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KANDLIKAR THIRD NUMBER MAP FOR FLOW BOILING IN MICRO-CHANNELS AND MICRO-GRAVITY

by

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As an extension of the recent work of Baldassari and Marengo, this note presents Kandlikar third number map for flow boiling in micro-channels and micro-gravity. Using several data points available in the literature, Kandlikar third number map was plotted vs. the hydraulic diameter as the characteristic dimension for flow boiling in micro-channels and micro-gravity. The ranges of the Kandlikar third number, calculated using the hydraulic diameter, are presented.

Key words: *two-phase flow, flow boiling, micro-channels, micro-gravity, Kandlikar third number*

In the 21st century, studies on flow boiling in micro-channels have gained significant attention in engineering community. Flow boiling in micro-channels is a necessary option for cooling high heat flux micro-devices. In recent years, there is an increasing use of micro-channels in the industry to yield compact geometries for heat transfer. Due to their large heat transfer surface area, the use of micro-channels can result in relatively high heat transfer coefficient when compared with the application at macro-scales. In many applications related to the refrigeration and air conditioning, micro-channels can be viewed as being responsible for the mitigation of environmental influences by enabling the use of smaller amounts of fluids. Also, flow boiling experiments under micro-gravity conditions are useful to understand of interfacial structures and heat transfer for the phenomena on ground in addition to their application to the innovative two-phase thermal management systems for the future space development. Recently, Baldassari and Marengo [1] presented a review article on flow boiling in micro-channels and micro-gravity. The researchers plotted maps of non-dimensional numbers employed in micro-channels flow boiling experiments in normal and in micro-gravity conditions *vs.* the hydraulic diameter (d_h) as the characteristic dimension. These non-dimensional numbers were Eotvos number (Eo), Weber number if total flow (liquid plus vapor) assumed to flow as liquid (We_{LO}), Weber number if total flow (liquid plus vapor) assumed to flow as vapor (We_{VO}), capillarity number if total flow (liquid plus vapor) assumed to flow as liquid (Ca_{LO}), Reynolds number if total flow (liquid plus vapor) assumed to flow as liquid (Re_{LO}), Reynolds number if total flow (liq-

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uid plus vapor) assumed to flow as vapor (Re_{VO}), boiling number (Bl), Kandlikar first number (K_1) and Kandlikar second number (K_2).

In the present note, the author would like to add a map of Kandlikar third number (K_3) values explored in the literature on flow boiling because Baldassari and Marengo [1] presented only Kandlikar first number (K_1) and Kandlikar second number (K_2) as non-dimensional numbers relevant to two-phase studies in micro-channels. In his reply to the discussion of Awad [2], Kandlikar third number (K_3) was derived recently by Kandlikar [3]. The new non-dimensional constant, K_3 is defined as [3, 4]:

$$K_3 = \frac{\text{Evaporation momentum force}}{\text{Viscous force}} \tag{1}$$

and represents the ratio of the evaporation momentum force, and the viscous force. Kandlikar [3] mentioned that this non-dimensional group K_3 had not been independently used yet, but it was relevant if the evaporation momentum and viscous forces were considered in a process. K_3 could also be represented as [3, 4]:

$$K_3 = K_1 \, Re_{LO} = \frac{K_2}{Ca_{LO}} \tag{2}$$

In his summary, Kandlikar [3] mentioned that recognizing the evaporation momentum force as an important force during the boiling process opened up the possibilities of three new relevant non-dimensional groups, K_1, K_2, and K_3. Any two of these groups could be represented by combining the third one with one of the other relevant non-dimensional groups Re_{LO}, We_{LO}, and Ca_{LO}. As a results, Kandlikar third number (K3) map of data in literature can be added to the list of figures of Baldassari and Marengo [1] using the above relation. This can be done using two different ways as shown in eq. (2). First, the values of Kandlikar first number (K_1) are multiplied by the values of Reynolds number if total flow (liquid plus vapor) assumed to flow as liquid (Re_{LO}). Second, the values of Kandlikar second number (K_2) are divided by the values of capillarity number if total flow (liquid plus vapor) assumed to flow as liquid (Ca_{LO}). Figure 1 presents K_3 map of data in literature. Also, Kandlikar third number map of only micro-gravity literature data can be added to the list of figures of Baldassari and Marengo [1] using the eq. (1) as presented in fig. 2.

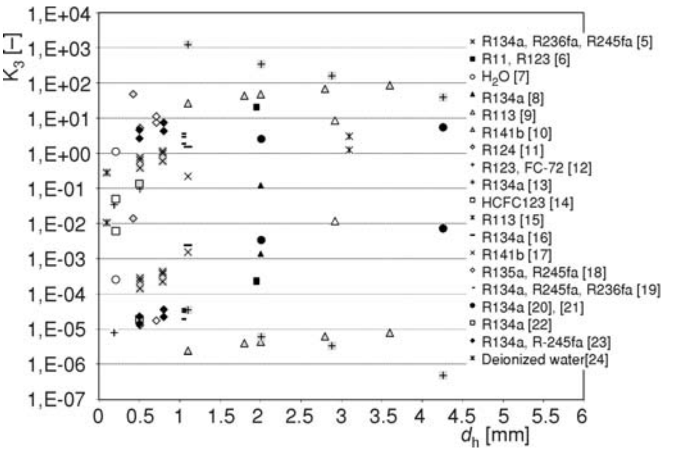

Figure 1. K_3 number map of data in literature

In figs. 1 and 2, the ranges of the Kandlikar third number, calculated using the hydraulic diameter (d_h) as the characteristic dimension, are presented. For K_3 number map of data in literature as shown in fig. 1, the maximum and minimum values of the Kandlikar third number, are obtained for Chen *et al*. data [13] in circular tubes with internal diameters of 1.10 and 4.26 mm using

R134a as the working fluid. For K_3 number map of only micro-gravity literature data as shown in fig. 2, the maximum and minimum values of the Kandlikar third number (K_3), are obtained for Ohta data [28] in test section of 8 mm diameter using R-113 as the working fluid.

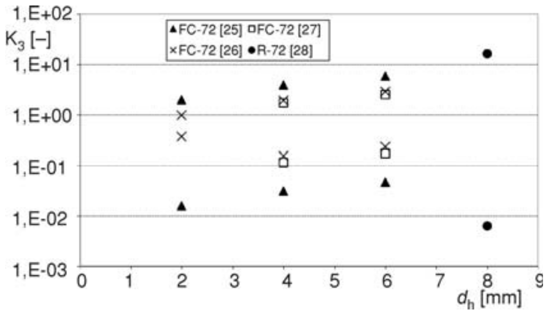

Figure 2. K_3 number map of only micro-gravity literature data

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Nomenclature

Ca – capillarity number, [–]
K_1 – Kandlikar first number, [–]
K_2 – Kandlikar second number, [–]
K_3 – Kandlikar third number, [–]
Re – Reynolds number, [–]

Subscripts

LO – total flow (liquid plus vapor) assumed to flow as liquid
VO – total flow (liquid plus vapor) assumed to flow as vapor

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