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A Preliminary Investigation on Designing of the Novel and First Italian elastoCaloric Device

Luca Cirillo[1*], Adriana Greco[1], Claudia Masselli[1], Suxin Qian[2]

[1] DII, University of Naples Federico II, Pl.e Tecchio 80, 80125 Naples, Italy
[2] Department of Refrigeration and Cryogenic Engineering, Xi'an Jiaotong University, Xi'an 710049, China

Corresponding Author Email: luca.cirillo2@unina.it

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ABSTRACT

The vapor compression used in refrigeration is responsible for about one-fifth of the world's energy consumption. One of the most promising alternatives is elastoCaloric refrigeration, which is gradually gaining acceptance in the scientific community. The fundamental element of elastoCaloric refrigeration is the shape memory alloy (SMA) which is capable of absorbing/releasing heat when subjected to stress cycles due to the transformation process of the martensitic phase. Their mechanical properties allow them to return to their initial shape once the load is removed. To date, there are a minimal number of prototypes of high-calorie chillers, and these are still far from the large-scale industrialization process. The preliminary stages for the design and development of the first energy-efficient chiller were presented in this work. The goal is to create a rotary prototype in collaboration with the University of Naples "Federico II", the University of Genoa, and the National Research Council that can represent a fundamental step towards new innovative techniques for refrigeration.

1. INTRODUCTION

In the twentieth century, refrigeration and air conditioning were among the innovations that greatly impacted society, bringing improvements to health, hygiene, and general well-being. There was a huge step forward compared to the Freon-based technology widely used in the 1960s. To date, there are many possibilities to significantly increase the efficiency, management, and maintenance of refrigeration systems [1-3]. Since the 1990s, with the Montreal Protocol [4], stricter rules have been defined for the production and consumption of polluting substances for the atmosphere produced or used by the old vapor compression systems: starting from 1996 CFCs have been gradually eliminated from developed countries. Subsequently, the HCFCs have been eliminated starting from 2020, and finally, the HFCs will be eliminated by 2036 as widely discussed in the works [5-10]. Unfortunately, ozone-depleting substances (ODS) are released into the atmosphere during the refrigeration system's maintenance, disposal, and transport processes. In fact, the harmful gases are trapped in the insulating layer, and the refrigerant charge escapes, creating dangers for the operators.

Innovation in refrigeration becomes a fundamental point for the scientific community, which is called to find innovative solutions for replacing technology based on vapor compression. There are renewable energy based plants [11, 12] but also solid-state refrigeration systems [13], which today represent the most eco-friendly solution compared to vapor-compression [14]. Many researchers state that it is possible to obtain energy efficiency values greater than 50% compared to typical traditional systems with solid-state technology. The absence of moving mechanical parts allows solid-state systems to be more reliable and require less maintenance and less acoustic impact. Finally, by not using refrigerant gases such as CFCs or HFCs, solid-state systems are cleaner than traditional systems, complying with the rules dictated by the global climate emergency. Solid-state systems are based on the caloric effect that certain materials develop when subjected to an external stress field. The caloric effect is a reversible thermal phenomenon when a magnetic [15] or electric field [16], pressure [17], or mechanical stress is applied.

The application of a magnetic or electric field sometimes requires high energy consumption to cause significant changes in temperature due to loading/unloading cycles [18]; Elastocaloric materials, on the other hand, are subjected to mechanical cycles that require less energy to cause considerable temperature variations.

The phenomenon of superelasticity is related to the temperature of the shape memory alloy used, its chemical composition, and the applied stress: above the stability temperature of austenite (Af), an SMA is superplastic and below the temperature of stability of martensite (Mf), shows shape memory behavior.

Many sectors such as automotive, robotics, civil engineering, and biomedical appreciate the properties of shape memory alloys, as reported in work [19].

Before applying the load/stress, the SMA is entirely in the austenite phase at the reference temperature. When the load is applied gradually and exceeds the saturation stress value, the phase change occurs: from the austenite phase to the martensite phase with consequent release of latent heat and reduction of entropy. Subsequently, the load is gradually reduced by verifying the inverse phase passage, (the saturation stress in the unloading phase and that of the loading phase do not coincide due to the hysteresis phenomenon well described in the work of Michaelis et al. [20]), in this last phase there is the increase of entropy and absorption of latent heat by the SMA, thus occurring the cooling phenomenon as shown in

Figure 1.

The materials in which a transformation occurs due to the application of an external field can be considered SMA materials. The discriminating factor in the choice of the elastoCaloric material is the temperature, which should always be lower than the operating temperature of the room to be cooled.

Starting a regenerative cycle in elastoCaloric systems is essential to obtain Curie temperatures calibrated in the operating conditions of magnetocaloric systems [21]. The reference thermodynamic cycle is the Brayton cycle, in which the caloric materials act both as a refrigerant and as a regenerator. A regenerative cycle was proposed by Aprea et al. [22] for a heat pump. The cycle allows their device to operate at temperature ranges above the adiabatic temperature change of the material.

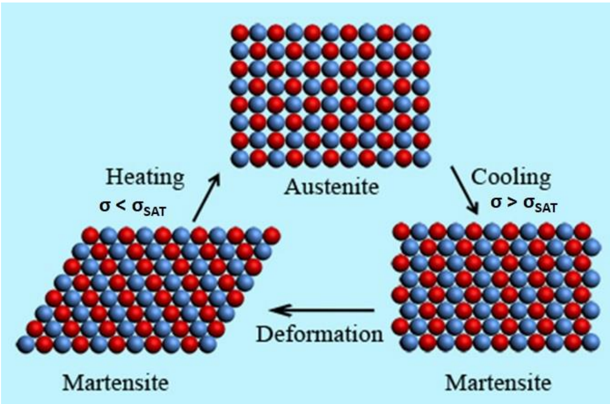


Figure 1. The regenerative cycle of elastoCaloric cooling effect

Gadolinium is the most widely used magnetocaloric material in the scientific community. It is used in many magnetocaloric refrigeration devices, some of which are close to commercialization. Some researchers state that magnetocaloric solid-state systems can have energy efficiency values greater than about 50% compared to traditional systems, but some experimental results have not been very encouraging in terms of COP, cooling power, and temperature difference [23]. An elastoCaloric prototype could be the solution for an increase in COP values and cooling capacity, as demonstrated in some works in the literature [24-28]. Preliminary steps of development of the first Italian elastoCaloric device were presented in this work.

2. ELASTOCALORIC MATERIALS - SMA

One of the most widely used SMA alloys (particularly NiTi) was the biomedical sector. Their mechanical properties have performance values suitable for the most varied sectors, as discussed in Jani et al. [19].

Knowledge of the properties of SMAs is a crucial point for the design and development of cooling systems, as demonstrated by the enormous interest shown by the researchers in Figure 2. For an accurate selection of the material suitable for the cooling system, Kirsch et al. [27], proposed a list of fundamental parameters be searched for in the high-calorie material:

- High values of latent heat (H);
- The application of mechanical stress must be reasonably low;
- Small mechanical hysteresis;
- Small thermal hysteresis (it is related to mechanical hysteresis;
- Transformation temperature is lower than the temperature of the environment to be cooled.

Unfortunately, these parameters do not coexist in any SMA league. Many researchers improve some of the previously listed parameters by adding other elements (Cr, Co, V, Cu, etc.) to the NiTi binary alloy [29]. Some of these alloys are showing significant improvements on the elastoCaloric effect (high-temperature variation), mechanical and thermal stability, and the useful life of the material.

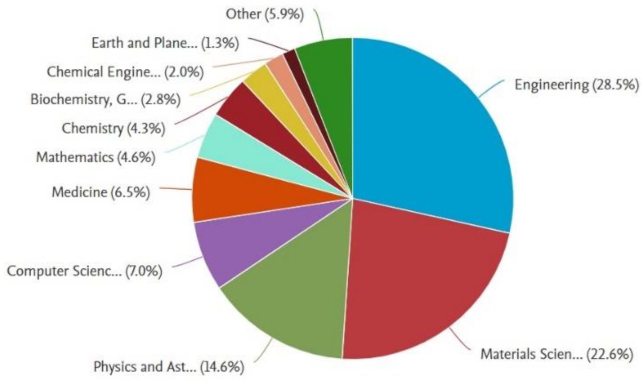


Figure 2. Publications on SCOPUS about elastoCaloric material from 1990 to 2021

ElastoCaloric materials are divided into three groups: MSMA (magnetic shape memory alloys), SMP (polymer-based shape memory alloys), and NiTi, Cu, and Fe-based shape memory alloys [30].

As previously stated, the elastoCaloric effect (eCe) occurs when there is a temperature change when a loading (increases the temperature) and unloading (decreases the temperature) cycle is applied; if the process is isothermal, a change in entropy also occurs. The entropy variation and the temperature variation are quantities that measure the elastoCaloric effect:

$$\Delta T_{ad} \approx -\frac{1}{\rho}\frac{T_0}{c}\Delta s_{iso} \tag{1}$$

$$\Delta s_{iso} \approx \frac{1}{\rho}\int_{\sigma_1}^{\sigma_2}\left(\frac{\partial \varepsilon}{\partial T}\right)_{\sigma} d\sigma \tag{2}$$

where, ρ is the material's density, ε is the applied strain, σ is the applied stress, c is the material's specific heat, and T_0 is the material's temperature. The equations above can be used only for estimating the adiabatic temperature changes if c is considered constant with temperature. A more precise and correct way of defining the adiabatic temperature changes is using the following equations [31]:

$$\Delta T_{ad} = T_2(S_{tot}, \sigma) - T_1(S_{tot}, \sigma = 0) \tag{3}$$

$$S_{tot} = S_{tot,\sigma=0} + \Delta s_{iso} \tag{4}$$

The total entropy at zero applied stress is defined as:

$$S_{tot,\sigma=0} = \int_{T_1}^{T_2} \frac{c}{T}\, dT \quad (5)$$

The specific heat at zero stress is commonly evaluated by calorimetry measurements, while the latent heat, ΔH, depends on the chemical composition of the material and the mechanical input applied [32].

In a recent paper by Michaelis et al. [20] latent heat was evaluated by an experimental approach: a direct electrical power input replaces the elastoCaloric material absorbed via adiabatic loading during the first strain loading pulse of the tensile cycle. The most used SMA alloy for elastoCaloric purposes is the NiTi binary alloy, as it shows transformation temperature values compatible with environmental conditioning and ease of supply as it is produced on a large scale.

Furthermore, the binary alloy of NiTi shows an essential dependence of the transformation temperature and latent heat according to the Ni concentration, as defined in work [33] and shown in Figure 3, where there is a clear correlation between Af and latent heat ΔH.

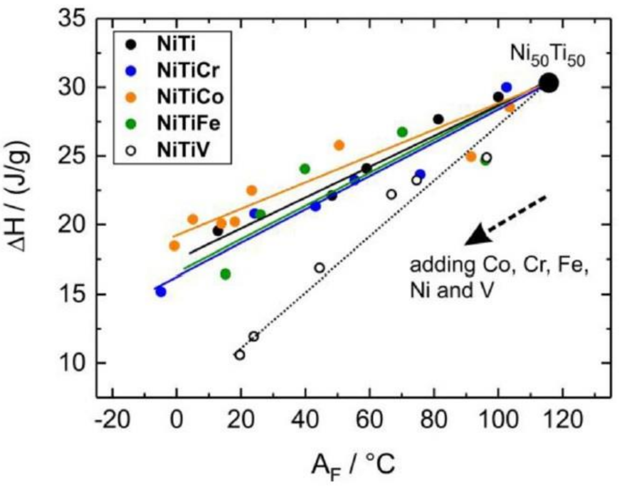


Figure 3. Correlation of NiTi SMA based: latent heat and transformation temperatures [25]

From the graph, the linear correlation of the Af temperature and the latent heat associated with the insertion of other elements such as Cr, Co, Fe, and V is very evident: the latent heat and the Af temperature decrease as the concentration of Ni in the NiTi alloy increases.

Figure 4 shows the dependence of latent heat on the hysteresis phenomenon.

The experimental work of Jaeger et al. [34] is essential in understanding the hysteresis phenomenon. They demonstrate how the thermal hysteresis is directly proportional to the amplitude of the mechanical hysteresis. Small amplitudes of thermal hysteresis and high latent heat values are fundamental parameters in elastoCaloric cooling systems. Recently, the literature suggests the quaternary alloy NiTiCuV as an elastoCaloric material, which provides better fatigue resistance, latent heat, and hysteresis amplitude than the NiTi binary alloy.

It is not convenient to have a material with a small mechanical/thermal hysteresis amplitude as it has been shown that it leads to an excessive decrease in latent heat and transformation temperatures. Therefore the NiTiCuV quaternary alloy represents a fair compromise to obtain the best performance in an elastoCaloric cooling system described in the paper [35].

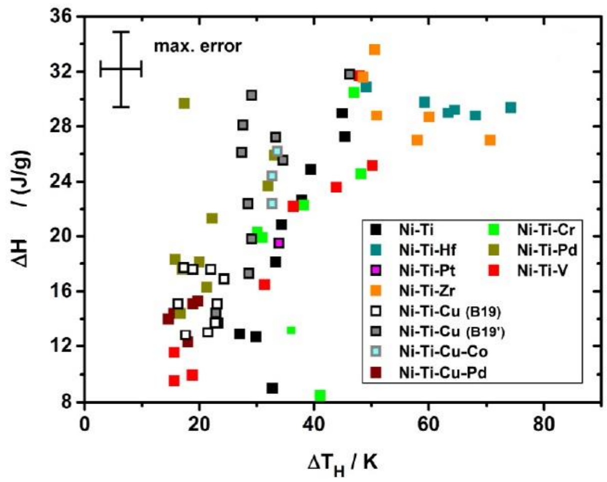
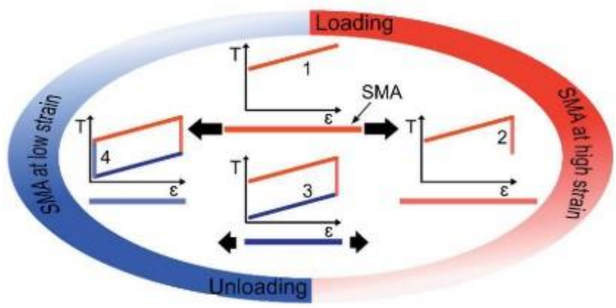


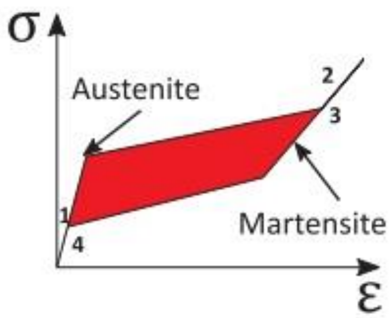
Figure 4. The trend of latent heat and thermal hysteresis of NiTi SMA based

3. ACTIVE CALORIC REGENERATIVE PROCESS

Many studies claim that the caloric regeneration process is more efficient than the traditional vapor compression process. The scientific community is now engaged mainly in the realization of models and experiments for caloric refrigeration devices, particularly magnetocaloric devices [22].



a)



b)

Figure 5. a) Adiabatic cooling cycle: SMA temperature as a function of strain ε in the four-stage cycle; b) The stress-strain graph during austenite and martensite transformation

As shown in Figure 5a, four phases make up the active regenerative thermodynamic cycle based on the Brayton cycle: loading; heat transfer (heating); unloading, heat transfer (cooling).

•During the loading phase, mechanical stress is applied to the caloric material in adiabatic conditions. The stress is such that the transformation from austenite to martensite is activated, and the effect is the temperature increase up to the ΔTad temperature.

•During the second phase (heat transmission): the caloric material is crossed by the working fluid, and the effect is the increase in temperature of the Tf fluid and the decrease in the temperature of the caloric material.

•During the third phase (unloading), the previously applied stress decreases with the consequent decrease in the temperature of the calorific material.

•In the last phase (heat transmission - cooling) the working fluid is made to flow through the caloric material, cooling down. This last phase represents the valuable effect of the cycle: the working fluid is brought to a lower temperature than the ambient temperature, thus allowing the refrigeration of the environment.

3.1 Active elastoCaloric regenerative process – AeR

To date, many experimental works take into account the NiTi alloy as an elastoCaloric material.

The elastoCaloric effect occurs when the material in the initial austenite phase is subjected to mechanical stress above a certain threshold. The phase transition (from austenite to martensite) causes an increase in the temperature of the elastoCaloric material, which is subsequently crossed by the working fluid until thermal equilibrium is reached. In the next phase, the stress is reduced with the consequent decrease in the temperature of the elastoCaloric material below the temperature level of the heat source (environment).

Finally, the working fluid is passed inside the elastoCaloric material, which, being at a lower temperature, absorbs heat from the fluid until thermal equilibrium is reached, as shown in Figure 5b; also, it shows that the area within the hysteresis curve is the non-recoverable work of the cycle.

3.1.1 Cooling efficiencies of elastoCaloric cycles

In the work of Schmidt et al. [36], a graphical approach is proposed to determine the work and the absorbed heat of an elastoCaloric cooling process. Their approach starts from an analytical description of the mechanical and thermal behavior (page 87 of [37]). Besides, they validated the graphical approach with an experimental approach.

The specific mechanical work (w) is determined by:

$$w = \frac{1}{\rho}\sigma\Delta\varepsilon \tag{6}$$

The specific mechanical work for the entire cycle (w_0) is equivalent to the integral over the four process steps of Figure 6b:

$$w_0 = \frac{1}{\rho}\oint \sigma \, d\varepsilon \tag{7}$$

By neglecting the irreversible contributions to the entropy change, the absorbed heat q_{ab} during the transition from phase four to phase one is derived from the following equation:

$$q_{ad} = \int T \, ds \tag{8}$$

The COP of the elastoCaloric cooling cycle can be calculated as:

$$COP = \frac{q_{ad}}{w_0} \tag{9}$$

4. STATE-OF-ART ABOUT ELASTOCALORIC PROTOTYPES

The scientific community is working on new prototypes of elastoCaloric coolers, and this section shows some of the devices with relevant results in the literature. As mentioned above, many of these devices use the binary alloy NiTi as an elastoCaloric material due to its mechanical and thermal properties [37]. Other alloys, such as the ternary alloy NiTiCu, can improve the performance in terms of the useful life of the material; in fact, in work [38] it was shown that the NiTiCu alloy can perform about 10 000 cycles of loading and unloading (in compression) before breaking, while with the same amount of load but in traction, the cycles before breaking are only 165 as shown in the work of Wu et al. The research is moving mainly on the optimization of the elastoCaloric material and its chemical composition to improve its qualities according to the points described above. Currently the elastoCaloric devices in the literature are far from large-scale commercialization as they are still in an experimental phase. Most of the devices are based on one-shot applications: the working fluid is in contact with the elastoCaloric material while subjected to mechanical stress, which usually occurs through mechanical or hydraulic pistons. Recently, some European research groups are designing regenerative devices [27, 39]. These devices allow a flow of cold and hot air at the same time.

4.1 Suggestions on future developments of the elastoCaloric cooling

Many researchers aim to create elastoCaloric refrigeration devices for the environmental conditioning of buildings. Engelbrecht in his work [40] defined in detail all the parameters that an elastoCaloric device must possess to be used and marketed on a large scale:

- increase the temperature range of the system from less than 20°C to at least 40°C;
- increase the fatigue life of eCMs in devices to more than 1 million cycles;
- find a practical solution to apply stress;
- demonstrate high efficiency;
- increase cooling capacity to meet end-user applications;
- coupling the elastoCaloric cooler with external components such as heat exchangers and efficient fluid circulators;
- development of control schemes and cycle tuning;
- designing an economic and efficient system.

The temperature range depends very much on the chemical composition of the material and how stress is applied (compression, tension, or torsion). Achieving high-temperature ranges means obtaining devices that can also be used in applications other than residential applications, thus considerably reducing the consumption that vapor compression systems generate.

Increasing the useful life of the material is another fundamental element because obtaining a material capable of withstanding many cycles without deterioration of the mechanical and thermal characteristics would make it possible to reduce the maintenance costs of the devices. Tusek et al. in their work [41] showed that applying a training cycle to the elastoCaloric material improves the fatigue resistance of the material. In particular, they are applying a minor initial strain and performing an intermediate strain cycle around the midpoint of the strain plateau at unloading results in an increase in the material's service life of approximately 35%. The increase in the useful life of the material is inversely proportional to the value of the applied stress; in fact, the greater the applied stress, the lower the fatigue strength of the elastoCaloric material. To obtain the elastoCaloric effect on the binary alloy NiTi, it is necessary to apply a minimum stress at least 450 MPa and a minimum deformation of the material of 3%, so the value of the stress is not small; therefore, many researchers are trying to create new alloys capable of achieving the elastoCaloric effect under lower mechanical stresses [36, 40], as in the case of ternary alloys CuZnAl, which require stress of about 250 MPa.

Another way to improve the service life of the elastoCaloric material is to apply mechanical stress that is different from tensile stress. In work [42], the application of mechanical stress on PVDF (polyvinylidene difluoride) alloys is done by torsion. The torsional stress and the mechanical work that is performed are significantly lower than simple tensile stress. Their work states that the coefficient of performance of a cooler subjected to torsional stress has values of around 8.8.

Another fundamental aspect is the low price of an elastoCaloric system compared to traditional vapor compression systems. The fluids present in elastoCaloric systems, being at low pressure, require mechanical objects (pistons, etc.) with low energy consumption, thus allowing the hydronic circuits of the device to be more economical than vapor compression systems.

Table 1 presents the elastoCaloric devices currently found in the literature and presented more comprehensive results than others.

Table 1. ElastoCaloric cooling device to date

Type	Dimensions	Stress Type	Material*	Cycle	Fluid	COP	Year	Reference
SMA ribbon plate	Length = 90 mm Width = 3.2 mm Thickness = 0.5 mm	linear tensile – max load 750 MPa	$Ni_{50.8}Ti_{49.2}$	One shot	Air	N.A.	2015	[39]
SMA ribbon plate	Length = 15 mm Width = 1.75 mm Thickness = 0.02 mm	linear tensile – max load 520 MPa	$Ni_{50.4}Ti_{49.6}$ $Ni_{29.6}Ti_{55}Cu_{12.6}Co_{2.8}$	One shot	Air	2.9-3.1 2.9	2016	[43]
SMA foils	Length = 15 mm Width = 2 mm Thickness = 0.03 mm	deflection on the bridge center	$Ni_{50.5}Ti_{49.1}Fe_{0.4}$	Cascade	Air	3.2	2017	[44]
SMA film/foil	Length = 5-30 mm Width = 0.5-3 mm Thickness = 0.03 mm	deflection on the bridge center	$Ni_{30.7}Ti_{54.7}Cu_{12.3}Co_{2.3}$ NiTiFe	Cascade Cascade	Air Air	6.7 5.5	2018	[45]
SMA ribbon plate	Length = 50 mm Width = 10 mm Thickness = 0.2 - 0.3 mm	linear tensile	$Ni_{55.8}Ti_{44.2}$ $Ni_{56}Ti_{44}$	Regenerative Regenerative	Water Water	N.A. N.A.	2017	[46]
Wires	Length = 30 mm D_w = 0.2 mm	Rotary tensile	N.A.	Regenerative	Air	N.A.	2018	[27]
Fiber	Diameter = 0.33 mm	Twist	PVDF polymer	One shot	Air	8.8	2020	[47]

*percentage by weight

5. THE FIRST ITALIAN PROTOTYPE

The regenerative system was the cornerstone of the idea for the first Italian prototype of an elastoCaloric chiller. The operation of the prototype is of the rotary type to ensure the simultaneous presence of hot and cold air (working fluid), unlike the one-stage operation. Figure 6a shows the initial design of the system: the elastoCaloric material composed of a certain number of wires is placed between two concentric disks, the synchronous rotation of which allows the elastoCaloric material to take part in the two phases (loading and unloading) of the cycle. Initially, some wires will be in the loading phase while others will be in the unloading phase, and after the complete cycle, all the wires will have taken part in the elastoCaloric phenomenon. The cyclical loading and unloading allow it to obtain a temperature profile along the entire channel through which the working fluid flows. Initially, the elastoCaloric chiller system will not be equipped with heat exchangers, but rather the cooling of the ambient air will be directly using air as the working fluid. The choice of using air as the working fluid is dictated by the fact that air presents fewer problems with leakage management, the mechanical elements to be used are less bulky, and to obtain a more economical device. The air passes throughout a channel made from two concentric cylinders. The air flows inside the annular region, meeting the elastoCaloric material arranged as shown in Figure 6b, which rotates in the opposite direction to the motion of the fluid. The inlet and outlet region of the air inside the duct is realized through two conveyors to minimize pressure drops inside the duct, allowing the intake of hot air and cold air extraction. In addition to obtaining a regenerative cycle, it is possible to operate at higher frequencies obtaining greater cooling power with this geometry. The latent heat released and absorbed by the eCM along the two half-circles during the loading and unloading phases is exchanged with the air, heating and cooling it, respectively. Assuming that the prototype works with optimized operating conditions (air velocity and mass flow rate, rotation frequency, intensity of loading and unloading stress), it is possible to observe a hot and a cold half-circle, stationary, even if the fluid rotates.

The idea is to put a very high quantity of elastoCaloric material inside the fluid flow channel. However, the right compromise has to be found since increasing the quantity of elastoCaloric material could lead to considerable load pedestals inside the channel, consequently lowering the system's efficiency.

The elastoCaloric material inside the system is a binary alloy of NiTi, whose optimal chemical composition will be studied at the experimental laboratory of heat transmission of the University of Naples "Federico II".

This system stems from the need to create a prototype for environmental conditioning for civil uses that could be an alternative to current systems on the market based on vapor compression technology.

5.1 Design and realization

The prototype has a macroscale size target occupying a total volume of 0.060 m^3 with a length of about 70 cm and a diameter of about 35 cm. The main objective is to increase the cooling power as much as possible, which, as described in the following report, depends on the amount of elastoCaloric material, the rotation frequency, and the latent heat:

$$\dot{Q} = \frac{m}{t}\Delta H = mf\Delta H \tag{10}$$

where, ΔH is the latent heat of the elastoCaloric material, which for NiTi binary alloy is approximately 11 J/g, since the quantity of the material is directly proportional to the cooling power, one of the objectives is to increase the mass of the elastoCaloric material as much as possible, optimizing the spaces and occupying most of the volume of the device, taking into account any pressure drops that may arise. The choice of the right frequency of rotation is also a fundamental parameter for the adiabatic transformation from austenite to martensite:

$$f = \frac{1}{2t_c} = \frac{1}{4\tau} \tag{11}$$

t_c is the time transfer of the fluid into the channel while τ is the thermal time constant. As the Biot number is much lower than 0.1, it is reasonable to neglect the temperature distribution along the wire, so the temperature remains constant at every point on the wire. The time constant can be defined as:

$$\tau = \frac{\rho c}{4h} D_w \tag{12}$$

The relationships above suggest working with a high mass of eCM, consisting of small elements with small diameter:

$$m = n_w m_w \tag{13}$$

$$m_w = \rho_w V_w \tag{14}$$

Therefore, many wires with a very small diameter (approx. 0.5 mm) and a length of approx. 50 cm can be inserted into the system.

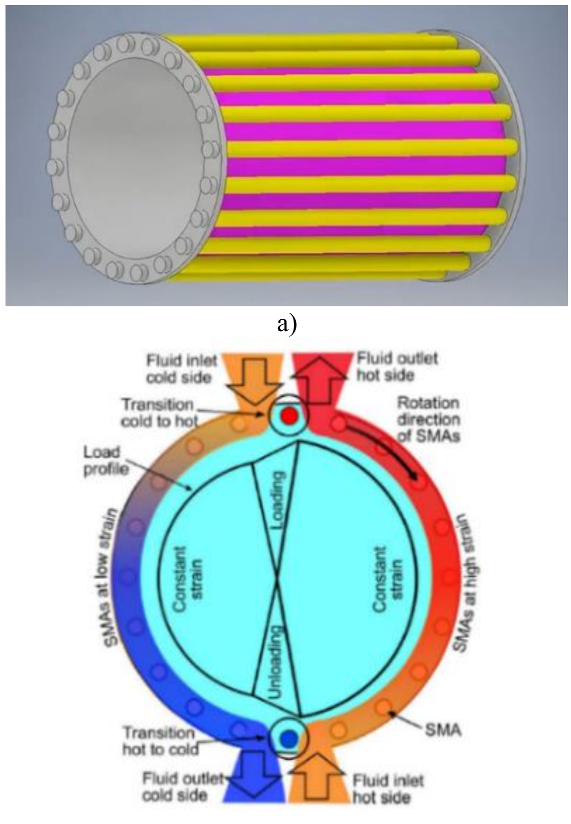


Figure 6. a) The Italian elastoCaloric device: A sketch of the prototype; b) Transversal section of the prototype

5.2 Some preliminary calculations

In this work, an analysis was carried out to compare the development of the heat transfer coefficient h, the frequency f, and the cooling power Q with the variation of the diameter size (0.3 to 1 mm), the airflow velocity as shown in Figure 7 (a,b,c).

The Nusselt number using the Whitaker relation [48]:

$$Nu = \frac{h\, D_w}{k} = \left(0.40\, Re^{\frac{1}{2}} + 0.06\, Re^{\frac{2}{3}}\right) Pr^{2/5} \qquad (15)$$

For the same wire diameter size, the heat transfer coefficient, cycle frequency, and cooling power increase as the airflow speed increases. As the wire diameter increases, it is clear that the cooling power also increases because of the higher value of the mass of the corresponding SMA.

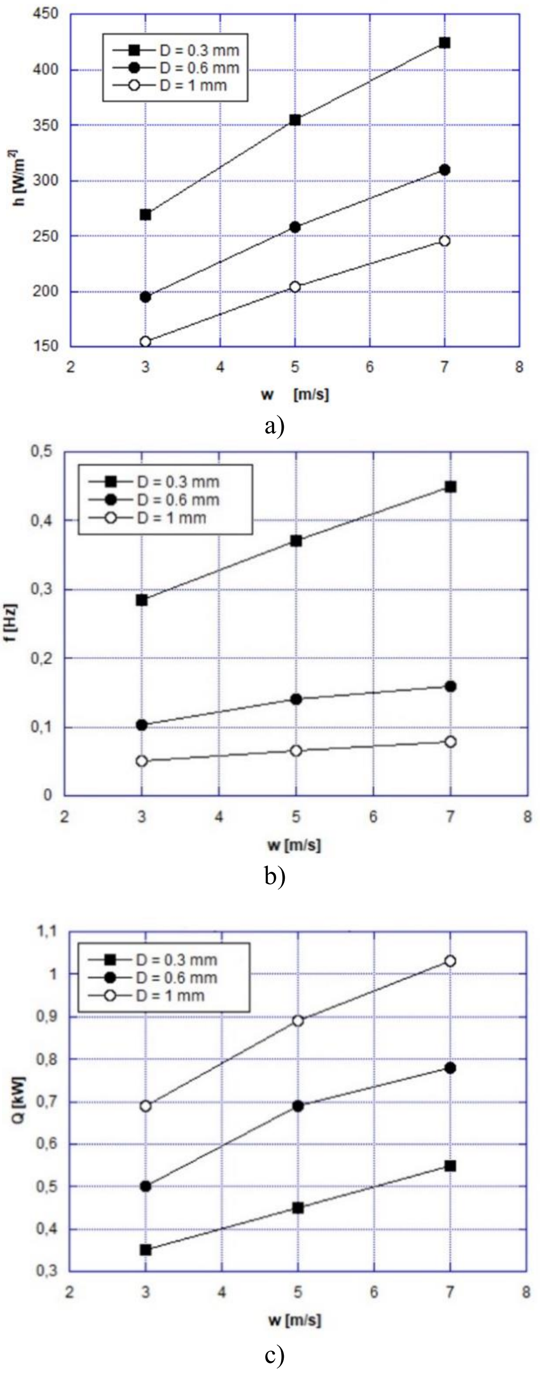


Figure 7. Heat transfer coefficient (a), frequency (b), and the cooling power Q (c) as a function of air velocity and wire's diameter

Finally, the cooling power was evaluated as a function of wire size (diameter) as a function of fluid velocity and a mass of elastoCaloric material of 111 g (Figure 8). At fixed SMA mass, the smaller is the wire diameter, the smaller the heat exchange time constant, the higher the maximum permissible rotation frequency, and, consequently, the greater the cooling power. As the value of the diameter increases, the stress applied is more significant, harming the COP performance coefficient value.

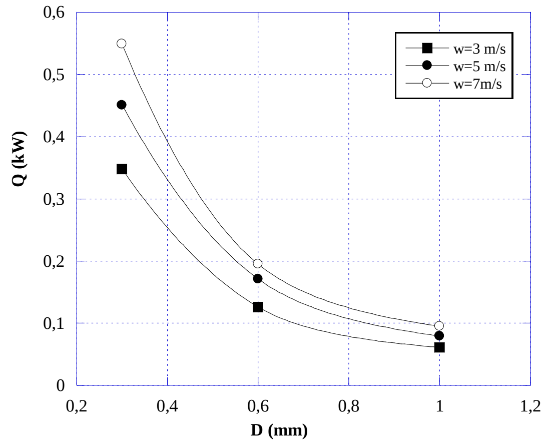


Figure 8. Cooling power as a function of the wire diameter varying the air velocity

The figure also clearly shows that the cooling power increases with air velocity at a fixed diameter, but this trend is more marked at lower velocity values.

6. CONCLUSIONS

According to the scientific community, the most promising solution that could constitute a valid alternative to vapor compression refrigeration could be elastoCaloric cooling. It belongs to solid-state technologies, and the use of solid materials characterizes it with no direct greenhouse effect, and it has also been theoretically estimated that solid-state chillers could have an energy efficiency 50-60% higher than that of vapor compression. Although the elastoCaloric refrigeration is very promising, the related state-of-the-art confers to it the status of initial state technology, little more than embryonic. The elastoCaloric prototypes developed in the world are about a dozen, and they are still far from prospects of commercialization for residential cooling applications.

In this work, a new way of refrigerating is illustrated: elastoCaloric refrigeration. A prior art eC system shows promising performance in generated temperature spam, cooling/heating capacity, and COP. The fatigue life of eCMs is a problematic issue in the commercialization of eC devices. This problem can be addressed by designing new material systems, using new manufacturing methods, and developing new devices.

Furthermore, Italy has not yet presented to the scientific community any elastoCaloric prototype. The SUSSTAINEBLE project was born from this idea with the challenge to build a demonstrative prototype of an elastoCaloric system with environmental conditioning. The prototype is planned to be rotary and composed of several bunches of NiTi or NiTi-based wires crossed by air as heat transfer fluid. In yellow color, the bunch of elastoCaloric elements is visible, and these elements are placed around the circumference of two co-rotating disks. The two discs' synchronous rotation, combined with the presence of customized tension drivers that cyclically load/unload the elastoCaloric elements, allows the elastoCaloric elements to experience, at the same time, different phases of the AeR (Active elastoCaloric Regenerative) cycle. Applying NiTi wires as SMA into the prototype, initial calculations are made. The first results highlighted the importance of using thin wires (<0.5 mm in diameter) to obtain high frequencies and, consequently, a high cooling power value. Furthermore, the direct proportionality of the eCM mass with the cooling power requires us to install many wires inside our prototype.

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NOMENCLATURE

Roman symbols

A	area, m^2
c	specific heat capacity, J kg^{-1} K^{-1}
D	diameter, mm
d	Distance between two wires, mm
f	frequency, Hz
G	elastocaloric term, kJ m^{-3}
H	Latent heat, J g^{-1}
h	convective heat transfer coefficient, W m^{-2} K^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
L	length of the wire, mm
m	Mass, kg
$\dot{m}$	flow rate, kg s^{-1}
n	number of times
p	pressure, Pa
Pr	Prandtl number
$\dot{Q}$	power, W
T	temperature, K
t	time, s
u	x-velocity field component, m s^{-1}
V	volume, m^3
v	y-velocity field component, m s^{-1}
$\vec{v}$	velocity vector, m s^{-1}
w	loading/unloading work, J g^{-1}
x	longitudinal spatial coordinate, m
y	orthogonal spatial coordinate, m

Greek symbols

A	Austenitic
AM	Austenite-to-Martensite transformation
ad	adiabatic
air	air
C	cooling
env	environment
f	fluid
load	loading
M	Martensitic
MA	Martensite-to-Austenite transformation
net	net
SMA	Shape Memory Alloy
span	span
unload	unloading