CFD-SUPPORTED DATA REDUCTION OF HOT-WIRE ANEMOMETRY SIGNALS FOR COMPRESSIBLE ORGANIC VAPOR FLOWS

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ABSTRACT

For obtaining turbulent fluctuations in compressible organic vapor flows, computational fluid dynamics (CFD) analysis tools were used to support the data reduction process of hot-wire anemometry signals. It was found that CFD can substantially contribute to the calibration process of actual hot-wire probes operated in the constant-temperature mode. Such an approach is beneficial for determining the dependency of the sensitivity coefficients on Reynolds and Mach numbers. Due to the small Kolmogorov scales, corrections are needed for probes with finite wire lengths. The experimental and numerical analysis considering the decay of turbulence downstream a grid indicated that a linear correction function based on the scheme proposed by Wyngaard led to consistent results for compressible organic vapors and air flows. Based on the new results, recommendations are provided for obtaining turbulent quantities of compressible organic vapor flows by means of hot-wire anemometry.

INTRODUCTION

The hot-wire anemometry (HWA) is still the most important tool for measuring turbulent fluctuations. However, a correct data reduction is inherently challenging, especially in compressible flows. The fundamental problem is that spatio-temporal fluctuations of velocity, density, and temperature affect a single scalar electrical output signal of a probe placed in a flow. Without further model assumptions of the flow and its turbulent behavior, it is not possible to resolve that issue. In particular, the finite length of wires introduces the need for corrections to cover the corresponding attenuation effect, as discussed by Smolyakov and Tkachenko [1].

Due to the high density, relatively small Kolmogorov scales are achieved in organic vapor flows consisting of complex molecules. Furthermore, flows of organic vapors in turbomachinery for organic Rankine cycle (ORC) power systems are typically characterized by compressibility and even non-perfect gas dynamics. All of these issues are increasing the difficulties of applying the hot-wire anemometry in such flows.

Since the advent of direct numerical simulations (DNS), large-eddy simulations (LES), and sophisticated turbulence modeling, it is now possible to study turbulent fluctuations and their impact on wires numerically in detail. Following this path, using reliable computational fluid dynamics (CFD) methods during the calibration and the data reduction process offers a chance to attack the fundamental metrological problem posed in HWA.

RESULTS AND DISCUSSION

In the present experimental and numerical study, a single hot-wire probe operated in the constant-temperature mode was considered as a representative working fluid for measuring turbulent fluctuations in a compressible flow of the organic vapor NOVEC 649 by 3M. The experiments were done in the test section of the closed-loop organic vapor wind tunnel CLOWT, see Figure 1.a. This test facility can be used for calibration of probes (Figure 1.b), and the wind tunnel operational envelope enabled, to a somewhat extent, the independent variation of Mach and Reynolds numbers and total temperature. As a practical test for HWA, the decay of turbulence downstream a grid was selected, too. The experimental study was combined with CFD analyses covering the flow and the heat transfer characteristics of wires placed in organic vapor flows (Figure 1.c). Furthermore, the applicability of the Taylor hypothesis and the possible impact of non-perfect gas properties on the turbulent spectra were theoretically considered.

The experimentally observed behavior of the sensitivity coefficients (namely, the practical identity of density and velocity sensitivities and their actual dependency on Mach and Reynolds numbers) was successfully simulated by CFD methods, see Figure 1.d. Based on the CFD study, it was possible to attribute the behavior of the sensitivities to the flow characteristics of the relatively high wire Reynolds number flows [2].

The high density of the organic vapor led to a relatively high Reynolds number for both wire and turbulence grid. Due to the resulting small Kolmogorov scale, corrections were needed to take into account the attenuation of high-frequency signals by using probes with finite wire lengths. The experimental and numerical analysis considering the decay of turbulence downstream a grid indicated that a linear correction function based on the scheme proposed by Wyngaard led to consistent results for compressible organic vapors and air flows. Based on the new results, recommendations are provided for obtaining turbulent quantities of compressible organic vapor flows by means of hot-wire anemometry.

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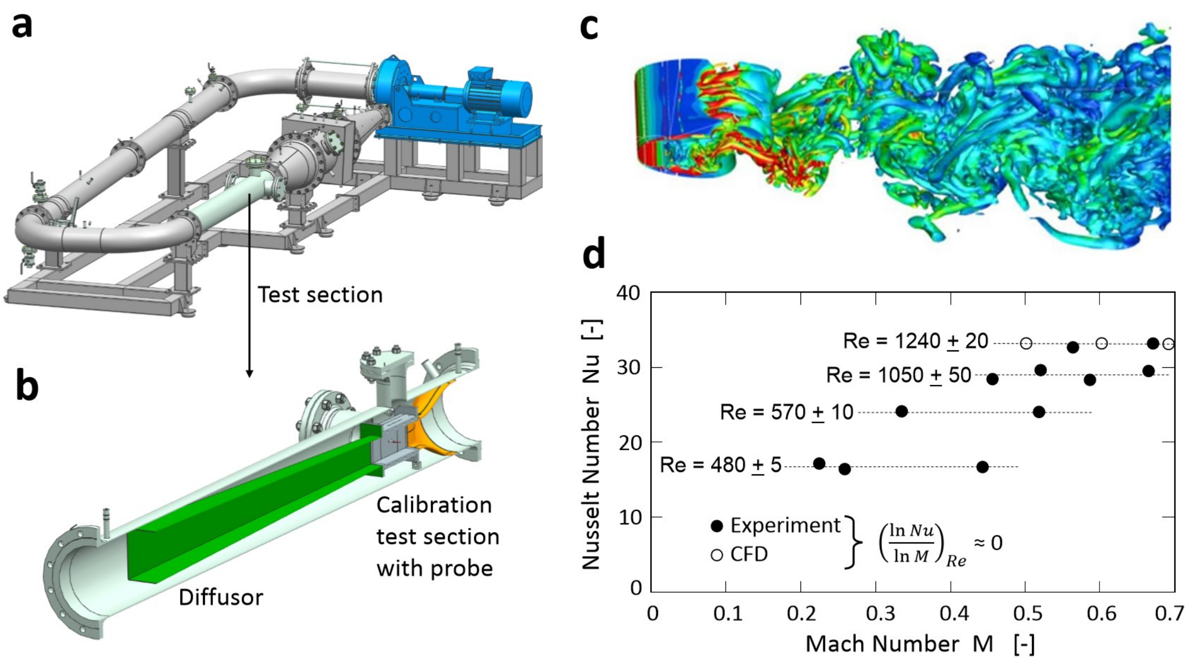

Figure 1. Illustration of the test facility used in the present study (a), details of the calibration test section (b), CFD simulation of flow past a hot-wire (c), and measured and computed Nusselt numbers for constant Reynolds numbers against Mach number (d)

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