文章编号:1000-8241(2012)12-0923-04

T形管内油水两相流动规律及其应用

魏丛达[1] 许晶禹[2] 王立洋[2] 刘海飞[2] 吴应湘[2]
1.中海石油(中国)有限公司深圳分公司,广东深圳 518067;2.中国科学院力学研究所,北京 100190

魏丛达等.T形管内油水两相流动规律及其应用.油气储运,2012,31(12):923-926.

摘要:油水两相混合物流经T形管路时,会产生流量分配不均、相含率和相分布重新分配的现象,此特性可用于多相混合物的分离作业。采用欧拉多相流模型和混合κ-ε湍流模型,研究了T形管垂直分岔次数、入口混合流速、入口含油率和流量配比等参数对T形管路中油水分离效率的影响。计算结果表明:增加分岔次数有利于油水分离;流量配比存在较优区间;较低的入口混合流速和入口含油率有利于提高分离效率。这些结论对T形管路结构优化和提高油水分离效率有重要的指导意义。

关键词:油水两相流动;T形管;多相分离;分离效率
中图分类号:TE832 **文献标识码:**A doi:10.6047/j.issn.1000-8241.2012.12.013

在石油工业中,利用管路系统输送油、气资源是当代能源运输最主要的方式之一。由主管道和分支管道相交构成的分岔管路是油气输送管网系统的重要组成部分,根据主管道和分支管道之间夹角的不同,可分为Y形分岔管路和T形分岔管路。当多相介质(如原油和水、天然气和凝析液或者油气水三相混合物)通过这些分岔管路时,在主管道下游和分支管道内不仅会产生流量分配不均匀的现象,而且各管路内的相含率和相分布等也会重新分配[1-2],有学者[3-5]提出利用这种相分配不均现象可达到多相分离的目的。由单个或多个分岔管路组成的管式分离器,具有结构简单、体积小、质量小、压降损失小等优点,特别适用于对设备体积和质量有严格要求的海洋平台。

目前,对于分岔管路内多相流动特性的研究主要集中在气液两相流动[6-7],有关液液两相流动的研究甚少。Yang等[8]在2006年利用垂直布置的分岔管路对油水两相流动进行实验研究,当入口为分层流动时分岔管路对油水两相的分离效果较好,而当入口为分散流时分离效果不明显,说明垂直分岔管路内油水分离效果对入口流型非常敏感。同年,Yang等[9]针对水平布置的分岔管路进行实验研究,结果表明:此时分岔管路对油水两相基本没有分离效果。Wang等[10]针对T形分岔管路油水分离进行实验研究和数值模拟,得到油水分离效率依赖于入口流型和含油率。虽然分岔管路可以作为分离器使用,但分离效率不高,分离性能易受入口工况和运行条件影响。以下采用数值模拟方法研究T形分岔管路分岔次数及入口流速、含油率对油水分离效率的影响。

1 数值模拟

多相流动数值模拟方法主要有两种:欧拉-拉格朗日方法和欧拉-欧拉方法。在欧拉-拉格朗日方法中,流体相被处理为连续相,通过直接求解时均N-S方程得到速度场和压力场,而离散相是通过计算流场中大量粒子的运动得到的,该模型的基本假设是:离散相(第二相)的体积分数很低,通常低于10%,可忽略其对连续相的影响。由于在本研究中,第二相油的体积分数不小于10%,因此,采用能够模拟第二相体积分数较高情况的欧拉-欧拉方法。计算选用的组成成分和物性参数:主相为水,密度为998 kg/m^3,动力粘度为0.001 kg/(m·s);分散相为油,密度为836 kg/m^3,动力粘度为0.031 kg/(m·s)。

1.1 控制方程

连续性方程:

$$\frac{\partial}{\partial t}(\alpha_k\rho_k)+\nabla\cdot(\alpha_k\rho_k\boldsymbol{u}_k)=0$$

$$\sum_{k=1}^{N}\alpha_k=1$$

式中:α为相含率;ρ为密度,kg/m^3;$\boldsymbol{u}$为速度矢量,m/s;k代表油相或水相。

动量守恒方程：

$$\frac{\partial}{\partial t}(\alpha_k\rho_k\boldsymbol{u}_k)+\nabla\cdot(\alpha_k\rho_k\boldsymbol{u}_k\boldsymbol{u}_k)$$
$$=-\nabla(\alpha_k p)-\nabla\cdot\boldsymbol{\tau}_k'+\alpha_k\rho_k\boldsymbol{g}+K(\boldsymbol{u}_k-\boldsymbol{u}_l)$$
$$+(\boldsymbol{F}_k+\boldsymbol{F}_{\mathrm{lift},k}+\boldsymbol{F}_{\mathrm{vm},k})$$

式中：p 为压力，Pa；$\boldsymbol{\tau}'$为压力应变张量，Pa；$\boldsymbol{g}$为当地重力加速度，m/s^2；K 为相间的动量交换系数；$\boldsymbol{F}$ 为外部体积力，N；$\boldsymbol{F}_{\mathrm{lift}}$为升力，N；$\boldsymbol{F}_{\mathrm{vm}}$为虚拟质量力，N；$l$ 代表第 l 相。

假定离散相以液滴形式存在于连续相之中，当离散的液滴直径较大时，需要考虑升力$\boldsymbol{F}_{\mathrm{lift}}$的作用：

$$\boldsymbol{F}_{\mathrm{lift}}=-0.5\ \alpha_k\rho_k|\boldsymbol{u}_k-\boldsymbol{u}_l|\times(\nabla\times\boldsymbol{u}_l)$$

附加质量力$\boldsymbol{F}_{\mathrm{vm}}$的定义式：

$$\boldsymbol{F}_{\mathrm{vm}}=\frac{1}{2}\alpha_k\rho_k\left(\frac{\mathrm{d}\boldsymbol{u}_l}{\mathrm{d}t}-\frac{\mathrm{d}\boldsymbol{u}_k}{\mathrm{d}t}\right)_l$$

式中：t 为时间，s。

油水两相的相间交换系数表达式：

$$K=\frac{\alpha_k(\alpha_k\rho_k+\alpha_l\rho_l)f}{\tau}$$

其中，液滴弛豫时间 τ 和曳力系数 f 分别为：

$$\tau=\frac{(\alpha_k\rho_k+\alpha_l\rho_l)(d_k+d_l)^2}{72(\alpha_k u_k+\alpha_l u_l)}$$

$$f=C_{\mathrm{D}}Re/24$$

$$C_{\mathrm{D}}=\begin{cases}24(1+0.15\,Re^{0.687})/Re,\ Re\leqslant 1\,000\\ 0.44,\ Re>1\,000\end{cases}$$

$$Re=\frac{\rho_k|\boldsymbol{u}_k-\boldsymbol{u}_l|d_k}{\mu_k}$$

式中：d 为当量长度，m。

混合 κ-ε 湍流模型：

$$\frac{\partial}{\partial t}(\rho_{\mathrm{m}}\kappa)+\nabla\cdot(\rho_{\mathrm{m}}\boldsymbol{u}_{\mathrm{m}}\kappa)=\nabla\cdot\left(\frac{\mu_{t,\mathrm{m}}}{\sigma_k}\nabla\kappa\right)+G_{k,\mathrm{m}}-\rho_{\mathrm{m}}\varepsilon$$

$$\frac{\partial}{\partial t}(\rho_{\mathrm{m}}\varepsilon)+\nabla\cdot(\rho_{\mathrm{m}}\boldsymbol{u}_{\mathrm{m}}\varepsilon)=\nabla\cdot\left(\frac{\mu_{t,\mathrm{m}}}{\sigma_\varepsilon}\nabla\varepsilon\right)$$
$$+\frac{\varepsilon}{\kappa}(C_{1\varepsilon}G_{k,\mathrm{m}}-C_{2\varepsilon}\rho_{\mathrm{m}}\varepsilon)$$

$$\rho_{\mathrm{m}}=\sum_{k=1}^{2}\alpha_k\rho_k$$

$$\boldsymbol{u}_m=\left(\sum_{k=1}^{2}\alpha_k\rho_k\boldsymbol{u}_k\right)/\left(\sum_{k=1}^{2}\alpha_k\rho_k\right)$$

$$\mu_{t,\mathrm{m}}=\rho_{\mathrm{m}}C_\mu\kappa^2/\varepsilon$$

$$G_{k,\mathrm{m}}=\mu_{t,\mathrm{m}}\left[\nabla\boldsymbol{u}_{\mathrm{m}}+(\nabla\boldsymbol{u}_{\mathrm{m}})^{\mathrm{T}}\right]:\nabla\boldsymbol{u}_{\mathrm{m}}$$

式中：ρ_{m} 为混合密度，kg/m^3；$\boldsymbol{u}_{\mathrm{m}}$为混合速度矢量，m/s；$\mu_{t,\mathrm{m}}$ 为湍流粘度，kg/(m·s)；$G_{k,\mathrm{m}}$为湍流动能，m^2/s^2；C_μ 为常量；κ 为湍流的脉动能量，J；ε为湍流的脉动动能耗散率。

1.2 几何模型

T 形多分岔管路(图 1)主管路和分支管路的管径均为 50 mm。采用结构化网格，并在分岔接头处对网格加密，以便提高计算精度。油水两相入口采用速度入口条件，主管路下游出口和分支管路出口处为充分发展的管流条件，壁面为无滑移条件。采用二阶迎风格式求解油水两相控制方程组，速度场和压力场的耦合采用改进 SIMPLE 算法，控制进、出口流量的相对误差小于 0.1%。

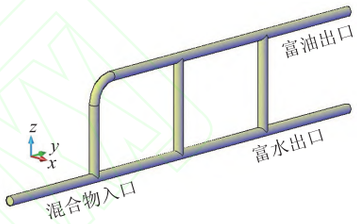

图 1　T 形多分岔管路三维几何模型

1.3 参数定义

为定量描述 T 形分岔管路的两相流动特性，定义如下相关参数。

油相相分配比：

$$f_{\mathrm{o}}=Q_{\mathrm{ob}}/Q_{\mathrm{oi}}$$

水相相分配比：

$$f_{\mathrm{w}}=Q_{\mathrm{wb}}/Q_{\mathrm{wi}}$$

混合流量配比：

$$f_{\mathrm{bi}}=\frac{Q_{\mathrm{wb}}+Q_{\mathrm{ob}}}{Q_{\mathrm{wi}}+Q_{\mathrm{oi}}}=\frac{Q_{\mathrm{b}}}{Q_{\mathrm{i}}}$$

T 形分岔管路分离效率：

$$\eta=|f_{\mathrm{o}}-f_{\mathrm{w}}|\times 100\%$$

下支管路水中含油率：

$$\alpha_{\mathrm{or}}=\frac{Q_{\mathrm{oi}}-Q_{\mathrm{ob}}}{Q_{\mathrm{wi}}-Q_{\mathrm{wb}}}\times 100\%$$

式中：Q_{oi} 为入口管路油相体积流量，m^3/s；Q_{wi} 为入口管路水相体积流量，m^3/s；Q_{ob} 为分岔管路油相体积流量，m^3/s；Q_{wb} 为分岔管路水相体积流量，m^3/s。

1.4 模型验证

为了验证所采用的计算模型，选取 Yang 等[8-9]的实验数据，对水平布置和垂直布置分岔管路内的油水两相流动特性进行数值模拟，并将所得结果与实验结

果比较(图 2)。其中，两组实验工况相同，入口流型均为分散流，混合流速为 1.8 m/s，入口含油率为 25%。显见，油水两相分配比的数值计算结果与实验数据吻合较好。当分岔管路水平布置时，在主管路和分岔管路之间，油水两相的相分配不均现象不明显，而当分岔管路垂直布置时，油水两相的相分配不均现象较明显，与 Yang 等得出的结论一致，说明利用欧拉多相流计算模型能够较好地对 T 形分岔管路内的油水两相流动进行模拟。

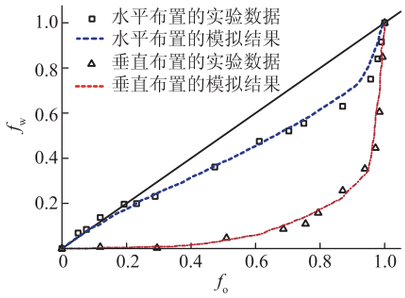

图 2　油水两相分配比数值模拟结果与实验数据的比较

2 结果与讨论

T 形分岔管路用于油水分离已获初步成功，然而，影响油水分离的因素较多，以下主要探讨结构参数和流动参数对 T 形管路油水分离特性的影响。

2.1 分岔次数

T 形管路的垂直分岔次数对支管路和主管路的相分配起着非常重要的作用。计算中，入口混合流速 v_m=2.0 m/s，含油率 α_o=0.3；分别选取一次、二次、三次、六次分岔结构，在相同的入口工况下，分别研究 T 形管路油水分离效率 η 和主管路下支管出口水中的含油率 α_{or}。

随着流量配比从 0 增加到 1，T 形管路的油水分离效率 η 均出现了“急剧上升—平缓过渡—快速减小”3 个变化阶段(图 3)，即流量配比对油水分离效率影响显著。针对 T 形管路的实际应用，需要找出曲线平缓过渡区间的流量配比范围，以便控制油水分离过程处于最佳运行状态。随着垂直管路分岔次数的增加，分离效率 η 逐渐增大，趋向于流量配比 f_{bi} 在 0.3～0.4 区间附近取得最大值，从一次分岔到六次分岔，分离效率的最大值分别为 38.06%、50.83%、61.25%和 70.52%，并且曲线中的“平缓过渡”阶段在整个流量配比过程中所占比例也逐渐增大。可见，分岔次数的增加不但能够提高分离效率，而且可以在更宽的流量配比范围内保持相对稳定的分离效率。

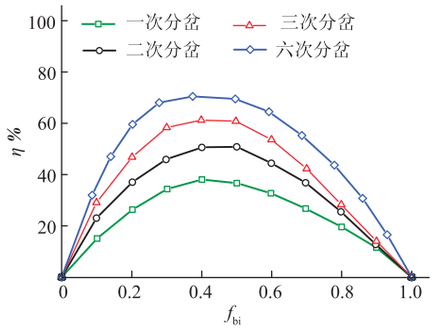

图 3　不同分岔次数下分离效率与流量配比的关系

油水混合物经过 T 形管路分离后，主管路下支管出口水中含油率是一个影响后续污水处理工艺的重要指标。与分离效率类似，当 T 形管路垂直分岔次数增加时，同样工况下的主管路下支管出口水中含油率明显降低(图 4)。因此，当 T 形管路用于油水分离作业时，可在条件允许的情况下通过增加垂直分岔管路数来改善分离效果、降低水出口的含油率指标。

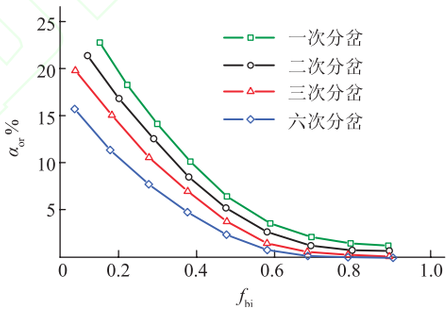

图 4　不同分岔次数下支管出口水中含油率与流量配比的关系

2.2 入口混合流速和入口含油率

当入口含油率相同时，增大混合流速 v_m 会降低分岔管路的油水分离效率(图 5)，这是因为混合流速增大使入口管路的流型发生了变化。过大的混合流速使入口的油以分散相的油滴存在于水中，这不利于油水两相在分岔接头处进行相的重新分配，从而恶化油水分离效果。此外，当入口混合流速一定时，较低入口含油率的分离效率最大值 η_{max} 略高一些，且低流速下分离效率“平缓过渡”区间较宽，说明较低的入口含油率更有利于分岔管路的油水分离。在不同工况下，油水分离效率最大值 η_{max} 分别为 77.56%、75.19%、62.32%和 61.23%，相对应的流量配比 f_{bi} 分别为 0.3、0.4、0.2、0.4。可见，T 形管路用于油水分离时，为达到较高的分离效率，最佳流量配比数值应该略大于入口含油率。

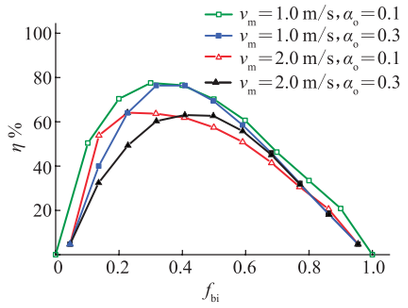

图 5　不同工况下三次分岔 T 形管路分离效率与流量配比的关系

随着流量配比的增大，下支管出口处水中含油率呈明显下降趋势(图 6)。当其他条件相同时，入口混合流速或含油率增大，均会使下支管出口水中含油率增大。为了降低水中含油率，可以增大 T 形管的流量配比，或者在低入口混合流速和低含油率下运行。

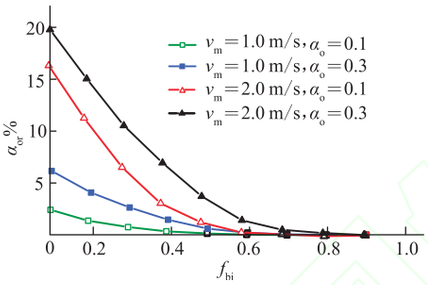

图 6　不同工况下 T 形管路下支管出口水中含油率与流量配比的关系

3 结论

对 T 形分岔管路装置中的油水两相流动进行数值模拟，分析了垂直分岔次数、入口混合流速和入口含油率对油水分离性能的影响，得出以下结论：

(1)T 形管路油水分离存在较优的流量配比区间。随着垂直分岔次数的增加，T 形管路对油水分离的效率显著提高，并可在更宽流量配比范围内保持较高的分离效率。

(2)油水两相混合物经过 T 形多分岔管路能够得到较好的分离，但分离效率受到入口混合流速、入口含油率的影响，T 形管路适用于低混合流速下的油水分离作业。

(3)欧拉多相流模型能够较好地模拟油水两相在 T 形管路内的流动。

参考文献：

[1] Buel J R, Soliman H M, Sims G E. Two-phase pressure drop and phase distribution of a horizontal tee junction[J]. International Journal of Multiphase Flow, 1998, 24: 775-792.

[2] Pandey S, Gupta A, Chakrabarti D P, et al. Liquid-liquid two phase flow through a horizontal T-junction[J]. Chemical Engineering Research & Design, 2006, 84(A10): 895-904.

[3] Azzopardi B J, Colman D A, Nicholson D. Plant application of a T junction as a partial phase separator[J]. Trans IChemE, 2002, 80(A): 87-96.

[4] Wren E, Azzopardi B J. The phase separation capabilities of two T-junctions placed in series[J]. Chemical Engineering Research & Design, 2004, 82(A3): 64-371.

[5] 王立洋，郭军，张军，等. T 型多分岔管路中的油水两相流动实验研究[C]// 第二十一届全国水动力学研讨会暨第八届全国水动力学学术会议文集. 北京：海洋出版社，2008: 582-588.

[6] Shoham O, Brill J P, Taitel Y. Two-phase flow splitting in a tee junction-experiment and modeling[J]. Chemical Engineering Science, 1987, 42(11): 2 667-2 676.

[7] Adechy D, Issa R I. Modeling of annular flow through pipes and T-junctions[J]. Computers & Fluids, 2004, 33: 289-313.

[8] Yang L, Azzopardi B J, Belghazi A. Phase separation of liquid-liquid two-phase flow at a T-junction[J]. AIChE Journal, 2006, 52(1): 141-149.

[9] Yang L, Azzopardi B J. Phase split of liquid-liquid two-phase flow at a horizontal T-junction[J]. International Journal of Multiphase Flow, 2007, 33: 207-216.

[10] Wang Li-yang, Wu Ying-xiang, Zheng Zhi-chu, et al. Oil-water two-phase flow inside T-junction[J]. Journal of Hydrodynamics, 2008, 20(2): 147-153.

(收稿日期:2012-01-04;编辑:关中原)

基金项目：国家自然科学基金资助项目“油气水三相分支管流的流动特性研究”，10572143。

作者简介：魏丛达，高级工程师，1967 年生，1991 年毕业于石油大学(华东)石油工程专业，现主要从事海洋石油开发技术研究。

电话：13823116580；Email：weicd@cnooc.com.cn

1.Corrosion and Protection Center, Beijing University of Science and Technology
2.SINOPEC Pipeline Storage and Transportation Company
3. PetroChina Inspection Technology Co., Ltd

OGST, Vol. 31 No. 12, pp. 912–916, 12/25/2012. ISSN 1000-8241; In Chinese

In the light of some oil pipeline sections being subject to bursting by corrosion, size of corrosion burst area as well as size and distribution of corrosion pits are measured, ingredients of the corrosion products are analyzed by SEM and XRD, and the residual strength of corroded pipeline is calculated and analyzed. The results show that the pipe coating was peeled basically, and the most serious corrosion thinning at the cracking opening could be seen with the maximum corrosion depth of 6.03 mm, corrosion pits appeared a discontinuous distribution, a major component of the corrosion products was Fe3O4, the corrosion product layer was relatively dense with many micro-cracks subject to maximum width of 8 μm, and corrosion residual strength at the cracking opening was the lowest, only 2.07 MPa. Based on the above analysis, overall corrosion conditions of the pipeline are basically revealed, and the analysis results can be taken as a reference basis for the development of a safe operation program.

Key words: oil pipeline, corrosion condition, residual strength, pipeline safety

Huang Liangliang: reading doctoral, born in 1985, graduated from Wuhan University of Science and Technology, inorganic non-metallic materials and engineering, in 2009, engaged in the research of corrosion protection, high-temperature coatings and other technologies.
Add: Room 224, Corrosion Building, Beijing University of Science and Technology, Bejing, 100083, P. R. China. P. R. China.
Tel: 010-62332067; Email: hluna@163.com

EXPERIENCE EXCHANGE

Technical approach to on-line control of flange leakage of gas pipelines

Peng Renshe[1], Yin Xudong[1], Li Pang[2]
1. PetroChina West-East Gas Pipeline Company
2. Jinhua Xin'ao Gas Company

OGST, Vol. 31 No. 12, pp. 917–918, 922, 12/25/2012. ISSN 1000-8241; In Chinese

Generally, long-distance gas pipeline operated with high pressure will be not shut down unless necessary, and if the flange connected with gas truck line leaks, it will be very difficult to plug the leakage under pressure by online way. This paper analyzes different leakages dangers occurring in flanges of pipeline, establishes a simulation test system, and puts forward a technical approach to the repair of damaged flange with high-pressure clampls, stopple and composite material repair technology. In the practical application process, a cost-effective technical solution should be selected under the premise of ensuring operation safety according to different flange leakage situations, and this is the key for successful control of flange leakage of pipelines.

Key words: gas pipelines, flange, leakage, online control, solution

Peng Renshe: senior engineer, born in 1960, graduated from Hebei Geological Institute, drilling engineering, in 1982, engaged in the technical management of operation equipments of long-distance gas pipelines.
Add: Room 1802, 18th Floor, Tongsheng Building, No. 458, Fushan Road, Pudong District, Shanghai, 200125, P.R.China.
Tel: 13918283957; Email: pengrenshe@petrochina.com.cn

Wellhead safety monitoring system and its application

Zhou Guoying[1], Xie Shuang[2]
1. SINOPEC Northeast Oilfield Company, Yakela Gas Recovery Plant
2. SINOPEC Northeast Oilfield Company, Exploration and Development Research Institute

OGST, Vol. 31 No. 12, pp. 919–922, 12/25/2012. ISSN 1000-8241; In Chinese

This paper analyzes the necessity for installation of wellhead safety monitoring system for Yakela Condensate Gasfield, and describes the composition of the wellhead safety monitoring system and its corresponding video monitoring, remote detection parameters, remote shut-in, high/low pressure automatic shut-in functions, highlighting the system configuration i.e. critical data detection, data acquisition equipment, communication mode, hydraulic control cabinet, video monitoring, and auxiliary facilities. The system has been widely used in Yakela Condensate Gasfield, which not only improves the safety management level of well control, but also realizes downsizing for efficiency.

Key words: high pressure oil and gas wells, Yakela Condensate Gasfield, wellhead safety monitoring system, RTU, hydraulic control cabinet

Zhou Guoying: engineer, born in 1980, graduated from China University of Petroleum (Huadong), automation, in 2005, engaged in the technology management of instrument automation and electricity.
Add: Yakela gas recovery plant, Tabei Post Office, Kuqa County, Xinjiang, 842017, P.R.China.
Tel: 18999621286; Email: zzzggy@sina.com

DESIGN & CALCULATION

The law of oil-water two-phase flow in T-shaped pipeline and its application

Wei Congda[1], Xu Jingyu[2], Wang Liyang[2], Liu Haifei[2], Wu Yingxiang[2]
1.CNOOC Shenzhen Branch Company
2. Institute of Mechanics, Chinese Academy of Science

OGST, Vol. 31 No. 12, pp. 923–926, 12/25/2012. ISSN 1000-8241; In Chinese

When oil-water two phase mixer flows through T-shaped pipeline, non-uniform flow distribution, and redistribution of phase volume fraction and phase distribution can occur, and this characteristic is more used in separation operations of multi-phase mixture. This paper analyzes the influence of parameters (such as vertical bifurcation number, mixing flow rate at inlet, oil-content at inlet and flow-rate proportioning, etc.) on oil-water separation efficiency in T-shaped pipeline with Euler multiple-phase flow model and mixing κ-ε turbulence model. The calculation results show that increasing the bifurcation number is available for oil-water separation. There is better range for flow rate proportioning. And the lower mixing flow rate and lower oil content at inlet are helpful for the improvement of separation efficiency. These results will be of significance in guiding structure optimization and oil and water separation efficiency.

Key words: oil-water two-phase flow, T-shaped pipeline, multiple-phase separation, separation efficiency