National Ilan University

國立宜蘭大學工程學刊第 9 期，26-37 頁，2013 年 12 月
Bulletin of College of Engineering National Ilan University No. 9, PP. 26-37, December 2013

Bulletin of College of Engineering
http://engineering.niu.edu.tw/main.php

磁性流體磁化表面張力之研究

何正義[1] 郭文堯[2] 林建勳[3]

1. 國立宜蘭大學機械與機電工程學系(所)教授
2. 國立宜蘭大學化學工程與材料工程學系(所)助理教授
3. 國立宜蘭大學機械與機電工程學系(所)研究生

摘要

本文將利用O型拉環法以探討磁性流體表面張力之研究，而實驗表面張力可藉由上拉試驗樣品之視重減少量而進行估算;此亦將取決於磁流樣品於磁場作用下產生之磁化強度而定。然實驗測試之結果將與Rayleigh公式求得之理論數據作進一步之比對。為呼應磁流表面張力實驗之要求，一套簡易、經濟用於估算磁性流體表面張力係數的小型拉環實驗機構將於此設計並建構完成。經以松本公司的磁流商業用品於工作磁場強度0~40mT區間進行實驗測試與理論分析，兩者結果顯示了相當吻合的趨勢。另於此發現磁流樣品體積濃度與外加磁場強度交互作用之效應將誘導磁流體之表面張力;亦即決定了磁流體之物理特性。

關鍵字: 磁性流體表面張力

***通訊作者 E-mail：jeho@niu.edu.tw**

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Using O-Ring Pulling Method to Predict Ferro-Surface Tension

Je-Ee Ho[1], Wen-Yao Kuo[2], Jian-Xun Lin[3]

1. Professor, Department of Mechanical and Electro-Mechanical Engineering, National Ilan University.
2. Assistant Professor, Department of Chemical and Materials Engineering; National Ilan University,
3. Graduate Student, Department of Mechanical and Electro-Mechanical Engineering, National Ilan University,

ABSTRACT

An O-Ring Pulling Method to predict the surface tension of ferrofluid is investigated in this study. Here the experimental surface tension, based on the ferro-weight loss of testing ample lifted up, is strongly dependent on the magnetic intensity and ferro-magnetization. And which could be further confirmed by analytic solution estimated from Rayleigh theory. To conduct the ferro-experiment of surface tension, a self-designed ring-pull mechanism with magnetic field action considered is then set up. That also features as a special faculty of smaller size, economics and efficient operation. After compared with the empirical and theoretic results using commercial ferro-sample provided by Matsumoto co., an excellent agreement, for ferro-concentration 0.03 and 0.003, will be delivered within the working magnetic intensity 0~40 mT. Here the coupling effect of denser ferro-concentration and stronger field imposed, responsible for the induction of ferro-surface tension, is found to be essential to determine the ferro-property.

Keywords: O-Ring Method, Ferro-Weight Increment

***Corresponding author email: jeho@niu.edu.tw**

1. INTRODUCTION

Ferro-fluid is known as a novel functional and intelligent material which contains magnetic solid particles of nano or micro scale, about the diameter of 100 nm or less, uniformly dispersed in the base carrier liquid or stable colloidal liquid, and its movement induced by surface tension could be effectively controlled by magnetic field enforced. Since 1960, many testing methods, related to surface tension, have attracted many researchers' interest. For example, an experimental formula, derived from geometric contacted angle between liquid surface and wall, was popularly discussed (Flament et al., 1996). However, the further understanding of ferro-property along phrasal interface was so inadequate that interfacial survey was then proceeded later (Dababneh et al., 1993; Amin et al., 2005). Recently, the availability of ferro-fluid has been extended to micro-electromechanical and biomedical field (Afkhami et al., 2010). And the measurement of scale-down to a certain size seems to be inevitable while surface tension in micro-channel study, as the driving force of ferro-flow, has gradually arisen public interest (Sudo et al., 1989). Of course, it will significantly increase experimental expense with the costly nano-scale ferro-sample and precise testing equipment involved in related research. Besides, micro-study of surface tension will still face a certain degree of impact, that is., several additional interfacial boundary conditions should be taken into account under the directional magnetic field imposed (Elborai, 2006).

To compensate above inadequateness, a ferro-experiment method, associated with modified Raleigh theory, to estimate the ferro-surface tension is developed. In which, an oil-based ferro-sample, with the particle size of 20 ~ 100 nm dispersed in volumetric concentration of 0.033, was provided by Matsumoto co. In addition, a testing mode, constituted by self-designed components in Fig.1, will be established as well, where apparent weight loss, arisen by ferro-sample lifted up, will be used to be accounted for the surface tension and the value could be promptly read by commercial weight-meter located below. That is quite different from a conventional way used in traditional ring-pull method, where a classy load gauge is needed to record the required strength lifting up liquid film from the ferro-surface.

2. EXPERIMENTAL ANAYSIS

To successfully examine the proposed model, several reasonable assumptions, without losing the global behavior, should be made in advance

1. Ferro-property for testing fluid used in this study is taken as isotropic.
2. Due to the diameter of testing dish is about the same as the size of permanent magnetism positioned below, magnetic field induced inside the ferro-sample is then considered to be uniform.
3. Since field intensity is assumed to be strong enough to overcome the effect of thermal agitation and Brownian motion, instant magnetization of collinear particles, uniformly distributed in solution, could be regarded as in synchronization with field applied, i.e., $M// H$.'
4. A linear relation exists among ferro-magnetization M , Ms for ferro-fluid and ferro-particle as well as ferro-volumetric concentration ϕ, that is, $M=\varphi Ms$.

Unlike traditional ring-pull method, the intensified ferro- gravity, caused by field imposed, will be counteracted by upward ferro-surface tension while the ferro-sample is gradually raised. That results into the apparent ferro-weight loss contained in testing vessel,and the lost value $\Delta W'$,depends on field applied, could be read directly and displays on the digital weight counter. Thus equivalent surface tension, predicted from Eqs.(1), might be easily accessed. In addition, the measurement of individual ferro-weight increment induced by field , as Δw in Eqs.(2), should be carried out before the lifting is in progress, and which will be used to correct the analytic approach of Eqs.(7).

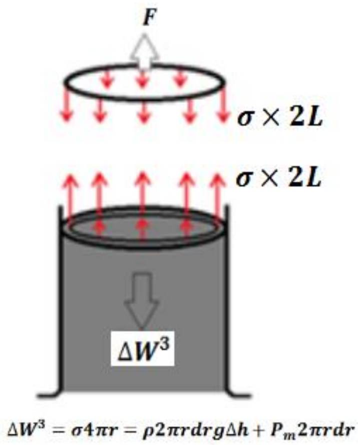

Figure 1. The sketch of ring-pull unit

$$F = \sigma 4\pi r = \Delta W' = \rho 4\pi r h(g + g_m) \quad (1)$$

$$\Delta W = \rho \pi R^2 h g_m \quad (2)$$

2-1 Experimental procedure

Prior to experimental process, several testing procedure should be specified in advance.

1. Set up the testing mechanism, illustrated in Fig.1, and ferro-sample φ 0.035 inside the testing vessel is prepared at 25℃.

2. Initially, estimate the total weight of dish and testing sample while field intensity is absent.

3. Separate the distance between magnet and dish to regulate magnetic intensity and qualify the increment of ferro-weight Δw. After then, slowly lift up ring-pull until the minimum apparent weight on the digital counter appears, and then estimate the maximum weight loss $\Delta w'$.

4. Duplicate the step (3) five times to generate magnetic intensity 2.4 mT~ 40 mT, and each records the individual weight increment Δw , weight loss $\Delta w'$ as well as magnetic intensity B.

5. Separately calculate both experimental and analytic surface tension through the definition of Eqs.(1), (2) and (7).

3. CORRELATED THEORY

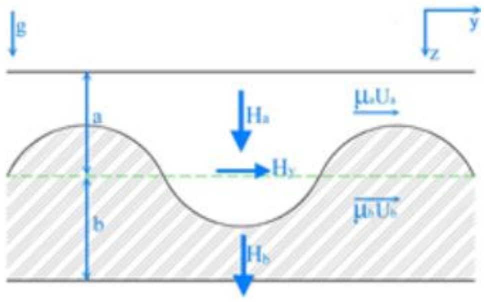

Figure 2. The sketch of ferro- oscillation wave

So far, the survey of experimental surface tension on field was discussed. Next we will forward to propose a theoretic model to validate above results. Accompanied with Rayleigh formula in Eqs.(3), an oscillating testing mechanism to investigate dynamical surface tension of ferro-sample is plotted in Fig.2. With the continuity of magnetic flux across the interface of small thickness a&b in (4), an induced static ferro-pressure relation might be yielded in Eqs.(5) by assigning oscillation frequency ω=0 (U_a =0 & U_b =0) and neglecting horizontal field intensity applied (Hy=0). Substituting Eqs.(4)~Eqs.(5) into Eqs.(3), a simplified ferro-dynamical model, in Eqs.(6),to determine static surface tension might be carried out. Here the quotient of weight-increment ration with surface tension coefficient, in the parentheses of Eqs.(7), could be regarded as a constant value by unity k remaining at a perfect plain ferro-surface.

$$\frac{k^2\mu_a\mu_b(H_a \quad H_b)^2}{\mu_a\,tanh(kb)+\mu_b\,tanh(ka)} = \quad gk(\rho_b \quad \rho_a)+k^3\sigma \tag{3}$$

$$Ha - H_b = M_0 \quad tanh(kb) = kb \quad \text{and} \quad tanh(ka) = ka \tag{4}$$

$$P_m \approx \frac{\mu_a M_0 H_a}{2} = \mu_a \overline{M} H_a = \rho_b g_m b \tag{5}$$

$$\therefore k = \sqrt{\frac{\rho_b[\,g + g_m(1 \quad \frac{\mu_a}{\mu_b})]}{\sigma}} = \sqrt{\frac{\rho_b g[1+\frac{\Delta w}{w}]}{\sigma}} \tag{6}$$

$$where, \frac{\Delta w}{w} = \frac{g_m(1- \quad \frac{\mu_a}{\mu_b})}{g}$$

$$\frac{[1+\frac{\Delta w}{w}]}{\sigma} = constant \tag{7}$$

4. RESULTS AND DISCUSSION

Previous to investigate the ferro-surface tension, the understanding of ferro-weight for commercial product is required, and both physical meanings "ferro-weight loss" and "ferro-weight increment" should be clearly interpreted in advance. In Fig.3, ferro-weight loss $\triangle W'$ on field is defined as the maximum reduced weight on the digital counter while the medium, subjected to field intensity, is lifted up. And the value, estimated from volumetric concentration ϕ0.033, behaves a quick increase from 0~0.005N as magnetic intensity falls within 0~40 mT. However, such increase, 0~0.0005N, accessed from ferro-solution of ϕ 0.0033 seems to be imperceptible. Base on above results, the weight loss proportional to ferro-concentration could be well identified and the ferro-induction becomes more active under the enforcement of strong magnetic intensity. To enclosure the calculation of surface tension in Eq.(7), weight-increment $\triangle W$, the increasing amount of ferro-weight under individual field action , should be determined out before the lifting process is in progress. In Fig.4, the magnitude, predicted from testing medium with ϕ 0.033 at 25 ^{o}C, is found to be nearly negligible uing the working region of field intensity less than 10 mT ,and then boosts up to 0.05 N by extending field strength to 40 mT. Corresponding to above working region, the maximum value, 0.005 N, will be further limited for case of ϕ 0.0003. Thus previous discussion for $\triangle W'$ in Fig.3 seems to be also available for the results accessed from ferro-weight increment $\triangle W$.

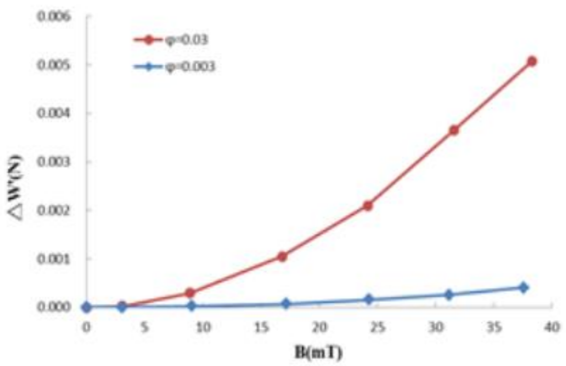

Figure 3. Weight loss vs. magnetic field for ψ0.04 and 0.004 at 25℃

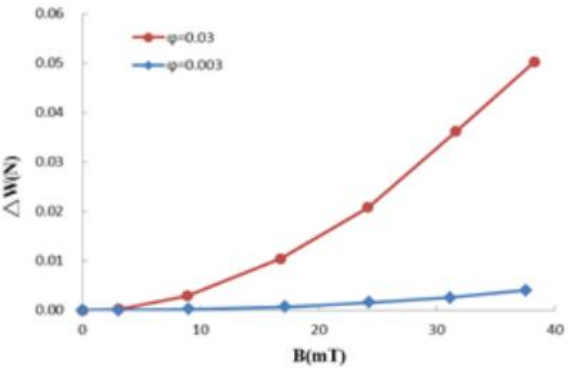

Figure 4. Weight-increment vs. mgnetic field for ψ0.04 and 0.004 at 25℃

At present, the discussion of ferro-weight comparable to volumetric concentration as well as field intensity has been done. Next we will proceed to understand the surface tension coefficient evaluated from o-ring pulling method and Rayleigh theory proposed, In Fig.5, empirical solution 0.03~0.08 N/m compatible with theoretic solution 0.03~0.07 N/m is achievable for volumetric concentration ψ0.033 while the working region of 0 mT~40 mT is imposed. As for the ferro-case of ψ0.0033 is experimented, a smaller variation of 0.03~0.035 N/m ,without obvious variation, will be obtained. Here both surface tension coefficients seem to be independent to field, but closely depends on the ferro-concentration.

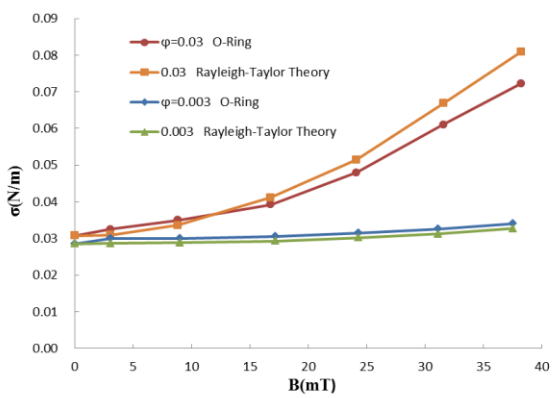

Figure 5. Surface tension vs. magnetic field for ψ0.04 and 0.004 at 25℃

5. CONCLUSIONS

Dissimilar to previous conventional hydraulic experiment, the modified o-ring pulling method, proposed in this study, makes ferro-empirical method become feasible to deal with the surficial tension on ferro-hydrodynamic boundary problem. By which, calculated capillary force, closely related to ferro-concentration, seems to be unnecessary as a function of field intensity while ferro-sample of low concentration is in use. Although experimental and theoretic solutions are found to be in agreement during the working region of 0~40 mT, an unstable ferro-surface tension, arisen from magnetic Brownian motion, will lead to the deviation of experimental and analytic results under the action of higher field. That attributes to Rayleigh model without the consideration of Brownian motion. In addition, the general Rayleigh model, with further arrangement, could be further simplified to become a static formulation approaching to the study of ferro-surface tension in this article.

NOMENCLATURE

$A^{'}$	area of the magnet [m^2]
B	induced magnetic field [mT]
H	magnetic field intensity [A/m]
K	plank's constant
M	instant ferro-magnetization [A/m]
M_o	instant magnetization at the surface of ferrofluid [A/m]
$\overline{M}^{-}$	axial field-average magnetization [A/m]
P_m	induced magnetic pressure [Pa]
T	absolute temperature [K]
V	volume of ferro-particle [m^3]
U_a	travel velocity of air film [m/s]
U_b	travel velocity of ferro-sample film [m/s]
a	thickness of air film [m]
g	gravity acceleration [m/s^2]
b	thickness of ferro- film [m]
g_m	magntic induced gravity [m/s^2]
k_y	directional wave number in y component
h	Initial height of test sample [m]
Δh	test sample elevated up [N]
$\Delta w^{'}$	apparent weight loss due to testing sample lifted up [N]
Δw	the increment of apparent weight [N]
ρ_a	density of air [kg/m^3]
ρ_b	density of ferro-sample [kg/m3]
μ_0	permeability of free space
μ_a	permeability of air [Henry/m]
μ_b	permeability of ferro-sample[Henry/m]
ϕ	volumetric fraction of particles or concentration of ferrofluid
ω	oscilation frequency [Hz]

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