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Abstract: The aim of virgin olive oil extraction process is mainly to obtain the best quality oil from the fruits, applying only mechanical actions and guaranteeing the highest overall efficiency. Currently, the mechanical methods used to extract virgin oils from olives are basically of two types: the discontinuous systems (obsolete) and the continuous one. Anyway the system defined as "continuous" is composed by several steps not all completely continuous, due to the presence of the malaxer, a devices that works in batch. The aim of the paper was to design, realize and test the first full scale sono-exchanger for the virgin olive oil industry, placeable immediately after the crusher and before the malaxer. From a constructive point of view, the innovative device is composed by a triple concentric pipe heat exchanger combined with two ultrasound probes. This mechanical solution allows synergically to better destroy the cell walls freeing the olive droplets and the minor compounds and to accelerate the heat exchange between the olive paste and the process water. This strategy could represent the first step towards the transformation of the malaxing step from a batch operation into a real continuous process, improving the working capacity of the industrial plants. Considering the heterogeneity of the olive paste that is composed by different tissues, the design of the sono-exchanger required a fluid dynamic analysis. The thermal and the mechanical effects of the sono-exchanger were monitored measuring the temperature of the product at the inlet and the outlet of the device, and the concentration of chlorophylls in the product respectively. The effects of the innovative process were evaluated in terms of extra virgin olive oil yields and quality, evaluating the main legal parameters, the polyphenol and tocopherol content. Moreover, the activity of the polyphenol oxidase enzyme into the olive paste was measured. Considering that the extra virgin olive oil represents one of the most traditional food into the Mediterranean area, an explorative survey on consumers' acceptability of the ultrasound technique for virgin olive oil extraction process was performed.

Highlights :

- A sono-exchanger has been designed, prototyped and tested
- High power ultrasounds enhance virgin olive oil quality.
- High power ultrasounds enhance virgin olive sensory evaluation
- High power ultrasounds inhibit the olive polyphenoloxidase enzyme
- Consumers' attitude to buy sonicated EVOO has been evaluated

1 Title:

2 **Engineering design and prototype development of a full scale**
3 **ultrasound system for virgin olive oil elaboration process**

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ABSTRACT

The aim of virgin olive oil extraction process is mainly to obtain the best quality oil from the fruits, applying only mechanical actions and guaranteeing the highest overall efficiency. Currently, the mechanical methods used to extract virgin oils from olives are basically of two types: the discontinuous systems (obsolete) and the continuous one. Anyway the system defined as “continuous” is composed by several steps not all completely continuous, due to the presence of the malaxer, a devices that works in batch. The aim of the paper was to design, realize and test the first full scale sono-exchanger for the virgin olive oil industry, placeable immediately after the crusher and before the malaxer. From a constructive point of view, the innovative device is composed by a triple concentric pipe heat exchanger combined with two ultrasound probes. This mechanical solution allows synergically to better destroy the cell walls freeing the olive droplets and the minor compounds and to accelerate the heat exchange between the olive paste and the process water. This strategy could represent the first step towards the transformation of the malaxing step from a batch operation into a real continuous process, improving the working capacity of the industrial plants. Considering the heterogeneity of the olive paste that is composed by different tissues, the design of the sono-exchanger required a fluid dynamic analysis. The thermal and the mechanical effects of the sono-exchanger were monitored measuring the temperature of the product at the inlet and the outlet of the device, and the concentration of chlorophylls in the product respectively. The effects of the innovative process were evaluated in terms of extra virgin olive oil yields and quality, evaluating the main legal parameters, the polyphenol and tocopherol content. Moreover, the activity of the polyphenol oxidase enzyme into the olive paste was measured. Considering that the extra virgin olive oil represents one of the most traditional food into the Mediterranean area, an explorative survey on consumers’ acceptability of the ultrasound technique for virgin olive oil extraction process was performed.

Keywords: virgin olive oil process, ultrasound, fluid dynamic analysis, virgin olive oil quality, consumers’ acceptability.

57 1 INTRODUCTION

58 Olive trees are an economic and social resource in the Mediterranean basin [1]. Virgin olive oil
59 (VOO) is the main component of the Mediterranean diet due to its excellent sensory and
60 nutritional qualities, and the benefits of consuming olive oil have been known since antiquity
61 [2]. This because olive fruit contains goodly concentration of hydrophilic (phenolic acids,
62 phenolic alcohols, flavonoids, and secoiridoids) and lipophilic phenolic compounds that are
63 known to possess multiple biological properties such as antioxidant, anticarcinogenic,
64 antimicrobial, antihypertensive, cardiotonic and antiplatelet benefits [3]. Manufacturers and
65 researchers are currently focused to the better understanding of the key elements that allow to
66 modulate the complex series of physical, physic-chemical, chemical and biochemical
67 transformations that occur during the EVOO elaboration, in order to develop innovative and
68 sustainable plant solutions able to increase simultaneously both yield and quality of product
69 [5][6]. Currently, the mechanical methods used to extract virgin oils from olives are basically of
70 two types: the discontinuous systems (obsolete) and the continuous one. The discontinuous-type
71 system is dying out because is characterized by a very low work capacity [7] requiring great
72 workforce. The “continuous-type” is generally comprised of a mechanical crusher, more
73 malaxers required to assure continuity to the process, and centrifugal decanter to separate the
74 oily phase. The “continuous” appellation refers to the fact that mechanical crusher, decanter and
75 vertical-axis centrifugal separator operate continuously; on the contrary the malaxer, which
76 actually is a machine working in batches, is located between these two continuous apparatuses.
77 For this reason the malaxation represents the bottleneck of the continuous extraction process
78 [6]. Moreover, the malaxer is a heat-exchanger characterized by a large volume combined with
79 a small surface, which makes the heat exchange slow. One industrial challenge of VOO plant
80 manufacturing sector is to design and produce advanced machines in order to transform the
81 discontinuous malaxing step in a full continuous phase, improving the working capacity of the
82 industrial plants and the efficiency of the heat exchange [8] [9].

Ultrasound (US) is an emerging technology that has already found application in the food industry [10][11][12] due to its significant effects into the processes, such as higher product yields, shorter processing times, reduced operating and maintenance costs, simplified manipulation and work-up, improved taste, texture, flavour and colour [13]. US has promising application also in the field of virgin olive oil industry, due to the mechanical and thermal effects useful to guarantee adequate oil yields, reducing the process time and improving the process efficiency [14] [15] [16]. Recently, Clodoveo and co-authors studied the mechanical and thermal effects of US in the virgin olive oil elaboration process, into a pilot scale plant [17][18][19][20]. The US mechanical effects are due to the cavitation phenomena. When highly energetic ultrasonic waves are coupled into liquids, alternating high pressure/ low pressure cycles create bubbles or voids in the liquid. Those bubbles grow over several cycles until they cannot absorb more energy so that they collapse violently during a high pressure cycle. This phenomenon of such violent bubble implosions, known as cavitation, is characterized by local extreme conditions such as very high temperatures, high cooling rates, high pressure differentials, shock waves and liquid jets. The effects of ultrasonic cavitation promote the rupture of the solids are present in the liquid medium, thereby increasing the total solid surface in contact with the liquid phase and mixing and the mass transfer [21][22][23][24][25]. In the case of olive paste, ultrasonic cavitation promote the rupture of cell walls that remained unbroken after crushing, releasing faster the oil and other minor compounds. Moreover, US can facilitate the mechanisms of thermal conduction and thermal convection if it is combined with a warming system, such as a heat-exchanger, due to the increment of turbulence into the matter [26][27]. This phenomenon can reduce significantly the duration of malaxation, representing a first step toward a continuous process. Working toward the development of an innovative US equipment for the extraction of VOOs, Clodoveo et al. suggested to combine an ultrasound system with a double-pipe heat exchanger. The main idea was to realize a more efficient heat exchange before pumping the olive paste inside the malaxers, resolving another weakness of the current equipment: the low overall heat transfer coefficient due to the disadvantageous ratio (r) ($r = S/V$) between the small malaxer surface area (S) and large volume (V) of olive paste [5]. In

fact, in this way, a cheaper and more constructive simplification of the current malaxing machine can be realized, excluding the jacket for heating the olive paste and providing to a thermal insulating the tank. Starting from these previous evidences and hypothesis, for the first time to our knowledge, an US system was designed, realized and tested in an industrial-scale VOO extraction plant. This innovative equipment, called “sono-exchanger”, engineering, designed and prototyped to be industrially implemented, was evaluated in terms of time consuming to maintain acceptable yields of oils. A 3D fluid dynamic analysis was performed by means Ansys Fluent to evaluate the cross section around the ultrasound devices and to evaluate the flow parameters of olive paste inside the sono-exchanger [28][29]. The influence of each geometrical parameters was performed to setup an optimal design of the sono-exchanger. After the industrial tests, the chemical and the sensory evaluations of the resulting VOOs were performed. Polyphenol oxidase (PPO) is one of the enzymes involved in the reduction of phenol content in the VOOs during the extraction process. During the crushing, when the cell structure is destroyed, and the enzyme and substrate are mixed. PPO catalyses the hydroxylation of monophenols (monophenolase) and oxidation of o-diphenols to o-quinones (diphenolase). Ultrasound causes enzyme inactivation by cell lysis due to the cavitation bubble implosion which generate spots of extremely high pressure and temperature, changing enzyme structural configuration and modifying its catalytic activity [30]. In order to verify this hypothesis, the activity of the PPO in the olive paste was measured with or without ultrasound treatment. However, when a great revolution is introduced in food technologies, one of the higher limits to its development is the consumers’ acceptability. In fact, prejudice is also a resident of the insiders. Nowadays human eating habits are characterized by some paradoxes: pleasure/health, technology/nature, innovation/nostalgia [31]. Additionally, food consumption is influenced by the omnivore’s dilemma: the simultaneous attraction (neophilia) and fear (neophobia) towards novel foods [32]. Actually, this issue affects the evolution of agro-food system, in particular the adoption of novel food technologies, namely by farmers and food manufacturers. The food neophilia-neophobia dichotomy seem to be mediated by the preference for natural [33]; [34]. Indeed, humans are dominated by an innate preference for foods not having

undergone excessive treatment or industrial processes involving the addition and/or reduction of nutrients or physical and chemical interventions.

A recent literature review [35] highlighted some key aspects about consumers preference for natural: plant foods are considered more natural than animal derived foods; physical treatments reduce to a smaller extent the level of perceived naturalness compared to chemical ones; type of industrial process matter for naturalness perceived by consumers; addition of new but not yet well known ingredients reduces the naturalness more than the addition of the most well-known ingredients.

Neophilia-neophobia dichotomy is also informed by the way individuals cope with risky events, when both emotional factors and a priori personal beliefs play a crucial role [36].

During the years, various conceptual models have been developed to provide insights into risk perception and technology acceptance. Lusk et al. [36] provide a comprehensive review of behavioural economic models and models from psychology and moral judgment. In particular, this review summarizes the following general conjectures: new food technology is perceived as riskier, and is less likely to be accepted, when there are potential risks with adoption, even low-probability risks deemed inconsequential by experts, because of biases in probability assessment; adoption of the new product is perceived as a loss relative to the status quo; people are risk averse over low-probability losses (such as those associated with food technologies); people do not perceive that they have control over whether they consume the new product; the new characteristic is perceived as unfamiliar or unusual; early names given to and discussions of the technology are emotional and negative and are more available to consumers; consumers do not associate appreciable benefits with the new technology; and moral judgments are evoked, and a food technology is perceived as unnatural or impure. Considering that the extra virgin olive oil represents one of the most traditional food into the Mediterranean area, an explorative survey on consumers' acceptability of the ultrasound technique for virgin olive oil extraction process was performed.

2 MATERIALS AND METHODS

2.1 The industrial processing plant before and after the prototype installation

Figure 1 represents the flow chart of the process, as it is available for the experimentation in ALOIA virgin olive oil plant manufacturing (Colletorto (CB), Italy). It consists of a typical entire continuous-type process, including the malaxing stage.

INSERT FIGURE 1

Figure 1 – Traditional continuous-type VOO extraction process scheme: 1, reception stage; 2, washing stage; 3, crushing stage; 4, mono pump; 5, malaxing stage; 6, separation stage; 7, clarification stage

The plant consists of the following devices:

1. Fruits reception: here, the harvested olives are led to the extraction plant. The olives drop in a hopper and lay down on a conveyor belt that carries them to the washing machinery.
2. Washing and leaf removal equipment: here, a vibrating screen and blower removes leaves and other debris to protect the extraction plant and avoid the off-flavours deriving from the presence of foreign bodies. After that, the olives are also washed to remove soil or other residues. Finished the pre-process stage, another conveyor belt carries the olives to the next phase.
3. Crushing equipment: it is the first of the extraction stage. The aim of crushing is the size reduction of olive fruit tissues and the breakdown of vegetal cells in order to facilitate the release of the oil by mean of a strong mechanical action that also produces heat due to the energy dissipation. In this plant there is a hammer crusher, type Alfa Laval 25HP equipped by means of 7 mm fixed grid and electrical engine rotating at 2800 RPM. The olive paste obtained come to the following stage by mean of a piping with an upstream mono pump.
4. Mono pump: it is a rotary positive displacement pump with an eccentric screw, also called progressive cavity pumps (Bellin 600M2/K6, rotating at 125 RPM). This kind of pumps are indicated for heavy-duty applications and they can be used to pump abrasives pastes, viscous products, oils, sludge, emulsions etc. The pump works driven

by means of an electrical engine. The Toshiba Vf-Ps1 vector inverter regulates the rotational speed of the pump varying its input frequency.

5. Malaxer: It consists in a cylindrical tank equipped by a shaft with rotating arms and stainless steel blades. The walls of the malaxing tanks are hollow allowing warm water to flow through these jackets to heat the olive oil paste. The olive paste is continuously agitated at a controlled temperature. Once the malaxing process has been completed, the paste is removed from the bottom of the tank by means of a pump that feeds the paste to a decanter centrifuge for subsequent treatment.

6. heating process (25-30 °C) together with a low and continuous kneading of olive paste (20-30 RPM for 30-45 min), needful to help the small droplets of the oil formed during the milling to merge into large drops (coalescence phenomena) that can successively be easily separated through centrifugal systems. Due to very long process times, to reduce downtimes in the plant manufacturing there are four simultaneous malaxers (Alfa Laval Atmosphere Module 650 – capacity of 650 liters). In this way, it is possible to consider like a continuous process but involves more economic efforts [38].

7. Decanter: It is a horizontal centrifuge. In this equipment is possible to perform the separation of phases, namely the separation of oil from solid and liquid phases of olive paste. This installation use Alfa Laval Uvnx-X20b-11g –stationary speed 3570 RPM, a three-phase centrifugal decanter where water is added to dilute the incoming paste that is divided into oil, vegetation water and solids (olive pomace) at the end of the process.

8. Vertical centrifuge: (Alfa Laval Uvpx 507agt-14) allow to clarify the extracted oily phase with lukewarm tap water added. In this way, the equipment separates the residual water and the solid impurities in order to obtain a clear oil.

The original plant is been modified by adding a “sono-exchanger” downstream of the crusher and upstream of the malaxer as shown in Figure 2.

INSERT FIGURE 2

Figure 2 - VOO modified extraction process scheme: 1.reception stage; 2.washing stage; 3.crushing stage; 4.pump; 5.malaxing stage; 6.separation stage; 7.clarification stage; 8. Ultrasonic probes; 9.heat exchanger

The sono-exchanger is made of two straight pipes connected by an elbow (cfr. Figure 3). A detailed fluid dynamic analysis is performed by means Ansys Fluent in the following paragraphs to design the cross section around the ultrasound devices and the pipe curvature. Two ultrasonic rod-style transducers (Sonopush Mono® 30-1500 W – 30 kHz) are plugged into the straight pipes through the bend. At last, a third ultrasound transducer (30-1400 W output power) is placed downstream the heat exchanger.

INSERT FIGURE 3

Figure 3 – picture of the sono-exchanger system

The ultrasonic probes inside the pipe provide a vibrational energy transfer to the olive paste due flowing through the sono-exchanger.

The heat exchanger is constituted by ViscoLine™ Annular heat exchanger (VLA) produced by Alfa Laval, adapt to non-Newtonian products with high viscosity, and products that contain particulates, has been used to fine-tune the temperature for the olive paste before that this reached the malaxer by mean a series of two heat exchanger. It consists of four concentric tubes. The product medium flows in between two service channels, and is heated from the inside and outside at the same time. The media fluid was water and flowed in opposite direction to the olive paste. The VLA unit scheme is shown in Figure 4.

INSERT FIGURE 4

Figure 4 - Inner structure and fluids directions inside the tubular heat exchanger to warm the olive paste.

2.2 Engineering design and prototype development

2.2.1 The sono-exchanger fluid dynamic analysis

In many studies, experimental approaches have been applied. Legay et al. have investigated the performances of a double-tube heat exchanger with and without the influence of ultrasonic vibrations [39]. But experimental test are expensive and they take a long time. On the contrary a 3D computational fluid dynamics (CFD) analysis was developed to gain insight into the flow inside the “sono-exchanger” and find the best position of the transducers that provides the

intensity of sonication. The problem of determining the pressure losses is important in order to give the indications needed to design the device and the pumping systems in a full-scale plant and avoid expensive experimental tests. The pressure trend around the probes and so flow velocities are very important because the ultrasound energy exchange is strongly affected by the olive paste consistency. Discontinuities inside flow, due to air bubbles, or separation flux phenomenon worsen the ultrasound transmission. So, the need and benefits of accurately predicting velocity profiles, concentration profiles and pressure drop of flow during the design phase is enormous and moreover it gives better selection of pumps, optimization of power consumption and thereby helps maximize the economic benefit.

2.2.2 *Physical model*

In the malaxation phase of the extraction process for virgin olive oil the product medium may be highly viscous and may seem to show a non-Newtonian behaviour (i.e. fluids which don't obey to Newton's law of viscosity and have an effective viscosity which is a function of the shear rate).

Therefore, it is important to understand the flow of non-Newtonian fluids thorough geometries to set up the cross section through which the flow runs. The essential difficulty of predicting non-Newtonian flows in the pipes of the ultrasound system, is selecting representative rheological parameters to describe the fluid used in the industrial applications.

The viscosity of these fluids is highly dependent on concentration or composition. In some cases, it is also affected by the history of the treatment such as cooling or heating which can lead to wide variations in the rheological behaviour.

In particular, the rheological characteristics of olive paste change from the inlet to the outlet of the olive extraction line [40]**Error! Reference source not found..**

Therefore, tabulated data may be inadequate and the problem is determining a sound and representative basis for the calculations. Di Renzo and Colelli demonstrated that a non-Newtonian model, expressed by a power law relation, describes the rheological behaviour of olive paste [41].

Experimental data on the apparent viscosity values and the related shear rates were collected. These data were processed by means of linear regression on a logarithmic scale to verify the consistency of the power law model for the rheological behaviour of olive paste.

2.2.3 Governing equations

The mass and momentum conservation equations for an incompressible fluid can be written as

$$\nabla \cdot \mathbf{v} = 0 \quad (1)$$

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \nabla \cdot \boldsymbol{\tau} \quad (2)$$

Where ρ is the density, \mathbf{v} is the velocity field, p is the pressure, and $\boldsymbol{\tau}$ is the deviatoric stress tensor. This tensor is related with the strain rate tensor.

Consider a fluid particle subjected to a shear stress τ (Figure 5). Since we are considering a fluid, this deforms continuously under the action of constant stress, so instead of determining the deformation we will have to determine the deformation speed.

INSERT FIGURE 5

Figure 5 – fluid deformation scheme

Assuming that the upper surface of particle is moving with the constant velocity v , in the time Δt it has covered the distance $v\Delta t$ producing the angular deformation:

$$\tan(\Delta\gamma) = \frac{v\Delta t}{y} \cong \Delta\gamma \quad (3)$$

The angular deformation speed, or shear rate, is given by:

$$\dot{\gamma} = \lim_{\Delta t \rightarrow 0} \frac{\Delta\gamma}{\Delta t} = \frac{v}{y} \quad (4)$$

And $\frac{v}{y}$ is the gradient of velocity along y dimension. It is possible to write the following

relation:

$$\tau = \frac{6F}{bA} = \mu \frac{6v}{by} = \mu \dot{\gamma} \quad (5)$$

301 Where the shear rate $\dot{\gamma}$ is always proportional at the shear stress τ through a constant μ defined
 302 viscosity.

For a Newtonian fluid μ depends only by the nature of the fluid and from its physical state but the olive paste has a non-Newtonian behaviour because the viscosity reduces with the rise of the velocity gradient. So, for some non-Newtonian fluid, the stress-deformation rate equation can be written as:

$$\tau = \mu(\dot{\gamma})\dot{\gamma} \quad (6)$$

As mentioned above, to approximate the behaviour of this fluid, it can be used the power-law model, which equation is:

$$\tau = k\dot{\gamma}^n \quad (7)$$

The viscosity for the power-law model is obtained dividing the eq. 7 with $\dot{\gamma}$:

$$\mu_{app} = k\dot{\gamma}^{n-1} \quad (8)$$

Where μ_{app} represents an apparent or effective viscosity, function of the shear rate, k is a measure of the average viscosity of the fluid (the consistency index) and n is a measure of the deviation of the fluid from Newtonian (the flow behaviour index, dimensionless). The value of n determines the class of the fluid:

- $n = 1 \rightarrow$ Newtonian fluid
- $n > 1 \rightarrow$ shear-thickening (dilatant fluids)
- $n < 1 \rightarrow$ shear thinning (pseudo-plastics)

In the present setup, it is neglected the dependency of k on temperature.

Finite-volume-based code is used to discretize and solve the coupled set of equations (1) (7) (8) employing commercial software Ansys Fluent 15.

2.2.4 Computational parameters

The pressure-based solver was used. In this approach, the pressure field is extracted by solving a pressure equation or pressure correction equation obtained by manipulating continuity and momentum equations. The flow was modelled as laminar, due to the high viscosity of olive paste, which remains laminar even at larger flow rates.

An important step in the setup of the model is to define the materials and their physical properties.

The fluid (olive paste) was defined in Fluent creating a new material. The fluid density was set to 1120 kg/m³ and non-Newtonian power-law model was used for specifying the viscosity.

The properties of the fluids are shown in the Table 1.

INSERT TABLE 1

Table 1 – Material properties and power-law parameters used

Heat transfer was neglected, and the flow was steady state. Procedure adopts the “simple” algorithm to perform the coupling between the pressure and the velocity.

The interpolations for velocities and pressure are based on second-order upwind and second order solver, respectively. Convergence criteria were set to 10^{-7} for all relative residuals. The solutions were considered converged when the normalized residuals were below 1×10^{-7} , and the area weighted average of molecular viscosity changed by less than 1% in less than 5000 iterations.

2.2.5 Grid validation

The numerical simulation process starts with creating the geometry for the pipe and the second step is to mesh the geometry. This was done using a commercial grids generator.

In this study, unstructured tetrahedral grid is fitted well due to its curved structure: triangular cells were used to mesh the surfaces of tube walls while the volume enclosed by these surfaces is filled with parallelepiped and tetrahedral elements. The zone types used for the boundary condition of inlet and outlet were, respectively, mass flow inlet and pressure outlet. In general the final results depend upon mesh geometries.

Considering the entire sono-exchanger geometry would require excessive CPU and RAM requirements, and also that the structure is axisymmetric, the domain independence study has been conducted on a part, doing a semi-3D simulation.

INSERT FIGURE 6

Figure 6 – a) modelled sono-exchanger geometry; b) detail

Grid independent test was performed for the physical model to obtain the most suitable mesh faces size in order to arrive at an optimal domain size which will exert a little influence on the physics of the flow without necessitating excessive computational effort.

INSERT FIGURE 7

Figure 7 – Different grid used to study the own influence on the results

Based on the computational effort and a detailed examination of the contours of velocity magnitude, to resolve the thin boundary layers with acceptable levels of accuracy over the range of conditions of interest here and to obtain grid independent solutions for the proposed model the grid in the Figure 7c is the more suitable choice. It has 1509197 elements with a skewness less than 0.825 (the worst element have a quality value of 0.824202).

INSERT TABLE 2

Table 2 – Comparison between the different kinds of mesh

The boundary conditions were the mass flow rate ($G_{inlet} = 0.278 \text{ kg/s}$) and the pressure downstream sono-exchanger peer to the value measured upstream the heat-exchanger ($p_{out} = 8 \text{ bar}$). The trend of the residual error for the continuity and for the three components of velocity are below 5×10^{-6} after 5000 iteration.

2.2.6 Energy transfer rate

The amounts of specific energy generated by the ultrasound transducers to be conveyed to the olive paste in the pilot plant, is equal to the optimal specific energy obtained from preliminary analysis carried out in static condition of small specimens with the same process experimented in previous studies. The specific energy, L_i , was obtained using the equation:

$$L_i = \frac{P_s \cdot t}{m}$$

Where P_s and t are the power delivered and the operating time of the transducer respectively. Analyses were conducted on the yield and quality of oil obtained from various trials in which it was made to vary the duration of the olive paste exposure to ultrasounds and evaluated what was optimal exposure and then the energy transmitted [12].

Take note of the optimal specific energy, it is possible to derive the optimal mass flow rate G_{id} , that absorbs this energy while it flows inside the sono-exchanger, using the following equation:

$$G_{id} = \frac{P_g}{L_i}$$

Where P_g is overall power output from ultrasonic transducers placed into plant manufacturing and L_i is the said optimal specific energy.

The size of the plant was made to obtain the optimal mass flow rate calculated in static condition [12]. The actual mass flow rate provided by the volumetric pump is:

$$G_p = \rho \cdot V \cdot r \cdot n_{el} \cdot \eta_v$$

Where ρ is the olive paste density, V the pump swept volume, τ the gear ratio between the volumetric pump and the electric engine that has a rotational speed equal to n_{el} , while η_v is the volumetric efficiency that depends from the rotational speed but especially from the operating pressure.

To avoid discontinuity in the olive paste delivered from the pump, because it is a not homogenous fluid with an high viscosity and a low delivery pressure can generate air bubbles, it is important continuously adjust the mass flow processed by the crusher varying the rotational speed, because a low value causes air infiltration (cfr. Figure 8). To reach this, is possible to vary the conveyor belt velocity upstream of the crusher. Thus it is difficult to keep mass flow rate steady to G_{id} and there could be small variations. To vary the speed of the electric engine, and then of the pump, an inverter has been placed between this and the electrical grid.

Given that, during operation conditions is impossible completely remove the olive paste discontinuity, the real exchanged power by the transducers must be reduced through an appropriate coefficient:

$$P = P_g \cdot \eta_d$$

Where η_d is a dynamic exchange efficiency index that depends of the pump delivery pressure and allows to taking into account the actual power absorbed by the paste than that transmitted by the ultrasounds system and to consider possible interferences at the introduction of energy.

INSERT FIGURE 8

Figure 8 – Treated olive paste a) Homogeneous; b) Discontinuous

Eligible values for η_d when the paste is well dense (Figure 8.a) are near to 0,75, instead, for very discontinuous olive paste (Figure 8.b), η_d goes down to 0,30-0,40.

2.3 Olives and oil samples.

Olive fruits of the cultivar Coratina (*Olea europaea* L.) having maturity index of 1.9 were harvested by a trunk shaker machine and processed 6 h after harvesting. The maturity index was determined according to the method proposed by the International Olive Council [42]. Husk was sampled from the decanter at regular time intervals and stored at 25°C until analysis. The wastewater was sampled from the horizontal centrifugal separator at regular time intervals and stored at 25°C until analysis. Three aliquot of olive oil (500 mL), obtained from each experimental test, was acquired and stored in dark bottles at 15°C until analysis.

2.4 Extraction yield

The extraction yield (EY_{EVOO}) is the amount of oil obtained by milling 100 kg of olives. The EY was calculated using the following equation:

$$EY_{EVOO} = \frac{W_{oil}}{W_{olives}} \cdot 100$$

where W_{oil} is the mass of the extracted oil (kg) and W_{olives} is the mass of the processed olives (kg) [5].

2.5 Virgin olive oils quality indices

2.2.1. Legal quality parameters

Olive oil acidity (% oleic acid per 100 g olive oil), peroxide value (meq O₂ kg⁻¹ oil) and UV determinations (K_{232} , K_{270} and ΔK) were carried out according to the EC Reg. 2568/1991 subsequent amendments [43]. The parameters K_{232} and K_{270} are the oil absorbance at 232 and 270 nm, respectively, and ΔK was calculated from the absorbances at 262, 268 and 274 nm.

Spectrophotometric determinations, K_{232} , K_{270} and ΔK analyses were carried out using a Shimadzu UV-1601 spectrophotometer (Shimadzu, Kyoto, Japan). Sensory analysis was carried out by eight assessors who were fully trained in the evaluation of VOO according to the official methods of the IOC (1996) and EC Reg. 2568/1991 [43].

2.6 Extraction of the Phenolic Fraction

The oil (10 g) was dissolved in 10 mL of hexane and extracted three times in a separating funnel with 7 mL of a mixture of methanol:- water (60:40 v/v). The hydro-alcoholic extract was washed with hexane and centrifuged 5 min at 4000 rpm using a PK 120 centrifuge (ALC International, Milan, Italy). The methanol phase was collected and evaporated in a vacuum flask using a rotary evaporator Mod. Laborota 4000 efficient (Heidolph instruments, Milan, Italy) at 40 °C. The residue was collected using 2 mL of methanol for the HPLC injection.

2.7 Determination of phenols.

The total phenols content in the polar fraction extracted from olive oil samples was measured by colorimetric methods using Folin-Ciocalteu reagent and HPLC-UV-MSn analysis [44]. The phenolic compounds in the EVOOs were analyzed as described by COI/T.20/Doc n. 29 method, with some modifications [45]. The method is based on direct extraction of the bio-phenolic minor polar compounds from olive oil by means of a hydro-alcoholic solution and subsequent quantification by HPLC-DAD with the detector at 280 nm. Syringic acid is used as the internal standard. The content of the natural and oxidised oleuropein and ligstroside derivatives, lignans, flavonoids and phenolic acids is expressed in mg/kg of tyrosol (Met. COI/T.20/Doc. n. 29, 2009). The oil (5 g) was dissolved in 10 mL of hexane, added of 1 mL of the internal standard solution (syringic acid, 0.015 mg/mL) and extracted three times in a separating funnel with 7 mL of a mixture of methanol/water (60/40 v/v). The hydro-alcoholic extract phase was collected, washed with hexane and centrifuged 5 min at 4000 rpm using a PK 120 centrifuge (ALC

International, Milan, Italy). The hydro-alcoholic phase was evaporated in a vacuum flask using a rotary evaporator Mod. Laborota 4000 efficient (Heidolph instruments, Milan, Italy) at 40°C. The residue was collected using 1 mL of methanol for the HPLC injection. HPLC analysis was performed using an HPLC Shimadzu mod. LC-10ADVP equipped with a UV-Vis (Photo) Diode Array detector (Shimadzu Italia, Milan, Italy), using a reverse phase column Spherisorb S5 ODS3 250 x 4.6 mm i.d. (Phenomenex, Castel Maggiore, BO, Italy). The following eluents phases have been used: Eluent A was water:trifluoroacetic acid (TFA) 97:3 v/v and eluent B was methanol:acetonitrile 20:80 (v/v). The elution gradient started from 5% eluent B and reached 60% B after 35 min at flow rate 1 mL min⁻¹. The injected volume was 20 µL and chromatograms were recorded at wavelength 279 nm. The acquisition software was Class-VP Chromatography data system vers. 4.6 (Shimadzu Italia, Milan, Italy). It was calculated the values of the response factors (RF) for 1 µg of tyrosol and 1 µg of syringic acid, and the ratio of the response factor of syringic acid to tyrosol, called RRF_{syr/tyr}.

$RF_{1\mu g}(\text{syringic acid}) = \text{Area syringic acid} / \mu\text{g syringic acid injected}$

$RF_{1\mu g}(\text{tyrosol}) = \text{Area tyrosol} / \mu\text{g tyrosol injected}$

$RRF_{syr/tyr} = RF_{1\mu g}(\text{syringic acid}) / RF_{1\mu g}(\text{tyrosol})$

The value of RRF_{syr/tyr} should be constant and should lie inside the range 5.1 ± 0.4 . It allows the final result to be expressed as tyrosol, using syringic acid as the internal standard. Biophenol content, expressed in mg/kg, is calculated by measuring the areas of the related chromatographic peaks according to the following formula:

$(\text{mg/kg}) = A_{ph} * 1000 * RRF_{syr/tir} * (W \text{ syr. acid}) / (A \text{ syr. acid}) * W$

where:

A_{ph} is peak areas of the biophenols recorded at 279 nm;

$A \text{ syr. acid}$ is the area of the syringic acid internal standard recorded at 279 nm;

1000 is the factor used to express the result in mg/kg;

W is the weight of the oil used, in grams;

$RRF_{syr/tir}$ is the multiplication coefficient for expressing the final results as tyrosol;

$W \text{ syr. acid}$ is the weight, in mg, of the syringic acid used as internal standard in 1 ml of

solution added to the sample.

Phenolic compounds were identified by comparing retention times, relative elution order and UV absorbance spectra with those of authentic standards, when available, or with those reported in the literature [46]; [47][48]. Identification was confirmed by LC/MS analysis (Savarese et al., 2007).

2.8 Carotenoid content

The concentration of total carotenoids was calculated by measuring the absorption at 449 nm of 0.25 g of oil dissolved in 10 mL UV-hexane, using a calibration curve obtained previously by measuring the absorption of solutions of β -carotene at known concentrations.

2.9 Tocopherol compounds

Tocopherol compounds were determined by HPLC according to the method reported by Clodoveo et al. 2013 [17].

2.10 Enzyme PPO: extraction and assay

The PPO extraction procedure was as reported by Clodoveo et al. 2016 [30]. Fruit samples were frozen in liquid nitrogen and pulverized with a pestle and mortar. One to five grams of frozen sample were used to obtain a dried acetone powder and stored at -20°C . Immediately before each PPO assay, 10 mg of acetone powder was resuspended in the proportion of 1:60 (w/v) in 0.1 M phosphate buffer, pH 6.2 with 0.3 mg mL^{-1} of type-II trypsin inhibitor, stirred for 1 h at 4°C , centrifuged at 5,000 g for 10 min at 4°C and filtered through glass wool. The crude extract was used for protein quantification and PPO assays. Protein concentration was determined by the Bradford method [49]. Polyphenol oxidase activity based on an initial rate of increase in absorbance at 410 nm was determined spectrophotometrically using ultraviolet-visible spectrophotometer Ultrospec 7000 (GE, Company, UK). The assays were performed at 30°C in a medium containing 0.1M sodium phosphate buffer, pH 6.2, 40 mM catechol, 10 μL of fruit enzyme extract in a total volume of 1 mL. Specific activity was expressed as $\mu\text{mol} \times \text{min}^{-1} \times \text{mg protein}^{-1}$.

2.11 An explorative survey on consumers' acceptability of "ultrasound VOO"

To evaluate this emotional factor, a survey was conducted on the large amount of people. A total of 961 consumers located in Puglia region, Italy, were enrolled for the study. The survey was conducted during the period of May 2015 to September 2015. Data were collected through an online based questionnaire (Google Form). First, the questionnaire was piloted through face to face interviews (n=30) to ensure the absence of possible ambiguous questions. The questionnaire contains a full explanation of the purpose of the study and its anonymous nature, together with specific completion instructions. It consists of four sections. The first section includes the demographic characteristics of the sample, such as gender, age, educational level, monthly family income, number of household members and presence of children. The second section assesses consumers' buying habits of EVOO. The third section of the questionnaire investigates consumers' purchasing motivations, measured on a 7-point Likert scale (1 – Strongly disagree; 2 – Disagree; 3 – Somewhat disagree; 4 – Neither agree or disagree; 5 – Somewhat agree; 6 – Agree; 7 – Strongly agree). The last section explores previous knowledge about ultrasound technology, quality judgment and intention to buy ultrasound EVOO.

Data were analyzed using descriptive statistics (mean and standard deviation for continuous variables; percentages of the sample for discrete variables). Successively, in order to examine relationships among variables an association analysis was performed. Measures of association are scaled so that they reach a maximum numerical value of 1 when the two variables have a perfect relationship with each other. They are also scaled so that they have a value of 0 when there is no relationship between two variables.

In particular we measured the association between all pairs of variables regarding consumers' demographic characteristics or buying habits or purchasing motivations vs. consumers' intention to buy ultrasound VOO. As measures of association, we compute the "Gamma" or "Cramer's V" indexes, depending on the variables compared (respectively ordinal vs. ordinal and nominal vs. ordinal). The "Gamma" index range from -1 to +1, indicating the strength and

the direction of the relationship (positive or negative). The “Cramer’s V” index range from 0 to +1, indicating only the strength.

2.12 Statistical analysis

Olive oil extraction experiments were performed in triplicate, and chemical analyses of the oil obtained were conducted in duplicate. The results were expressed as mean value (mv) \pm Standard Deviation (SD). Statistical analysis was carried out using Microsoft Excel software. Significant differences between treatments were determined using one-way ANOVA followed by “t-test”. Regard to the extraction and assay of enzyme PPO, the one-way analysis of variance (ANOVA), using the Tukey’s honestly significant differences (HSD) post hoc test, with the SPSS Base 11.5 software (SPSS Inc., Chicago, IL, USA) was performed. Statistical significance for the tests was set at $p < 0.05$. Regard to the extraction and assay of enzyme PPO as well as the HPLC polyphenol quantification, one-way analysis of variance (ANOVA), using the Tukey’s honestly significant differences (HSD) post hoc test, with the SPSS Base 11.5 software (SPSS Inc., Chicago, IL, USA) was performed. Statistical significance for the tests was set at $p < 0.05$.

3 Results

3.1 Fluid-dynamic results

As above briefly mentioned, one of most important evaluation to check inside the Sono-exchanger is pressure and velocity (in according with Bernoulli law) around the probes. Figure 9 shows the velocity distribution along the sono-exchanger and it permit to check the inlet velocity (0.078 m/s) and every critical condition, for example the flow around the head of the probes, where the value of the velocity is the max, 0.156 m/s.

INSERT FIGURE 9

Figure 9 – Velocity contours

From the inlet the flow accelerates in according to the cross-section area decreasing and slows down when the cross-section area increases until it stops near the wall and the transducer tip. Figure 10 shows velocity variation in the two cross section as indicated in Figure 6a while the flow approaches the elbow. Note the asymmetrical distribution of velocity intensity due to the centrifugal effects.

It is therefore possible to plot the velocity trend along a linear pattern (cfr. Figure 11), where the local reference system matches with the global showed in Figure 6a. Note only an half geometry is plotted in abscissa of Figure 11, because this is symmetric along the bending, therefore it is going to present a same trend for the other side.

INSERT FIGURE 10

Figure 10 – velocity variation in the two cross section of Figure 6a approaching the elbow

INSERT FIGURE 11

Figure 11 – Velocity trend for half geometry.

Figure 12 and Figure 13 show the pressure trend along the sono-exchanger and the pressure drop along the same linear pattern respectively. Note the pressure is highly uniform around the probes to allow an efficient energy exchange. The greatest difference of pressure around the two probes, measured at the tip of each, is approx. 0,15 bar.

INSERT FIGURE 12

Figure 12 – Pressure contours (Pascal)

INSERT FIGURE 13

Figure 13 – Pressure drop trend along half geometry (static pressure, Pascal)

From the analysis, results that there is a pressure loss of 0.2414 bar along all the sono-exchanger, and the higher loss depends of the reducing of transition area due of the section of the transducer and also by the curved section.

In static condition, many tests were conducted varying the operating time to perform the more suitable specific energy. The mass of olive paste treated was always the same, equal to 3 kg, while the transmitted power of the transducer was equal to 150 W. In the Table 3 are collected the different trials:

INSERT TABLE 3

Table 3 – Static results

Analysis demonstrates that an operating ranging time between 180 and 240 seconds, allows to obtain the best yield and VOO quality in terms of acidity value, peroxide value and UV absorption (K_{270} and K_{232}). Also that, the final paste temperature reached in this operating conditions is less than 27°C, borderline value to consider the extracted oil as Virgin Olive Oil. For this time the specific energy transmitted to the olive paste is equal to 9000 J/kg.

In the manufacturing plant, where there are three transducers, the total installed power is 4400 W and to obtain the required energy exchange, it is necessary to have a mass flow rate equal to 0.489 kg/s (1760 kg/h). Table 4 contains the data of some extraction processes:

INSERT TABLE 4

Table 4 – Data recorded during the olive paste working

Table 5 reports the perceptual mass flow rate variation between ideal and operating condition:

INSERT TABLE 5

Table 5 – Variation between static and dynamic condition

3.2 Influence of the ultrasound treatment on the extra virgin olive oil quality

3.2.1 Effect on virgin olive oil quality indices

According to 2568/1991 subsequent amendments [43], EVOO is a liquid fat that conforms to a series of chemical and sensory parameters (free fatty acids < 0.8 g oleic acid/100 g oil; peroxide value < 20 meqO₂/kg; K_{232} < 2.50, K_{270} < 0.22, median of defects = 0, median of fruity > 0), and is free of defects. All samples showed very low values of acidity, peroxide value, K_{232} and K_{270} so that they were defined as belonging to the commercial class of “extra virgin” olive oils.

Considering these chemical parameters, no significant differences were found attributable to the ultrasonic treatment ($p < 0.05$) (data not shown). This result is in agreement with previous data available in literature [17][18].

3.2.2 *Influence of the ultrasound treatment on the concentration of minor compounds of EVOO*

The phenolic compounds are important minor compounds in the evaluation of the quality of the EVOO. They are strongly related to the EVOO shelf life because of their antioxidant ability, have bioactive activities and are also responsible of pungent and bitter sensory attributes [19]. Furthermore they have been included in a specific health claim for virgin olive oil by European Union [18]. Total phenols showed significant higher values in the EVOO obtained applying the ultrasound treatment. These results are in contrast with previous researches. At pilot scale, Clodoveo et al. [18] observed a reduction of total phenol content of EVOO when the ultrasound treatment was applied to the crushed olive paste. These observation was confirmed in 2015 by Bejaoui et al. [16]. Clodoveo et al. [18] explained this reduction of VOO phenolics by the enhancement of the oxygen action for the non-enzymatic oxidation and its influence on the endogenous enzymes such as “Polyphenol oxidase,” “Peroxidase,” and “b-glucosidase,” as well as the orientation of the phenolics, with hydrophilic properties, to the air-oil interface. Observing Figure 8, it is clear that the discontinuity in the olive paste delivered from the pump should be avoided. In fact, when the olive paste is not homogenous, air spaces are dispersed into the mass, favouring the oxidative reactions. The extraction tests were conducted monitoring the homogeneity of the olive paste and continuously adjusting the mass flow processed by the crusher, varying the rotational speed, because a low value causes air infiltration. In addition to the total phenol content, composition of phenolic fraction was determined (Table 6).

INSERT TABLE 6

Table 6 – Effect of ultrasound treatment on the phenolic composition (mg/kg) in olive oils cv. Coratina.

A significant increment of tyrosol, secoiridoid derivatives (dialdehydic form of elenolic acid linked to hydroxytyrosol (3,4-DHPEA-EDA), dialdehydic form of elenolic acid linked to

tyrosol (r-HPEA-EDA), aldehydic form of elenolic acid linked to hydroxytyrosol (3,4-DHPEA-EA) 1 was observed for EVOO extracted after the ultrasound treatment of olive paste. The higher increase was observed for the secoiridoids derivatives p-HPEA-EDA, (17%) and 3,4-DHPEA-EA (20 %). The same average was releaved for all the others compounds. In fact also the Hydroxytyrosol (3,4-DHPEA) and Tyrosol (p-HPEA) showed an increase of 14 and 15% respectively, going from control to sonicated samples (1,5mg/kg vs 1,8 mg/kg). The lignans (+) acetoxysterivative showed an increase ranging equal to 16%. Finally a less significant value was observed for the p-HPEA-EA (11%).

Regard to the sensorial evaluation, the oils obtained by treating the olive paste by means ultrasound were characterized by a more harmonic taste than those obtained with the traditional method which were perceived more aggressive.

INSERT FIGURE 14

Figure 14 Sensory evaluation of EVOO obtained by the traditional (a) and the innovative (b) ultrasound treatment of olive paste.

The significant increment of polyphenols in the sonicated oils can be also attributed to the effect of ultrasound on polyphenoloxidase (PPO) activity. Figure 14 shows the ultrasound inhibition effect of olive PPO. The EVOO quality is intimately affected by its content in phenolic compounds. PPO is responsible for oxidative losses of phenolics during olive paste malaxation. EVOO phenols play a key role in the shelf life of the product due to their activity delaying oxidation processes. They act as chain breakers by donating radical hydrogen to alkylperoxyl radicals, produced by lipid oxidation and contribute to the formation of stable derivatives. Comparing the EVOOs samples extracted by means the traditional and the innovative system, an average increase of about 48% of α -tocopherols and of about 30% of carotenoids were observed after ultrasound treatment.

INSERT FIGURE 15

Figure 15 Ultrasound inhibition effect of olive PPO. Olive paste was sonicated for 2, 4, 6, and 8 min before malaxation. Asterix indicate statistical significance vs control untreated (Anova test, $p < 0.05$)

3.3 Consumers' acceptability of the ultrasound system for virgin olive oil elaboration process

The respondents, on average, are 39 years old and the majority are females (55.4%). The average number of household members is between three and four. Almost 45% of the sample has a university or post graduate educational level and about 68% has a monthly family income up to €3,000 (Table 1). It is worth mentioning that in the sample individual has an educational level higher than the regional population.

INSERT TABLE 7

Table 7 –Demographic characteristics of the sample

Most of respondents buy EVOO one or two times per year (54%), through direct channels like mills or olive farms (73%) in container of 3 litre or bigger (78%) at a price lower than 7 € per litre (70%). A common habit, within the sample, is to consume vegetable oils but at lesser extent than EVOO.

INSERT TABLE 8

Table 8 Consumers buying habits

The respondents somewhat agree or agree (average valuation 5 or 6 on a seven-point Likert scale) with those statements about health (statements: 6, 20, 21, 22, 23, 24, 25) and taste (statements: 1, 19) as the main purchasing motivations of food and EVOO. They also agree that EVOO is very important for their diet (statement 16), probably because it is considered a natural and genuine condiment (statement 5) and their consumption is also due to family tradition (statement 7). Finally, they somewhat agree that routine is important in purchasing food (statement 13) but, at the same time, they somewhat agree that new technologies can improve food quality.

They somewhat disagree (average valuation lower than four point) that price and advertising (statements 9 and 15) really affect, respectively EVOO and food consumption. The valuation of other statements (2, 3, 4, 8, 10, 14, 18) is on average equal to 4-point (neither agree or disagree).

INSERT TABLE 9

Table 9 Consumers purchasing motivations

Most of respondents think that EVOO produced applying ultrasound technique has the same quality (49%) or even a better quality (19%) than EVOO extracted with other actual methods. The majority of the sample (51%) is willing to buy ultrasound EVOO but only a small proportion (9%) is willing to pay a price higher than that they actually pay for EVOO.

INSERT TABLE 10

Table 10 Consumers' intention to buy

The association analysis shows that there is a statistical significant association between some consumers' characteristics (demographic characteristics, buying habits and purchasing motivations) and their intention to buy ultrasound EVOO.

About the consumers' demographic characteristics, we find that the higher the educational level or the monthly family income the higher the intention to buy ultrasound EVOO.

The intention to buy ultrasound EVOO is inversely associated with intensity of consumption of other vegetable oils. There is, also, an association between the place of buying EVOO and the intention to buy ultrasound EVOO.

Finally, some purchasing motivations affect intention to buy ultrasound EVOO. In particular, the liking of EVOO taste, the liking of EVOO with bitter and spicy taste or with fruity taste, the valuation of EVOO healthiness, the liking of novelty foods, the attitude toward the impact of new technologies on food quality, the relevance of EVOO for diet and the liking of tasty food, they all positively affect the intention to buy ultrasound EVOO. In addition the last is positively associated with the previous knowledge of ultrasound technologies.

INSERT TABLE 11

Table 11 Results of association analysis

CONCLUSION

The application of ultrasound in the virgin olive oil production process offers an interesting number of advantages due to their mechanical and thermal effects. The ultrasound technology is able to induce the rupture of cell walls, recovering the oil and

minor compounds trapped in the uncrushed olive tissue, increasing the work capacity of the extraction plant and reducing the process time. One of the most important challenge of this paper was to design and build a sono-exchanger able to improve the working capacity of the industrial plants, performing a real continuous process by means of simply equations. A 3D fluid dynamic analysis was performed by means Ansys Fluent to evaluate the cross section around the ultrasound devices and to evaluate the flow parameters of olive past inside the sono-exchanger. The influence of each geometrical parameters was performed to setup an optimal design of the sono-exchanger and the results demonstrate the pressure drop and velocity field are suitable to ensure the best ultrasounds diffusion. No alteration of the EVOO quality parameters were observed into the EVOOs obtained by means the ultrasound treatment of olive paste. The ultrasound treatments gave oils with significantly higher contents of tocopherols, carotenoids, and phenolics. The significant increment of polyphenols in the sonicated oils can be also attributed to the effect of ultrasound on polyphenoloxidase activity. Moreover, ultrasounds improve the sensory evaluation of the samples. Regarding to the Consumers' acceptability of the ultrasound system for virgin olive oil elaboration process, some purchasing motivations affect intention to buy ultrasound EVOO. In particular, the liking of EVOO taste, the liking of EVOO with bitter and spicy taste or with fruity taste, the valuation of EVOO healthiness, the liking of novelty foods, the attitude toward the impact of new technologies on food quality, the relevance of EVOO for diet and the liking of tasty food, they all positively affect the intention to buy ultrasound EVOO.

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References

- [1] Amirante, R., Clodoveo, M. L., Distaso, E., Ruggiero, F., & Tamburrano, P. (2016). A tri-generation plant fueled with olive tree pruning residues in Apulia: An energetic and economic analysis. *Renewable Energy*, 89, 411-421.
- [2] Clodoveo, M. L., Camposeo, S., De Gennaro, B., Pascuzzi, S., & Roselli, L. (2014). In the ancient world, virgin olive oil was called "liquid gold" by Homer and "the great healer" by Hippocrates. Why has this mythic image been forgotten?. *Food Research International*, 62, 1062-1068.
- [3] Clodoveo, M. L., Dipalmo, T., Crupi, P., Durante, V., Pesce, V., Lovece, A., Mercurio, A., Laghezza, A., Corbo, F., Franchini, C. (2016). Comparison between Different Flavored Olive Oil Production Techniques: Healthy Value and Process Efficiency. *Plant Foods for Human Nutrition*, 1-7.
- [4] Clodoveo ML, Camposeo S, Amirante R, Dugo G, Cicero N, Boskou D (2015) Research and Innovative Approaches to Obtain Virgin Olive Oils with a Higher Level of Bioactive

Constituents in the book: Olives and Olive Oil Bioactive Constituents, Boskou D. (Ed.),
AOCS Press, Urbana, IL - USA pp 179 -216. ISBN: 978-1-630670-41-2.– pp 179 -216.

[5] Clodoveo, M. L. (2012). Malaxation: Influence on virgin olive oil quality. Past, present
and future—An overview. *Trends in Food Science & Technology*, 25(1), 13-23.

[6] Clodoveo, M. L. (2013). New advances in the development of innovative virgin olive oil
extraction plants: Looking back to see the future. *Food research international*, 54(1), 726-
729.

[7] Clodoveo, M. L., Hbaieb, R. H., Kotti, F., Mugnozza, G. S., & Gargouri, M. (2014).
Mechanical strategies to increase nutritional and sensory quality of virgin olive oil by
modulating the endogenous enzyme activities. *Comprehensive Reviews in Food Science
and Food Safety*, 13(2), 135-154.

[8] Clodoveo, M. L., Dipalmo, T., Schiano, C., La Notte, D., & Pati, S. (2014). What's now,
what's new and what's next in virgin olive oil elaboration systems? A perspective on
current knowledge and future trends. *Journal of Agricultural Engineering*, 45(2), 49-59.

[9] Clodoveo, M. L. (2013). An overview of emerging techniques in virgin olive oil
extraction process: Strategies in the development of innovative plants. *Proceedings of
AIIA Conference, Viterbo, Italy, 8-12 September 2013* *Journal of Agricultural
engineering*, XLIV, Supplement 1, 297-305.

[10] Chemat, F., & Khan, M. K. (2011). Applications of ultrasound in food technology:
processing, preservation and extraction. *Ultrasonics sonochemistry*, 18(4), 813-835.

[11] Chandrapala, J., Oliver, C., Kentish, S., & Ashokkumar, M. (2012). Ultrasonics in food
processing. *Ultrasonics sonochemistry*, 19(5), 975-983.

[12] Ashokkumar, M. (2015). Applications of ultrasound in food and bioprocessing.
Ultrasonics sonochemistry, 25, 17-23.

[13] A. Patist, D. Bates, Ultrasonic innovations in the food industry: from the laboratory to
commercial production, *Innov. Food Sci. Emerg.* 9 (2008) 147–154.

- [14] A. Jiménez, G. Beltrán, M. Uceda, High-power ultrasound in olive paste pretreatment. Effect on process yield and virgin olive oil characteristics, *Ultrason. Sonochem.* 14 (2007) 725–731.
- [15] Cravotto, G., Boffa, L., Mantegna, S., Perego, P., Avogadro, M., & Cintas, P. (2008). Improved extraction of vegetable oils under high-intensity ultrasound and/or microwaves. *Ultrasonics sonochemistry*, 15(5), 898-902.
- [16] Bejaoui, M. A., Beltran, G., Sánchez-Ortiz, A., Sanchez, S., & Jimenez, A. (2015). Continuous high power ultrasound treatment before malaxation, a laboratory scale approach: Effect on virgin olive oil quality criteria and yield. *European Journal of Lipid Science and Technology*.
- [17] Clodoveo, M. L., Durante, V., La Notte, D., Punzi, R., & Gambacorta, G. (2013). Ultrasound-assisted extraction of virgin olive oil to improve the process efficiency. *European Journal of Lipid Science and Technology*, 115(9), 1062-1069.
- [18] Clodoveo, M. L., Durante, V., & La Notte, D. (2013). Working towards the development of innovative ultrasound equipment for the extraction of virgin olive oil. *Ultrasonics sonochemistry*, 20(5), 1261-1270.
- [19] Clodoveo, M. L., & Hbaieb, R. H. (2013). Beyond the traditional virgin olive oil extraction systems: Searching innovative and sustainable plant engineering solutions. *Food research international*, 54(2), 1926-1933.
- [20] Clodoveo, M.L., Camposeo, S., Amirante, R., Dugo, G., Cicero, N., Boskou, D. (2015) Research and Innovative Approaches to Obtain Virgin Olive Oils with a Higher Level of Bioactive Constituents. In: Research and Innovative Approaches to Obtain Virgin Olive Oils with a Higher Level of Bioactive Constituents in the book: *Olives and Olive Oil Bioactive Constituents*, Boskou D. (Ed.), AOCS Press, Urbana, IL - USA pp 179 -216. ISBN: 978-1-630670-41-2.– pp 179 -216.
- [21] Roy, R. A. (1999). Cavitation sonophysics. In *Sonochemistry and Sonoluminescence* (pp. 25-38). Springer Netherlands.

- [22] Seya, P. M., Desjoux, C., Bera, J. C., & Inserra, C. (2015). Hysteresis of inertial cavitation activity induced by fluctuating bubble size distribution. *Ultrasonics sonochemistry*, 27, 262-267.
- [23] Desjoux, C., Fouqueray, M., Lo, C. W., Seya, P. M., Lee, J. L., Bera, J. C., ... & Inserra, C. (2015). Counterbalancing the use of ultrasound contrast agents by a cavitation-regulated system. *Ultrasonics sonochemistry*, 26, 163-168.
- [24] Amirante, R., Distaso, E., & Tamburrano, P. (2014). Experimental and numerical analysis of cavitation in hydraulic proportional directional valves. *Energy Conversion and Management*, 87, 208-219.
- [25] Santos, H. M., Lodeiro, C., & Capelo-Martínez, J. L. (2009). The power of ultrasound (Vol. 171). WILEYVCH verlag GmbH & Co. KGaA, Weinheim.
- [26] P. Amirante, M.L. Clodoveo, G. Dugo, A. Leone, A. Tamborrino, Advance technology in virgin olive oil production from traditional and de-stoned pastes: influence of the introduction of a heat exchanger on oil quality, *Food Chem.* 98 (2005) 797–805.
- [27] M. Legay, B. Simony, P. Boldo, N. Gondrexon, S. Le Person, A. Bontemps, Improvement of heat transfer by means of ultrasound: Application to a double tube heat exchanger, *Ultrason. Sonochem.* 19 (6) (2012) 1194–1200.
- [28] Amirante, R., Catalano, L. A., & Tamburrano, P. (2014). The importance of a full 3D fluid dynamic analysis to evaluate the flow forces in a hydraulic directional proportional valve. *Engineering Computations*, 31(5), 898-922.
- [29] Amirante, R., Catalano, L. A., Poloni, C., & Tamburrano, P. (2014). Fluid-dynamic design optimization of hydraulic proportional directional valves. *Engineering Optimization*, 46(10), 1295-1314.
- [30] Clodoveo, M. L., Dipalmo, T., Crupi, P., Durante, V., Pesce, V., Maiellaro, I., ... & Franchini, C. (2016). Comparison Between Different Flavored Olive Oil Production Techniques: Healthy Value and Process Efficiency. *Plant Foods for Human Nutrition*, 71(1), 81-87.

- [31] Biltekoff, C., 2010. Consumer response: The paradoxes of food and health. In *Annals of the New York Academy of Sciences*. pp. 174–178.
- [32] Rozin, P., 1976. The Selection of Foods by Rats, Humans, and Other Animals. *Advances in the Study of Behavior*, 6(C), pp.21–76.
- [33] Rozin, P. et al., 2004. Preference for natural: Instrumental and ideational/moral motivations, and the contrast between foods and medicines. *Appetite*, 43(2), pp.147–154.
- [34] Evans, G. et al., 2010. Reliability and predictive validity of the Food Technology Neophobia Scale. *Appetite*, 54(2), pp.390–393.
- [35] Cicia, G. et al., 2012. Il sistema agroalimentare ed il consumatore postmoderno: nuove sfide per la ricerca e per il mercato. *Economia agro-alimentare*, 13(1), pp.117–142. Available at: http://www.francoangeli.it/Riviste/Scheda_Rivista.aspx?IDarticolo=45475.
- [36] Siegrist, M. et al., 2008. Perceived risks and perceived benefits of different nanotechnology foods and nanotechnology food packaging. *Appetite*, 51(2), pp.283–290.
- [37] Lusk, J.L., Roosen, J. & Bieberstein, A., 2014. Consumer Acceptance of New Food Technologies: Causes and Roots of Controversies. *Annual Review of Resource Economics*, 6(1), pp.381–405. Available at: <http://dx.doi.org/10.1146/annurev-resource-100913-012735>.
- [38] Amirante, R., & Catalano, P. (2000). PH—postharvest technology: fluid dynamic analysis of the solid–liquid separation process by centrifugation. *Journal of agricultural engineering research*, 77(2), 193-201.
- [39] Legay, M., Le Person, S., Gondrexon, N., Boldo, P., & Bontemps, A. (2012). Performances of two heat exchangers assisted by ultrasound. *Applied Thermal Engineering*, 37, 60-66.
- [40] Amirante, P., Tamborrino, A., Leone, A., & Clodoveo, M. L. (2008). Assessment of the viscosity value in olive oil paste using different blade rotation speed in an innovative mixer. In *Central theme, technology for all: sharing the knowledge for development. Proceedings of the International Conference of Agricultural Engineering, XXXVII Brazilian Congress of Agricultural Engineering, International Livestock Environment*

Symposium-ILES VIII, Iguassu Falls City, Brazil, 31st August to 4th September, 2008.

International Commission of Agricultural Engineering (CIGR), Institut für Landtechnik.

[41] Di Renzo, G. C., & Colelli, G. (1997). Flow behavior of olive paste. *Applied Engineering in Agriculture*, 13(6), 751-755.

[42] IOOC, 2001. Trade Standard Applying to Olive Oil and Olive Pomace Oil. International Olive Oil Council, In COI/T.15/NC no. 2/Rev. 10; COI/T.20/Doc. no. 24

[43] European Commission Regulation No 61/2011 of 24 January 2011 amending Regulation (EEC) No 2568/91 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. *Official J. Eur. Union* L 23/1, 27.1.2011.

[44] Alessandri S, Ieri F, Romani A (2014) Minor polar compounds in extra virgin olive oil: correlation between HPLC-DAD-MS and the folin-Ciocalteu spectrophotometric method. *J Agric Food Chem* 62(4):826–835

[45] Sacchi, R., Paduano, A., Fiore, F., Della Medaglia, D., Ambrosino, M. L., & Medina, I. (2002). Partition behavior of virgin olive oil phenolic compounds in oil-brine mixtures during thermal processing for fish canning. *Journal of agricultural and food chemistry*, 50(10), 2830-2835.

[46] Montedoro, G.F., Servilli, M., Baldioli, M., Selvagini, R., Miniati, E., Macchioni, A., 1993. Simple and hydrolyzable compounds in virgin olive oil. 3. Spectroscopic characterizations of secoridoid derivatives. *Journal of Agricultural and Food Chemistry* 41, 2228–2234.

[47] Mateos, R., Espartero, J.L., Trujillo, M., Rios, J.J., León-Camacho, M., Alcudia, F., Cert, A., 2001. Determination of phenols, flavones, and lignans in virgin olive oils by Solid-Phase Extraction and High-Performance Liquid Chromatography with Diode Array Ultraviolet Detection. *Journal of Agricultural and Food Chemistry* 49, 2185–2192.

[48] Brenes, M., Hidalgo, J.H., Garcia, A., Rios, J.J., Garcia, P., Zamora, R., Garrido, A., 2000. Pinoresinol and 1-acetoxypinoresinol, two new phenolic compounds identified in olive oil. *Journal of American Oil Chemistry Society* 77, 715–720.

921 [49] Bradford, M. M. (1976). A rapid and sensitive method for the quantitation of microgram
922 quantities of protein utilizing the principle of protein-dye binding. Analytical
923923 biochemistry, 72(1-2), 248-254.
924924

Table 1 – Material properties and power-law parameters used

Fluid	Density [kg/m ³]	Consistency Index, k [Pa·s ^{n}]	Behaviour Index, n
olive paste	1120	68	0.184

Table 2 – Comparison between the different kinds of mesh

	<i>Cells</i> <i>number</i>	<i>Area-Weighted Average Velocity Magnitude (m/s)</i>			<i>Area-Weighted Average Static pressure (Pa)</i>		
		Arbitrary			Arbitrary		
		Inlet	Out	cross section	Inlet	Out	cross section
REV a)	562868	0,078136	0,078013	0,081105	824284	800000	812113
REV b)	919887	0,078077	0,077995	0,080689	824363	800000	812184
REV c)	1509197	0,078030	0,077983	0,081160	824374	800000	812184
REV d)	2302130	0,078030	0,077963	0,081233	824856	800000	812434

Table 3 – Static results

m (kg)	P_s (W)	t (s)	L_i (J/kg)
3	150	120	6000
3	150	180	9000
3	150	240	12000
3	150	300	15000

Table 4 – Data recorded during the olive paste working

	Test 1	Test 2	Test 3	Test 4	Test 5
Malaxing time (<i>min</i>)	30	30	-	-	-
Mass of uniform harvested olive (<i>kg</i>)	551	456	461	462	464
Crusher working time (<i>min</i>)	18	16	17	16	16
Crusher working time (<i>h</i>)	0,300	0,267	0,283	0,267	0,267
G_{op} Mass flow rate (<i>kg/h</i>)	1836,67	1710,00	1627,06	1732,50	1740,00
G_{op} Mass flow rate (<i>kg/s</i>)	0,5102	0,4750	0,4520	0,4813	0,4833
Inverter frequency (<i>Hz</i>)	20	20	18	18	18
Upstream Transducer Power (<i>W</i>)	3000	3000	3000	3000	3000
Downstream Transducers Power (<i>W</i>)	1400	0	1400	1400	1400
p_{outs} exit pressure of the sono exchanger (<i>bar</i>)	8,1	8,0	7,8	8,2	7,9
L_i operating specific energy (<i>J/kg</i>)	6468,2	4736,8	7301,5	6857,1	6827,6

Table 5 – Variation between static and dynamic condition

$G_{id} \text{ (kg/s)}$	$G_{op} \text{ (kg/s)}$	$Variation \text{ (\%)}$
0,4889	0,5102	4,17
0,4889	0,4750	2,84
0,4889	0,4520	7,55
0,4889	0,4813	1,56
0,4889	0,4833	1,14

Table 6 Effect of ultrasound treatment on the phenolic composition (mg/kg) in olive oils cv. Coratina.

Sample	OHTy	Ty	OHTy-EDA	Ty-EDA	AP	OHTy-EA	Ty-EA	TPC	Total Carotenoids	α -Tocopherol
C ₁	1.5± 0.2a	2.9± 0.0a	322.5± 16.1b	107.4± 4.0a	39.9± 1.5a	111.6± 4.5a	12.0± 0.3a	611.2±18.3a	26.88±1.05a	144±4.8a
C ₂	1.2± 0.3a	3.1± 0.2b	280.0± 13.4a	105.2± 4.2a	39.9± 1.4a	131.4± 5.4b	11.8± 0.2a	585.1± 16.8a	28.84±1.12a	154.5±5.15a
C ₃	1.8± 0.1ab	2.8± 0.1a	306.2± 18.4ab	107.2± 5.9a	41.1± 1.9a	112.8± 4.6a	13.2± 0.3b	598.2± 16.6a	27.72±1.08a	148.5±4.95a
C ₄	1.8± 0.1ab	3.4± 0.1b	287.3± 16.5a	115.5± 4.4a	41.4± 1.6a	112.8± 3.7a	12.8± 0.2b	584.0± 15.4a	26.32±1.02a	141.0±4.7a
S ₁	1.9± 0.1b	3.7± 0.1c	384.5± 26.8c	121.8± 5.8b	44.6± 2.0ab	143.2± 4.5c	13.2± 0.2b	728.0± 19.2b	35.35±1.10b	242.4±5.05d
S ₂	2.0± 0.1b	3.7± 0.2c	401.7± 19.0c	123.6± 5.6b	44.5± 2.4ab	161.4± 4.8d	15.3± 0.4c	768.0± 18.6b	33.6±1.05b	230.4±4.8c
S ₃	1.8± 0.1ab	3.6± 0.1c	389.0± 14.7c	134.0± 5.1c	47.3± 1.4b	134.3± 4.8bc	13.5± 0.4b	739.0± 18.6b	34.3±1.07b	235.2±4.9cd
S ₄	1.6± 0.1a	3.1± 0.1a	366.0± 17.1c	117.7± 3.6b	43.9± 1.6ab	124.1± 3.2b	13.2± 0.4b	683.8± 14.2b	31.85±0.99b	218.4±4.55b

OHTy: hydroxytyrosol, Ty: tyrosol; Ty-EDA, dialdehydic form of elenoic acid linked to tyrosol; OHTy-EDA, dialdehydic form of elenoic acid linked to hydroxytyrosol; Ty-EA, aldehydic form of elenoic acid linked to tyrosol; OHTy-EA, aldehydic form of elenoic acid linked to hydroxytyrosol; AP: 1-acetoxy-pinoresinol; TPC: total phenol content compounds. Values are averages of three replicates (n = 3). Values followed by different letters in columns are statistically different (p < 0.05)

Table 7 – Variation between static and dynamic condition

	Sample		Population of Puglia region*	
	N. cases	%	N.	%
Total	961	100.0	4,090,105	100.0
Age (years)				
Mean	38.8	-	42	-
Std dev	15.1	-	N/A	-
Gender				
Male	448.0	46.6	1,984,227	48.5
Female	513.0	53.4	2,105,878	51.5
Number of household members				
Mean	3.6	-	2.57	-
Std dev	1.2	-	N/A	-
Educational level				
Primary education or none	9.0	0.9	867,010.00	24.78
Lower secondary education	52.0	5.4	1,203,900.00	34.41
Upper secondary education	469.0	48.8	1,067,440.00	30.51
Graduate and Postgraduate studies	431.0	44.9	359,950.00	10.29
Monthly family income (€)				
< 1.000 €	90.0	9.4	N/A	N/A
1.000 – 2.000 €	353.0	36.7	N/A	N/A
2.000 – 3.000 €	213.0	22.2	N/A	N/A
3.000 – 4.000 €	106.0	11.0	N/A	N/A
4.000 – 5.000 €	67.0	7.0	N/A	N/A
> 5.000 €	132.0	13.7	N/A	N/A

Source: our elaboration on data from National Institute of Statistics – ISTAT (2014).

Note: Data about educational level of regional population are restricted to resident aged 15 years or more.

Table 8 – Consumers buying habits

How often do you buy extra virgin olive oil?	N. cases	%
1 or 2 times per year	515.0	53.6
more than 2 times per year but not monthly	224.0	23.3
monthly	222.0	23.1
Do you also buy other vegetable oils (e.g. seed oils)?		
No not at all	378.0	39.3
Yes, but to a lesser extent	547.0	56.9
Yes, significantly	36.0	3.7
Usually, where do you buy the extra virgin olive oil?		
Large-scale retailer (hypermarket, supermarket, minimarket, discount)	133.0	13.8
Specialty shop (e.g. gourmet shop, wine shop)	27.0	2.8
Mill or farm	701.0	73.0
More than 1 channel (large-scale retailer and other channels)	100.0	10.4
Usually, in what format do you buy extra virgin olive oil?		
0,50 L or smaller	8.0	0.8
0,75 or 1 L	201.0	20.9
bigger than 1 L (3-5 L)	522.0	54.3
bigger than 5 L	230.0	23.9
What is the price you regularly pay for extra virgin olive oil last year?		
< 4 €/L	85.0	8.8
4 - 7 €/L	584.0	60.8
7 - 10 €/L	277.0	28.8
> 10 €/L	15.0	1.6

Table 9 Consumers purchasing motivations

Statements		Min	Max	Mean	Std dev
1	I consume extra virgin olive oil because I really like its taste	1	7	6	1,4
2	I like extra virgin olive oil with spicy and/or bitter taste	1	7	4	2,1
3	I like extra virgin olive oil with a fruity taste	1	7	4	1,9
4	I like extra virgin olive oil with a sweet taste	1	7	4	1,9
5	I consume extra virgin olive oil because it is natural and genuine condiment	1	7	6	1,4
6	I consume extra virgin olive oil because is healthy	1	7	6	1,4
7	I consume extra virgin olive because of family tradition	1	7	6	1,8
8	Extra virgin olive oil is an expensive condiment	1	7	4	1,8
9	I would increase consumption of extra virgin olive oil if it was costly	1	7	3	2,0
10	I like to try novelty foods	1	7	4	1,9
11	New technologies enhance the quality of food	1	7	5	1,8
13	I preserve routine in purchasing food	1	7	5	1,7
14	For me, the brand is very important in choosing food	1	7	4	1,8
15	For me, advertising is very important in choosing food	1	7	3	1,5
16	Olive oil is very important in my diet	1	7	6	1,6
18	I am very experienced in assessing the quality of extra virgin olive oil	1	7	4	1,7
19	I really like tasty food (pleasant, original, rich in flavour)	1	7	6	1,5
20	Health is very important for me	1	7	6	1,3
21	I am very interested in the issues affecting my health	1	7	6	1,3
22	I do my best to keep my health in good condition	1	7	6	1,3
23	Diet is very important for health	1	7	6	1,2
24	I am very interested in healthy foods	1	7	6	1,3
25	I do my best to follow an healthy diet	1	7	6	1,5

Table 11 Results of association analysis

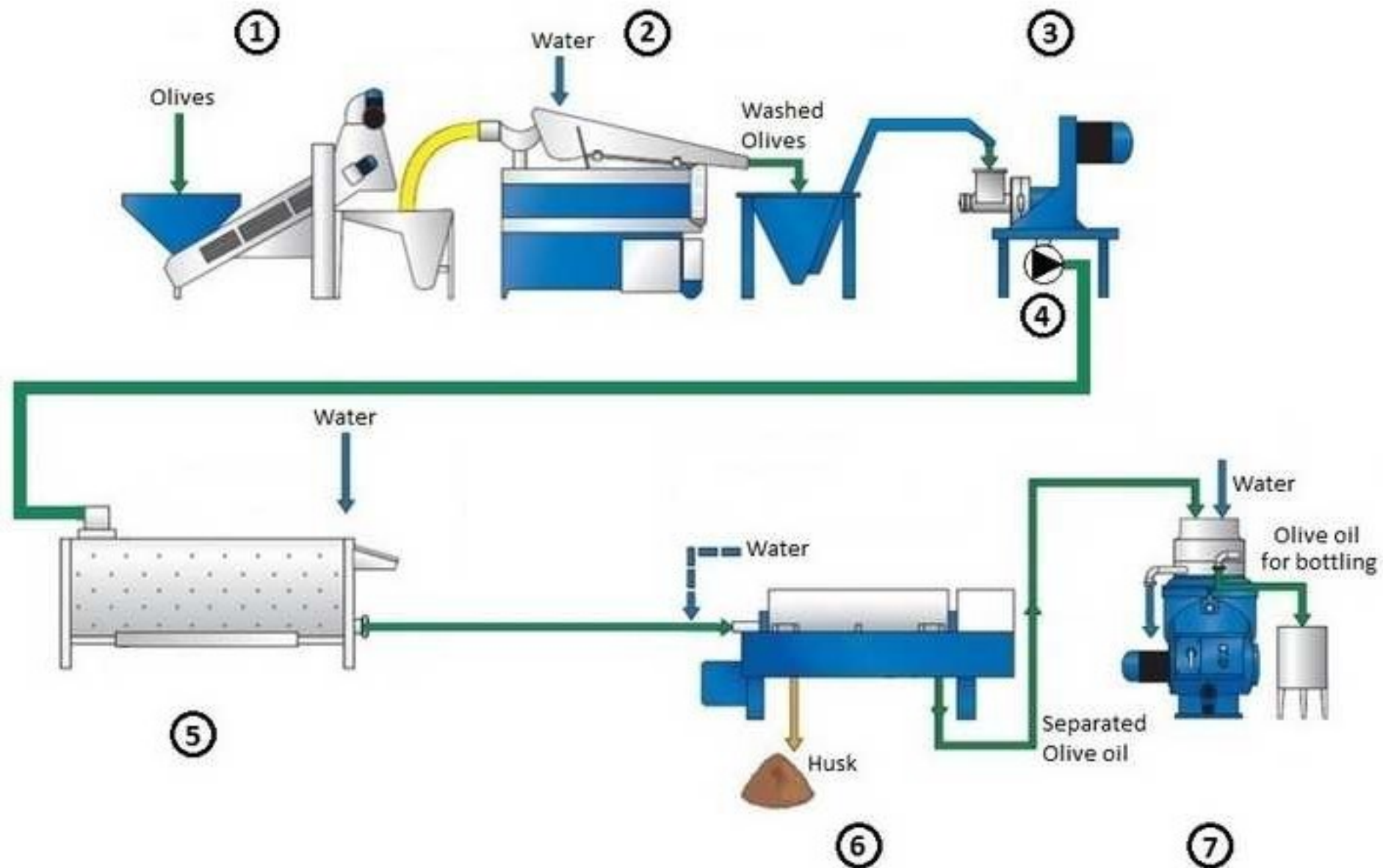
Pair of variables	Gamma	Cramer's V
Demographic characteristics vs. intention to buy ultrasound EVOO:		
- educational level vs. intention to buy	+0.13***	N/A
- family income vs. intention to buy	+0.16***	N/A
Buying habits vs. intention to buy ultrasound EVOO:		
- level of consumption of other vegetable oils vs. intention to buy	-0.09*	N/A
- place of buying EVOO vs. intention to buy	N/A	+0.10**
Purchasing motivations vs. intention to buy ultrasound EVOO:		
- liking of EVOO taste (STATEMENT N. 1) vs. intention to buy	+0.15 ***	N/A
- liking of bitter and spicy EVOO (STATEMENT N. 2) vs. intention to buy	+0.10***	N/A
- liking of EVOO fruity taste (STATEMENT N. 3) vs. intention to buy	+0.18***	N/A
- valuation of EVOO healthiness (STATEMENT N. 6) vs. intention to buy	+0.12 ***	N/A
- liking of novelty foods (STATEMENT N. 10) vs. intention to buy	+0.14***	N/A
- new technologies enhance food quality (STATEMENT N. 11) * intention to buy	+0.28***	N/A
- relevance of EVOO for diet (STATEMENT N. 16) vs. intention to buy	+0.07**	N/A
- liking of tasty food (STATEMENT N. 19) vs. intention to buy	+0.11***	N/A
- knowledge of ultrasound technologies vs. intention to buy	N/A	+0.19***

*Note: the table shows only the estimated value of association with an approximate significance level lower than 1% (***), 5% (**) or 10% (*).*

Table 11 Results of association analysis

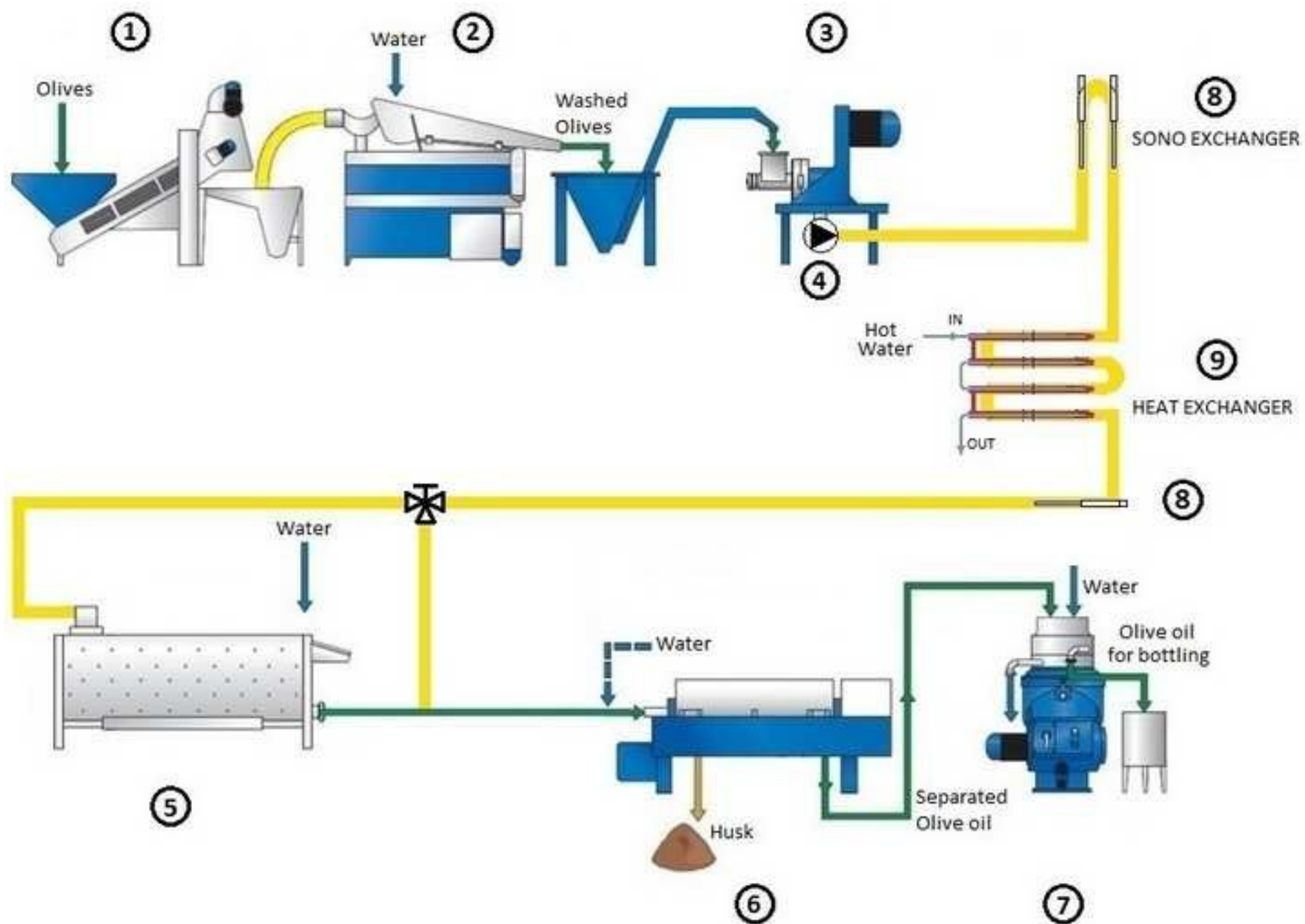
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- new technologies enhance food quality (STATEMENT N. 11) * intention to buy	+0.28***	N/A
- relevance of EVOO for diet (STATEMENT N. 16) vs. intention to buy	+0.07**	N/A
- liking of tasty food (STATEMENT N. 19) vs. intention to buy	+0.11***	N/A
- knowledge of ultrasound technologies vs. intention to buy	N/A	+0.19***

*Note: the table shows only the estimated value of association with an approximate significance level lower than 1% (***), 5% (**) or 10% (*).*



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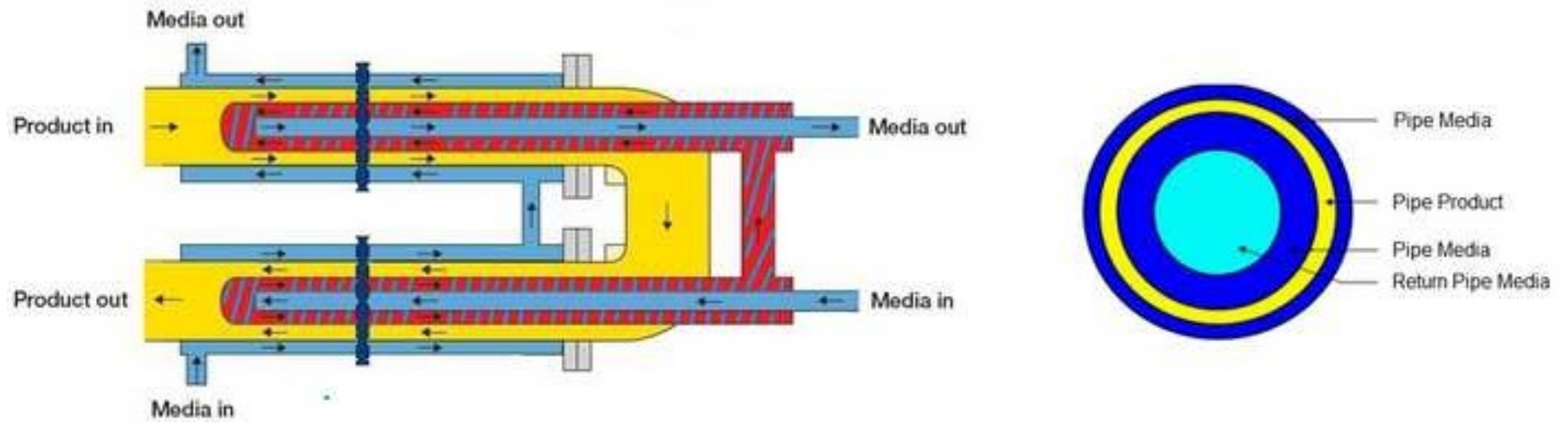
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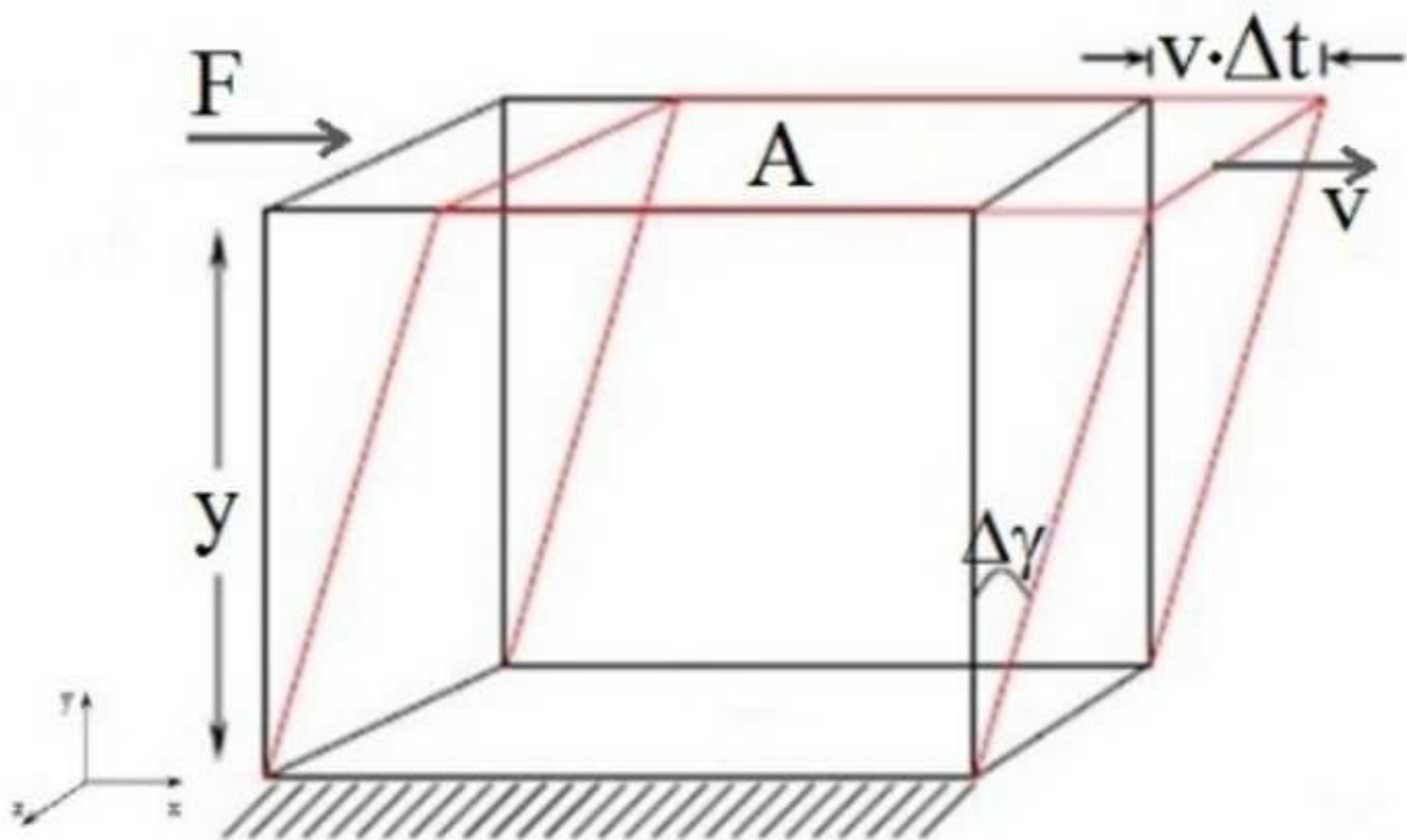
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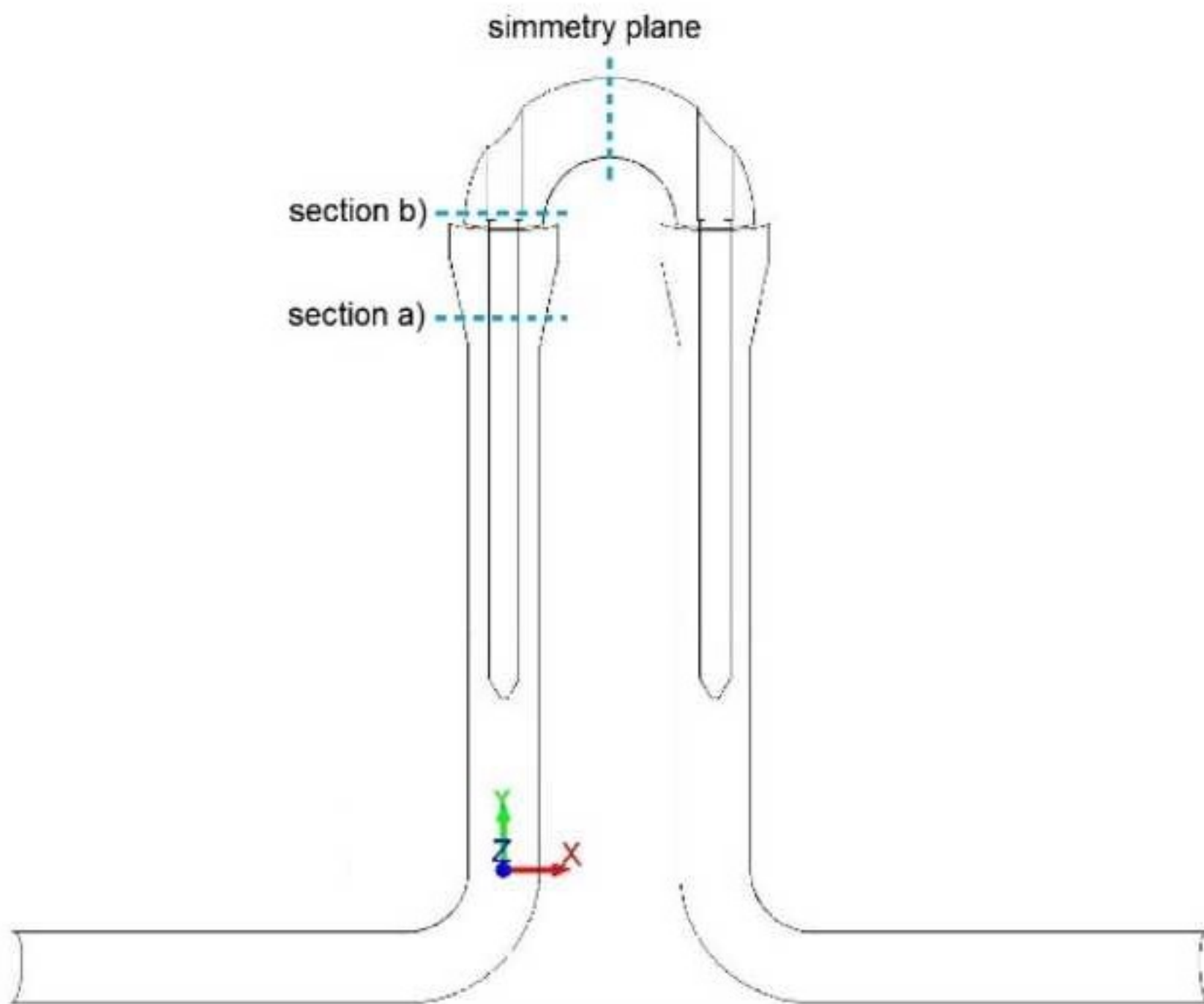
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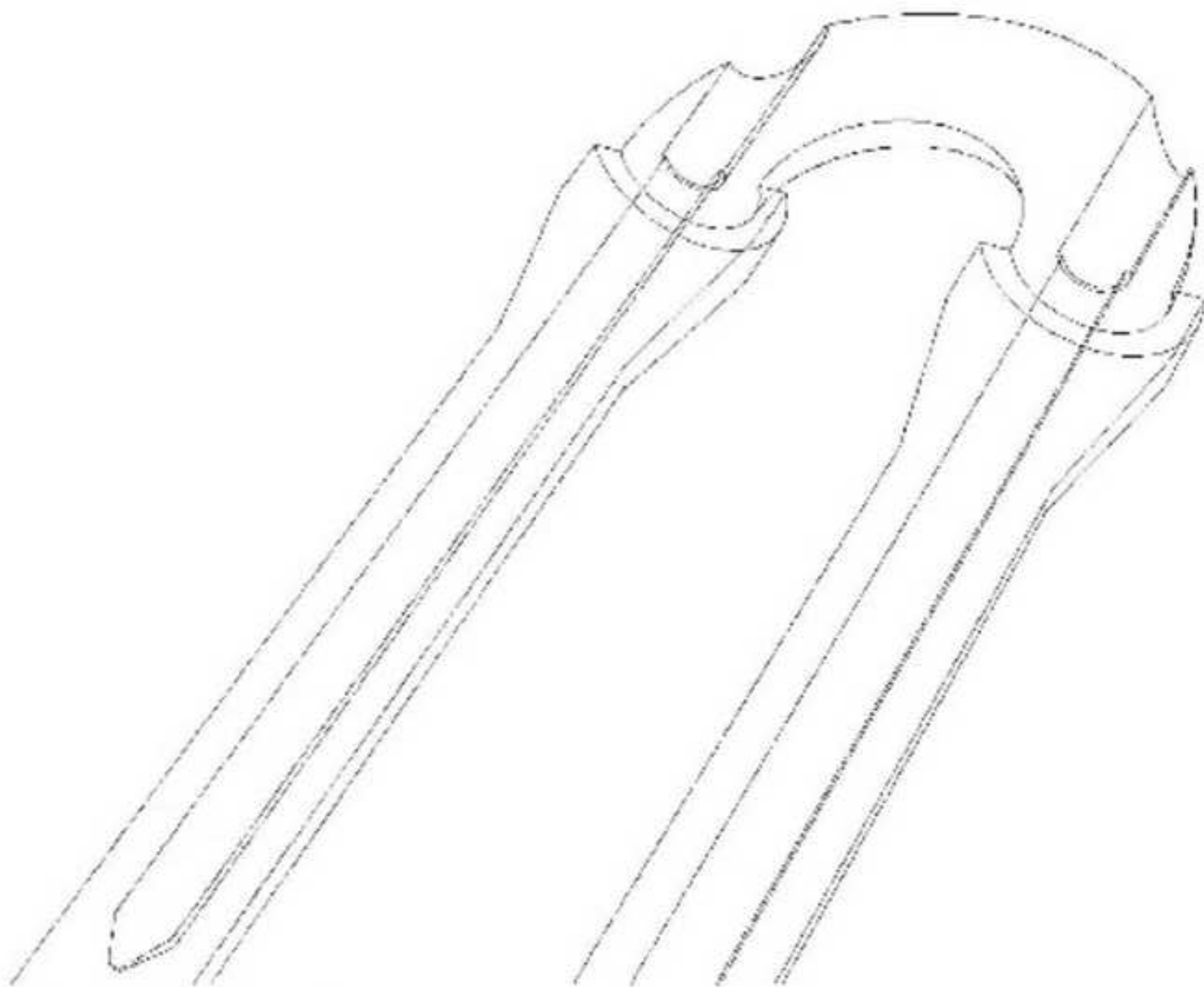
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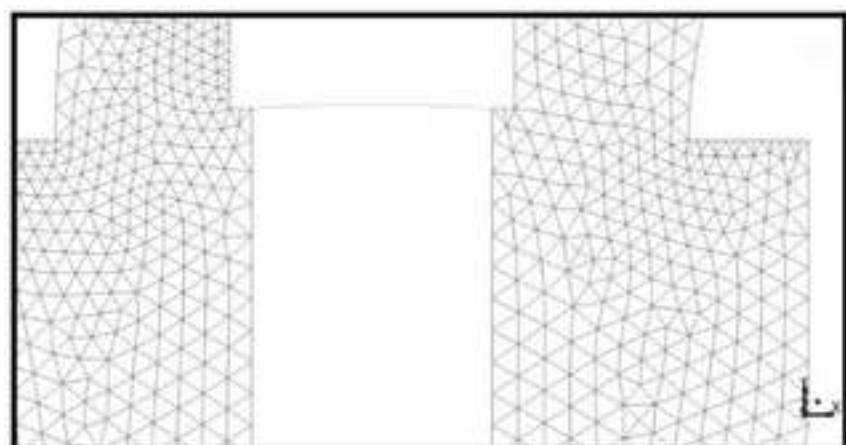
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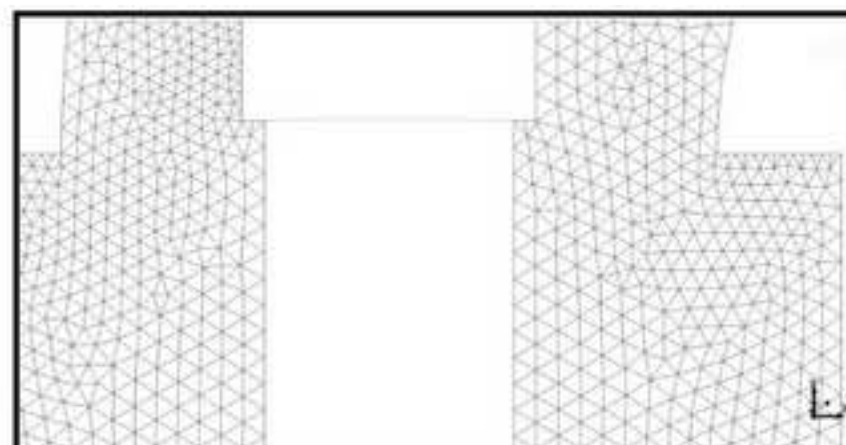


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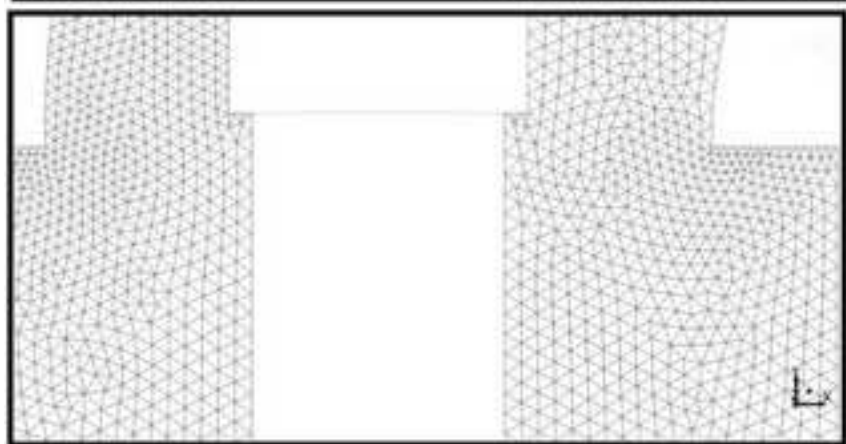
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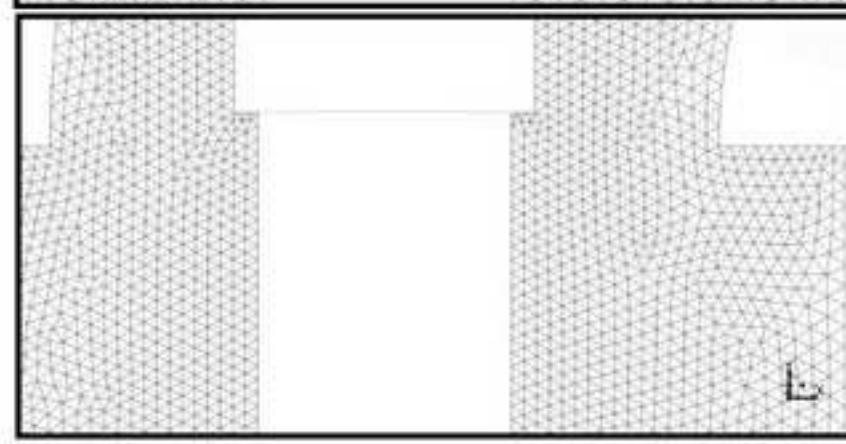
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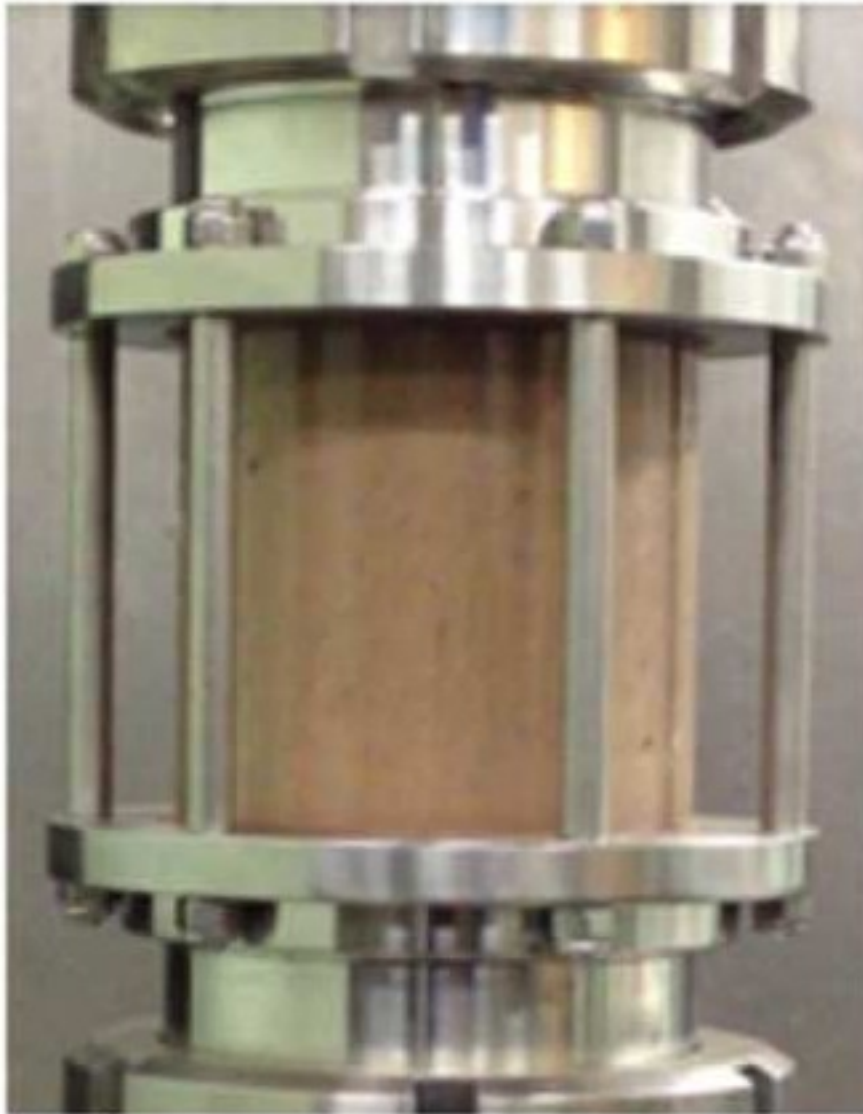
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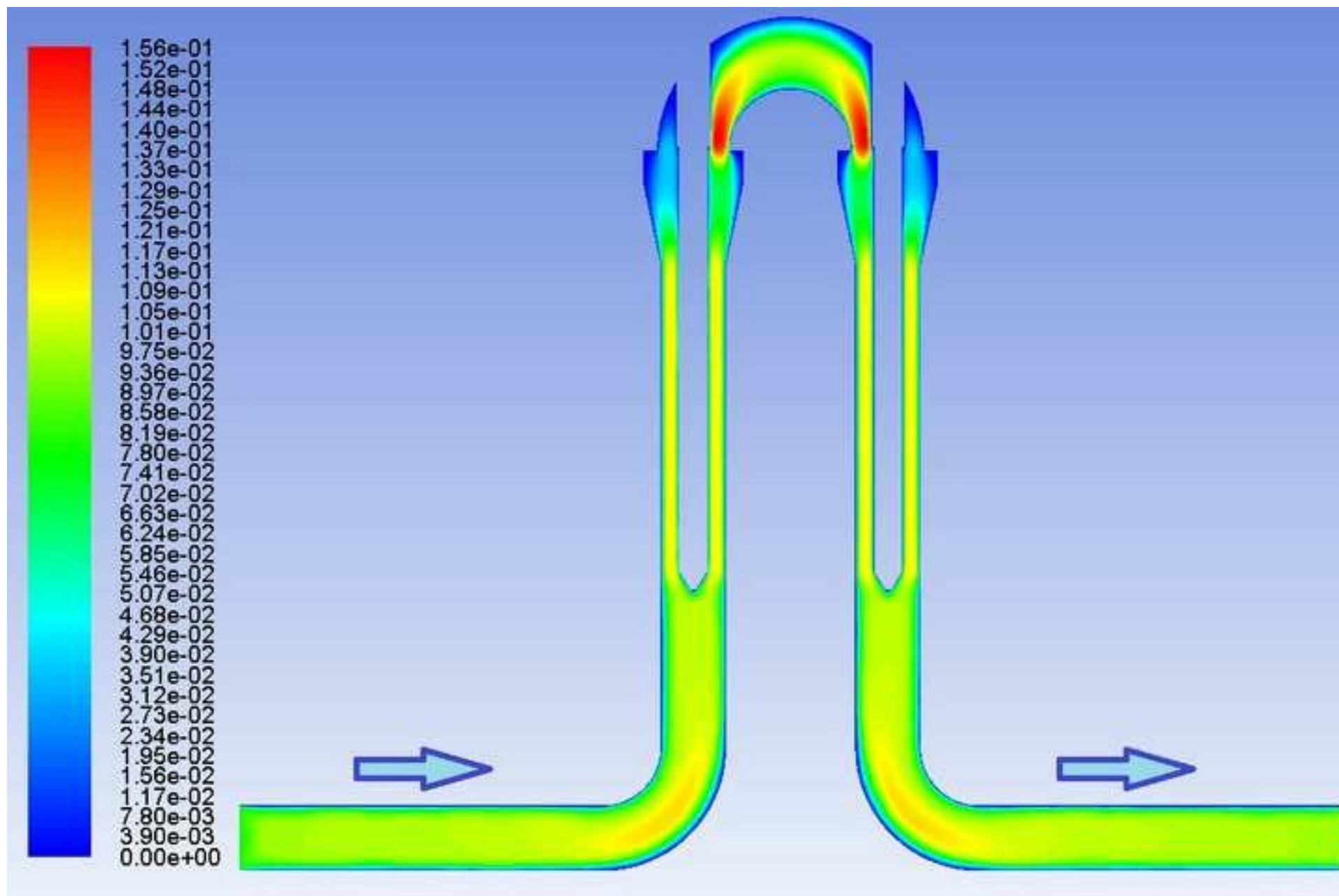
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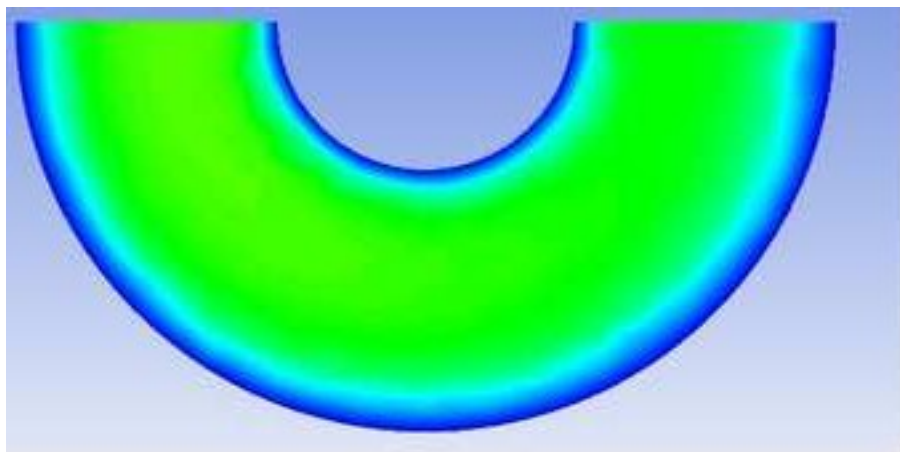
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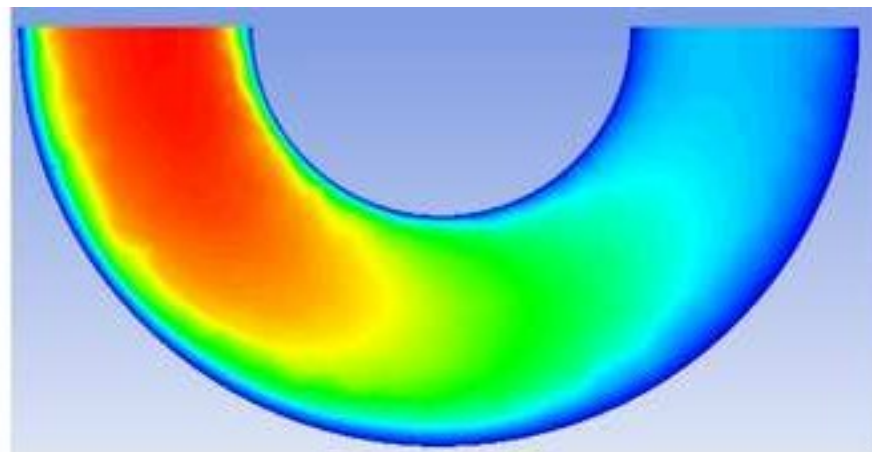


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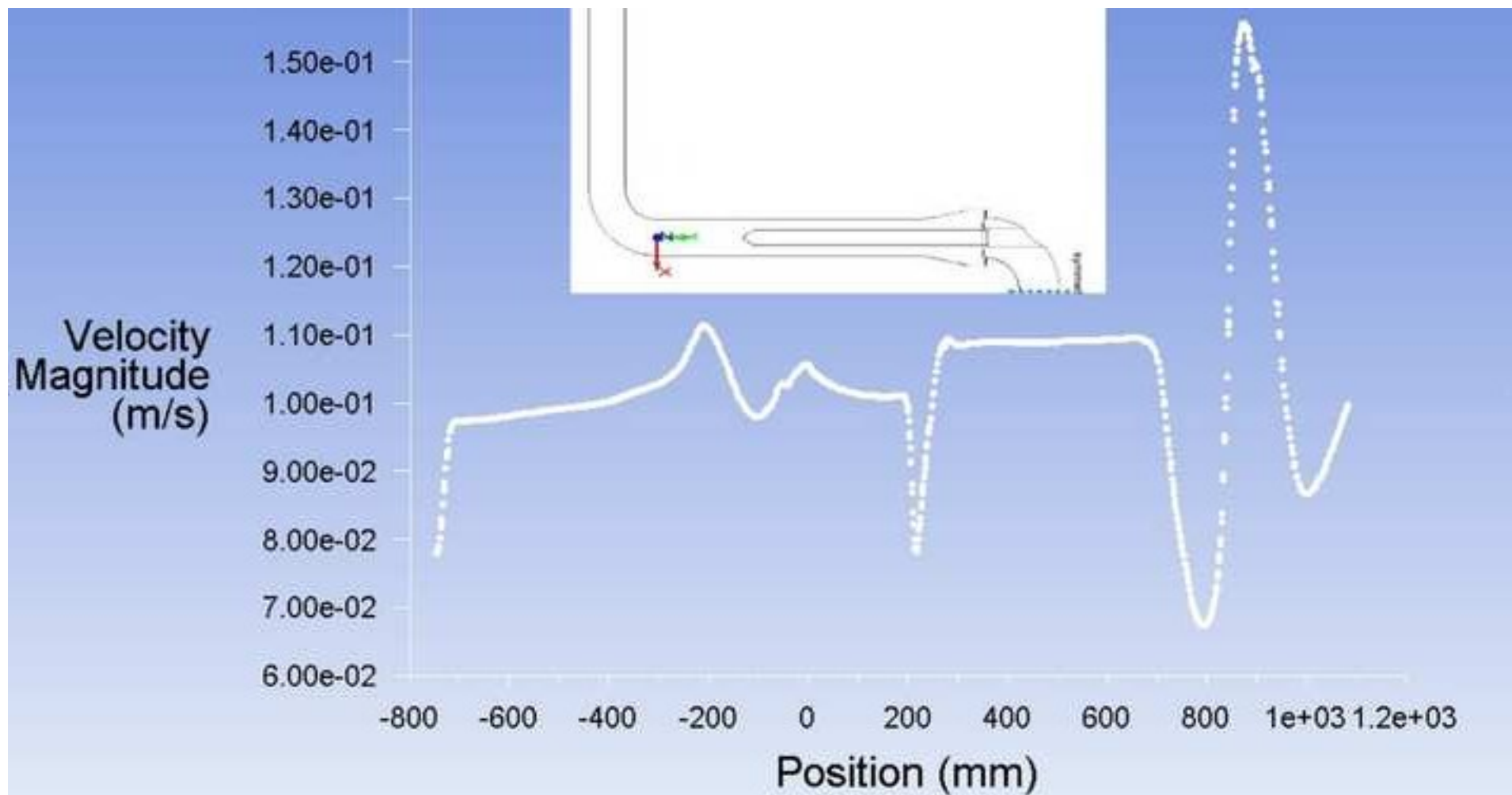
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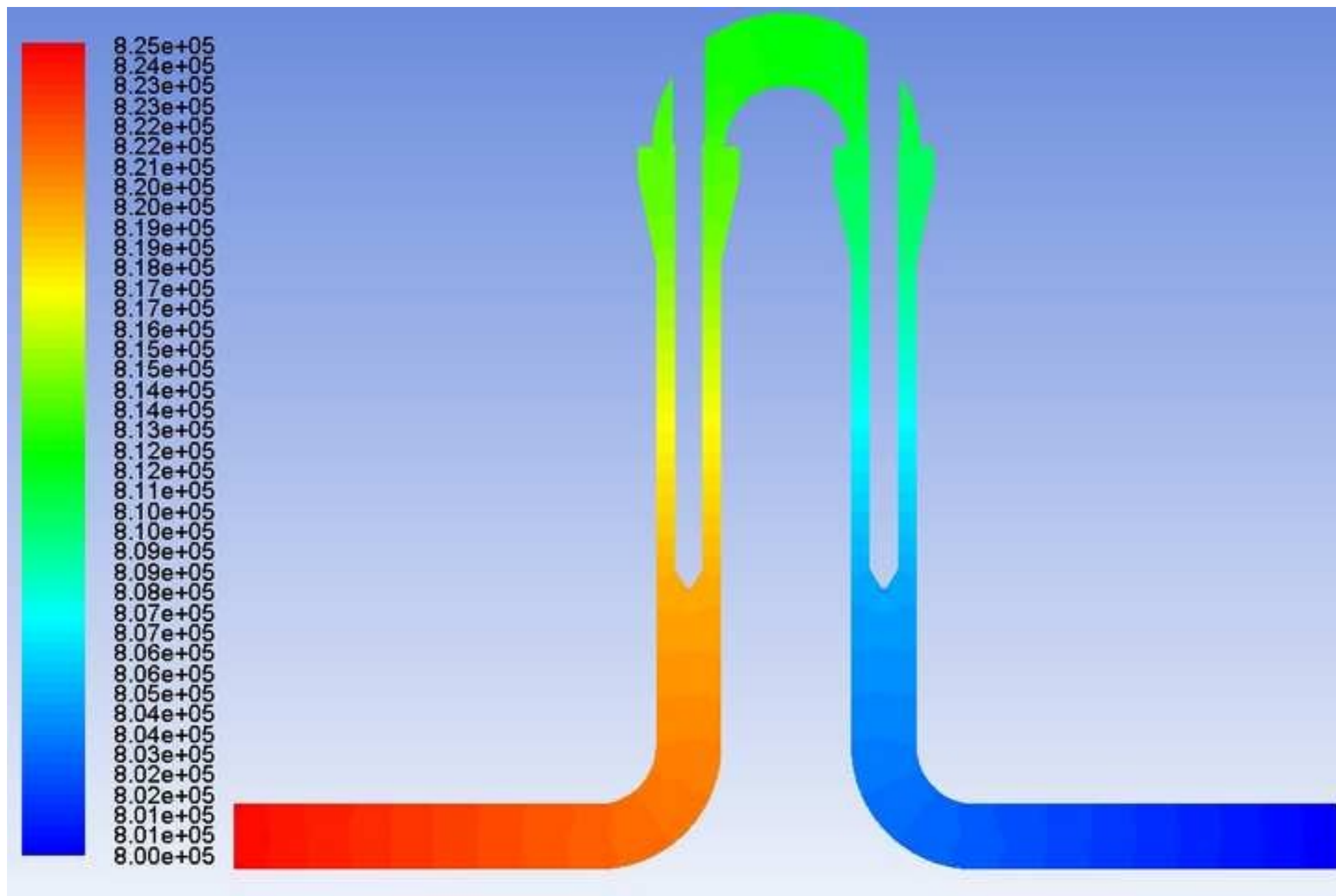
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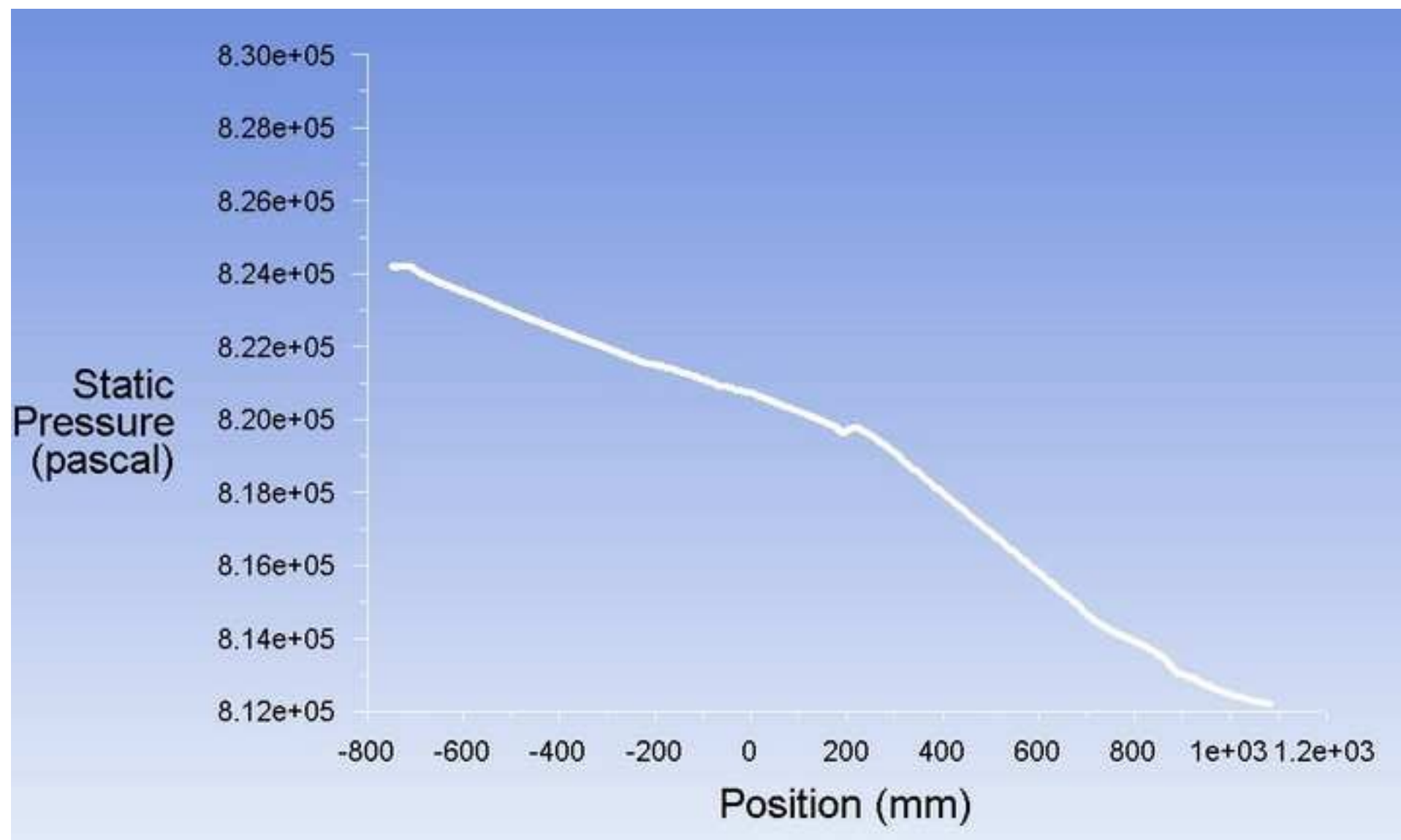
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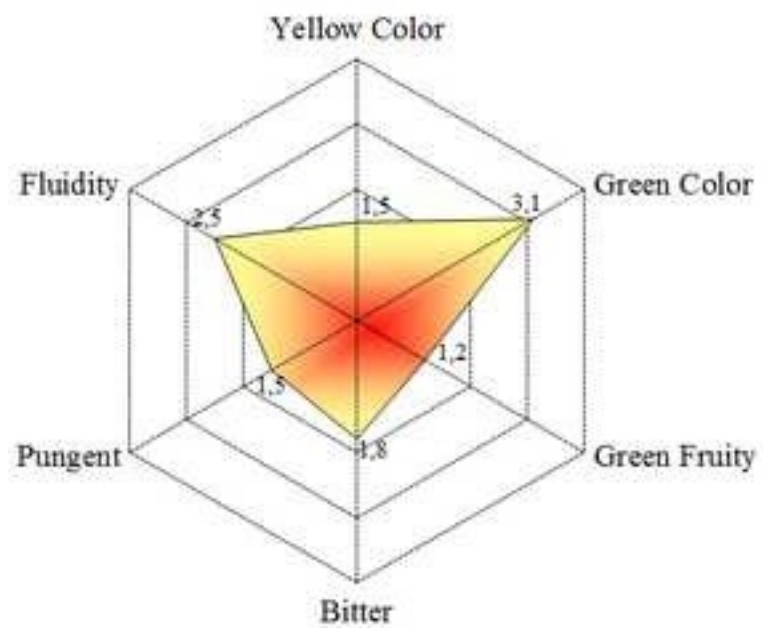
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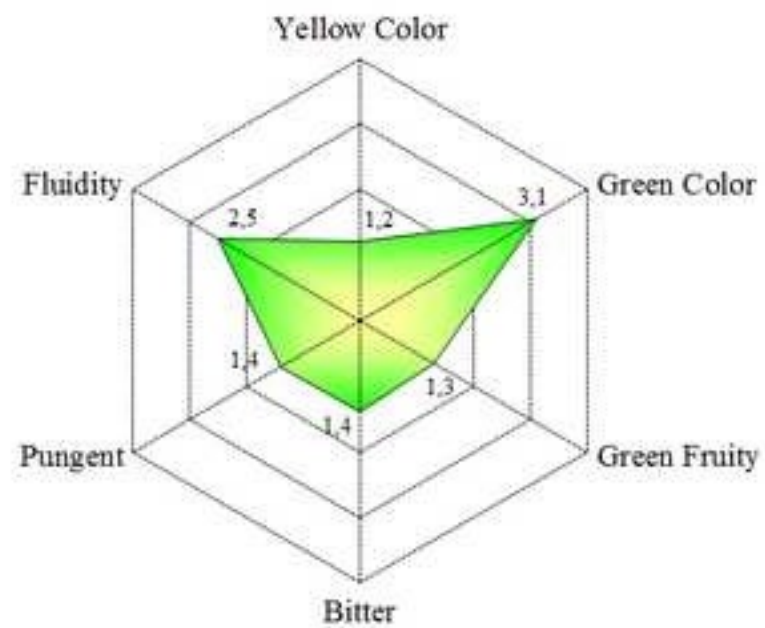


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a)



b)

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