

INSTABILITY AND TRANSFER AT LIQUID/LIQUID METAL INTERFACE SUBMITTED OR NOT TO THE ACTION OF A MAGNETIC FIELD. PART II

M. Al Radi, G. Cognet

*LEGI/PAMIR – CNRS/INPG, BP 53, 38041 Grenoble Cedex 09, FRANCE
(Mahmoud.alradi@hmg.inpg.fr, gerard.cognet@ensqi.inpg.fr)*

Introduction. A flow of liquid (aqueous solution) is realized in a cylindrical vessel with a rotating lid and a fixed bottom. A small annular channel is carved at the bottom and filled with a liquid metal (gallium) (Fig. 1). This metal is submitted or not to a rotating magnetic field according the same symmetrical axis as the vessel.

We observe similar transfer laws in the solid/liquid and liquid/liquid cases for laminar flow by using experimental, numerical and analytical means; on the contrary it results a great difference in turbulent flow. This important feature is interpreted by the occurrence of waves at the liquid/liquid interface which strongly increases the transfer.

We treat the occurrence of the periodic instability following a Kelvin-Helmholtz type analysis; and we show from the experiments the dominating role of the interfacial tension and viscosity over instability.

The influence of a magnetic field on the characteristics of the flow is also discussed.

1. Instability and mass transfer at liquid/liquid interface. The electro-diffusional method is used for mass transfer measurements between the liquid solution with active ions and the electrode mounted flush to the wall [5]. In that study the electrode is made of Gallium which is in solid or liquid state depending on the temperature (melting point: 29.8°C). The flow is realized in a cylindrical vessel with a rotating lid and a fixed bottom where is located the ring-shaped electrode. According these experimental conditions the transfer data are registered and discussed in connexion with the interfacial instability. Under the control, or not of a magnetic field.

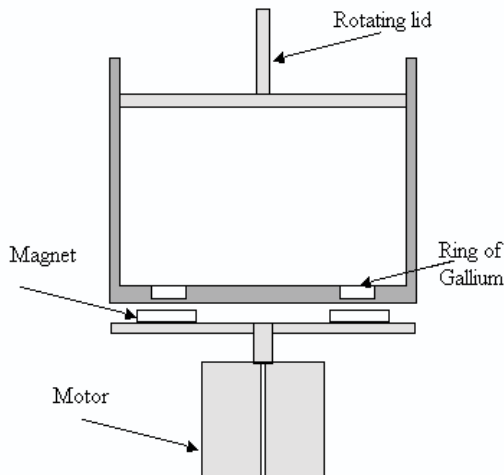


Fig. 1. Device with rotating magnetic field.

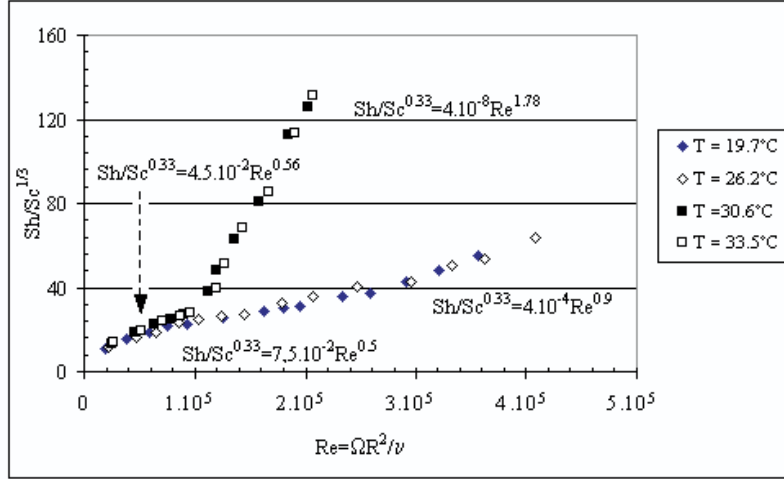


Fig. 2. Non-dimensional mass transfer vs Reynolds number. Two cases of interface: solid/liquid and liquid/liquid.

As the rotation of the lid is progressively increased from a critical speed one observes the appearance and growth of regular waves at the liquid/liquid interface (on the surface of the liquid-metal ring). From the beginning the amplitude of the waves is nearly negligible (Fig. 3a) then becomes significant (Fig. 3b); that produces a sharp change in the mass transfer power law:

$$\text{Sh}/(\text{Sc})^{1/3} = a\text{Re}^b$$

Through the development of the instability the power exponent **b** is suddenly increased from 0.56 to 1.78 (Fig. 2).

The waviness of the interface is obviously an amplifying factor for the transport phenomena between the two liquids. We propose to consider that it is the resulting effect of three contributions

- The waves increase the surface of exchange compared to the smooth interface
- The renewal of the liquid layers is favoured along the wavy interface and enhances the mass transfer.
- The amplitude of the waves is similar to a parameter of roughness, which has a disturbing effect on the rotating fluid near the bottom of the vessel and consequently increases the mass transfer.

For a more complete analysis it should be necessary to consider these contributions in 3D flow conditions, which represent a more efficient but more complex situation for the mass transfer compared to the 2D model which was used.

This simple model was built, adapted from the principle of Kelvin-Helmholtz instability in which the surface tension and the viscosity of the two fluids are taken into account [1]. It is representative of the experimental results near the critical point and the first stage of amplification of the waves at the interface. The pictures (Fig. 3a, b, c, d) obtained for increasing rotational velocity of the bulk flow ($\omega = 1.9; 3.4; 7.0; 12.3$ rad/s), point out the appearance of 2D travelling waves, the growth of their amplitude with progressive development of 3D perturbations.

This evolution shows the non-linear effects of the waves on the circular flow which is at first purely periodic and progressively contains harmonics then spots with turbulent features. In that way the transition from smooth plane to nearly chaotic interface between the two liquids is observed through a large range of

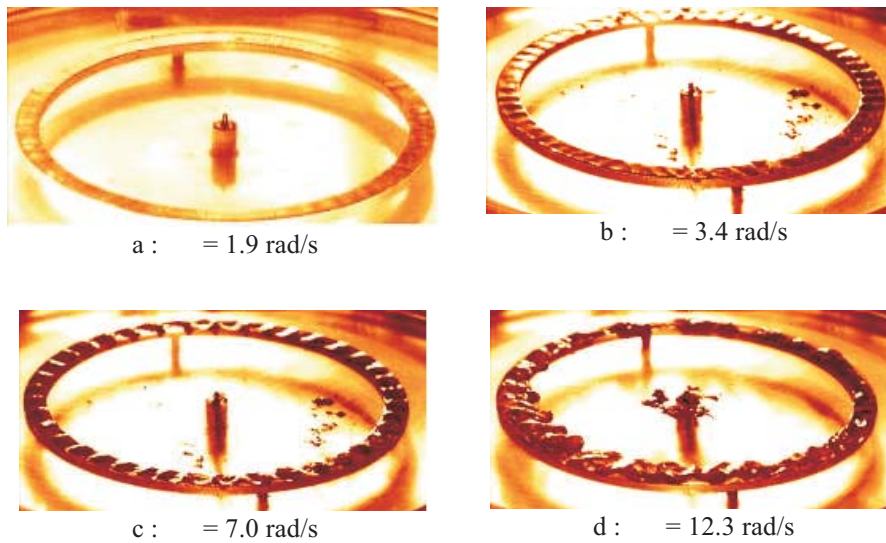


Fig. 3. Interface instability in relation with rotational velocity of bulk flow.

Reynolds numbers. From this point of view this “two-phase” flow looks similar to dynamic systems with few degrees of freedom and/or with a high degree of symmetry (for example: Taylor–Couette flow or Rayleigh–Bénard instability). So that critical speed from which a change occurs in the mass transfer law can be interpreted as a bifurcation point. Consequently it is interesting to test the influence of a second control parameter on this (non-linear) flow system.

2. Instability control: influence of a magnetic field. One uses magnets displayed on a rotating disk under the vessel (Fig. 1). In that way the gallium ring is submitted to a periodic rotating magnetic field which is active for damping or amplifying the waves when the interfacial instability occurs. The influence of this control parameter has been identified according the time period and the sense of rotation. The effect upon the wavy regime is clearly shown on the Fig. 4 , where the magnetic field reduces the amplitude of the waves, until they nearly disappear.

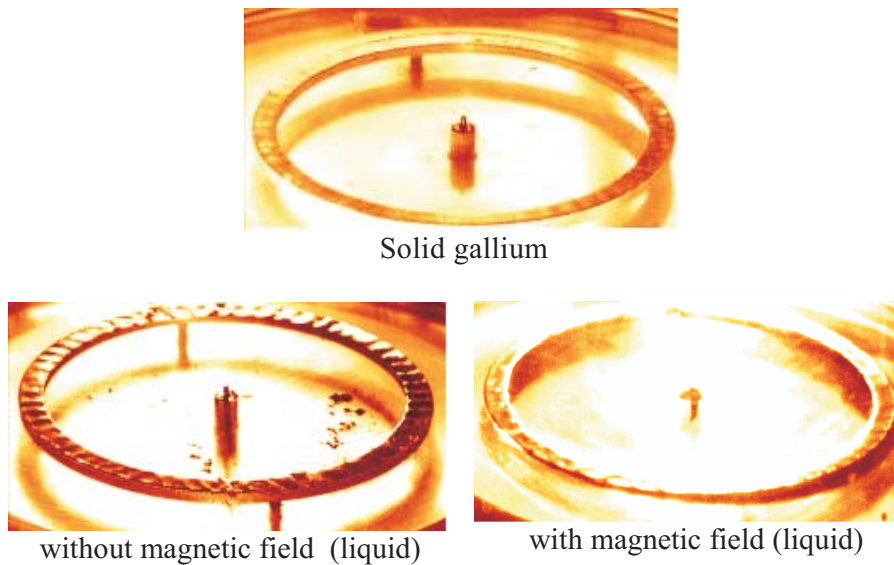


Fig. 4.

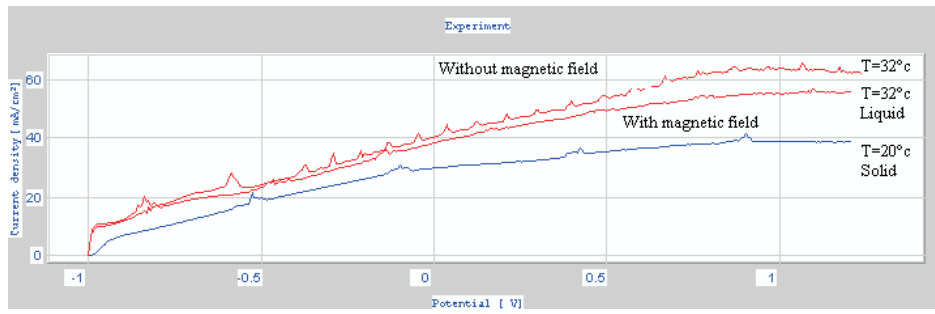


Fig. 5. Influence of the magnetic field on the interface mass transfer.

The result on the mass transfer is pointed out on the mass flux recording obtained with or without magnetic field. (0–0.5 T). In that case the mass transfer is reduced by 20% when the magnetic field is imposed to the liquid gallium ring (Fig. 5).

3. Conclusion. This study clearly shows the interest of coupling transfer measurement and instability analysis of liquid-liquid two-phase flow. The electro-diffusional technique is particularly convenient in that case. The mass transfer through a liquid/liquid interface is identified in connexion with stability criteria. Wavy instability corresponds to a great change in the transfer law which explains very important phenomena.

The action of a control parameter (varying magnetic field) demonstrates the richness of this non-linear flow system.

REFERENCES

1. M. ALRADI. Contribution à l'analyse des phénomènes de transfert et d'instabilité à une interface liquide/liquide. Thèse de Doctorat INPG, 2004.
2. M. ALRADI, G. COGNET. Instability and transfer at liquid/liquid metal interface submitted or not to the action of a magnetic field. *Magnetohydrodynamics*, vol. 39 (2003), no. 3, pp. 315–320.
3. M. DAGUENET, F. AOUANOUK, G. COGNET. Calcul du flux limite de diffusion sur la surface d'une sonde circulaire située dans le plan d'un disque tournant. *C. R. Acad. Sc. Paris*, vol. 2714 (1970), pp. 328–331.
4. T. FUNADA, D.D. JOSEPH. Viscous potential flow analysis of Kelvin-Helmholtz instability in a channel. *J. Fluid Mech.*, vol. 445 (2001), pp. 263–283.
5. M. SOUHAR, G. COGNET. Measuring Techniques in Gas-Liquid Two Phase Flows. In *IUTAM Symposium*. (Nancy, 1983, Springer Verlag), pp. 723–744.