On the relation between the scalar spectrum and the Stanton number in rough ducts

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Turbulent scalar transport is ubiquitous in both industrial applications and the environment. It is well known that rough walls can affect turbulent scalar transport significantly and thus affect the performance of heat transfer equipment or the dispersion of pollutants in atmospheric flows. Therefore, recent years have seen a renewed interest in the effect of roughness on scalar transport.[1,2,3] Most of the recent work focuses either on the characterization of turbulent quantities or the shape of the wall roughness function. In this work, a novel relation between the scalar spectral density and the Stanton number for flows past rough walls is presented. The derivation is based on a previously established relation between the friction factor and the energy spectrum.[4] By blocking different parts of the scalar spectrum[5,6] - the energetic, the inertial-convective, viscous- convective and diffusive range -, the role of scalar fluctuations of different sizes becomes clear. When considering only the viscous- convective and diffusive range of the scalar spectrum, the Stanton relation exhibits the following scaling with respect to the Prandtl number, $St \sim Pr^{-n}$, where $n = 0.43 = 0.47$. This finding matches well with results reported in literature[7] as well as results from direct numerical simulations with a Reynolds number of $Re_\tau = 360$, wall roughness sizes of $k_s/D = 0.02 - 0.08$ and $Pr = 1 - 6$. Additionally, analytical anlysis suggests that Stanton number data for rough channels should collapse onto a single curve when using two different non-dimensional groups, as is shown in figure 1. These results emphasize the importance of the smallest scales of scalar transport in understanding turbulent scalar transport in the presence of a rough wall.

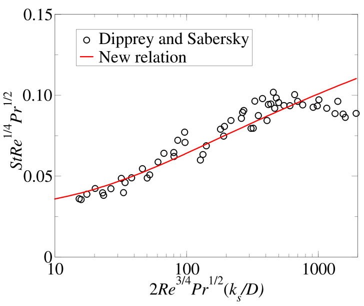

Figure 1: Experimental rough wall data[7] plotted using new non-dimensional groups. The new relation holds for when k_s is smaller than 36 times the Batchelor length scale.

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