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HYBRID-SYNTHETIC IMPINGING JETS

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Abstract: *Impinging jets can achieve the highest convective heat or mass transfer rate. An increase beyond present limits is possible by pulsation of the flow. The extreme case of the synthetic jets could be particularly effective – were there not the re-ingestion of the fluid. A solution brings the new concept of non-zero time mean hybrid synthetic jet.*

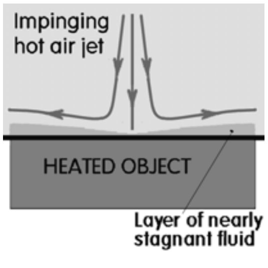
Keywords: ***Synthetic jet, impinging jet, heat transfer, mass transfer.***

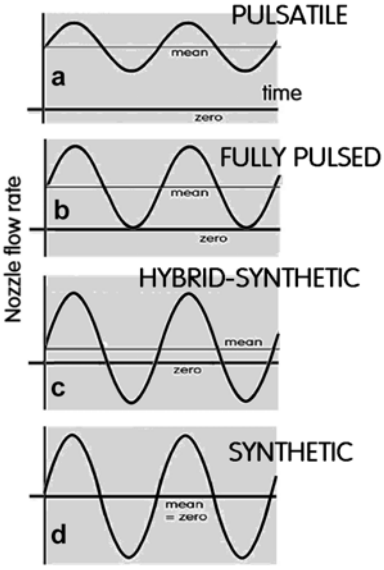
1. Introduction

Effectiveness of cooling, heating, and drying by a fluid is limited by a layer of the fluid, usually very thin (typically of the order 0.1 mm or less) held on the transfer surface by viscous forces. The transport crosses this layer by the much less effective conduction mechanism. The highest transfer rates are achieved by the fluid impinging on the surface as an accelerated jet, penetrating so as to leave the shortest remaining conduction distance. Nevertheless, the limiting effect of the stagnant layer is still there (Fig. 1).

2. Destroying the layer by pulsation

The idea of eliminating the conduction layer or at least decreasing its influence by pulsation of the flow has been there for at least half a century. It is supported by numerical solutions (e.g., Xu et al.,





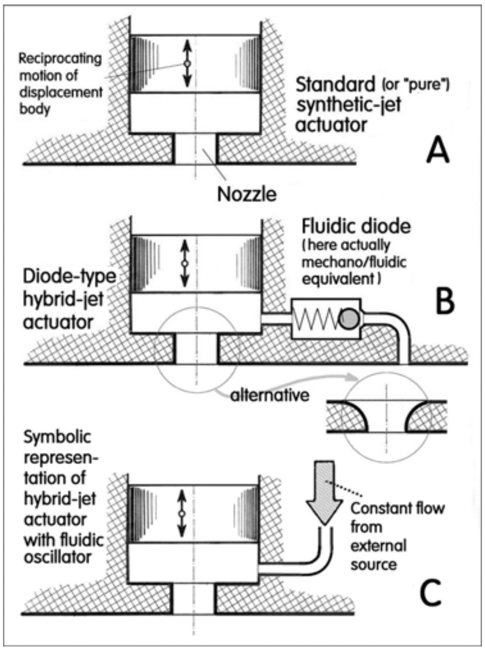


Fig. 1:(Left) The limit to convective transfer rate is imposed by the layer held on the surface by viscosity.
Fig. 2: (Middle) Pulsations of the jet can destroy the conduction layer.
Fig. 3: (Right) Synthetic jets: A – pure zero time-mean flow B – hybrid-synthetic jet with enhancement by pumping C – Action of fluidic oscillator symbolically represented by the superimposed steady flow.

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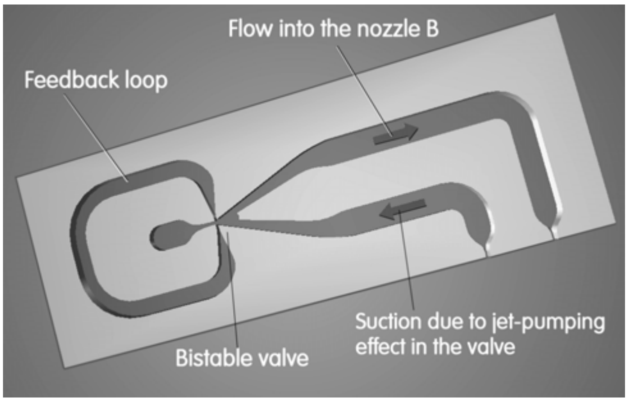


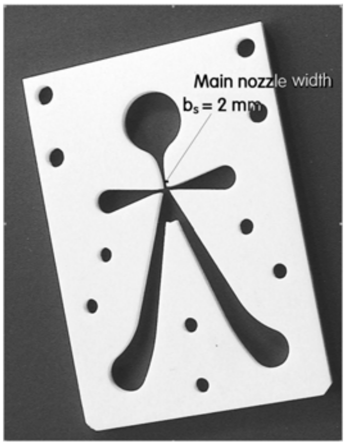


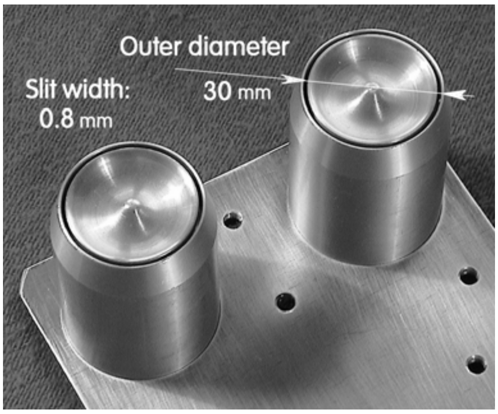
Fig. 4: (Left) A typical fluidic oscillator (here with the Spyropoulos-type feedback loop, Tesař V., et al. (2007a).

Fig. 5 (Right) Photograph of the bistable diverter valve, laser-cut in 5mm thick Teflon, used in the tests described in Tesař, 2009).

2010) but experimental verification has been so far inconclusive – some researchers have, in fact, found the pulsation actually decreasing the heat transfer effectiveness. Other factors that has led to non-acceptance of the idea in practice were: (a) complexity and cost of the mechanical pulsators compared with the simple nozzle for steady flow, and (b) the power required to generate the pulsation. New impetus came recently from two directions. The first was the development in synthetic jets – the extreme in pulsation intensity (case d in Fig. 2) which should act on the layer most effectively (Pavlova & Amitay 2006), The other was development of fluidics – no moving-part flow control. Fluidic oscillators based on hydrodynamic instabilities (usually bolstered up by a feedback) are inexpensive and consume very low power. The problem with synthetic jets e.g. in cooling is their gradual loss of effectiveness due to re-ingestion of the fluid already heated in previous cycles.

3. The solution

The answer was found in the ***hybrid-synthetic*** jet - with superimposed small steady flow component, case (c) in Fig. 2. The idea was first introduced by Trávníček in 2005. There are two alternatives. In the first one, following the original scheme of Trávníček, Tesař, & Wang (2005), cf. also Trávníček, Vít, & Tesař (2006), schematically represented as case B in Fig. 3, the necessary fresh outside fluid replacing the already heated one flows into the displacement-type actuator during the suction part of the period. It escape in the next part of the period is prevented in this illustration by the non-return valve, in actual operational actuators replaced by a no-moving-part fluidic diode (Tesař, 2008).



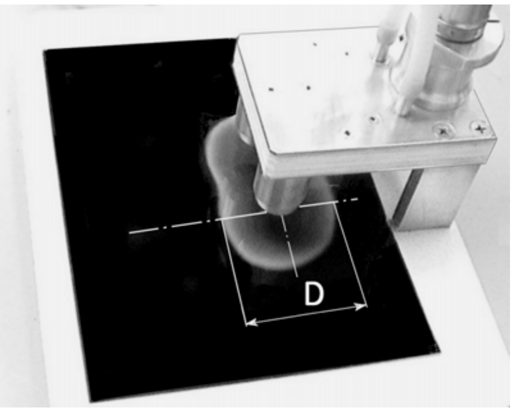


Fig. 6: (Left) The pair of annular nozzles used in the laboratory model. Each nozzle was connected to one of the two outlets of the fluidic valve.

Fig. 7: (Right) Definition of the characteristic distance D measured on the impingement distance covered with thermochromic liquid crystals.

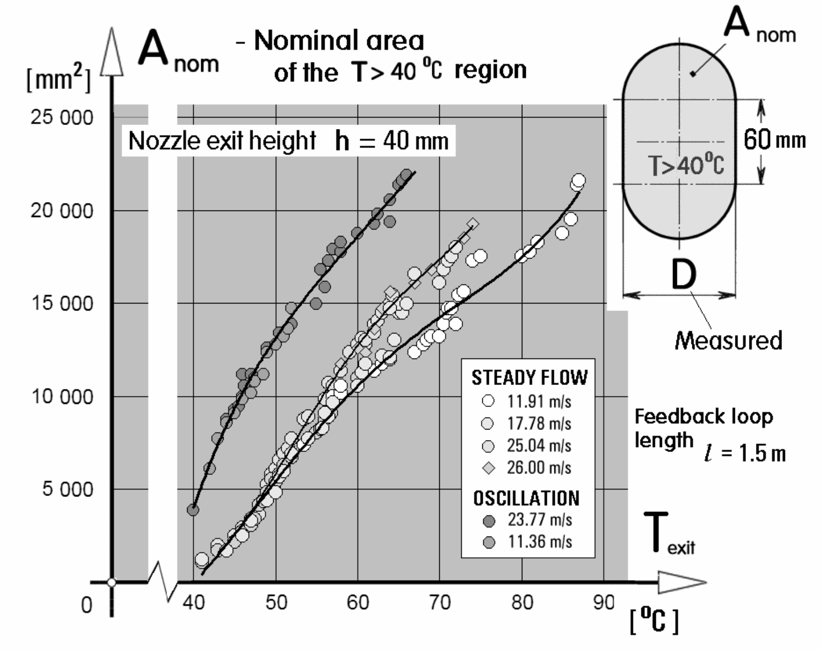


Fig. 8: The extent of the nominal (simplified) hot spot area A evaluated from the measured distance D in heating by steady flow and by hybrid-synthetic jets. The advantage of the latter case is here convincingly demonstrated.

In the other version, Tesař, Hung, & Zimmerman (2006), the actuator is supplied with the fluid from an external source. The oscillation is generated in the oscillator consisting of a diverter valve (Fig. 5) with a feedback loop (e.g. as shown in Fig. 4). This way, it is possible to eliminate all moving components – such as the piston schematically represented in the case C, Fig. 3. The return flow into the nozzle during the suction phase is generated by the jet-pumping effect of the flow through the main nozzle in the valve.

Successful tests that demonstrated convincingly the increase in heat transfer made possible by synthetic jets, are described in Tesař (2007a). The nozzles, shown in Fig. 6, were with annular exits due to the reasons discussed in Trávníček & Tesař (2003). Each nozzle was connected to one of the two the outputs of the valve shown in Fig. 5, cut in 5 mm thick Teflon plates. There were 2 plates stacked on top of one another, both with 2 mm wide main nozzle – so that the impinging nozzle exit area was 3.7-times larger than that of the main nozzle in the oscillator. Oscillation frequency was in the tests shown in Figs. 7 and 8 adjusted to either 10 Hz or 14 Hz, with negligible difference in the heating effect. This rather low frequency levels required feedback loop length 1.5 m - obviously much longer than in Fig. 4, so that it could not be laser-cut in the plate and had a form of a Teflon tubing. Air supplied into the oscillator was heated using the heater from a commercial hot-air gun. Typical heating-nozzle exit velocities were ~17 m/s, at which the power dissipated by hydraulic losses in the oscillator, nozzles and electric heater upstream from the oscillator, was mere 5 W, a value practically negligible compared with the supplied heating power input ~1 kW.

The effectiveness of the heating was evaluated by means of thermochromic liquid-crystals, a foil containing them covering the impingement surface. This particular crystals reacted by initial colour change when the temperature reached 40 °C, and the location of this change could be quite accurately measured as shown in Fig. 7. The next Fig. 8 shows that under the impinging hot air, the area of the region with temperatures higher than 40 °C was significantly larger with the hybrid-synthetic jet than with steady hot-air jet.

4. Conclusions

A model of an impingement heating device with two nozzles operated in opposite phases of a hybrid-synthetic jet, generated by a no-moving-part fluidic oscillator, was built and tested using the temperature field visualisation by means of thermochromic liquid crystals. It was demonstrated that the operation in the hybrid-synthetic annular jet regime exhibits a substantially higher total heat transfer rate than steady jets. Depending on the regime, the increase is to 300% and even more, though values 180% – 200% may be more typical.

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References

Pavlova A., Amitay M. (2006) Electronic Cooling Using Synthetic jet Impingement, Journ. of Heat Transfer, Vol. 128, p. 897.

Tesař V., Zhong S. (2003) Efficiency of Synthetic Jet Generation, Zhongguo Hangkong Taikong Xuehui Huikan, Vol. 35, p. 45, Taiwan .

Trávníček Z., Tesař V. (2003) Annular Synthetic Jet Used for Impinging Flow Mass Transfer", International Journal of Heat and Mass Transfer, Vol. 46, p. 3291.

Tesař V., Trávníček Z. (2005a) Increasing Heat and/or Mass Transfer Rates in Impinging Jets, Journal of Visualization,Vol. 8, p. 91.

Tesař V., Trávníček Z. (2005b) Pulsating and Synthetic Impinging Jets, Journal of Visualization,Vol. 8, No. 3, p. 201.

Trávníček Z., Tesař V., Wang A.-B. (2005) Enhancement of Synthetic Jets by Means of an Integrated Valve-Less Pump, Part II: Numerical and Experimental Studies, Sensors and Actuators A, Vol. 125, p. 50, 2005.

Tesař V., Hung C.-H., Zimmerman W. (2006) No-Moving-Part Hybrid-Synthetic Jet Actuator“ Sensors and Actuators A, Vol. 125, p. 159.

Trávníček Z., Vít T., Tesař V. (2006) Hybrid Synthetic Jets as the Nonzero-Net-Mass-Flux Synthetic Jets, Physics of Fluids, Vol. 18, p. 081701-1.

Tesař V., et al. (2007a) Experimental Investigation of a Fluidic Actuator Generating Hybrid-Synthetic Jets, Sensors and Actuators A, Vol. 138, p. 213.

Tesař V. (2007b) Configurations of Fluidic Actuators for Generating Hybrid-Synthetic Jets, Sensors and Actuators A, Vol. 138, p. 394.

Trávníček Z. et al. (2007) Bifurcated and Helical Impinging Jet Controlled by Azimuthally Arranged Synthetic Jets, Proc. of HEFAT 2007, Paper TZ1; Sun City, South Africa, p.35 July 2007.

Trávníček Z., Tesař V., Kordík J. (2007) Double-acting Hybrid Synthetic Jets with Hexagonally Arranged Nozzles, Proc. of FLUCOME 2007, Paper 12, Tallahassee, U.S.A., Sept. 2007.

Trávníček Z., Tesař V., Kordík, J. (2008) Performance of Synthetic Jet Actuators Based on Hybrid and Double-Acting Principle, Journal of Visualization, Vol.11, p. 221.

Tesař V. (2008) Valve-less rectification pumps, in “Encyclopedia of Microfluidics and Nanofluidics“, Ed.: Dongqing Li, publ. by. Springer Science+Business Media, p. 2132.

Trávníček Z., Tesař V. (2008) Synthetic Jets used to Control Spreading of an Annular Impinging Jet, Proc. of ISFV13 and FLUVISU12, Nice, France, July 2008.

Tesař V. (2009) Enhancing Impinging-Jet Heat or Mass Transfer by Fluidically Generated Flow Pulsation, Chem.Eng. Research and Design, Vol.: 87, p. 181.

Tesař V., Něnička V. (2009a) Phase-Synchornised Investigations of Triggered Vortices in Impinging Jets, Proc of “ENGINEERING MECHANICS 2009”, p. 1321, Svratka, May 2009.

Tesař V., Něnička V. (2009b) Study of Vortical Structures in Impinging Jets - New Methods and Approaches Proc. of ExHFT-7, Krakow, Poland, June-July 2009.

Tesař V., Něnička V. (2009c) Instability Structures in Impinging-Jet Flows, Proc. of EMT 2009, p. 335, Liberec, November 2009.

Xu et al., (2010) Turbulent impinging jet heat transfer enhancement due to intermittent pulsation, Journ. of Thermal Sciences, Vol. 49, p. 1247.