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Counter-flow Microfluidics for Stable Flow Thermodynamics

NIEL CREWS, Louisiana Tech University

Microfluidic thermal reactors are able to achieve high temperature ramping rates due to their low thermal mass. Of these, the most thermodynamically efficient are flow systems that rely on a steady-state temperature distribution to induce temperature change of the moving fluid. Rather than inserting or extracting heat at controlled time intervals, the fluids are heated and cooled only through local heat transfer with the substrate material in which the microchannels are embedded. In addition to accelerated ramping and reduced energy consumption, such systems have the potential to provide greater control of the heating rates. This is because the temperature change is simply a function of the fluid velocity vector with respect to the stable temperature distribution within the material. However, the operation of such a system is complicated by the thermal perturbation that the fluid flow introduces into the system. When predicting the temperature change of the fluid, it is common to ignore the effect of the fluid flow on the original temperature distribution within the substrate. However, this has been shown to be the dominant behavior in many scenarios. This behavior is particularly problematic in polymeric microfluidic devices, where thermal conductivities are on the order of 0.2 W/m-K. This presentation will address a powerful solution to this thermal instability. By implementing a counter-flow microfluidic geometry, it will be shown how the temperature smearing common to microflow thermal reactors can be virtually eliminated. The deleterious effect of the insulative properties of popular polymer substrates is minimized, allowing for higher flow rates and temperature ramp rates. This is achieved by creating a preferred heat path for the thermal energy that is being driven into or out of the fluid during flow. Theory will be presented; experimental data will be discussed; application to lab-on-a-chip systems will be demonstrated.