Molecular Gas Flow in a Fish Trap Nozzle - Challenge to the Second Law of Thermodynamics

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Abstract

During examination of molecular gas flow in freeze dryers in near-vacuum properties, an idea came up to model a molecular fish trap nozzle (Figure 1). An appropriate shape of this fish trap nozzle allows to separate free flowing molecules into 2 chambers, and obtain a pressure gain in an isothermal environment (molecular flow "diode"). In the first point of view this behavior conflicts with the Second Law of Thermodynamics. But this is not the case. By focusing this problem on stochastic (molecular flow) scale, and not on continuum gas mechanics, there is no problem with any physics laws. For example, probability of separating N molecules to exactly one half of a room by random movement without help of a rectifier is [1 : 2^N]. Therefore it is not impossible, but very unlikely, to separate 1 mol of gas without a rectifier. The only constraint is to ensure a big Knudsen Number (say: Kn > 2 or more).

The Mathematical Particle Tracing interface of COMSOL Multiphysics® with simple Newtonian particles was used to model this case. Particle-particle collisions and molecular surface adsorption were not considered in reference to the Knudsen Number and simplicity of this model. Modeled particles are full elastic with "bounce" condition on wall contact. Equal numbers of particles were released in 2 chambers with mirrored vectors and start positions.

Simulation results show a significant separation and accumulation into the chamber on the diverging part of the fish trap nozzle (Figure 2), (Figure 3). Real fishes would take the other way around. In contrast to "Maxwell's Demon" this fish trap nozzle is a fully passive device and needs no kind of valves or moving parts. It is a kind of "thermodynamic diode". Best results on separation seem to appear on L>>h , where L is length and h gap size of the fish trap nozzle. Understanding the mechanism of separation is very simple. A converging nozzle will behave like a prism mirror by adding reflection angles after several reflections in the nozzle, a diverging nozzle let particles pass through. Maybe this challenge to the 2nd Law will lead to new technologies like passive vacuum pumps or energy harvesting with nano-scale sieves at atmospheric pressure (if surface absorption and particle-particle collisions really can be neglected)

Reference

Vladislav Cápek et al., Challenges to the Second Law of Thermodynamics, Springer, 2005.

Figures used in the abstract

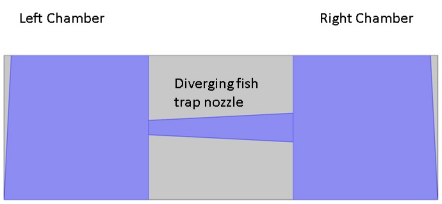

Figure 1: Geometry of Fish Trap Nozzle and Chambers

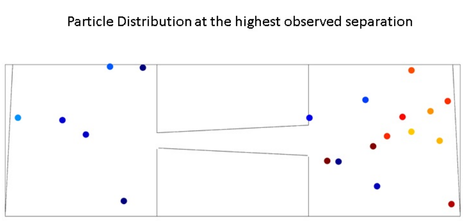

Figure 2: Distribution of Particles after specific time

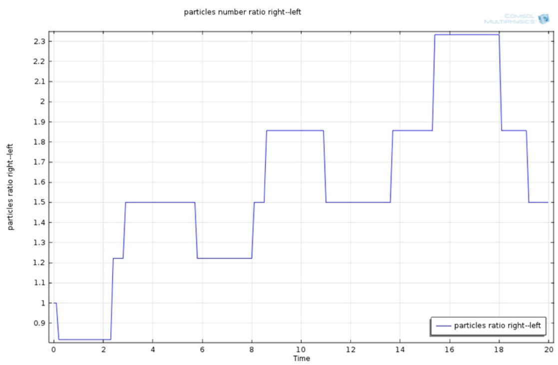

Figure 3: Distribution Ratio of Particles over time