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A methodology to select the experimental plant instrumentation based on an a priori analysis of measurement errors and instrumentation cost ☆

R. Mastrullo [a], A. Rosato [a,*], G.P. Vanoli [b], J.R. Thome [c]

[a] D.E.TE.C., Facoltà di Ingegneria, Università degli Studi di Napoli Federico II, p.le Tecchio 80, 80125 Napoli, Italy
[b] Dipartimento di Ingegneria, Università degli Studi del Sannio, corso Garibaldi 107, Palazzo dell'Aquila Bosco Lucarelli, 82100 Benevento, Italy
[c] Laboratory of Heat and Mass Transfer (LTCM), Faculty of Engineering (STI), École Polytechnique Fédérale de Lausanne (EPFL), Station 9, Lausanne, CH-1015, Switzerland

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Abstract

An experimental apparatus for evaluating carbon dioxide local heat transfer coefficients during flow boiling has been set up at University of Naples Federico II. In this paper, the local heat transfer coefficient measured is evaluated relative to the measurement error, varying the type and costs of the instrumentation. The analytical analysis has been performed prior to construction of the test facility. The main aim of the work is to provide a methodology that allows one to reach the best compromise between measurement accuracy and financial resources in the selection of the instrumentation.

Keywords: Error analysis; Instrumentation; Heat transfer coefficient; Cost

1. Introduction

> "...I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be...".

Sir William Thomson had already said these words in the year 1883, recognizing the fundamental significance of the quantitative description of the physical world by doing experiments and making measurements.

However, it is important to understand how to analyze and draw meaningful conclusions from it. If the result of a measurement is to have any meaning, it cannot consist of the measured value alone. An indication of how accurate the result is must also be stressed. Along with the result, it is therefore essential to provide some indication of the measurement error. Without this indication, it is impossible to quantify the reliability of the test data and to compare the data to similar results obtained in different laboratories or found in the same laboratory by using different methods. To underestimate the measurement error, indeed, may result in technical problems in subsequent applications. On the contrary, to overstate the measurement error diminishes the measurement quality, obtained perhaps thanks to expensive equipment and complex methods.

Notably, error analysis can be very useful in the design phase of a test facility. Indeed, before constructing a test facility, it can be used to help choose the most reliable technique for a given measurement [1] or to identify the importance of measuring systems and thereby determine where expensive measuring systems are required and where they are not.

2. Aim of the work

Increased concern about the environmental impact of refrigeration technology is leading toward design solutions aimed

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* Corresponding author.
E-mail address: antonio.rosato@unina.it (A. Rosato).

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at improving the energy efficiency of the related applications, using eco-friendly refrigerants, i.e. ozone-friendly and with the least possible greenhouse effect [2,3], and minimizing the charge. In this respect, carbon dioxide is seen today as one of the most promising refrigerants and is raising great interest in industrial and scientific fields [4–6]. However, to maximize the performance of vapor compression systems, a detailed analysis of the heat exchangers is of particular importance. To optimise the design of the evaporators and condensers, the accurate knowledge of heat transfer coefficients is fundamental. An experimental apparatus for evaluating CO_2 local heat transfer coefficients during flow boiling in a circular, horizontal, smooth, stainless steel tube has been set up at University of Naples Federico II.

In this paper, the relative measurement errors of the CO_2 local heat transfer coefficient measurements are evaluated varying the type and cost of the instrumentation. This analytical analysis has been performed before the construction of the test facility taking into account only the measuring system errors and neglecting the system-sensor interaction errors (they cause the achieved value of the measurement in the sensor to be different from the available value of the measurement where the sensor is located at that given time) and the system disturbance errors (these are due to the fact that the presence of a sensor changes the system). The identification and estimation of measuring system errors has been based on manufacturers' specifications.

The main purpose of this study is to suggest a methodology usable to select the instrumentation in order to reach the best compromise between measurement accuracy and financial resources.

3. Propagation of errors

Frequently, the result of an experiment will not be obtained directly. Rather, the measurand Y depends upon a number of input quantities $X_1,\ldots, X_N$ according to the functional relationship f:

$$Y = f(X_1, \ldots, X_N) \quad (1)$$

Let $x_1,\ldots, x_N$ be the measured values of $X_1,\ldots, X_N$. Substituting $x_1,\ldots, x_N$ in Eq. (1), it is possible to obtain an estimation y of the measurand Y. The absolute measurement error δy associated to the evaluation of y can be calculated as the root-sum-squared combination of the absolute measurement errors $\delta x_1,\ldots, \delta x_N$ associated to the evaluation of $x_1,\ldots, x_N$ [7], if $\delta x_1,\ldots, \delta x_N$ are independent and casual, so that:

$$\delta y = \sqrt{\left(\frac{\partial y}{\partial x_1}\delta x_1\right)^2 + \ldots + \left(\frac{\partial y}{\partial x_N}\delta x_N\right)^2} \quad (2)$$

Eq. (2) is known as the general formula for the propagation of errors.

4. Experimental apparatus

A schematic view of the plant is shown in Fig. 1. The refrigerant loop consists of a magnetic gear pump, a preheater, a diabatic test section, an adiabatic test section, a shell and tube heat exchanger, a plate heat exchanger, a tube in tube subcooler and a liquid reservoir.

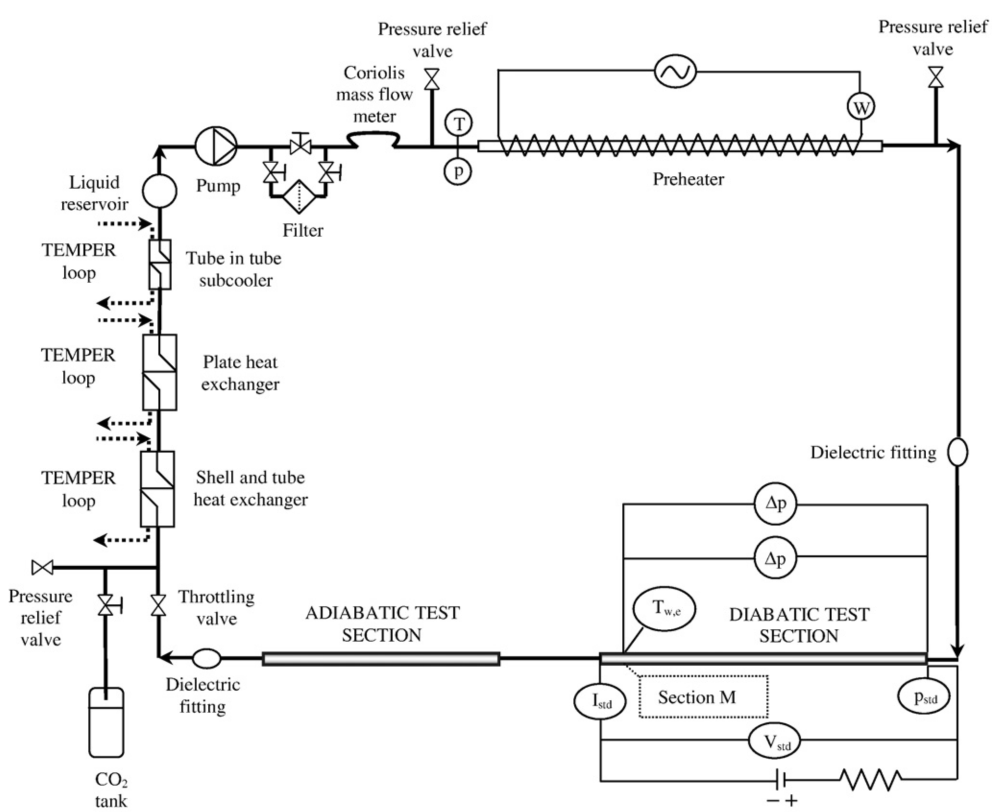

Fig. 1. Experimental apparatus.