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The Plateau Method

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10.1 Introduction

The Plateau method has been called from the Belgium physicist Joseph Plateau. The method originates from an accidental event in 1840, when an assistant leaked some oil into a container filled with a mixture of water and alcohol. Plateau observed that the drops of oil shaped into perfect spheres in the mixture. The densities of both water–alcohol and oil phases were indeed matched by chance, thus cancelling by buoyancy the weight of the oil drop.

10.2 Principle

The method of density matching between two immiscible phases was originally devoted to mixture of oil (the inclusion) in fully miscible water–alcohol mixtures (the host phase) [1–2]. Density of the water–alcohol host phase can be finely adjusted by varying the concentration of alcohol.

This method can be directly generalized to any method of density matching between two immiscible or partially miscible phases. Solid phases in a liquid (host) phase can also be compensated by buoyancy. The host phase has thus to be finely adjusted by different means as e.g. using completely miscible mixtures with variable concentration.

In the method, weight is compensated by buoyancy such that

$$g\Delta\rho = \varepsilon. \quad (10.1)$$

with $\Delta\rho = \rho_I - \rho_H$ the difference of density between the levitated, inclusion phase (density ρ_I) and the density-varied liquid host phase (density ρ_H). ε is a constant which has to be made as small as possible. g is the Earth's gravity acceleration constant.

In order to give an example, let us consider an investigation that needs a steady milli-*g* environment with two phases of density difference on order $\Delta\rho \sim 100 \text{ kg m}^{-3}$. Here, $\varepsilon \sim 1 \text{ N m}^{-3}$ and the same environment in Earth-bound situation will correspond to a steady density matching on order $\Delta\rho \sim 0.1 \text{ kg m}^{-3}$.

The host phase is made with two components 1, 2 whose mass concentration of component 1, c , is varied to have density ρ_H of the host phase adjusted. Assuming the additivity of volume, which is valid for small c , one obtains

$$\frac{1}{\rho_H} = \frac{c}{\rho_1} + \frac{1-c}{\rho_2} \quad (10.2)$$

The accurateness of the weight compensation can also be estimated by the value of the Bond number Bo . It compares the capillary to gravity forces and can be expressed by comparing the typical size R of the inclusion to the capillary length $l_c = (\frac{\sigma}{g\Delta\rho})^{1/2}$ (σ is the interfacial tension):

$$Bo = \left(\frac{R}{l_c}\right)^2 = \frac{\Delta\rho R^2}{\sigma} g \quad (10.3)$$

Small values of the Bond number thus correspond to a high efficiency of the weight compensation. It is worth noting that for the same Bond number value, one can either reduce g or $\Delta\rho$ such that the product g or $\Delta\rho$ keeps constant, in a way similar to buoyancy reduction as in Equation (10.1).

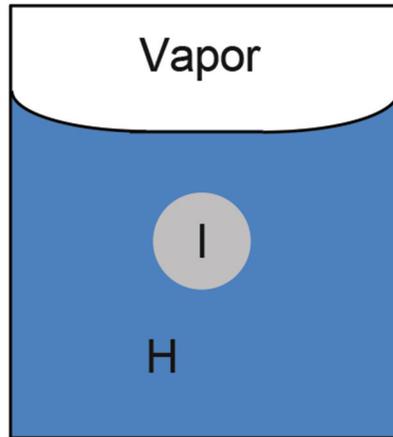


Figure 10.1 The Plateau principle. I: inclusion phase. H: host phase, made of miscible liquids whose density is adjusted by varying its concentration to match the inclusion density.

Density matching has thus to be carefully and finely adjusted by varying the concentration of a component of the host liquid. This gives a number of constraints on the method. They are concerned with temperature, aging due to the miscibility of one of the components with another (e.g., oil in alcohol), preferential evaporation of one of a component, and the general requirement of having the smallest possible variation of key parameters, for example, hydrodynamic, thermodynamic, or optical properties when varying concentration. To face these difficulties, a number of improvements have been considered. They are mainly concerned with using sets of isomeric and homologous organic compounds to match the density of pure water [3], mixtures of isotopes (cyclohexane and deuterated cyclohexane [4], water and heavy water [5]). These constraints have to be matched with other constraints specific to the experiment concerning, for example, the values of surface tension, viscosity, refractive index, etc. This method has been successfully used in the past to study the stability of liquid bridges [6], the influence of sedimentation on colloidal coagulation [5], or phase transition very near a liquid–liquid critical point [4].

10.3 Temperature Constraint

In order to achieve a density control on order of 0.1 kg m^{-3} , temperature has to be maintained constant. Typically, the temperature density variation is on order $1 \text{ kg m}^{-3} \text{ K}^{-1}$, which means that a temperature control on order $\pm 0.1 \text{ }^\circ\text{C}$ is needed. Note that this temperature constraint gives also a further limitation on the study of phenomena where larger temperature variations are observed, for example boiling and thermocapillary motion.

In order to keep levitated the inclusion phase over a larger temperature range, one can try to also fit the temperature density variation of both inclusion and host phases. With $\alpha_i = \left(\frac{\partial \rho}{\partial T}\right)_p$ the density thermal expansion coefficient for component $i = 1, 2$, one has

$$\rho_i = \rho_{i0} + \alpha_i (T - T_0) \quad (10.4)$$

Here, T_0 is a reference temperature, where component density is ρ_{i0} . From Equation (10.2), one gets the thermal derivative of the host phase:

$$\alpha_H = c \left(\frac{\rho}{\rho_1}\right)^2 \alpha_1 + (1 - c) \left(\frac{\rho}{\rho_2}\right)^2 \alpha_2 \quad (10.5)$$

Making $\alpha_H = \alpha_I$ necessitates a careful choice of the host components to fulfill both density matching over a large range of temperature. An example is known in a partially miscible liquid mixture of methanol and partially deuterated cyclohexane. The levitation of the methanol (inclusion) phase is ensured over a large range of temperature in a cyclohexane +5.5% partially deuterated cyclohexane mixture (host phase) as $\alpha_H = -0.96 \text{ kg m}^{-3} \text{ K}^{-1}$ and $\alpha_I = -0.95 \text{ kg.m}^{-3} \text{ K}^{-1}$.

10.4 Other Constraints

In the classical Plateau method where three components are present (oil, water, alcohol), there is a significant change of density matching with time as alcohol either evaporates or mixes with the oil phase. To overcome this difficulty, a number of improvements have been proposed:

Using only two immiscible liquids of equal density. A large number of transparent organic liquid pairs immiscible with water have been listed with their physical data in Refs. [3, 7]. Such compounds are numerous, but most show some miscibility with water (e.g., dibutyl phthalate or isobutyl benzoate). However, with only two components, fine density adjustment can be made only by temperature changes to improve the tuning.

Using sets of isomeric and homologous organic compounds. The compositional change with time can be diminished by using sets of isomeric and homologous organic compounds to match the density of pure water [3].

10.5 Concluding Remarks

The Plateau method, based on density matching, is appealing by its simplicity for compensating buoyancy on Earth. It is, however, limited to mixture of immiscible liquids and to solids in liquids. A number of difficulties have to be overcome to obtain reliable data, for example, the difference of temperature variation of host and inclusion phase densities, weak miscibility between phases, and differential evaporation of phases. These difficulties can in general be solved, which makes the Plateau method a very useful and largely employed technique for compensating gravity on Earth.

References

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