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New Physical Effect Permits Factor-of-Ten Reduction in Energy Requirements for Cooling

Danil B. Doubochinski[1, a], Jonathan Tennenbaum[2,b]

[1]Quantix - Société de Recherche et Développement en Technique Vibratoire, 86, Rue de Wattignies, 75012 Paris, France

[2]Essenerstr. 14, Berlin 10555, Germany

[a]doubochinski.danil@gmail.com, [b]j.tennenbaum@freenet.de

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Abstract. A revolutionary new technology for cooling and refrigeration, based on applications of nonlinear coupled oscillations to the atomization and evaporation of liquids, opens the way to order-of-magnitude reductions in the energy requirements for cooling and refrigeration in a wide range of applications. The basic principles of the new cooling method are presented, together with results of certified measurements carried out on laboratory prototypes of the new cooling process.

Introduction

Developing more efficient technologies for refrigeration, air conditioning, and the cooling of industrial plants, is key to saving energy and to increasing economic productivity of the world's nations. The present paper summarizes results of research into a *fundamentally new* method for cooling and refrigeration, which can provide enormous increases in energy efficiency in a broad range of potential applications. The new cooling technology was made possible by theoretical and experimental discoveries in the domain of *energy transformation by nonlinearly coupled oscillations* [1-10], and involves *new principles* and *new physical phenomena* which are the focus of continuing research by the authors and their collaborators.

The new cooling method uses nonlinear interactions, generated in a mixture of air and water by a combination of pulsation frequencies inside a specially-designed "reactor", to atomize the water into droplets of 0.1 micron diameter or less. As we shall explain in more detail below, this nonlinear atomizing process requires only a very small amount of externally-applied energy, and has the *extraordinary* property – apparently never observed before – that it actually *consumes* thermal energy from the air-water medium. Highly non-equilibrium, cascade-like processes inside the reactor, effectively convert a portion of latent heat of the air-water mixture into mechanical work of overcoming the surface tension of water droplets, breaking them down finally into droplets of submicron size. The result is a sharp drop in temperature inside the reactor, which accounts for about 50% of the total cooling effect of the prototype devices. Exiting the atomizing "reactor" in an unstable water-air mixture, the submicron-sized water droplets rapidly evaporate, producing the remaining 50% of the cooling effect. Depending upon the application, this water vapor can either be released to the environment, or condensed and recirculated to provide a close-cycle system with water as the coolant medium.

Measurements on prototype systems

Laboratory prototypes built by the company QUANTIX, have been extensively tested and their physical parameters and performance measured under various conditions. Measurements carried out by the French industrial certification agency VERITAS, demonstrated Coefficients of Performance (COPs) far superior to those of existing refrigeration systems based on the Carnot cycle, for the corresponding inlet and outlet temperatures (see Table 1 below). However, the prototypes used in the

VERITAS measurements were very far from optimized. Using detailed data from the laboratory prototypes, experts from the French industrial laboratory LAMI-ENPC and the Technical Center of AREVA made projections for the COPs that could be attained by optimized systems based on the new cooling method, arriving at much higher figures (right column of Table 1). In some cases the COP of a fully optimized system would be *10 times higher than the theoretical maximum for systems based on the Carnot cycle*, for the same inlet and outlet temperatures.

Table 1 Coefficients of Performance (COP) for the new cooling process

initial temperature **°C**	final temperature **°C**	COP of prototype system (from measurements)	COP for optimized system (AREVA estimates)
44.7	19.7	7.1	9.7
59	28.5	10.3	12
69.2	34.8	8	17.8
77.8	35.6	10	19.4
95.3	39.1	15.4	65.2

Optimizing the technology for various specific applications will require additional R&D, but the basic feasibility is well established. The invention is protected by international patents [11].

Background

Cooling by evaporation of water is commonplace in Nature and has been known since the dawn of civilization. Atomizing water in order to increase its effective surface area and thereby accelerate the evaporation process, is also well known. The reason why this method has not supplanted conventional compression-expansion refrigeration until now, lies above all in the limited effectiveness of existing technologies for the atomization of liquids, particularly where very small droplets are required. Presently existing methods – mainly high-pressure nozzles and ultrasonic radiators – consume *far too much power* compared to the actual rate of evaporation achieved, or have *too low overall productivity*, to make atomization-evaporation systems competitive with conventional refrigeration systems in most applications. The vast majority of industrial atomizing systems produce droplets whose average diameters are on the scale of *tens or hundreds of microns*, which is much too large to yield a rate of evaporative cooling that would applicable for refrigeration. To obtain *submicron* droplets in a reliable fashion is difficult and has up to now required much greater amounts of power.

In this context the new vibratory cooling process, described here, constitutes a fundamental breakthrough. The atomizing reactor is based on a different *systems-design philosophy,* as well as the discovery of *new physical principles* governing certain kinds of nonlinear interactions among coupled oscillating systems. The distinguishing features of the design philosophy can be summarized as follows:

1. The priority is placed on utilizing the *internal resources* of a physical system (i.e. the oscillatory energy and the latent heat of the air-water mixture, in the case of the atomizing reactor), thereby minimizing the requirements for energy input from the outside.

2. Physical systems and their components are considered not in isolation, but always in interaction with each other, with outside systems and sources of excitation. In this context, a typical feature of nonlinear interactions, is the existence of discrete sets of stable or quasi-stable dynamic regimes in the interacting systems.

3. The exchanges of energy are self-organized around specific sets of frequencies, in such a way that the participating components of the system (oscillating water droplets, for example) are able to absorb energy by "modulating" their interactions with the other components.

The new atomizing and cooling process is a product of ongoing research based on the discovery, four decades ago, of a novel type of self-organizing interaction among oscillating systems with widely differing frequencies – so-called *argumental interactions* – and of “quantized” modes of behavior in argumentally-coupled oscillators, having no equivalent in the classical theory of oscillations [1-10]. Argumental interactions are characterized by the property, that the exchange of energy is regulated by phase-frequency-amplitude fluctuations in the participating oscillating systems, while each of them operates at very nearly its own proper frequency and retains (in the mean) its characteristic dynamic parameters. Argumental interactions can be demonstrated in a variety of electro-mechanical devices, the simplest of which belongs in every physics classroom [8]: a pendulum (1 Hz) interacting with an alternating-current electromagnet (30-1000 Hz), located below the lowest point of the pendulum’s trajectory. Set into motion, the pendulum’s motion evolves into one of a discrete set of stable oscillatory regimes, possessing a discrete series of stable amplitudes. An essential condition for this “quantization” phenomenon is the strong *spatial inhomogeneity* of the magnetic field of the solenoid: the field exerts a significant influence on the pendulum only within a narrow “interaction zone” around the solenoid, outside of which the field strength drops rapidly to zero. This inhomogeneity permits the pendulum to *modulate* the alternating force field and to regulate its exchange of energy with that field via small shifts (fluctuations) in its phase.
Following up on this discovery, it became clear that argumental interactions can provide a new mechanism for the efficient coupling and exchange of energy between oscillatory processes whose frequencies can differ by many orders of magnitude. It was demonstrated experimentally, that a single high-frequency source can "feed" not just one, a *large number of different argumental oscillators at the same time*, each operating near its own proper frequency and in any one of a “quantized” array of modes. This is a special case of a more general principle, called *multiresonance,* which plays a key role in the new atomizing and cooling process: *the simultaneous coupling of ensembles of oscillating systems, in a self-organizing and self-regulating manner, across an orders-or-magnitude-wide range of frequencies.*

Detailed description of the process

We shall now describe the new atomizing and cooling process in more detail, focussing on the series of physical transformations occuring from the moment of injection of a given portion of water into the “atomizing reactor”, to the exit of the corresponding cloud of submicron droplets from the reactor, and their subsequent evaporation. In reality, of course, the process occurs continuously, with different stages occuring at different locations within the system.
It should be emphasized, that the account given here is based on a combination of experimental investigations, mathematical modelling, and measurements carried out on prototype systems. The latter include temperature and pressure measurements made at different points inside and outside the atomizing reactor, as well as observations of droplet size and composition of the air-water mixture generated by the device.

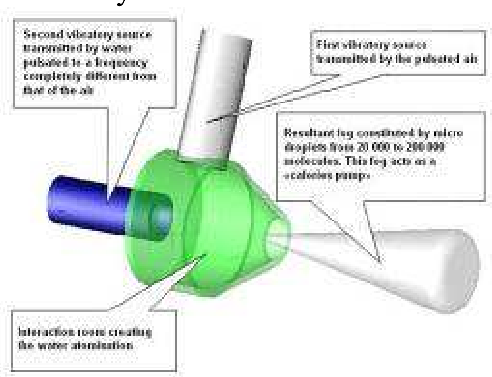

Figure 1 Schematic of atomizing reactor

Figure 2 Small-scale prototype

Fig. 1 shows the reactor of the device in schematic form. A pulsating flow of water enters through a tube at the left, and interacts with a pulsating flow of air arriving from a compressor through a second tube. Of crucial importance is to insure that air and the water pulsate at widely differing frequencies. In the current prototype apparatus the compressor itself already produces a pulsating air flow, at 50 Hz. By the choice of compressor and characteristics of the channel connecting the compressor with the reactor, the pulses can be sharpened to have the form of "delta functions". The air thus arrives into the reactor in short "puffs", 50 times per second. Exciting the necessary pulsation of the water can be accomplished in a number of ways. The current design exploits certain hydrodynamic processes taking place in the tube and outlet delivering the water into the reactor. This "preparation" insures that the water is already in a heterogeneous vibrational motion at the point it encounters the air flow.

The atomization process begins at that point, through argumental interactions between the air and water. We could describe the process as "*multiresonant atomization*".

When the pulsed air flow strikes the surface of the water injected into the reactor, the interaction causes the water to "explode" into a cloud of droplets of different sizes, each in a highly agitated, pulsating state. The density of spatial heterogeneities is greatly increased. The smaller droplets, whose diameters adapt to the spectrum of vibrations of the air, have much higher resonant frequencies than the original water surface. The spectrum of water vibrations is enriched and greatly intensified toward the higher-frequency end. At the same time, new high-frequency spectral components are generated in the air, as a result of interaction with the pulsating water droplets and the shock-wave-like signals provoked by droplet "explosions". There are intense interactions between packets of air and droplets of various sizes. Multiresonance causes the droplets to absorb more energy from the pulsed air environment, provoking further ruptures and explosions which produce droplets of even smaller diameters.

With the increasing density of heterogeneities, the increasing surface-area of the droplets and the growing intensity of high-frequency components in the pulsation spectra, the energy exchanges between the droplets and the thermal medium become ever more efficient. With the decrease in diameter of the droplets, the surface tension is greatly weakened, and the droplets become increasingly unstable. The cascade accelerates, until the original mass of water has distintegrated into droplets of submicron size.

Up to the point of exit from the dense medium in the atomizing reactor, the amount of evaporation has remained extremely small. Emerging from the reactor is an extremely heterogeneous mixture of air, some water vapor, and submicron droplets of a large spectrum of sizes, ranging from 200.000 molecules to only 20.000 molecules. Due to their instability, the smallest droplets evaporate nearly instantly, cooling the entire mixture by as much as 40 or more degrees within a small fraction of a second.

The thermal conversion effect

We have emphasized, that a large part of the cooling effect occurs *prior* to the evaporation of the microscopic water droplets produced in the cooling reactor, but instead is produced *during the atomization process itself*. Analysis of experimental data obtained by measurements carried out on a prototype cooling apparatus, demonstrates that: (a) a large temperature drop occurs immediately within the reactor chamber itself, before significant evaporation has taken place, and (b) the evaporation of water droplets, exiting the reaction chamber, can account for only about 50% of the total heat energy lost by the air-water mixture in the course of the cooling process, i.e. for only half of the cooling effect.

The implication is, that inside the reactor a portion of latent heat of the air-water mixture has somehow been converted into mechanical work – i.e. the work of overcoming surface tension, necessary in order to break the water down into submicron droplets.

This conclusion is confirmed by calculations of the minimal energy required for atomization of a given quantity of water into droplets of the observed size. Estimating the change in surface tension energy, corresponding to the atomization of 1 cm^3 of water into droplets of diameter 0.1 micrometer, we arrive at a figure of approximately 4.4 J. By comparison, the external input energy, consumed by the atomizing reactor during the time corresponding to the atomization of 1 cm^3 of water, is only about 2 J. Evidently the additional energy, required for the work of atomization, has been taken from the thermal energy of the water and air supplied to the reaction chamber. The corresponding loss of thermal energy reveals itself in an anomalous drop in the temperature of the air-water mixture at the point of exit from the reaction chamber, relative to the point of entry.

It should be emphasized that this anomalous effect of conversion of thermal energy into mechanical work of atomization, occurs under highly non-equilibrium conditions inside the cooling reactor: in an unstable, violently agitated mixture of air and water droplets having an rich spectrum of oscillatory frequencies, and in which we can expect large localized gradients of pressure and temperature to occur. In a sense, the vibratory energy provided from outside (via a pulsating pump) functions as a kind of "catalyst" for this non-equilibrium conversion process.

This result is evidently of great theoretical and practical interest, and calls for further detailed investigations.

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