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Convective thermal fluxes in unsteady non-homogeneous flows

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Abstract

In this paper we describe a novel experimental apparatus consisting of a thermoelectric driven heating and cooling device that could be used in didactic laboratories and research. Is possible to model common environmental flows by means of convective cooling and/or heating. We describe here a four cell device, in a 3D enclosure, but furthermore, it is possible to generate a convective flow of complex profiles using an array of thermoelectric devices (Peltier/Seebeck cells) controlled by a thermal proportional-integral-derivative controller (PID controller) generating a multisource buoyant flux. When convective heating and cooling takes place the combination of internal waves and buoyant turbulence is much more complicated if the Rayleigh and Reynolds numbers are high in order to study entrainment and mixing. The experiments made by our thermoelectric driven device could be used to analyze complex mixing, in either low or high Prandtl numbers, using scalar or heat transport in different liquids. From the varied experiments carried out with our device, we can compute and visualize the fields of velocity, vorticity, density and their gradients, here just a few configurations and the corresponding flows will be shown.

Keywords: Thermoelectricity, Thermoelectric device, Heating-Cooling, Convection, PIV, Vorticity.

1. Introduction

To study the motion of convective flow through the more refined temperature and heat flux control thermoelectric device coolers and heaters is a clear advantage for the scientific study of the effects of convective flow [1, 2]. These flows are not easy to vary taking into consideration Neumann or Dirichlet wall boundary conditions. A convenient way of controlling and measuring the heat inputs and outputs is using thermoelectric devices. The discovery of the Seebeck (1882) and the Peltier effects (1834) are the basis of thermoelectricity, [4,5] there were little practical applications of the phenomenon until the middle 1950s [1-3]. Prior to then, the poor thermoelectric properties of known materials made them unsuitable for use in a practical refrigerating device. [6], from the mid-1950s to present days the major thermoelectric material design approach was that introduced by A.V. Ioffe, with semiconducting compounds such as Bi2Te3 [3]. The development of practical thermoelectric cooling and heating devices is based on the reversibility of thermoelectric coolers: they are compact, their response is fast and the degree of cooling or heating may be controlled by the Intensity or Voltage of the electric current supplied. It is important to consider the inherent non-linear asymmetry between heating and cooling.

The magnitude defined as the coefficient of performance (COP) characterizes the efficiency of the thermoelectric module. This coefficient is defined as the total heat transferred through the thermoelectric module (Q_p) divided by the electric input power:

$$COP = \frac{Q_p}{Q_{te}} \quad (1)$$

Unfortunately, compared to vapour-compression refrigeration, they are limited in the heat flux that they can accommodate and exhibit a lower coefficient of performance. These two limitations have generally limited thermoelectrics to applications characterized by low heat flux although they offer an excellent range of boundary fluid control.

The development of new thermoelectric materials and thin structures, in consequence, the interest in the application of thermoelectrics to electronic cooling increased. The dimensionless product, *ZT*, characterizes the usefulness of thermoelectric materials for refrigeration, where *T* is the temperature (in *K*). The *Z*-factor measures the global performance of the thermoelectric material and is given by

$$Z = \frac{\alpha^2}{R \cdot k} \quad (2)$$

where α is the Seebeck coefficient, R is the electrical resistivity, and *k* is the thermal conductivity. The Z parameter depends mostly on the material properties of the thermoelectric elements [4-9]. Equation (2) has implicitly the assumption of locality as well as linearity. There are three basic ingredients that produce higher figures of merit, basically, high Seebeck coefficients α, high electrical conductivities (or low Resistances R=1/σ) and low values of the thermal diffusivity κ all will depend in some extent on the detailed topology of the generalized forces and fluxes because the non-local effects may be important in complex flows.

For electronic cooling applications, it is necessary to improve the values of *ZT* over the temperature range of 300° to 325° K or below. *ZT* values equal to or greater than 1, over different ranges of temperature varying from 375° to 975° K, have been obtained for different materials, as skutterudite and Zn4Sb3-based materials. Different studies conclude that the *ZT* value is enhanced with a decrease of the grain size of the semiconductor material (as it reduced toward the nano-scale) [6].

High Seebeck coefficients α, high electrical conductivities (or low Resistances R=1/σ) all will depend in some extent on the detailed topology of the generalized forces and fluxes (in Onsager / Prigogine terms) because the non-local effects may be important in complex flows.

Because the material thermoelectric effects implicitly assume a local effect as well as a linea one. Experimental evidence [6] shows dependence between the value of the Seebeck coefficient measured in the samples and the fractal dimension of the FeSi2 concentration iso-lines as well as a strong anisotropy.

The boundary layers despite the fact that they play a very important part in the thermal behaviour and other structures (a Rayleigh number of order 1011 is typical of a large space in a building with a heated wall of height 5 m and the temperature difference of 10°C between the wall and the air). However, at high boundary layer Rayleigh number, one might reasonably assume that effects of molecular viscosity are small compared to those of turbulent mixing and that the entrainment assumption applies which is used frequently in the analysis of buoyant ventilation [7].

The TCDD device is very useful to model flows in closed rooms as this instrument is also an enclosure and it allows to generate hot and cold focus as in a room, also is possible to visualize the vertical structure of the flows with stratification, an, considering the initial condition of Rayleigh-Taylor [8, 9].

As another example, our device allows studying the early stages evolution of the turbulent mixing layer and its complex configuration taking into account the dependence on the initial modes in order to analyze its spectral and self-similar information later [10-11]. The diagnostic of turbulent mixing is based on schlieren and shadowgraph visualization method with a planar laser sheet, through the methodology of the method Particle Image Velocimetry (PIV) [12].

This paper is organized as follows: section 2 shows the control and basic control parameters of the TCDD and 3 describes the structure and possible thermoelectric initial working conditions investigated as experimental set-up, section 4 describes the methodology of some of the possible tests, section 5 describes initial results using the image processing method. Finally, some results and conclusions obtained by using TCDD experiments are presented

2 Control and basic Parameters of the Thermoelectric Convective Didactive Device (TCDD)

The aim of the design of the TCDD was to cover a wide range of possible fluxes both Laminar and Turbulent, the geometry of Thermal differences may include both 4 convective isolated sources of 4 cm x 4 cm or even extend the parameter space to the extended Layers of 20 cm x 10 cm. The parametrization of the buoyancy terms are due to Richardsons and Rayleigh numbers, Prandtl numbers as the ratio of kinematic molecular viscosity (or momentum diffusivity) to molecular thermal diffusivity, are also fundamental, but basically, depend on molecular fluid properties. The experiments were mostly performed with fresh water (Salty brine experiments introduce ney parameters in the problem, such as Schmidt and Peclet numbers).

To relate heat transfer from the thermoelectric devices to the enclosure let us clarify the conductive and convective local properties:

Fourier law relates the heat flux per unit area $\frac{1}{A}\frac{dQ}{dt}$ to the perpendicular temperature gradient $\overrightarrow{\nabla_L T}$ and the thermal coefficient of conduction k as:

$$\frac{dQ_{cd}}{dt} = -kA\nabla T \quad (3)$$

The dimension of k are $[k]$ = $MLT^{-3}Q^{-1}$ and typical values for copper and aluminium are $k_{cu} = 9.2x10^{-3}$ kcal $s^{-1}m^{-1}$ K^{-1} for $k_{AL} = 4.8x10^{-3}$ kcal $s^{-1}m^{-1}$ K^{-1}.

The thermal diffusivity κ has dimension $[\kappa]=L^2T^{-1}$. In fluid convection is measured locally by the convective coefficient as

$$\frac{dQ_{cd}}{dt} = -kA\Delta T \quad (4)$$

If we want to estimate the Nussel number it consists of the ratio of convective to conductive transfer, so,

$$Nu = \frac{Q_{cu}}{Q_{cd}} = \frac{h\Delta T}{k} \quad (5)$$

The Nusselt number expresses the ratio of fluid motion, either advection, forced or Natural Convection induced heat transfer compared with the conduction due only to the molecular heat transfer due to a stagnant fluid.

Two basic flow parameter define the effects of buoyancy, the Richardson number Ri, and the Rayleigh number Ra:

$$Ra = \frac{ag\Delta TL^3}{\kappa\,\nu} \quad (6)$$

where a is the thermal expansion coefficient, g the gravitational acceleration, ΔT the temperature diference, across L the depth of the fluid, or side of the enclosure ν is the kinematic viscosity and κ the thermal diffusivity that defines the Prandtl number as, $Pr = \frac{\nu}{\kappa}$.

Above a critical Ra, the buoyancy force overcomes the dissipative effects of viscosity and thermal diffusivity at the same time and convective motion sets in.

Of course, the Nussel number Nu is always equal o tor larger than one. Malkus derived a simple general law from dia mensional analysis showing that for high Reynolds number, there exist a power law as

$$Nu = c\,Ra^{1/3} \quad (7)$$

If we want to study the motion of a sharp density interface, in terms of the Richardson number, depicted as:

$$Ri = \frac{ga\Delta\rho l}{\rho u'^2} \quad (8)$$

where $\Delta\rho$ is the density difference across the salt solution interface, or temperature thermocline the integral length scale l of the turbulence is modelled here by the image analysis.

The entrainment is the advance of a front or interface, V_e divided by the r.m.s. turbulent local velocity

$$E = \frac{V_e}{u'} \quad (9)$$

And in general there is a power law relationship between then:

$$E = c\,Ri^m \quad (10)$$

With c and m constants.

The advantage of the TCDD is the possibility of covering large parameter maps as well as obtaining accurate velocity and temperature data at different parts of the fluid as well as tear boundaries.

The subsequent analysis, confirm the overall physical picture of non-Boussinesq convection described earlier. Our results are, however, for a large Prandtl number as well as large Rayleigh number. The flow pattern is characterized by long, thin plumes which span the convection field. A simple model of the heat transfers into the plumes, across the thin thermal boundary layers on the top and bottom walls, allows the calculation of the central temperature under the assumption of complete mixing no direct influence of one boundary layer upon the other. The values obtained agree reasonably well with the measured central temperature. The central temperature adjusts itself so that heat fluxes from boundaries are equal, and temperature fluctuations at the centre symmetrical, at a cost of very different temperature drops and Rayleigh number for each boundary drag and heat diffusion, and convective motion sets in. The early works in this field were mostly focused on the onset of convection. In recent years, significant advances have led to the introduction of different turbulent states, far beyond the onset of convection, with various scaling laws.

The TCDD started as a project with university-industrial collaboration that explores thermoelectric driven convection. The result was the design and creation of the device called Thermoelectric Convective Didactive Device and, from now on, it will be called TCDD (Figure 1) which is a thermoelectric driven convective apparatus made by Berotza Company [1-3].

Figure 1. The Thermoelectric Convective Didactive Device (TCDD) with its control panel, computer measuring and control of temperature.

They include a novel technique, using thermoelectric (Peltier) heating-cooling elements in order to generate a lateral heat flux gradient (time-dependent). The best feature of this easy to use the device is easy to measure and calibrate the experiment with convective flows, very easy to have stable conduction and heat transfers in the environment, it is the advantage of other thermoelectric devices, including Joule, Seebeck, Thompson and Peltier effects.

The results of this model provide maybe use to estimate the vertical temperature distribution along the device. They also provide an explanation for the phenomenon observed in laboratory scale models whereby the natural convection boundary layer may detach from the heated wall and form one or more horizontal intrusions.

TCDD device is a useful apparatus for fluids dynamics laboratories and research proposed for the community of student and professor focus in Environmental and geophysical flows, technical professional schools or industry may incorporate practical research in several fields such as environmental flows (thermal plumes in the atmospheric boundary layer (ABL) or thermohaline convection), fluid dynamics and heat transfer (enclosed flows) or nuclear, civil and industrial engineering (ventilation, nuclear reactor cooling or chemical thermal reactions).

Several other effects, as well as Fourier's heat conduction, can be used to design a new generation of laboratory experiments where applied physics and fluid dynamics are closely linked, for example, Thomson gradient driven effects or even magnetic influenced (Nernst-Ettingshausen effect). Good thermal control and high reliability are a major advantage of the thermoelectric modules used in the experimental convective box. The control of thermoelectric coolers is better, they enhance the cooling of electronic modules and they allow a higher power [4,6].

Some practical and didactic application to be prepared using TCDD are described here. By assuming the boundary layer to be fully turbulent and that the effects of molecular viscosity are therefore negligible it is then possible to model the boundary layer as a buoyant plume developing as a result of a vertically distributed source of buoyancy. The differential equations governing the flow in both the boundary layer and in the room itself have been solved using a numerical technique for the transient cases of a sealed room and a ventilated room. [7, 8].

3. Description of the Thermoelectric Convective Didactive Device (TCDD)

The analysis between experimental and numerical results for cases of advanced mixing or non-mixing process at a density interface due to body forces [10] and gravitational acceleration was studied considering the fractal and spectral structure in the facility of removable plate experiments for Rayleigh-Taylor flows [9,11] or for the analysis of experiments of convective plumes and the structures of non-homogeneous flows [12].

Using the ESS and self-similarity structures for the velocity and vorticity field and study the behaviour of intermittent flow for the mixing and stirring layer [13-15].

The progress of the mixing front and the topological characteristic of the merging plumes and jets are associated in different configurations in order to compare the behaviour of the evolution of each phenomenon and the evolution in the set.

The program DigiFlow capable of analysis using the PIV method and in synthetic schlieren [19]. This allows the highly accurate pattern matching algorithms developed for synthetic schlieren to produces a local velocity field. The boundary condition effects and the role of combining the topological 3D and 2D characteristics of the individual flows relate to the scale to scale turbulent and inverse cascades.

An important consideration apparent in the evaluation of the intermittency and the multi-fractal dimensions is that velocity, vorticity and volume-fraction or scalar concentration exhibit different scaling laws [16, 18]. This highlights the need for further comparisons to numerical simulations with different initial conditions, and detailed experiments, which is an important issue to understand the properties of mixtures and to relate them to geometric (multi-fractal) and dynamical mixing properties of the flows.

The dissipation fields which are influenced by the velocity gradients at the viscous scales. The similar function curves might imply that the flow structure maximizes the entropy of the structures jets and plumes in overall mixing [16].

We present a Thermoelectric driven heating and cooling experimental device in order to map the different transitions between two-dimensional convection in an enclosure and the 3 D complex flows.

The size of the box is of 0.2 x 0.2 x 0.1 m and the heat sources or sinks can be regulated both in power and sign [2,3]. The buoyancy driven flows are generated by Seebeck and

Peltier effects in 4 to 40 wall positions. The parameter range of convective cell array varies strongly with the topology of the boundary conditions and buoyancy [4]. At present side and vertical heat fluxes are considered and estimated as a function of Rayleigh, Peclet and Nusselt numbers, but the tilting possibilities of the Berotza company built experimental device also allow to heat/cool at any angle [5, 6]. Fluid visualizations are performed by Particle Image Velocimetry method, Particle tracking and shadowgraph/schliering [4].

This paper presents a novel device, its physical foundation and its basic circuits. In this work, some experimental studies of a convective flow generated by a heat flux will be described just enumerating a list of different boundary conditions that may be used. The experiments include a novel technique, using thermoelectric (Peltier) heating-cooling elements in order to generate a lateral heat flux gradient (time-dependent). Good thermal control and high reliability are one of the major advantages of the thermoelectric modules used in this experimental convective box shown in Figure 2.

We can also examine the influence of subsequent vortices and waves, initially in a one dimensional (or plane configuration) and, furthermore, in a two-three dimensional configuration. The TCDD device is also useful to evaluate the variability of entrainment values. Then, it is possible to compare the entrainment coefficient values of laboratory experiments with those of atmospheric, oceanic or astrophysical phenomena.

The entrainment may actually be related to the ratio of the flux to gradient Richardson numbers as well as the turbulent Schmidt or Prandtl number [12] and their structure functions [14, 18].

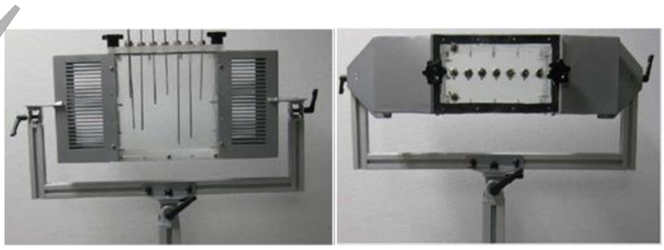
The tank used in the experimental and didactic device is of 0:2 0:2 0:1 m and the heat sources or sinks can be regulated both in power and sign. The thermal convective driven flows are generated by the electronic use of Seebeck and Peltier effects in 2 wall extended positions of 0.05 x 0.05cm each. The parameter range of the convective cell array varies strongly along the boundary conditions which may be of Dirichlet or Newman types, using either Temperature or Heat fluxes. Side heat fluxes are varied between 0 and 100 Watts and estimated as a function of Rayleigh, Peclet and Nusselt numbers. PIV and SFIV techniques reproduce the patterns arise by setting up a convective range of possibilities.

3.1 Different configurations of the The TCDD

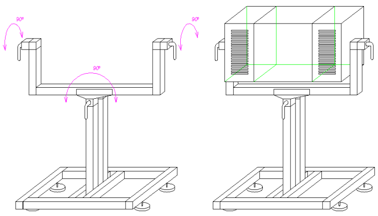
Redondo and Garriga (1995) [20] developed for the first time a breeze experimental model by using both Newman and Dirichlet conditions at the base of a brine filled tank [3, 5, 6]. These early designs have developed into a modern computer regulated TCDD's as the one presented here. The TCDD made by Berotza company is an optimized Perspex enclosure of plane area 0.2 m x 0.2 m and 0.1 m thickness [1-3]. The thermoelectric device has four Peltier (coolers/heaters) capable to reproduce convective flows, for steady-state situations and in transients. Then the buoyancy-driven flows are generated by Seebeck and Peltier effects in 4 walls extended positions of 0.05 x 0.05 cm each which can be regulated independently.

The heat sources or sinks can be regulated both in power and sign [2]. As shown in Figures 2 some technical device of the thermoelectric driven heating and cooling device. Is possible to see the set-up of the thermoelectric device and temperature regulating circuit designed by Berotza company. Image (a) is showing the manifold temperature probes at different positions (8 thermocouples) and Image (b) show the Sideway-top view of the temperature probe positions of the thermoelectric convective didactive device (TCDD). The unit is provided with 8 calibrated thermocouples placed near the cooling-heating side walls. The temperature measuring points may be registered and analyzed in any computer with the software provided.

Another advantage of the TCDD, not discussed here, but presented in [17], the improvement is to control the angle of the device, it permits to change the angle and have convective flows with different inclination, and visualize the different with plane experiment. The motion of the fluid may become totally isolated, this device allows a range of cenital and azimuthal angles from 180º and 360º. For instant, the device presents an advantage in the laboratory of fluids mechanics, because have many options and independency to study the convective flows with different angles and the combination of heat and cool. For example, this device is well suited for ventilation studies because it has side heating or cooling cells, as depicted in figure 3, the possibility of tilting and side or top views [1- 4].



a) b)



c)

Figure 2. Photograph of the Thermoelectric Convective Didactive Device (TCDD) in two of the possible positions of the framework supporting the heating-cooling cells.

There are different kind of flows that may be experimentally modelled by the TCDD due to the configurations of the Peltier cells. The device presents a systematic classification of this configuration considering only the four Peltier cell model with two in opposing sides. We can either heat/cool both vertical sides or top and bottom depending on the device angle. The short list of heating (H)-cooling (C)-no heat flux (N) configurations are: HHCC, CCHH, HCHC and CHCH, leave aside all possible non-straight angle configurations. Or other simpler setups like CCCC or HHHH, i.e., cooling or heating everywhere at both sides. You can even set up a more complex pattern such as HCCH or CHHC as shown in Figure 3. In the precise set up of the initial conditions of the convective enclosure (TCDD) It is important to consider the non-linearity of the Joule effect coupled with the Peltier effect (Positive to Heat, H) or (Negative to cool, C); So far experiments have only been done in equilibrium situations, where H and C cells correspond with 100 Wats per cell. [16, 19]

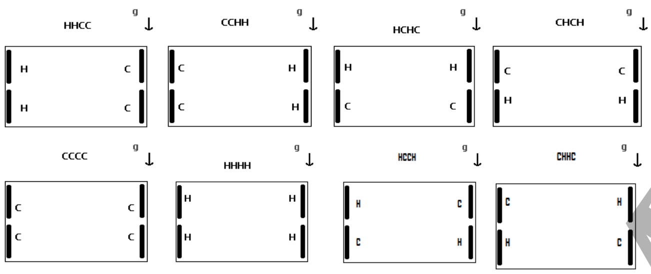


Figure 3. Different combinations of heating and cooling of TCDD.

Therefore, the range of possible experiments and patterns which arise by setting up a convective flow generated by a non-uniform buoyant heat flux, such as the ones described here is very large. Including the no-heat cells, (N), without the buoyancy and gravitational effects.

The visualizations of the experiments described here [5-7] are performed by particle tracking and shadowgraph/schliering [19]. Quantitative information from the video images is obtained using fluid flow processing systems as discussed in section 4.

The Thermoelectric Convective Didactive Device or TCDD is a very versatile instrument because its four cells, placed in opposing walls may also be inclined in the three axes, producing differential buoyancy, as the cells, can heat, cool or have zero heat flux in different ratios. At least 3000 quasi-steady combinations are possible (parallel or perpendicular to gravity thermal fluxes). Patterns arise by setting up a convective flow generated by a buoyant heat flux [20]. As the TCDD experiments are recorded on video, a sequence of images obtained with an important temporal resolution (for example, 0.01 s). This is crucial to analyze the mixing structures as well as the dispersion relations of basic instabilities [10] using spectral and fractal analysis on the images. This approach improves and complements the typical experimental and numerical studies on the convective cells which could be compared with remote sensing observations of the atmosphere and the ocean, detecting well these complex types of structures [16, 17].

The studies that can be carried out are varied, for example, diffusion measurements in the transition from a homogeneous linearly stratified fluid to a cellular or layered structure.

Another case study, the evolution of the turbulent mixing layer and its complex configuration is studied taking into account the dependence on the initial modes at the early stages and its spectral, self-similar information [12].

4. Method and Image Analysis

Several experiments of TCDD will be described, analyzed and coupled with complex mixing and scalar or heat transport. Figures 4 show a visualization example by means of direct streamlines at the centre-plane of the enclosure. It is obtained from a heating-cooling convective experiment using the Digiflow tools for advanced image processing for fluid mechanics developed by Department of Applied Mathematics and Theoretical Physics (DAMTP) of the University of Cambridge. Here a single cell by heating in the bottom left side and cooling in the bottom right side, may be expressed as NHNC, as described above.

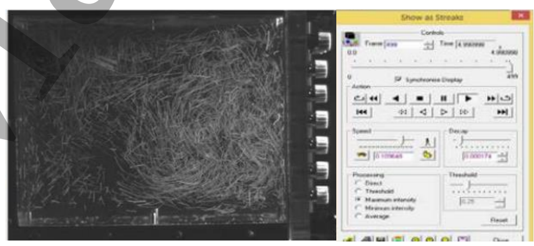


Figure 4. The Digiflow program showing streaks from PT-PIV in a TCDD experiment. Different convective patterns are visible.

For the image processing analysis, the first step was to recorder a video of the experiments for higher Reynolds numbers had to be done with a very fast video camera with a 200 to 500 Hz sampling frequency, where the analysis was performed with a tracers added in a fluid, using the particle tracking technique (PT), particle image velocimetry (PIV) and the correlation image velocimetry (CIV). As the computer controls the video, remote control of the processing is possible and images could be digitally enhanced before analysis. The simplest method is to use VirtualDub software to divide the experimental video into snapshots, using ImaCalc [10, 13] for final processing and DigiFlow [16] (Figure 5) or MatLab script language to perform C/PIV.

The steps to prepare experiments in the TCDD apparatus are simple, once the driving parameters described in section 2 are chosen: the first step is to mix the water with the microparticles, considering de density of the particles needs to be similar to the fluid studied in kg/cm^3.

The quantity of the particles will depend on the method of analysis as Particle Tracking Velocimetry or Particle Image Velocimetry. In order to have enough particles for each interrogation box, because it is important to have good precision. After mixing the water with the particles, is necessary to fill the apparatus with the liquid (water with particles), without foam and air bubbles in the box. Moreover, in the steps, field of view and size of video recording, it is necessary to focus the area of study, in this case, the box of the device TCDD, with the camera with high enough speed and resolution, choosing the appropriate speed of video according to the velocity of the particles in the device, which also depends on their size and buoyancy.

The next steps are to turn on the TCDD heat fluxes and select the combination of heating and cooling studied. In some case, you need to synchronize the video camera with the laser and grab the sequence of images, as well as power and temperature variations with good quality and speed. The last step may be either done online, or in a separate previously recorded suite. Performing then the complete analysis of the image sequence, including transient periods with the extensive flow possibilities of the program DigiFlow [10]. Although this program has plenty of different features, only the PIV analysis part is used. The results obtained are the maps of field velocities, vorticity structure, streamline, etc. Fractal and spectral analysis [16] need the program ImaCalc [9, 10].

5. Results and Discussion

Results of the study case are based on an array of thermoelectric Peltier cells performed by [1], placed in the base of the tank is used to trigger alternate heating or cooling at either side, thus creating non-stationary convection. The flow then was also visualised with pearlescence or pliolite particles, showing clearly the convective cell structure and its evolution in time. Here, with a much more versatile apparatus, the enhanced high-velocity analysis and particle tracking (PT) and velocimetry (PIV) may also be used to evaluate the density, temperature and velocity field, using also a thermal IR camera. Several examples are shown to in light the possibilities of the TCDD with Advanced Image Analysis.

Figure 5 shows a striking split in the vorticity intensity due to the different behaviour that the fluid flow has in different zones. While the fluid motion in the lower layer contains higher horizontal vorticity, in the upper layer the vorticity is substantially reduced. Since the convection is stronger in the lower part, then the vorticity lower in the tank is higher. The rapid decrease of vorticity just at the interfacial lines of the different fluid layers' setups HCHC or HHHC might be an interesting result of this experiment. This could mean that a large density gradient functions as a vorticity filter in a fluid motion field.

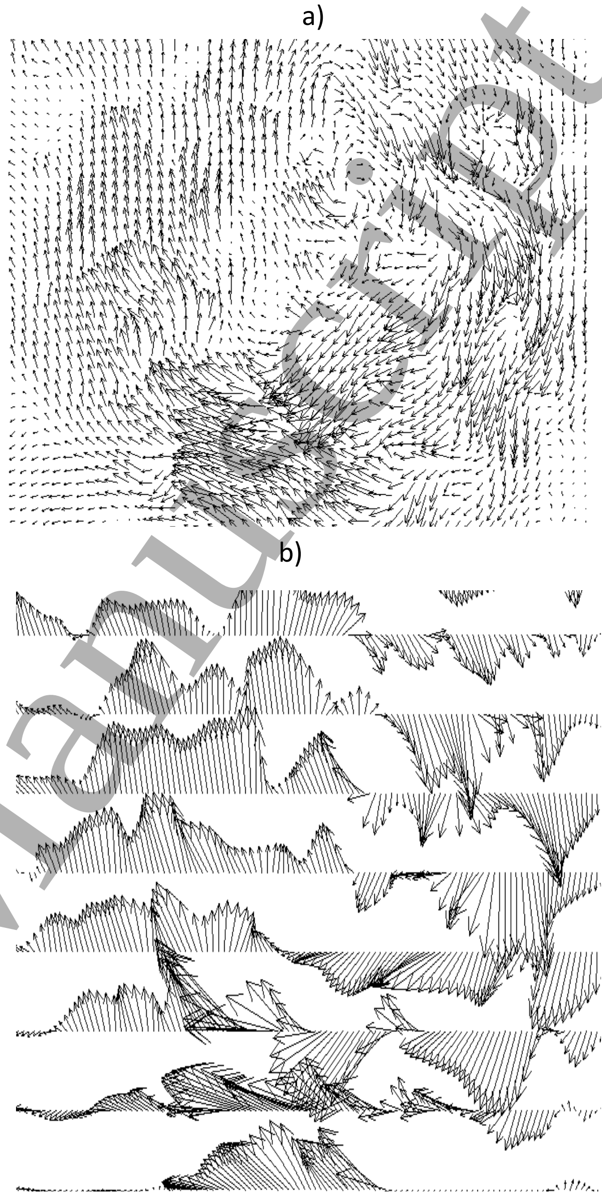


Figure 5. Vorticy map obtained from the PIV velocity vectors (a) and magnitude of velocity in one direction (b) (same experiment as in Figure 4).

Figures 6 show some of the patterns in 3D convection, from the CPIV of the pliolite particle laden flow which is started by a configuration CCCH, meaning in this case that there is cooling at both cells on the left wall of the tank, there is cooling in the bottom layer but heating in the upper side of the right wall. The stainless steel studs correspond to the thermocouple positions, 2 cm from the walls that may be recorded continuously, and even may be used to control, via PDI electronics the power of the 4 thermoelectric modules.

The dissipation and intermittency may also be evaluated in time, from velocity and vorticity.

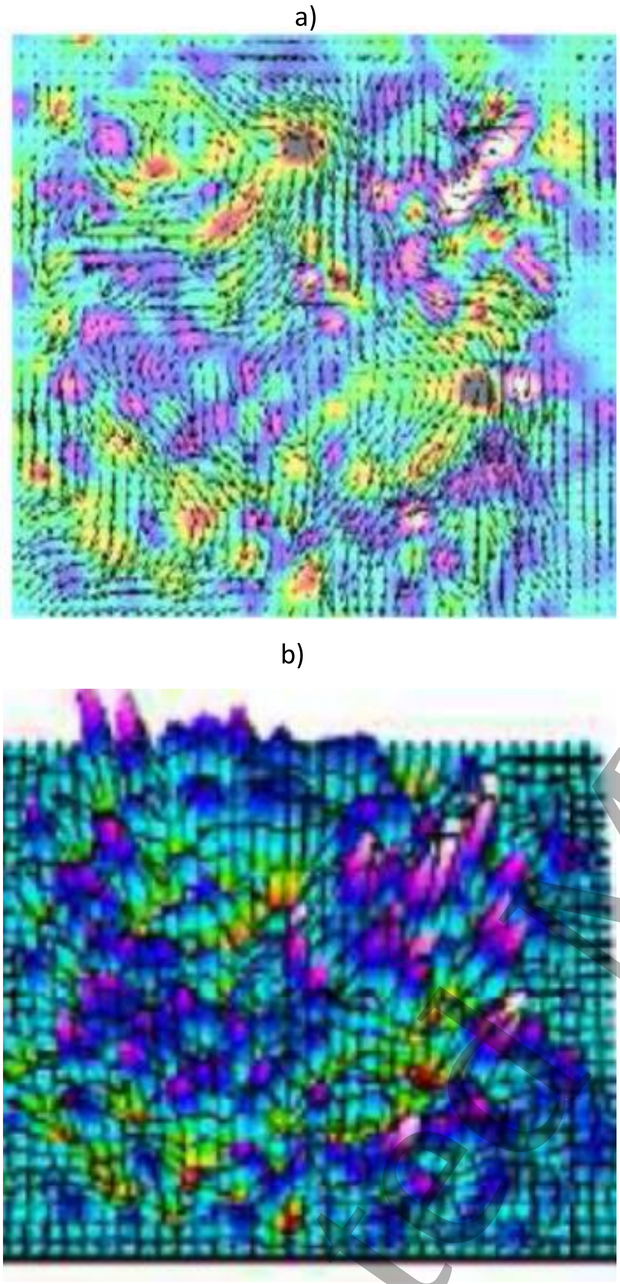


Figure 6. Results with DigiFlow on PIV. It is shown the vorticity-velocity visualization (a) and its 3D view (b).

Figure 6 shows the field velocities and vorticity maps v(x,y,z,t) for a single vertical plane at the centre of the TCDD. The instantaneous velocity and vorticity are generated per unit area of the base surface if his the fluid layer height and v(z,t) is the vertical density profile at the time t.

Another possible visualization technique is to show the streamlines as depicted in Figures 7 and Figure 8 shows a transient, where several vorticity generators are clearly detected, present the vertical flow patterns at the central plane of the fluid domain using the streamline.

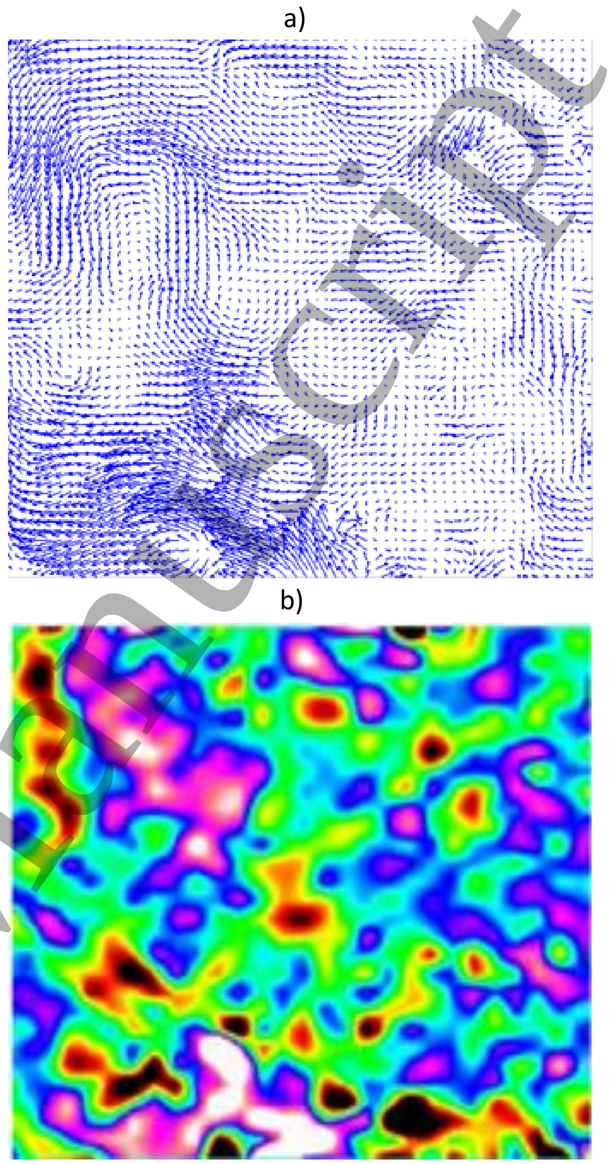


Figure 7. Description of the velocity stream functions from a complex thermoelectric driven transient flow. Field velocities (a) and maps of the vortex (b).

As future developments of the TCDD, used as a benchmark of the numerical and experimental device, we consider that this instrument has great possibilities because it is easy to use and experiments can be made quickly and with better control than traditional 2D Temperature controlled experiments. The characteristics described above, and in [19] facilitate studies based on experiments. For example, this kind of experiments can be very useful to determine the evolution of scales thanks to the relation between structure functions [12, 18], fractal analysis and spectral analysis. The analysis of self-similarity and the fractal structure of buoyancy-driven flows can also be analyzed by these experiments.

a)

b)

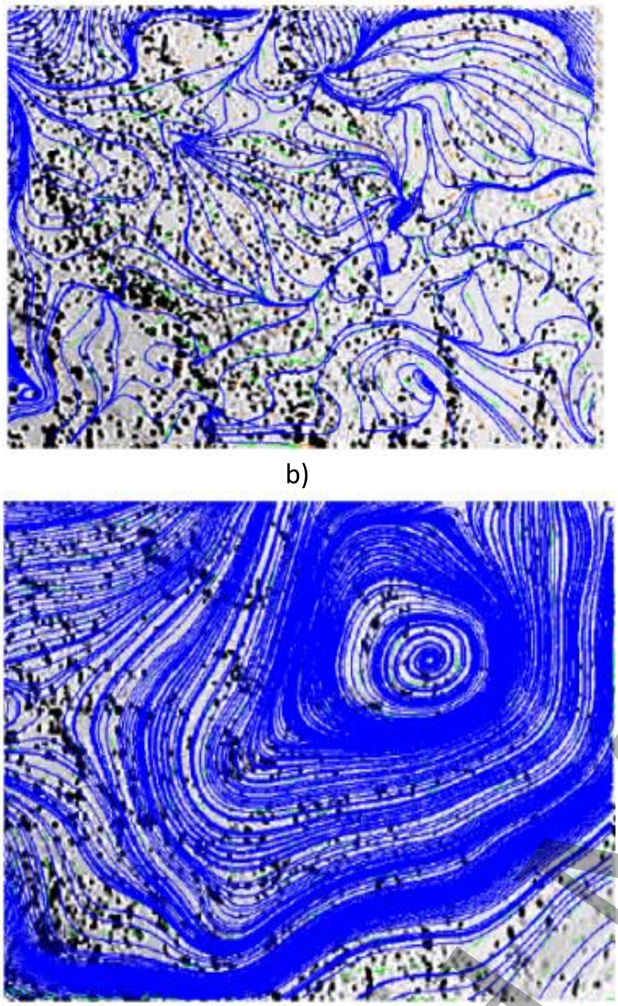


Figure 8. Description of the stream lines at different times while a large single convective cell is formed. The configuration is HHCC as described in the text and the average velocity is 2 cm/s.

6. Discussion and Conclusions

Results of an experimental study of different regimens from a local source of convective flows are considered in this paper. Is important to consider that the convective flows in fluid mechanics need to study more deeply, a thermoelectric device proposes and with some examples publish in this paper, bring power tools for the research community. We present a university-industrial collaboration: we describe the Thermoelectric Convective Didactive Device or TCDD to made experiments on complex driven heat flows in an enclosure. The measurement procedures were standardized for accuracy and reproducibility carried out in ambient temperature and standard conditions. Visualizations containing a heated vertical surface have been developed. By assuming the boundary layer to be fully turbulent and that the effects of molecular viscosity are therefore negligible, it is then possible to model the boundary layer as a buoyant plume developing as a result of a vertically distributed source of buoyancy [19].

The thermoelectric device was studied with a different combination of heat and cool, through the images processing method as PIV, in order to estimate the field velocity and the vorticity maps. These experiments were compared with a high Reynold number. These experiments present a potential vorticity structure for mixing flows and radial direction.

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