CONDUCTION AND INERTIA CORRECTION FOR TRANSIENT THERMOCOUPLE MEASUREMENTS. PART I: ANALYTICAL AND NUMERICAL MODELLING

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ABSTRACT

Thermocouples are often used for temperature measurements. Under transient conditions, measurement errors can occur due to capacitive inertia and heat conduction along the stem of the thermocouples. The present study presents a correction of these thermocouple measurement errors caused by transient inertia and conductive effects using a simplified analytical approach and its numerical solution. Based on an energy balance the mathematical modelling is derived and analytically solved for specific boundary conditions. Further numerical discretizations have been implemented with different model complexities. Thereby the models show the significance of the necessary correction as well as the good agreement with theoretical considerations a corresponding experimental validation is continued in Part II.

INTRODUCTION

Thermocouples are the most commonly used measurement technique for local temperatures. The pairing of two different metallic wires generates a temperature-dependent voltage through the Seebeck effect. However, the sensor reading is always the temperature of the measuring tip and may differ from the actual temperature of the surrounding heat source. The thermal inertia of the thermocouple material and heat conduction along the thermocouple stem can cause measurement errors as shown in Fig. 1 for a temperature step change. Part I describes the analytical and numerical modelling of the thermocouple thermodynamics considering a simplified one-dimensional approach to correct such temperature measurement error. Due to transient thermal loads superimposed with capacitive inertial effects of the thermocouple a time-dependent correction is necessary.

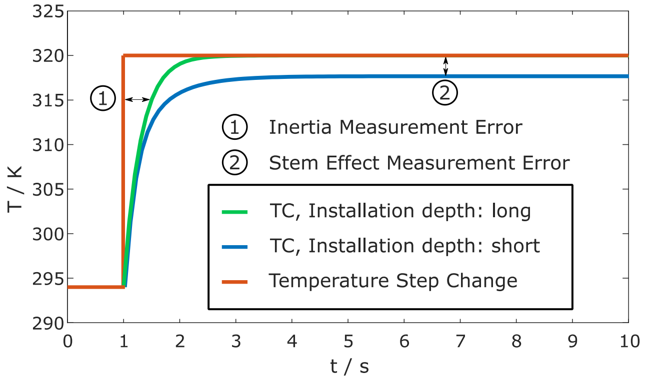


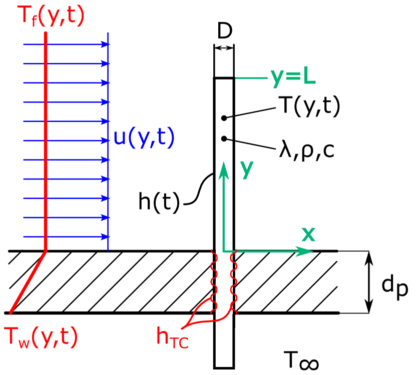
Figure 1. Numerically simulated temperature profiles for different installation depths of a temperature step change showing the qualitative behavior of the thermocouple measurement errors

RESULTS AND DISCUSSION

Considering a thermocouple (TC) installed into a test channel for fluid flow temperature measurements, an energy balance for an infinitesimal wire section is formulated by

$$\frac{\partial T\,(y,t)}{\partial t} - \frac{\lambda_{TC}}{\rho\, c}\frac{\partial^2 T\,(y,t)}{\partial y^2} - \frac{4\,h(y)\,[T_f(y)-T(y,t)]}{\rho c D} = 0. \tag{1}$$

In this context, heat is convectively transferred from the outer flow field onto the TC surface, whereas heat is constantly conducted by an equivalent TC conductivity λ_{TC} towards the stem end of the TC at ambient temperature as visualized in Fig. 2. Adopting constant fluid properties and a literature based [1] heat transfer coefficient h specific analytical solutions can be derived. In this regard taking into account the boundary conditions of an adiabatic tip of the thermocouple, the Dirichlet condition of an ambient temperature T_0 at the TC stem as well as the initial condition of $T = T_0$ two issues can be highlighted. On the one hand, dimensionless analytical solutions show that a simplified approach for inertia and stem effect correction cannot be represented by a single time function, which is commonly proposed for dynamic inertia correction [2]. On the other hand the applied boundary conditions do not sufficiently reflect the reality in the experimental setup or rather convoluted configurations cannot be solved analytically. Consequently, based on the analytical modelling a more flexible numerical solution is preferred where even complex multi-layered TC configurations are solved. However, also more simple approaches have been investigated numerically merging the bottom wall conditions into an effective convective wall contact coefficient h_{TC}. Fig. 1 concludes the analytical and numerical modelling applied on TCs of different installations depths within a channel flow imprinting a temperature step change.



d_p	Thickness plate
D	Diameter
h	Heat transfer coefficient
λ	Thermal conductivity
ρ	Density
c	Capacity
u	Velocity
T	Temperature

Figure 2. Schematic modelling of the investigated thermocouple

To sum up, the theoretical considerations are met fully by our numerical simulations, but still require experimental validation data. It is envisioned, that by an identification of various thermocouple types and reproducible installation procedures by their heat conduction coefficient λ_{TC} and convective wall contact coefficient h_{TC} a correction of the measurement errors can be generalized.

REFERENCES

[1] B. Weigand. *Analytical Methods for Heat Transfer and Fluid Flow Problems*. Second Edition. Springer. 2015.

[2] F. Bernhard. *Handbuch der Technischen Temperaturmessung*. Second Edition. Springer. 2014.