

Surface Tension Measurement of Melted Metals and Slag by the Methods of Image Analysis¹

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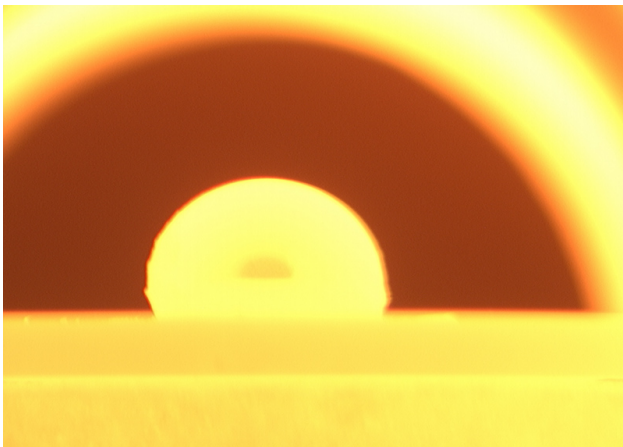
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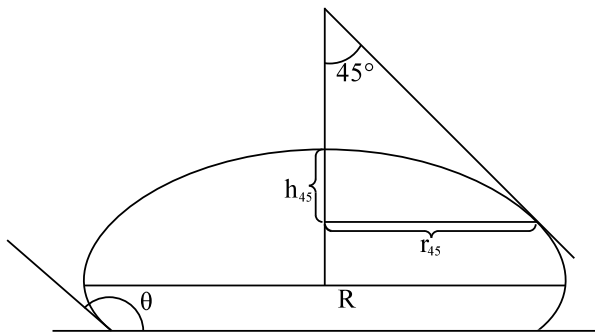
Motivation

- surface tension – another way of measuring quality of materials, solders, fuels, iron, ink (printing)
- measuring HOT materials like melted metals
- these materials will be used in production



Traditional Method

- hand measuring with ruler (1927)
- error prone



Introduction

- Axisymmetric Drop Shape Analysis (ADSA)
- determining the surface tension from the image
- concentrated on efficient image processing
- glass vane of the furnace, hard to see objects inside

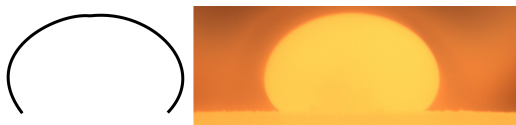


Method Overview (I)

- drop profile driven by the Laplace–Young equation

$$p = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = 2\gamma H$$

- fitting this equation to the profile of the drop



- fitting is highly dependent on quality of extracted drop shape
- small difference in drop shape results in big deviation in result (hand measurement)

Method Overview (II)

- Laplace–Young equation rewritten to system of differential equations
- functions of the arc length s

$$\begin{aligned}\frac{dx}{ds} &= \cos \varphi, \\ \frac{dy}{ds} &= \sin \varphi, \\ \frac{d\varphi}{ds} &= 2b + cy - \frac{\sin \varphi}{x}\end{aligned}$$

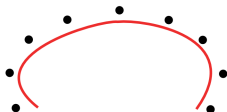
- fitting theoretical profile that is not explicitly solvable to the extracted drop shape

Fitting

Objective function

$$E(\mathbf{x}_0, \theta, b, c) = \sum_{\mathbf{x} \in \Omega} w(\mathbf{x}) d^2(\mathbf{x}, \mathcal{L}(\mathbf{x}_0, \theta, b, c))$$

- minimize error of the fitting
- minimized value is sum of weighted normal distance between picture points (contour) and theoretical Laplacian profile
 - more points than hand driven measurement
- Levenberg–Marquardt method for minimization
 - searching parameters
 - in every step, computing PDEs



Stage 1 - Finding the Drop

- finding and recognizing the drop and its boundary
- estimation of approximate height of the drop
- contour segments are found (horizontal and vertical segmentation)
- testing size of found objects
- whole contour is sum of all other contours

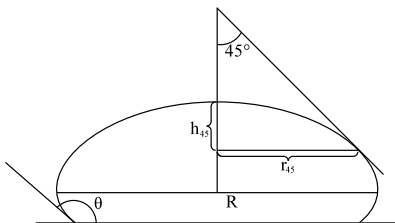


Stage 2 - Preliminary Determining the Surface Tension

- Dorsey method
- approximate expression of Laplace–Young equation
- computation of approximate surface tension
- result used in the 3rd stage

$$\gamma = \left(\frac{0.052}{q} - 0.1227 + 0.0481q \right) R^2 g \rho$$

where q is $q = \frac{r_{45} - h_{45}}{R} - 0.4142$



Stage 3 - Precisely Determining the Surface Tension

- use determined parameters from 2nd stage to initialize minimization
- iteratively fitting theoretical profile to the extracted contour



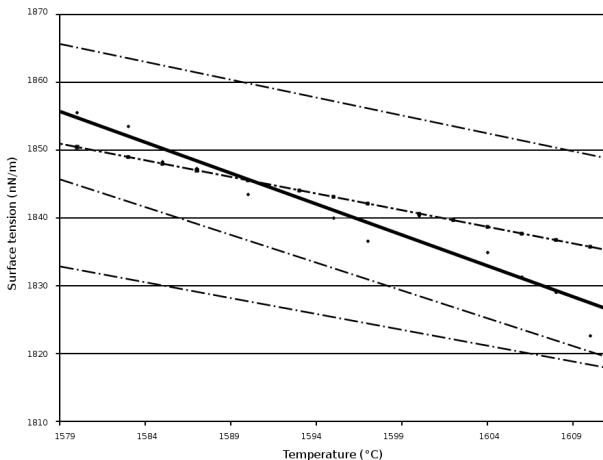
Achieved Results

- Mercury (Hg) taken as a testbed
- surface tension not precisely known yet
- only estimation is available $\langle 465; 485 \text{ mN/m} \rangle$
- our results fit the estimated interval of the surface tension

Measurement	Surface Tension [mN/m]
1	469.72
2	470.08
3	469.35
4	465.37






Achieved Results

- melted iron



our measurement - solid line, measurements from [4] - dashed lines

Thank You

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