abstract: In order to solve effectively the suspend stability of weighting materials in sea water drilling fluid, a new activity agent of weighting materials is developed, which can resist against salt, calcium and high temperature. This paper introduces the activity mechanism of barite, and lists the experiment results of new kind of activity barite in high temperature (180~210 °C) and high density (1.8~2.4 g·cm⁻³) in sea water drilling fluid.

Key Words: activity barite, weighting agent, suspend properties, sea water drilling fluid

Research and Practice of Improved Drilling Fluid Properties *Shen Wei* (26)

Abstract: Several factors effecting drilling drag of extended reach well are discussed this article. In order to utilize sufficiently all advantages of Polyglycol Enhanced Mud, some technical measures were brought forward, by which the lubricity of PEM mud is improved, and the ability of anti-sticking of drilling fluid enhanced, resulting in reduction of drilling drag.

Key Words: extended reach well, drag, anti-sticking, lubricity

Influence of High Temperature on Strings Helical Buckled in Vertical Wells *Gao Baokui, Gao Deli* (30)

Abstract: Analytic solution is established to describe axial force distribution of strings helical buckled in vertical wells when slack down from the top. When temperature increases, deformation will develop under post buckling conditions, and it is difficult to describe axial force with analytic method, so numerical method is used. Near the point where well diameter changes, high temperature causes a sharp leap of load, local friction will turn direction to keep the continuity of axial force.

Key Words: string, helical buckling, temperature, axial force, friction

Calculation of Pressure Wave Speed in Cooled Crude Oil Pipelines *Zhang Zubin, Zhang Guozhong* (33)

Abstract: The pressure wave-speed should be mastered during the operation of crude oil pipelines. After the heated pipeline shut down, the oils shrinkage with temperature decreasing and the yield stress emerges when cooled to some extent. Therefore, hot-oil pipeline initial restart pressure wave-speed is different from that in usual fluid, which is dependent on the range of cooling, the exerted pressure and the propagated distance, besides crude oil and pipe properties. From the principles of momentum conservation and mass conservation, the formula of pressure wave-speed in the fluid with cooling contraction and yield stress has been derive.

Key Words: crude oil pipelines, pipeline transportation, yield stress, pressure wave-speed, calculation

Low Temperature Treatment of Natural Gas *Liu Peilin* (37)

Abstract: Low temperature separation, uses the high energy from the well stream to throttle and reduce pressure, then remove the condensate. This technical feature of process and equipment is simple, reliable, and easily for maintainance etc. This method is suitable for high pressure and high flow-rate condition, but is seldomly used since pressure declines quickly.

Key Word: low-temperature separation unit, hydrates, dew point, heating coil, dehydration

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Study and Application of Geo-Steering Drilling System *Lin Guanghui* (39)

Abstract: Geo-steering (GST) drilling is a new technology for evaluating the formation collegially while drilling. It was published in early 1990's, and has been applied in drilling engineering since the middle of 1990's. Its main surveying system is consisted of a GST sub, LWD (Logging While Drilling), and MWD (Measuring While Drilling). The GST sub is just a few meters above the drilling bit. The main characteristic of formation, such as lithology, physics and chemicals, can be measured after very short footage of new hole been drilled. Based on the analysis of the geological and reservoir data of the offset wells, it can be predicted what formation to be drilled. Soft-landing is a profile design to set the landing point (enter horizontal interval) into the proposal position and for the geological target. The well profile can be designed and modified according to the data from offset wells and GST surveys before and while drilling.

Lufeng 22-1 Oil Field is a large-scale field with quite thin bed. There are many structural faults through the reservoir. The pay zone is mainly sandstone but interlining with other lithology. The GST and Soft-landing technology was applied in the field to drill five(5) horizontal wells. It indicated that the technology was helpful and valuable for drilling through the faults and modifying the profile to land the horizontal section in the perfect geological target effectively. This treatise discusses how to use the technology for Soft-landing and drilling ahead the horizontal interval in ideal pay zone.