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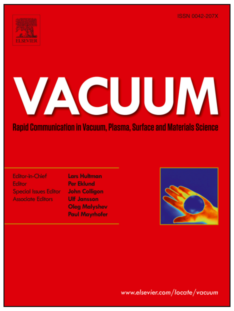

Virtual prototype of a low-cost vacuum baffle based on thermoelectric cooling

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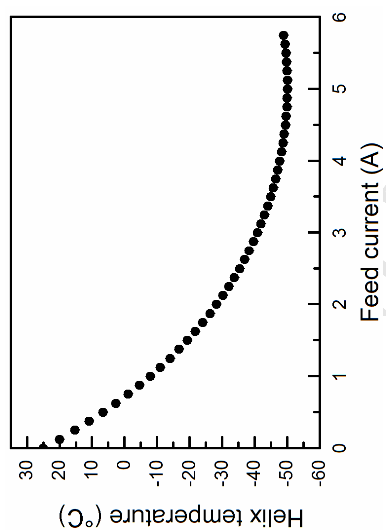
Helix temperature (°C)
Feed current (A)
30
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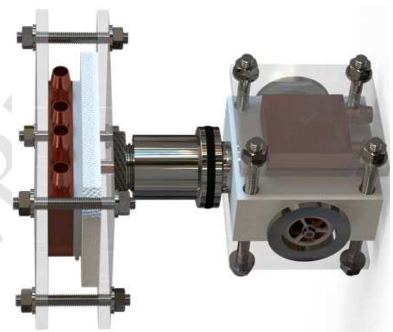

Virtual prototype of a low-cost vacuum baffle based on thermoelectric cooling

Keywords: baffle, vacuum, thermoelectric cooler, TEC, heat transfer, finite element method

Highlights

- We developed a novel low-cost vacuum baffle based on thermoelectric cooling.
- A helix serves as a trapping surface for vapors from the process chamber and pumps.
- A virtual prototype of the TEC-based baffle serves as a proof-of-concept.
- The trapping surface can be cooled down up to -50 °C.
- We discuss different strategies to further optimize the TEC-based baffle.

Abstract

Contaminants can enter vacuum systems from two main sources: backstreaming of oil vapors from the diffusion and mechanical pumps, and vapors generated as byproducts in the process chamber. Both sources can be hindered by using an appropriate baffle.

We developed a virtual prototype of a low-cost baffle for vacuum systems that is cooled down with thermoelectric coolers (TECs). Compared to compressor cooling systems, TECs have useful advantages for this application: they are compact, silent, vibration-free, almost maintenance-free, inexpensive, widely commercially available, and capable of providing a precise temperature control. The baffle is partly built inside a tee vacuum fitting. A refrigerated cooper helix provides the trapping surfaces for contaminants flowing between the process chamber and the vacuum pumps. The cost of the baffle is below USD 250.

The proof-of-concept model, implemented by the finite element method, showed that, when using TEC1-12706 modules, the helix can reach temperatures as low as -50 ºC. According to our analysis, this temperature is more than enough for trapping the contaminants described above.

1. Introduction

Many modern technological processes require clean high vacuum environments. Diffusion pumps (coupled with mechanical pumps) can achieve high vacuum pressures (3×10^{-8} mbar [1]) and are relatively inexpensive and easy to maintain. Their greatest drawback is the backstreaming of oil vapors that could potentially contaminate the chamber where the process of interest is taking place.

Likewise, some of these processes produce, as byproduct, contaminants that must be kept from entering into the vacuum system: the pipes and, especially, the pumps. One example is the pulsed laser deposition of thin films of alloys containing elements with high vapor pressure, such as sulfur, selenium, or tellurium [2]. These contaminants travel down the vacuum pipes and may not only be hazardous to the operator´s health, but could also degrade the properties of the oils used in the pumps.

Cold traps and baffles are used to prevent these problems. A cold trap is a system of cooled walls (usually with liquid nitrogen, i.e., with temperatures between -210 °C and -196 °C) that traps vapor particles (e.g. water) and thus reduces the pressure of the system, effectively acting as a pump. In contrast, baffles rarely operate at such low temperatures, so they are usually uncappable of condensing water vapors and don’t act as pumps. Instead, the baffles’ main purpose is to trap contaminant vapors going up or down the vacuum pipes. When baffles work at very low temperatures (under -130 ºC), then they also act as cold traps [3].

Either cold traps or baffles at liquid nitrogen temperatures are the most effective devices at trapping contaminants, but they also require high capital and operating costs: an initial cost of several thousand dollars and a constant supply of liquid nitrogen, which could cost several thousand dollars per year [3]. Moreover, the demand of liquid nitrogen must be carefully estimated, or it could run out during operation. Using other cooling baths, with varying cooling temperatures, may lower the liquid nitrogen operating costs. But still, any cooling bath requires a guaranteed supply.

One way of avoiding the problems of liquid nitrogen traps is pumping cooled liquids through the baffles. But this approach also has some drawbacks: the compressor needed to keep the liquids at the desired temperature requires space and capital cost, causes noise pollution, and may transmit vibrations to sensitive equipment.

We propose a new baffle technology that overcomes the disadvantages associated with liquid nitrogen or compressor cooling systems. Our baffle is aimed at trapping both oil vapors going up the vacuum pipes (in the direction of the process chamber) and chalcogenide contaminant vapors (i.e. sulfur, selenium, or tellurium) [4–6] going down the vacuum pipes (in the direction of the diffusion pump). This application does not require temperatures in the range of liquid nitrogen, but in the -50 °C to -30 °C range, as we discuss in Section 3. Thus, we developed a baffle device that is cooled down with thermoelectric coolers (TECs, aka Peltier modules). TECs offer useful advantages over compressor cooling systems for vacuum baffles: they are compact, silent, vibration-free, almost maintenance-free, inexpensive, widely commercially available, and capable of providing a precise temperature control.

A water block attached to each TEC's hot side dissipates the released heat and insures the best performance from the TEC. A constant source of room-temperature water close to the baffle is readily available for the refrigeration of the diffusion vacuum pump. Water connections require a periodical check-up for potential leaks, but since the diffusion pump is already cooled using a water line, our TEC-based baffle adds very little extra maintenance to the vacuum system.

Very few researchers have reported works on thermoelectrically refrigerated baffles, but those reports are more than 50 years old [7,8]. Nobody has yet reported a recent attempt making use of the outstanding improvement in TECs in the last years, which has led to many other practical cooling applications [9,10].

Given their obvious advantages, we decided to push the design with a new type of baffle geometry and propose an operational and commercially competitive TEC-based baffle.

2. Trapping mechanisms

We designed our optically opaque baffle to prevent the four possible ways of transmission of particles: (1) bouncing off the cold surfaces (i.e. non-unity sticking coefficient), (2) reemission of trapped particles (3) surface migration along the walls, and (4) collisions between two particles, of the same kind or not (e.g. oil particles with background gas particles).

The temperature of the surfaces determines the first three ways of particle transmission through the baffle. The probability of reemission of a particle will depend upon the equilibrium vapor pressure of that kind of particle at the temperature of the system. When a cold surface is present, the equilibrium vapor pressure will tend toward the equilibrium vapor pressure at the coldest surface in the system [11]. Therefore, lower surface temperature implies lower equilibrium vapor pressure and lower reemission. Similarly, lower surface temperature leads to higher sticking coefficient and lower particle creeping along the surfaces [12].

Particles may not always accommodate completely to the baffle temperature after a single collision [13]. This incomplete thermalization means that the equilibrium vapor pressure of the particles might not correspond to coldest surface in the system (inside the baffle) and therefore, the reemission of trapped particles would be higher than expected. Moreover, when particles collide with other particles, their trajectory deviates from a straight line and might not hit a baffle with a single-bounce arrangement [13]. Finally, if there are multiple trapping instances for a particle, the trapping probability increases drastically (e.g.: the trapping probability is squared in a double-bounce compared to a single-bounce).

That is why it is preferable to use a minimum double-bounce arrangement [11,14]. This configuration hinders numbers 1, 2, and 4 of the ways of particle transmission through the baffle, as it increases the trapping probability, maximizes the thermalization of the vapor particles with cold surfaces, and minimizes the probability that particles bouncing off other particles miss the baffle surfaces.

3. Operating temperatures

Several researchers have studied how high can the surface temperature be to successfully trap backstreaming diffusion oil particles. Crawley and Miller measured that the ultimate pressure of the system decreased by a factor of 2 when the temperature of the baffle changed from room temperature to -5 ºC [8]. Oswald et al. measured significant reductions in oil backstreaming (up to a factor of 50) when the temperature of the baffle changed from room temperature to -15 ºC [15]. Poslawski stated that temperatures from -25 °C to -35 ºC are adequate for condensing diffusion pump fluids [7], although more modern diffusion oils -such as DC704, DC705, Santovac 5, or Fomblin- have much lower vapor pressures than those considered by Poslawski [16]. Therefore, with these oils, the limiting temperatures could be even higher.

Chambreau et al. analyzed, not only the backstreaming of diffusion pump oil, but also of mechanical pump oil, as well as the contribution of water particles to the vacuum system's performance [3]. Here we describe their main conclusions.

Baffles working below -130 °C can effectively cryopump water vapor, increasing the pumping speed and lowering the final pressure of the vacuum system. At higher temperatures, the vapor pressure of water increases to the point where partial cryopumping may occur. This is an undesirable phenomenon because the slow desorption of water from the baffle would lead to excessively long pump-down and/or bake-out times. Thus, Chambreau et al. recommend temperatures below -130 °C or above -50 °C for preventing the partial cryopumping of water.

Small amounts of mechanical pump oil backstream to the diffusion pump during the repeated vacuum cycles and, from there, enter the vacuum pipes. These mechanical pump oils have a much higher vapor pressure than diffusion pump oils ($\sim 10^{-5}$ mbar for Inland 19, compared to 4×10^{-10} mbar for Santovac 5 at room temperature [3]). For this reason, Chambreau et al. argued against using a baffle temperature of around -10 ºC and proposed working at around -50 ºC.

The same reasoning applies to the particles generated in the process chamber. As follows from the vapor pressure tables [17], the vapor pressure of sulfur is higher than that of diffusion pump oils but lower than that of common mechanical pump oils: $\sim 10^{-6}$ mbar at room temperature, $\sim 10^{-10}$ mbar at -30 ºC, and $\sim 10^{-11}$ mbar at -40 ºC. The vapor pressures of selenium and tellurium -though high when compared to other elements- are orders of magnitude lower than that of sulfur and diffusion and mechanical pump oils.

Therefore, we designed the baffle to operate at a temperature between -30 ºC and -50 °C, as it will trap chalcogenide and oil particles while still letting water molecules pass through.

4. Baffle design

As previously stated, our goal was to develop a low-cost and almost maintenance-free baffle, based on thermoelectric coolers (TECs), that could stop the flow of chalcogenide and oil vapors through the vacuum pipes. Fig. 1 is a rendered image of the TEC-based baffle, while Fig. 2 shows a 3D section view.

Fig. 1. Rendered image of the developed TEC-based baffle.

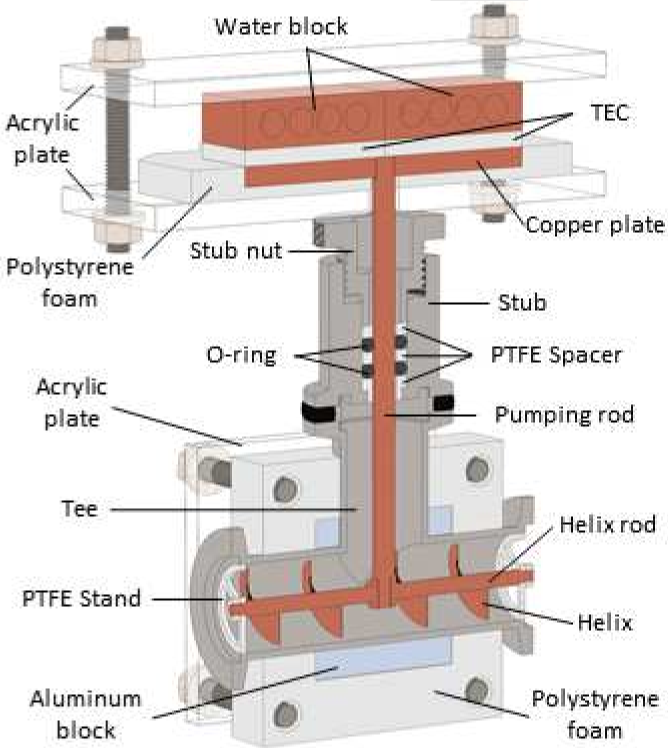

Fig. 2. 3D section view of the developed TEC-based baffle. The lateral TECs and the water blocks, visible in Fig. 1, cannot be seen here.

We selected an inexpensive and widely commercially available TEC to cool down the baffle: the TEC1-12706 module, which supports a maximum current of 6 A at 14 V. Such as most common modules, this TEC has elements unsuitable for high vacuum (especially the silicone sealing). Thus, we mounted two TECs on the atmospheric side and thermally connected them to the trapping surface located on the vacuum side. The trapping surface consists of a copper helix, which is wrapped around a copper rod (from now on called helix rod) that runs through the major axis of a tee vacuum fitting. Another copper rod (from now on called pumping rod), perpendicular to the helix rod, thermally connects the helix and the helix rod with the TECs.

The helicoidal geometry of the trapping surface responds to the need of trapping vapor particles efficiently. In contrast to the common chevron-type fins design, the helix-shaped design is very easy to cool down with a simple thermal connection (i.e. with the helix and pumping rods). The helix has also good trapping capability due to its multiple-bounce arrangement (particles must undergo several collisions to pass through it) without blocking the flow in the vacuum pipe.

The helix rod is held centered in the tee by two stands placed at the ends of the rod. These stands are shaped so that they can withstand the weight of the inner parts of the baffle while, at the same time, allow maximum conductance (reciprocal of flow resistance). They are made of PTFE because PTFE is a good thermal insulator and it shows very low rate of outgassing in vacuum [18]. Transmission by migration along the surfaces is mitigated by the PTFE stands placed at the ends of the tee. Since these stands are in contact with the inner walls of the tee, the particles are diverted around the wall of the stands.

Introducing elements in vacuum pipes decreases its conductance. Thus, to minimize the conductance loss due to the helix and the helix rod, the tee that holds them is one size bigger than the fittings in the vacuum system: if the vacuum system has NW16 fittings, the tee has NW25 fittings. Reducers are used to transition between flange sizes.

The heat is pumped from the helix and the helix rod through the pumping rod. The pumping rod is screwed into the helix rod on one end and into a copper plate on the other end. The copper plate distributes the heat load between the cold plates of the two TECs. Two copper water blocks cool down the TEC's hot plates using room-temperature water. A thin layer of thermal paste is applied between the water blocks, the TECs, and the copper plate to maximize the thermal conductance. Polyurethane foam is used to isolate the cold surfaces of the copper block from the environment. Two acrylic plates, pressed with four threaded rods and nuts, help holding together the water blocks, the TECs, the copper plate, and the foam, while increasing thermal conductance at the interfaces.

A specially designed stub, machined from a vacuum blank stub, acts as the gate between the atmospheric and vacuum sides. Inside the stub, the vacuum seal is assured with a series of two silicone O-rings (with a service temperature from -54 ºC to 204 ºC [19]) and PTFE spacers assembled around the pumping rod. Two O-rings are preferred over a single O-ring to prevent the seal-leakage caused by a small displacement or tilt in the pumping rod. In this way, the mechanical stress is divided between the two O-rings, maintaining their rated sealing properties. A stub nut is screwed into the stud to apply pressure on the O-rings. Well-made O-rings in a static seal environment can achieve pressure levels as low as 10^{-8} mbar [20], which is the lowest pressure attainable by diffusion pumps [1].

The tee is cooled down with two additional TECs. To this end, a two-piece machined block with flat external surfaces is soldered to the tee. The block is made of aluminum for its high thermal conductivity. The TECs -refrigerated with copper water blocks- cool down the opposite faces of the aluminum block, while two acrylic plates hold and press all these components together. Polyurethane foam is used to isolate the tee and the aluminum block from the environment. Cooling down the tee has a triple purpose: i) helps to achieve the lowest possible temperature in the helix by minimizing radiation heat transfer, ii) reduces the time it takes to reach the operating temperature, and iii) hinders the process of particle creeping along its internal walls and could act as another trapping surface (if low enough temperatures are reached).

The tee, the stub, and the stub nut are made of 304 stainless steel. Compared to aluminum, 304 stainless steel has lower thermal conductance, has higher resistance to corrosive vapors and to cleaning products, and achieves lower vacuum pressures. All the materials used in the TEC-based baffle are vacuum-compatible for pressures below 10^{-8} mbar.

The baffle design allows for a very simple in situ cleaning procedure. Reversing the TECs' polarity warms up the baffle (in this case, the water blocks keep TECs' cold sides at room temperature). This procedure evaporates the trapped volatile materials such as chalcogenide glasses without dismantling the device. Under air or nitrogen flow, a well-designed venting system can carry the evaporated elements safely away from the vacuum system and the personnel. The TECs and the silicone O-rings limit the maximum service temperature to 150-200 °C. For a thorough cleaning routine, the baffle can be easily disassembled: ISO quick flanges (aka QF, KF or NW) allow for an easy removal, while both copper rods can be unscrewed. The helix and the interior walls of the tee can then be cleaned with trichloroethylene, acetone, and isopropanol.

5. Proof-of-concept model

Virtual prototypes have the advantage over physical prototypes of being less time- and cost-consuming, particularly when re-designs are needed. We developed a proof-of-concept model using the finite element method to demonstrate the feasibility of the proposed device and to predict its performance under different working conditions.

We performed a heat transfer analysis in steady-state of a simplified 3D model, where we exploited symmetry and eliminated unnecessary geometrical details to reduce computational cost. We added extended pipes to the ends of the tee to consider the effect of heat flux through the vacuum pipes. TECs consist of multiple n-type and p-type semiconductor legs connected electrically in series and thermally in parallel between two ceramic plates. The aim of the proof-of-concept model was to predict the thermal behavior of the integrated system, rather than to analyze the heat transfer inside the TEC. Thus, we adopted the approach implemented and validated by Soprani et al. [21], which preserves average heat fluxes and reduces computational effort. By considering the weighted mean of semiconductor and air properties, we determined the effective properties of a homogenous and isotropic thermoelectric layer between the ceramic plates.

5.1. Governing equations

The fundamental equation governing heat transfer is the law of conservation of energy:

$$\rho C \frac{\partial T}{\partial t} + \nabla \cdot \boldsymbol{q} = Q \qquad \text{(eq. 1)}$$

where ρ is the mass density [kg/m^3], C is the specific heat capacity [J/(kg×K)], T is the absolute temperature [K], $\boldsymbol{q}$ is the heat flow density vector [W/m^2], and Q is the generated heat by unit volume [W/m^3]. In steady-state, $\frac{\partial T}{\partial t} = 0$, thus eq. 1 becomes:

$$\nabla \cdot \boldsymbol{q} = Q \qquad \text{(eq. 2)}$$

The heat conduction in the device is governed by Fourier's law:

$$\boldsymbol{q} = -k\nabla T \qquad \text{(eq. 3)}$$

where k is the thermal conductivity of the material [W/(m×K)]. When there is no heat source, it follows that:

$$\nabla \cdot (-k\nabla T) = 0 \qquad \text{(eq. 4)}$$

Moreover, in the homogeneous thermoelectric layer, thermal conduction is combined with the driving reversible Peltier effect (eq. 5) and the irreversible Joule effect (eq. 7):

$$\boldsymbol{q} = -k\nabla T + \Pi \boldsymbol{J} \qquad \text{(eq. 5)}$$

where $\boldsymbol{J}$ is the volumetric current density vector [A/m^2], and Π is the Peltier coefficient of the material [V]. The second Thomson relation, valid for time-reversal symmetric materials, relates the Peltier coefficient to the Seebeck coefficient, S, [V/K] as follows:

$$\Pi = ST \qquad \text{(eq. 6)}$$

Finally, the heat generated by Joule heating is:

$$Q = \frac{\boldsymbol{J} \cdot \boldsymbol{J}}{\sigma} \qquad \text{(eq. 7)}$$

where σ is the electric conductivity of the material [S/m].

Therefore, the governing equation for steady-state heat transfer in the homogeneous thermoelectric layer results:

$$\nabla \cdot (-k\nabla T + ST\boldsymbol{J}) = \frac{\boldsymbol{J} \cdot \boldsymbol{J}}{\sigma} \qquad \text{(eq. 8)}$$

5.2. Boundary conditions

In this proof-of-concept model, we considered:

- a thermal resistance of 4 W/(m×K) at the outer boundaries of the ceramic plates of the TECs, corresponding to the contribution of a 0.1 mm thick layer of thermal paste [21].
- perfect thermal contact at any other interface in the assembly.
- convective boundary conditions following Newton's law, with natural air convection at the outer surface of the device, and water forced convection at the water block inner tube's surface:

$$-\boldsymbol{n} \cdot \boldsymbol{q} = h(T - \theta) \qquad \text{(eq. 9)}$$

where $\boldsymbol{n}$ is the surface normal vector, h is the convective coefficient across the solid-fluid surface [W/(m^2×K)], and θ is the temperature of the fluid (air or water) [K].

- room temperature boundaries at the ends of long vacuum pipes connected to the baffle.
- symmetry boundaries at the xz-plane (see Fig. 4b):

$$-\boldsymbol{n}\cdot\boldsymbol{q} = 0 \quad \text{(eq. 10)}$$

- negligible radiation heat transfer (due to similar temperatures among facing surfaces in the vacuum cavity, and between the ambient air and the outer surfaces of the device).

5.3. Material properties

To accurately model the thermal behavior of the device, we used isotropic temperature-dependent material properties. To this end, we fitted reported data to polynomials, using the least-squares method, over the temperature range of interest (220-300 K) (Table I). Then we calculated the effective properties of the homogeneous thermoelectric layer by considering that the TEC1-12706 module has a 27% of bismuth telluride and a 63% of air between the ceramic plates [21].

Table I. Temperature-dependent material properties in the 220-300 K range: thermal conductivity (k), Seebeck coefficient (S), and electrical conductivity (σ). The coefficients were determined by fitting polynomials to the data reported in the cited references.

Material	k [W/(m K)]	Ref.
Aluminum 6061-T6	$(4.30449\times10^{1})+(7.15063\times10^{-1})T+(-1.47829\times10^{-3})T^2+(1.14085\times10^{-6})T^3$	[22]
Copper	$(3.60117\times10^{2})+(7.98619\times10^{-1})T+(-3.74837\times10^{-3})T^2+(5.02411\times10^{-6})T^3$	[23]
Stainless steel 304	$(6.71279)+(3.30858\times10^{-2})T+(-2.24127\times10^{-5})T^2+(2.54631\times10^{-8})T^3$	[24]
Alumina	$(9.4849\times10^{1})+(-6.44708\times10^{-2})T+(-1.20755\times10^{-3})T^2+(2.5434\times10^{-6})T^3$	[23]
PMMA	$(2.68111\times10^{-1})+(-1.11311\times10^{-3})T+(4.99560\times10^{-6})T^2+(-6.82192\times10^{-9})T^3$	[25]
Polyurethane foam	$(3.19897)+(-5.58943\times10^{-2})T+(3.63879\times10^{-4})T^2+(-1.03896\times10^{-6})T^3+(1.09857\times10^{-9})T^4$	[26]
PTFE	$(1.73676\times10^{-1})+(9.64208\times10^{-4})T+(-3.22831\times10^{-6})T^2+(3.71896\times10^{-9})T^3$	[24]
Silicone (O-rings)	$(1.97789\times10^{1})+(-2.34987\times10^{-1})T+(9.43281\times10^{-4})T^2+(-1.26193\times10^{-6})T^3$ $(220\text{ K}<\text{T}<253\text{ K})$ $(2.55712\times10^{-1})+(5.47693\times10^{-5})T$ $(253\text{ K}<\text{T}<300\text{ K})$	[27]
Air	$(-4.20714\times10^{-4})+(1.03548\times10^{-4})T+(-4.94048\times10^{-8})T^2$	[28]
Bi_2Te_3	$(5.39069)+(-2.37427\times10^{-2})T+(3.68443\times10^{-5})T^2$	[29]

Material	S [V/K]	Ref.
Bi_2Te_3	$(3.85366\times10^{-5})+(8.40813\times10^{-7})T+(-9.25784\times10^{-10})T^2$	[29]

Material	σ [S/m]	Ref.
Bi_2Te_3	$(6.01285\times10^{5})+(-3.70646\times10^{3})T+(9.35486)T^2+(-8.64519\times10^{-3})T^3$	[29]

5.4. Operating conditions

The device will operate with both air and water at $\theta = 298\ K\ (25\ °C)$. Natural air convection coefficient was set to $h_{air} = 10\ W/(m^2 \times K)$ (typical values range from 2 to 25 W/(m^2×K) [30]), while we estimated a forced water convection coefficient of $h_{water} = 10.000\ W/(m^2 \times K)$ [30,31].

The electric current supplied to the TEC1-12706 modules was an input of the model. We analyzed the behavior of the device for feed currents ranging from 0 to 5.75 A. To keep the analysis simple, all TECs were operated at the same current. The effective scalar current density, J, driven across a homogeneous thermoelectric layer is related to the feed current, I_{feed}, as follows [21]:

$$J = x_{BiTe}\frac{I_{feed}}{A_{leg}} \quad \text{(eq. 11)}$$

where $A_{leg} = 1.69\times10^{-6}\ m^2$ is the cross-sectional area of a thermoelectric leg, and $x_{BiTe} = 27\%$ is the volume fraction of semiconductor materials between the plates for the TEC1-12706 module [21].

5.5. Results

We analyzed the steady-state temperature distribution throughout the entire baffle as a function of the feed current (Fig. 3). We found that feed currents over 2.1 A can maintain the cold surfaces of the baffle within the desired temperature range of -50°C to -30 °C. A feed current of 5 A supplied to the TEC1-12706 modules achieved the minimum temperature of -50 °C at the helix surface (Fig. 3 and 4). But the baffle operates more efficiently with 4A, as it reaches a temperature only 2 °C higher at the helix surface while consuming 37 % less power (340 W for 5 A vs 215 W for 4 A).

Part of the inner walls of the tee reach temperatures as low as -42 °C with a feed current of 5A and -40 °C with 4A. This means that, under these conditions, these walls act as trapping surfaces as they hinder the particle creeping along them.

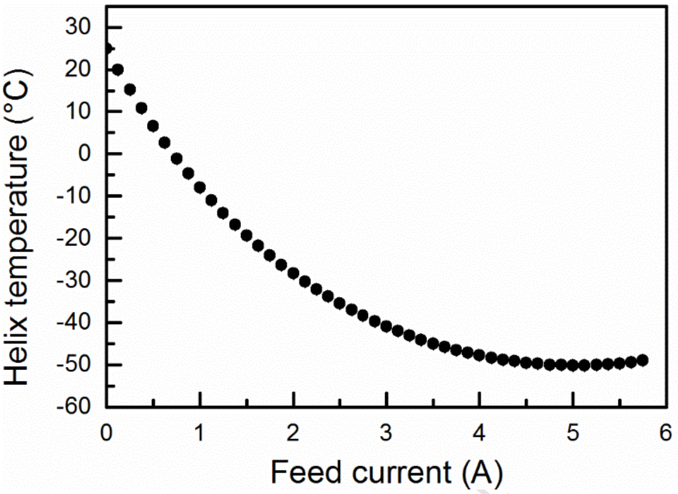

Fig. 3. Dependence of helix temperature with the feed current supplied to the TEC1-12706 modules.

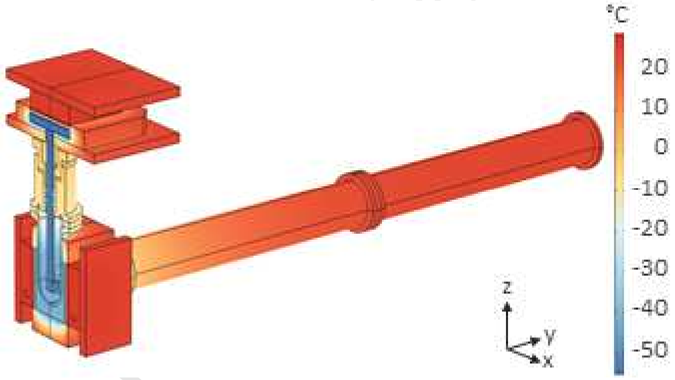

Fig. 4a. Finite element analyses of the temperature field in the TEC-based baffle connected to a long vacuum pipe ($I_{feed} = 5A$).

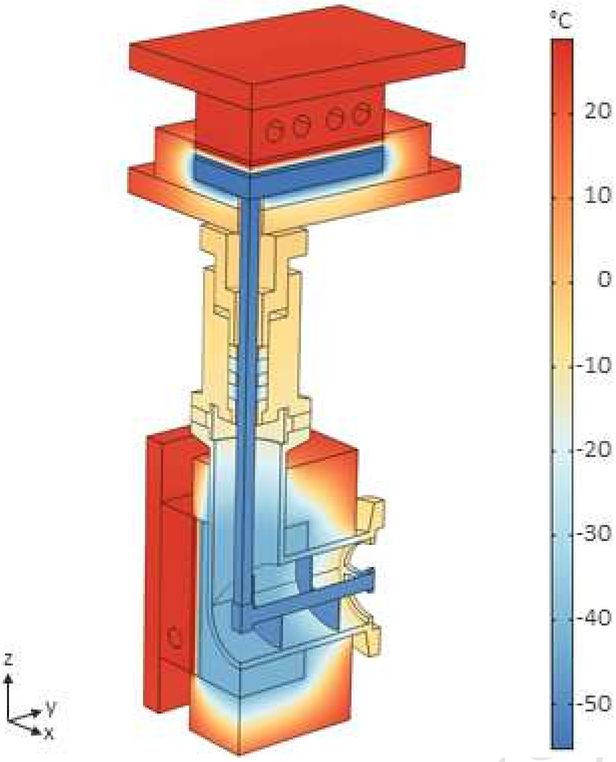

Fig. 4b. 3D section view of the temperature distribution in the TEC-based baffle ($I_{feed} = 5A$).

6. Conclusions and future work

We presented a novel design of a vacuum baffle based on thermoelectric cooling. A virtual prototype, analyzed by the finite element method, proved that the trapping surfaces can reach -50 °C when the baffle is cooled down with TEC1-12706 modules fed with 5A. Even lower temperatures could be achieved with higher power rating TECs and more efficient water blocks. However, -50°C is enough for trapping oil vapors and chalcogenide contaminants while avoiding the undesirable partial cryopumping of water.

The virtual prototype consumed 215 W ($I_{feed} = 4A$) to cool the helix of the baffle down to -48 °C, which is roughly half of the power requirement of a compressor used in baffles cooled down with pumped liquids [3].

All the components of this TEC-based baffle are either commercially available or simple to manufacture. The cost of the whole baffle is lower than USD 250 (manufacturing costs not included). The most expensive components are the tee (USD 80) and the four water blocks (USD 40).

Our TEC-based baffle may be used in small or medium sized high vacuum systems (up to NW50 flanges and pressures above 10^{-8} mbar). The baffle can be easily adapted for larger systems using other sizes or types of flanges. The vacuum seal may be improved for systems requiring ultra-high vacuum using a ceramic-to-metal seal, instead of the series of two silicone O-rings and PTFE spacers. In this case, the ceramic material must satisfy several requirements: low thermal conduction, low outgassing, and similar expansion coefficient to stainless steel (to maintain the vacuum seal throughout a large temperature range).

The virtual prototype of the TEC-based baffle presented here is intended to serve as a proof-of-concept. A physical prototype is currently under development that will provide real temperature values at the trapping surfaces. The materials and dimensions will be optimized in future works. Of special importance is the optimization of the geometry of the helix, that must meet the requirement of a minimum two-bounce arrangement while providing a maximum conductance. Furthermore, since both pairs of TECs could operate at different power inputs, we also expect to optimize the feed currents that make the best compromise between cooling temperatures and consumed power.

7. Acknowledgments

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Virtual prototype of a low-cost vacuum baffle based on thermoelectric cooling

Highlights

- We developed a novel low-cost vacuum baffle based on thermoelectric cooling.
- A helix serves as a trapping surface for vapors from the process chamber and pumps.
- A virtual prototype of the TEC-based baffle serves as a proof-of-concept.
- The trapping surface can be cooled down up to -50 °C.
- We discuss different strategies to further optimize the TEC-based baffle.