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基于光学传感器的成品油识别方法

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摘要：为了改进现有的成品油管道油品检测方法，从油品介质的本质出发，寻找能够体现油品本质的特征来检测和识别成品油。通过分析光的变化磁场的电磁感应对介质的作用以及光在介质分子间能量传递过程建立的电子云导体模型，运用能量守恒原理对光在介质中的传播以及折射现象进行了研究，对不同成品油及其混油的折射率进行测量及相关计算，得到了计算成品油折射率和识别混油的方法。通过光学传感器接收探头与油品接触面的菲涅尔反射信号，分析光与介质的相互作用，从而完成对油品的识别以及对不同混油的区分，相对误差＜0.02％。实验结果为油品的识别和开发研究提供了理论依据，在分析成品油管道运输中混油的成分、推断其混油状态、扩散过程等方面有一定应用前景。

关　键　词：光学传感器；成品油；混油；折射率；识别
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Optical sensor for product oil identification

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Abstract：To improve the existing method to detect the product oil in pipeline sequence transportation，it is necessary to set a new method for product oil identification and detection based on the characteristics that reflect the quality of oil. This paper researches a optical sensor and a new method for product oil identification and mixed oil distinguish and calculates the light intensity of the Fresnel reflection occurred at the interface between the product oil and a measuring probe. The product oil and oil mixtures are analyzed by using the principle of energy conservation and the inductor model of an electron cloud . Using the optical sensor，the product oils can be identified exactly，and different oil mixtures can be distinguished from each other successfully in a relative error less than 0.02％. The experimental results provide a theoretical basis for the identification of product oil，which shows that the proposed optical sensor has a great application prospect in analyzing the compositions of oil mixtures and predicting the mixing and diffusing conditions of oil transported in product pipelines.

Key words：optical sensor；product oil；mixed oil；refractive index；identification

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1 Introduction

Recent years, as the lack of petroleum resource, loss reduction during the oil transportation and store processing becomes extremely important. Oil mixing loss takes up a great proportion in total loss of them. Precision oil identification can, to great extent, avoid oil mixture accidents, especially during the product oil sequence transportation. Several testing methods have been used for monitoring the oil mixture in product pipeline, such as density measurement, ultrasonic measurement, optical measurement, labelled atom detection and fluorescence detection[1-2]. Different kinds of product oil whose densities are very close cannot be distinguished by density measurement. Ultrasonic measurement cannot get rid of disturbs from murmurs caused by gas bubble, pipe scaling, pump working and other sound source. Because of the low precision, optical measurement has less application in pipeline sequence transportation. The precision of labeled atom detection is seriously affected by oil viscosity and dispersion coefficient, its interpretation accuracy needs to be improved further. Fluorescence detection has a requirement on high sensitivity of testing system, and has no ability to identify different oil products. These testing methods cannot meet the need of pipeline sequence transportation. Product oil identification should be completed with the characteristic that reflect the quality of oil. Refractive index is the material characteristic of a certain medium, and it can show the interaction between light and medium. Chemical structure analysis and liquid properties testing can be processed by refractive index measurement, which is suitable for complicated mixture properties analysis[3-4]. The properties of Lights are shown when lights are scattering. They are widely used in various measurements[5-7]. Traditional view believes that electric field of the light plays a major role in interacting between light and medium. Generally, it is explained that the vibrator model of electron in the medium is forced to vibrate by alternating electric field of the light. Without effect of magnetic field, the refraction index calculating formula derived from traditional theory has no sufficient accuracy. Relevant researches indicated that magnetic field of the light also play an indispensable role in light propagation and light refraction[8].

2 Methods

2.1 Theory

When the light enters a medium from vacuum, one part of the light is reflected, and the rest enters the medium. In the medium, one part of the light is scattered, one part is absorbed and the other is refracted. The part of light refracted is the only part received in refractive index measurement, while the parts of the light reflected, scattered and absorbed are no longer be considered as incident light of refractive index measurement. All the parts of light interact with medium, but the energy of them are independent from each other. Considered as the incident light, the refracted part is separated from others. The light in the following text stands for this part of light. Each electron in the medium molecule forms an electron cloud in a certain shape corresponding to the range of space it appears. All the electron clouds can be seen as conductors those are independent from each other, because each of the electrons is restricted within its specific space in the molecule. When the alternating magnetic field of the light exists in the electron cloud conductor, an electric current is induced by the changing magnetic induction of the light. Actually, the induced current is a statistical result of the electron circular motion, which is the motion-superposition of the original electron movement. The electron cloud can be seen as a coil, which the light exchanges energy with, when they interact with each other. Caused by induced current, energy is stored in the electron cloud conductor which is considered as an inductor. This part of energy is transferred continuously between light and electron cloud inductor when the light is refracted in the medium. The energy which the electron cloud inductor received from the light is:

$$W_E=\frac{V}{2\omega^2\mu_0\langle g\rangle}\left(\frac{\mathrm{d}B_M}{\mathrm{d}t}\right)^2=\frac{V}{2\mu_0\langle g\rangle}B_{M0}^2\sin^2\omega t \quad (1)$$

where V, is the equivalent volume of the electron cloud inductor; ω is the angular speed; t is time; $\mu_0=4\pi\times10^{-7}$ H/m, is vacuum permeability; $\langle g\rangle$ is the space average value of the shape and direction factor of the electron cloud; $B_M=B_{M0}\cos\omega t$, is the magnetic induction of the light in the medium. Compared with electrons, nuclei contribute little to energy transfer. The effect caused by nuclei on light refraction can be neglected. So the energy of one molecule interact with light is approximately the sum of all electron clouds in the molecule. The average exchange energy density in the medium is:

$$W_{\mathrm{re}}=\frac{\rho(1+\chi)^2B_0^2}{4\mu_0}\sum_{i=1}^{z}\left(\frac{V}{\langle g\rangle}\right)_i, \quad (2)$$

Where ρ is the molecule density of the medium; χ is the magnetic susceptibility of medium; B_0 is the amplitude of the magnetic induction of the light in vacuum; z is the number of electrons in the molecule; i stands for electron i in the molecule. For most transparent media, the absolute value of the magnetic susceptibility is much less than 1. During the process of light refraction, the law of energy conservation is always being followed. The velocity of light in the medium is $1/n$ that of light in vacuum. So the light energy of unit volume in vacuum should equals to that of $1/n$ unit volume in the medium. n is the refractive index of the medium. The energy of light in the medium is composed of the part energy in the light refracted and all the exchange energy in the medium:

$$\frac{B_0^2}{2\mu_0}=\frac{\dfrac{\rho(1+\chi)^2B_0^2}{4\mu_0}\displaystyle\sum_{i=1}^{z}\left(\frac{V}{\langle g\rangle}\right)_i+\dfrac{B_0^2}{2\mu_0}}{n}, \quad (3)$$

When there are kinds of molecules in the medium, the refractive index is:

$$n=1+\frac{1}{2}(1+\chi)^2\sum\left[\rho\sum_{i=1}^{z}\left(\frac{V}{\langle g\rangle}\right)_i\right]_j\approx$$

$$1+\frac{1}{2}\sum\left[\rho\sum_{i=1}^{z}\left(\frac{V}{\langle g\rangle}\right)_i\right]_j, \quad (4)$$

where j stands for molecule j in the medium. The statement of the electron clouds in the product oil is described as:

$$\sum\left[\rho\sum_{i=1}^{z}\left(\frac{V}{\langle g\rangle}\right)_i\right]_j=\rho_{\mathrm{o}}D_{\mathrm{o}}, \quad (5)$$

where ρ_{o} is the density of the product oil; D_{o} is the material property factor of the product oil. D_{o} shows the property of all the molecules in the product oil and has relationship with the shape, volume and direction of each electron cloud. Thus, the expression of product oil refractive index can be written as:

$$n_{\mathrm{o}}=1+\frac{1}{2}\rho_{\mathrm{o}}D_{\mathrm{o}}, \quad (6)$$

and the refractive index of product oil mixture can be expressed as:

$$n_{\mathrm{m}}=1+\frac{1}{2}\rho_{\mathrm{m}}\left(\frac{\rho_{\mathrm{o1}}V_{\mathrm{o1}}}{\rho_{\mathrm{o1}}V_{\mathrm{o1}}+\rho_{\mathrm{o2}}V_{\mathrm{o2}}}D_{\mathrm{o1}}+\frac{\rho_{\mathrm{o2}}V_{\mathrm{o2}}}{\rho_{\mathrm{o1}}V_{\mathrm{o1}}+\rho_{\mathrm{o2}}V_{\mathrm{o2}}}D_{\mathrm{o2}}\right), \quad (7)$$

where n_{m} and ρ_{m} are the refractive index and density of the product oil mixture respectively; ρ_{o1} and ρ_{o2} are the densities of two kinds of product oil; V_{o1} and V_{o2} are the volumes of two kinds of product oil; D_{o1} and D_{o2} are the material property factors of two kinds of product oil.

2.2 Tests and discussions

The optical sensor attains the light intensity of fresnel reflection occurred at the interface between product oil and measuring probe. The experimental data are the average value of 5 tests. －10＃ diesel, 93＃ gasoline and 97＃ gasoline are the samples of the tests. Every two of three product oil samples are mixed respectively in volume ratio 1∶2 and 1∶4. Twelve mixture samples are prepared for the experimental testing. The experimental data of twelve mixture samples are shown in Tab. 1.

N is the test number of mixture sample; V_d is the volume of －10＃ diesel; V_{g1} is the volume of 93＃ gasoline; V_{g2} is the volume of 97＃ gasoline; ρ_m is the density of the mixture sample; n is the measurement value of mixture sample refractive index; n' is the calculated value of mixture sample refractive index; R_n is the error of the mixture sample refractive index.

Tab. 1 Experimental data of mixture samples

N	V_d(ml)	V_{g1}(ml)	V_{g2}(ml)	ρ_m(g/ml)	n	n'	R_n
1	200	400	0	0.765 8	1.507 8	1.509 3	0.001 5
2	200	0	400	0.768 8	1.521 2	1.522 5	0.001 3
3	0	200	400	0.729 8	1.548 2	1.547 7	－0.000 5
4	200	800	0	0.750 2	1.518 2	1.519 4	0.001 2
5	200	0	800	0.753 6	1.536 4	1.535 1	－0.001 3
6	0	200	800	0.730 2	1.551 4	1.550 2	－0.001 2
7	400	200	0	0.804 6	1.485 2	1.484 1	－0.001 1
8	400	0	200	0.806 2	1.491 6	1.490 7	－0.000 9
9	0	400	200	0.728 4	1.540 2	1.541 1	0.000 9
10	800	200	0	0.820 6	1.473 8	1.474 2	0.000 4
11	800	0	200	0.821 4	1.477 2	1.478 1	0.000 9
12	0	800	200	0.727 8	1.536 8	1.538 5	0.001 7

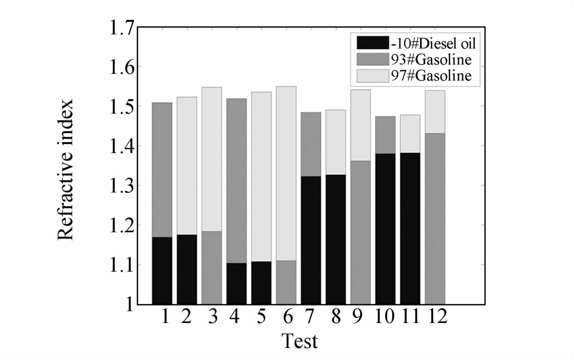

Fig. 1 Graphical representation of the results

Graphical representation of the experimental results is shown in Fig. 1. Test data are classified into three groups to be compared and analyzed. Group1 is composed of test1, test4, test7 and test10. Group2 is composed of test 2, test5, test8 and test11. Group3 is composed of test3, test6, test9 and test12. From the experimental results of group1, it can be seen that the refractive index of mixture decreases from 1.518 2 to 1.473 8 in turn, when the volume proportion of -10＃ diesel increases from 20％ to 80％ in -10＃ diesel and 93＃ gasoline mixture. The result above shows that the changes of mixture refractive index can still reflect the differences of product oil mixing degree, even though the product oils mixed are similar. The same conclusion also can be drawn from the experimental results of group2 and group3. Comparing the experimental result of test1 with that of test2, the densities of two mixture samples which －10＃ diesel mixes respectively with 93＃ gasoline and 97＃ gasoline in the proportion of 1∶2 are very close. The density difference is only 0.003 0 g/ml, while the refractive index difference is 0.013 4. From the contrast mentioned above, it is revealed that different product oil mixtures can be identified by their refractive indexes, even though the density differences of mixtures are very close. The same conclusion can be achieved from the compare between test4 and test5, test7 and test8, test10 and test11.

3 Conclusions

The optical sensor and a new method for product oil identification and mixed oil distinguish are tested. The calculation formula of product oil refractive index derived from the inductor model of electron cloud is verified. The relative error is less than 0.02%, while the relative errors of traditional methods are between 0.17% and 0.5%. The mixing degree of two product oil is exactly reflected by accurate calculation of refractive index. If the achievement is applied to product pipeline, the product oils and the mixtures can be identified and analyzed during the process of pipeline sequence transportation. Accidents and economic loss caused by mixed oil can be reduced. The advantages of product pipeline batch transportation will be developed adequately.

References:

[1] BAMBERGER J A , GREENWOOD M S. Measuring fluid and slurry density and solids concentration non-invasively [J]. *Ultrasonics*, 2004,42,1-9:563-567.

[2] ADMOWSKI J C, BUIOCHI F, SIGELMANN RA. Ultrasonic measurement of density of liquids flowing in tubes [J]. *IEEE Transactions on Ultrasonics Ferroelectrics and Frequencyontrol*, 1998,1:48-56.

[3] YANG W B, WANG J L, ZHANG G L, *et al.*. Intertwisted fibrillar diamond-like carbon films prepared by electron cyclotron resonance microwave plasma enhanced chemical vapour deposition [J]. *Chinese Physics*, 2003,12(11):1257-1260.

[4] DIMITROV V, KOMATSU T. Refractive index based optical basicity and chemical bonding of single component B_2O_3, SiO_2 and GeO_2 glasses [J]. *Physics and Chemistry of Glasses-european Journal of Glass Science and Technology Part B*, 2008,49(2):97-99.

[5] ZHAO M F, LIAO Q, CHEN Y, *et al.*. Fiber sensor for biomass′ online testing[J]. *Opt. Precision Eng.*, 2007,15(4):478-485. (in Chinese)

[6] WANG X C, FAN W Q, WU X C. Steady-state photon transport in multi-layered mismatched medium[J]. *Opt. Precision Eng.*, 2007,15(5):656-661. (in Chinese)

[7] JIA H H, CHANG S L, YANG J K, *et al.*. Study on error of non-line-of-sight light propagation by single-scattering model[J]. *Opt. Precision Eng.*, 2007,15(1):40-44. (in chinese)

[8] ZHANG T. Effect of magnetic field of light on refractive index [J]. *Chinese Physics*, 2004,13(8):1358-07.

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●下期预告

基于高斯分布的星像点精确模拟及质心计算

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为满足星敏感器仿真系统的精度需求，提出了基于高斯规律的模拟星像点的灰度扩散方法和高斯质心提取算法。模拟星像点像素按照二维高斯分布规律置灰度值，对称中心是映射坐标而不是取整的中心像素坐标，以准确模拟实际星像点散焦及像差导致的灰度扩散。高斯质心提取亚像素定位过程包括像素粗定位和偏差精定位两个步骤，基于高斯规律建立了一个分段函数实现偏差精定位。在星像点噪声为 $N(0,\ 1.2^2)$ 的仿真条件下，整个偏差区间[－0.5，0.5)像素内，高斯质心定位标准差为 0.007 像素，远小于灰度重心法的 0.041 像素和加权灰度重心法的 0.026 像素，而 3 种方法对模拟星图的处理结果一致。仿真实验表明：模拟星像点高斯灰度扩散法是合理准确的，高斯质心提取算法简单精确，精度高于传统灰度重心法。