CANCAM 2019

UNIVERSITÉ DE SHERBROOKE

27th Canadian Congress of Applied Mechanics

May 27-30, 2019 | Sherbrooke (QC), Canada

Reconciling thermodynamics and CFD: exergy tubes. Application to better understand transfers in supersonic ejectors

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Invited speaker, Symposium on Energy Efficiency,

28th of May 2019, CANCAM 2019, Université de Sherbrooke

Ejectors are well known passive devices used to entrain and compress a fluid stream. They have been widely used at the beginning of the last century for steam locomotives, and modern applications ranges from steam powerplants to remove non-condensable gases, propulsion as thrust boosters, coolant circulation in boiling nuclear reactors, thermal-compression from waste heat recovery or expansion work recovery in refrigeration cycles, pneumatic transport, etc. Whatever the application, the physical concept is rather simple: A primary fluid at high pressure and temperature is accelerated into a nozzle (primary nozzle) to convert its pressure/thermal energy into kinetic energy by venturi effect. The high velocity jet exhausting this primary nozzle entrains a secondary stream into a secondary coaxial nozzle, the ejector body, to a higher pressure plenum. In the previously cited applications, the working fluids can be liquids, vapors or gases, both eventually containing solid particles (pumping and transport of particles, chemicals, slurries, etc.) which can potentially make the flow within the ejector a complex multiphase system. This talk will focus on single-phase supersonic ejectors which are used in thermal compression applications. In this case both streams are gas or vapor (here air) and are also accelerated to sonic and supersonic velocities within the ejector. The primary stream obviously becomes sonic in the primary nozzle while the secondary stream could reach sonic speed according its entrainment within the ejector body. In the existing literature two important features are known to be important in the understanding of supersonic ejector operation: (i) the transfers occurring between both streams through the developing shear layer should play a key role in the ejector performance,(ii) the choking of the secondary stream in the ejector body which make the ejector operation stable and at maximum efficiency. The leitmotiv of this presentation is to show that although we can have access to many local data within this device by CFD and by measurements, those two features were not properly resolved by a lack of physical oriented post-processing and analysis. The point (i) is the focus of the paper which briefly describes a general method; it will be more detailed during the talk. For this point we developed a general post-processing approach based on the local exergy exchange between both streams within the ejector, and we proposed the concept of exergy tube as a visualization tool. This method gives valuable qualitative and quantitative results in terms of exergy exchanges and destructions and could allow to define new criteria for ejector design. The choking of the secondary stream (ii) is not addressed in the paper because limited space, but it will be discussed during the oral presentation. Here again, although a significant number of CFD results exist for supersonic ejectors, the assumed physics, still being used to setup one dimensional models, is to consider an effective throat where the secondary stream reaches unity Mach number as in convergent nozzle. We indeed proved that phenomenology exists but seems not to be the dominant process that limits the flow rate and hence the entrainment rate of the ejector. By using simple thermodynamic and fluid flow theory for compressible multi-stream flows, which has been in fact published in 1965, we showed the compound-choking mechanism is mostly the correct process that leads to entrainment limitation.

Prof. Yann Bartosiewicz, graduated in France from Polytechnic Institute of Grenoble (INPG) with a major in turbulence modeling. He obtained his PhD from Université de Sherbrooke in beginning 2003 on CFD simulation of supersonic plasma jets under non-equilibrium conditions. The same year he joined Natural Ressources Canada (CANMET) with a NSERC Postdoc fellowship where he started his activity on supersonic ejectors and their used in refrigeration cycles. Since then, he has been developing a strong experience in modeling (CFD and 1D) and interpreting the flow physics within such devices in different situations (single-phase, two-phase, perfect gas vs real-gas conditions). In 2005 Prof. Bartosiewicz joined Université catholique de Louvain (UCLouvain) in Belgium as professor. At UCLouvain, he has been further developing his knowledge on ejectors both on simulation and experiments and he has been also working on numerical simulation in nuclear thermal-hydraulics where his recent work contributed to better understand turbulent heat transfer in liquid metal conditions by doing LES and DNS of different configurations (channel, impinging jet and backward facing step). At UCLouvain he was the head of the thermodynamic and fluid mechanic division between 2012-2016 and Chairman of the Belgian Nuclear Education Network between 2014-2016. He gave several lectures at von Karman Institute (VKI) concerning two-phase choked flows and simulations of low Prandtl heat transfer and different invited talks about ejector technology . His teaching duties concern thermodynamics, thermal cycles and nuclear thermal-hydraulics.

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