# IMPLEMENTATION OF INDUCTIVE PROCESSES IN GENERAL-PURPOSE EQUIPMENT TO STREAMLINE HEAT TRANSFER PROCESSES

# IMPLEMENTAREA PROCESELOR INDUCTIVE ÎN ECHIPAMENTELE DE UZ GENERAL PENTRU EFICIENTIZAREA PROCESELOR DE TRANSFER DE CĂLDURĂ

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**Abstract.** The paper explores the energy efficiency of general-purpose installations, particularly the equipment used in the espresso coffee production process, and the unique functions of hydraulic systems. By implementing eco-design principles and innovative, highly efficient solutions, we can significantly reduce the negative environmental impact and transform citizens into eco-consumers. Our study aims to explore ways to decrease energy consumption in hydraulic systems of standard installations, particularly in heat transfer processes in solids and liquids, which account for up to 97% of energy consumption in such installations. We present an innovative solution that converts electric energy into heat in liquids using inductive heat transfer. The instant heating inductive boiler, based on inductive heat transfer phenomena, eliminates the convective and conductive heat transfer losses associated with the operation of the boiler with the resistive heating element. We provide the design methodology for dimensioning this type of equipment and create a simulation model for necessary verifications in MatLab Simscape. With its practical benefits, the new inductive boiler reduces the preheating period to 7.5 seconds compared to the 90 seconds of systems with resistive heating elements, thereby eliminating the need to keep the coffee machine at operating temperatures during breaks and providing a reliable solution for energy efficiency.

***Keywords:*** *coffee machines, inductive heating boiler, hydraulic systems, design methodology, simulation.*

**Rezumat.** Lucrarea se referă la instalații de uz general, în special la echipamentele pentru procesul de producere al cafelei espresso, precum și la particularitățile funcțiilor sistemului hidraulic. Îmbunătățirea eficienței energetice a instalațiilor de uz general prin punerea în aplicare a principiilor de proiectare ecologică și a soluțiilor inovatoare de eficiență sporită va reduce impactul negativ asupra mediului și va transforma cetățenii în consumatori ecologici. Obiectivul studiului este de a investiga posibilitățile de reducere a consumului de energie în sistemele hidraulice ale instalațiilor comune, în special în procesele de transfer termic în corpuri solide și lichide, care reprezintă până la 97% din consumul de energie în astfel de instalații. Lucrarea prezintă o soluție inovatoare pentru transformarea energiei electrice în căldură în lichide folosind transferul inductiv de căldură. Boilerul inductiv inovator de tip instant se bazează pe fenomene de transfer termic inductiv și elimină pierderile de transfer de căldură convective și conductive asociate funcționării cazanului cu elementul de încălzire rezistiv. Este prezentată metodologia de proiectare a acestui tip de echipament, iar modelul de simulare pentru verificările necesare este creat și rulat în MatLab Simscape. Noul boiler inductiv reduce perioada de preîncălzire la 7,5 secunde față de cele 90 secunde a sistemelor cu boilere de încălzire rezistive, eliminând necesitatea menținerii aparatului de cafea la temperaturi de funcționare in timpul pauzelor.

***Cuvinte cheie:*** *aparat de cafea, boiler de încălzire inductiv, sisteme hidraulice, metodologie de proiectare, simulare.*

## 1. Introduction

The scientific and engineering part of our society seeks new ways to quantify and minimize products' adverse environmental impact. Creating energy-efficient and less harmful products encourages consumers to be eco-conscious, enhancing our well-being.

Reducing energy consumption in technological processes and their influence on the environment fully complies with the provisions of the Environmental Strategy for 2014-2023 approved by Government Decision nr. 301 of 24.04.2014 and Government Decision nr. 102 of 05.02.2013 on the Republic of Moldova Energy Strategy until 2030, both for industrial use and domestic needs [1-3].

The study refers to standard equipment, especially coffee machines. For most people, every morning starts with a delicious cup of coffee or some other type of beverage, and finding a solution that would increase the efficiency of every coffee machine or kettle will reduce electricity consumption considerably.

The work aims to analyze the power consumption of a super-automated coffee maker and develop a solution that implements inductive heat transfer and considerably improves its efficiency.

## 2. Synthesis of construction principles and aspects of operation of electromechanical systems of conventional coffee machine

### 2.1. Espresso extraction process

Espresso is a popular pressurized percolation coffee brewing that originated during the 19th-century Italian Industrial Revolution. The discovery of the concept of extracting coffee under high pressure in less than 30 seconds while considerably increasing the quality brought coffee consumption to quite another level. The conclusion of multiple experiments was a set of outlined technical parameters for extracting a certified Italian Espresso carefully preserved by the Italian Espresso National Institute [4].

The manufacturers are considering the finest tuning of all the parameters described above, which should be considered during the expresso extraction in modern equipment, depending on the necessary class and the production productivity.

As mentioned in the introduction of the paper, the present study focuses on the super-automated category of coffee machines and provides a detailed description of these Electromechanical Systems (EMS).

### 2.2. Description of the electromechanical system in modern devices

Super-automated coffee machines are the most advanced and sophisticated. During the espresso extraction process, the machine's electromechanical system must perform several actions: grind the coffee beans to the required size, measure the right amount of coffee for a cup, pump water through the heating system into the preparation unit to raise the water temperature from about 10˚C to 95˚C, and dispense espresso and steam as needed. Considering all the steps the system must perform and the raw materials for brewing coffee, the system contains several subsystems operated by the control system. Figure 1 shows the diagram of such an EMS in which the control unit is performing the necessary steps of the production process through three subsystems [5-7]:

- **Grinding system**: The coffee beans are received in the grinder, which is tuned for a proper coffee fraction for the best performance of the present hydraulic subsystem. The dozing step follows the grinding process. The necessary amount of ground coffee is ground using one of the two well-known methods: time- and volume-based.

- **Hydraulic system:** During the grinding process, the hydraulic subsystem prepares for the extraction process, which will be performed as soon as the grinding is finished. The components of this system will vary depending on the type of unit. In this case, the system is based on instant heating boilers, which are the most efficient ones due to the amount of water that is heated. The system is designed to instantly heat the water as low as 10˚C to the operating temperature for the extraction. To produce hot water and steam for milk frothy, the number of instant boilers could be more significant than one and depends on the machine's performance.
- **Extraction system:** The final subprocess is the extraction itself. The coffee machine performs the extraction based on the brewing unit type of system. The central role played by the brewing unit is designed to perform all the expresso extraction steps done by a barista operating a professional, high-performance coffee maker. The ground coffee is moved into the extraction chamber, tampered with by the preset force, the espresso is extracted, and the processed coffee is thrown into the garbage.

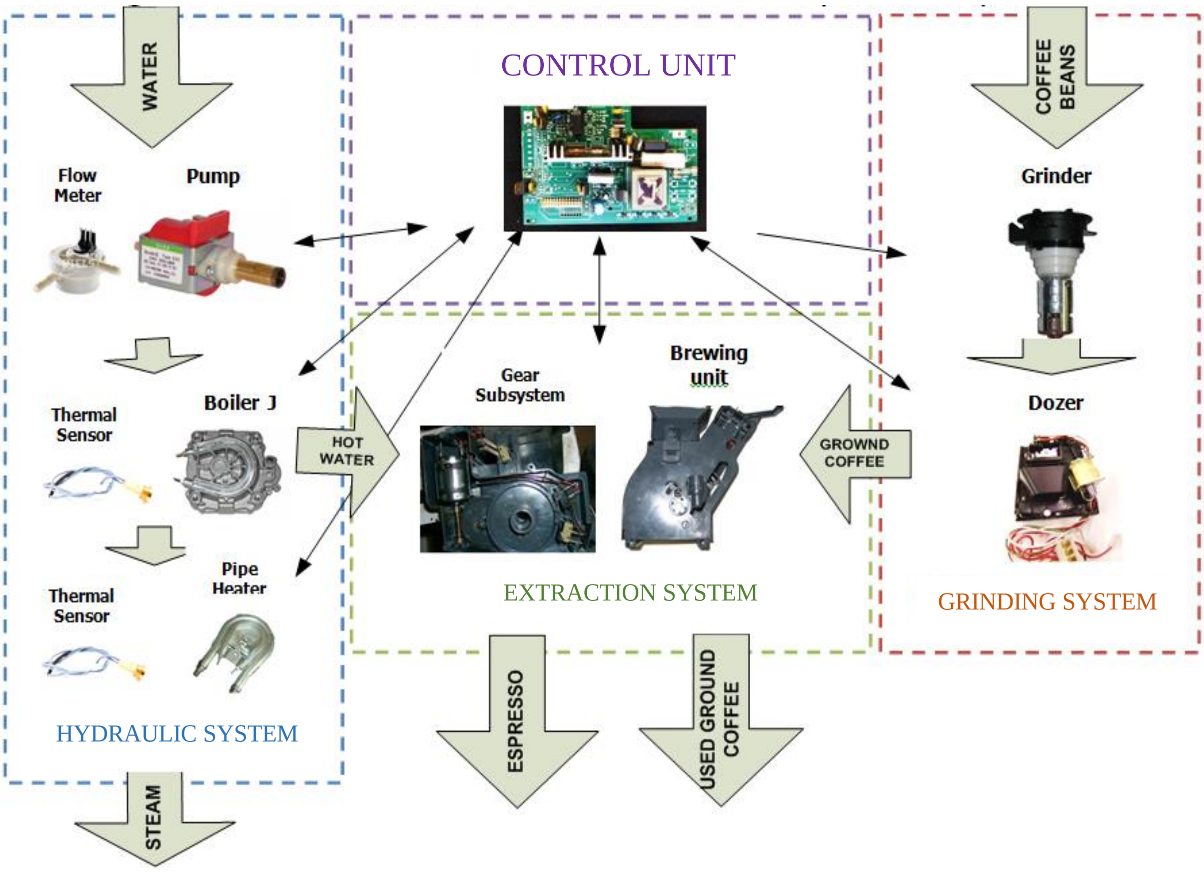



**Figure 1. Diagram of the super-automatic electromechanical system of the SAECO ROYAL series [7]**

An assessment is essential for understanding the energy usage of an electromechanical system. The analysis should cover the information that needs to be examined for this goal.

The energy consumption data collected in previous research revealed that about 99% of the total energy consumption belongs to the hydraulic system, with 97% for heating water and 2% for pumping it. This information will guide research to streamline the coffee extraction process and optimize the operation of the hydraulic system. An instant boiler with an inductive heating process will be designed and implemented to lower energy consumption and increase efficiency.[8]

## 3. Dimensioning of the inductive heater

### 3.1. Input data for the calculations

A set of internal data is needed to perform the necessary calculation, which is presented in Table 1 below.

*Table 1*

**Input data for calculations of the power required to heat water.**

| Parameter Value | Parameter Name |
|---|---|
| $\theta_i = 10^\circ C$ | - initial water temperature at the inlet to the heater |
| $\theta_f = 95^\circ C$ | - required temperature at the outlet of the heater |
| $\gamma_{ap} = 997 \frac{kg}{m^3}$ | - water density |
| $\gamma_{ot} = 7860 \frac{kg}{m^3}$ | - iron density |
| $c_{ap} = 4180 \frac{J}{kg \cdot K}$ | - thermal mass capacity (specific heat) of water |
| $c_{al} = 900 \frac{J}{kg \cdot K}$ | - capacitatea termică masică (căldura specifică) al aluminiului |
| $c_{ot} = 459.8 \frac{J}{kg \cdot K}$ | - capacitatea termică masică (căldura specifică) al fierului |
| $q_{ap} = 3.06 \cdot 10^{-6} \frac{m^3}{s}$ | - debitul apei necesar |
| $t_{h.ap} = 60 s$ | - timpul de încălzirea al volumului necesar de apă trecută prin încălzitor |

An important aspect to consider is the enthalpy and the total volume of steel required to ensure that.

### *3.2. The calculus of the inductive heating boiler [9-11]*

- The calculus for the power required to heat the water. Eq. (1)

$$P_{i.ap} = q_{ap} \cdot c_{ap} \cdot \gamma_{ap} \cdot \left(\theta_f - \theta_i\right) \tag{1}$$

- The dimensions of the workpiece (ferromagnetic lamb with water pipe in it) are determined and specified.
  - ***The surface temperature of the heating part is calculated***.
    For this calculation, the acuity of the thermal chain in a heat exchanger that has the following forms will be considered. The heat transfer process in the resistive heater in the SAECO boiler will be regarded as in the inductive heater calculations. Eq. (2)

$$\theta_{si} = \frac{P_{i.ao}}{m_{i.saeco} \cdot c_{al}} \cdot t_{h.ap} + \theta_i \tag{2}$$

  - ***The coefficient of convective heat transfer is calculated***.
    Considering the parameters of the SAECO ROYAL resistive heater and the material from which it is made (aluminum), the convective heat transfer coefficient will be determined geometrically based on its thermal transfer process. Eq. (3)

$$h_c = \frac{P_{i.r}}{\pi \cdot d_{c.ap.i.r} \cdot l_{c.ap.i.r} \cdot \left(\theta_f - \theta_i\right)} \quad (3)$$

Where: $l_{c.ap.i.r}$ - the length of the water channel in the resistive heater; $d_{c.ap.i.r}$ - diameter of water channel in resistive heater; $P_{i.r}$ - active power of the resistive heater.

- ***The mass of the workpiece of the inductive heater is calculated. Eq. (4)***

$$m_{i.i.ot} = \frac{P_{i.ap}}{\theta_{si} \cdot c_{ot}} \cdot t_{h.ap} \quad (4)$$

- ***The volume of steel required in the workpiece is calculated to ensure optimal conductions of heat transfer. Eq. (5)***

$$V_{n.ot} = \frac{m_{i.i.ot}}{\gamma_{ot}} \quad (5)$$

- ***The area of the required surface area of the water channel is calculated. Eq. (6)***

$$S_{c.ap.nec} = \frac{P_{i.ap}}{h_c \cdot \left(\theta_f - \theta_i\right)} \quad (6)$$

- ***The length of the water pipe to provide the required surface area is calculated. Eq. (7)***

$$L_{c.ap.calc} = \frac{S_{c.ap.nec}}{\pi \cdot d_{c.ap.i.i}} \quad (7)$$

Where: $d_{c.ap.i.i}$ - diameter of the water channel of the inductive heater.

The calculation steps described in the table above resulted in the necessary dimensions of the water channel, and the shape and form of the workpiece and the inductor were calculated according to the parameters shown in the figure below.

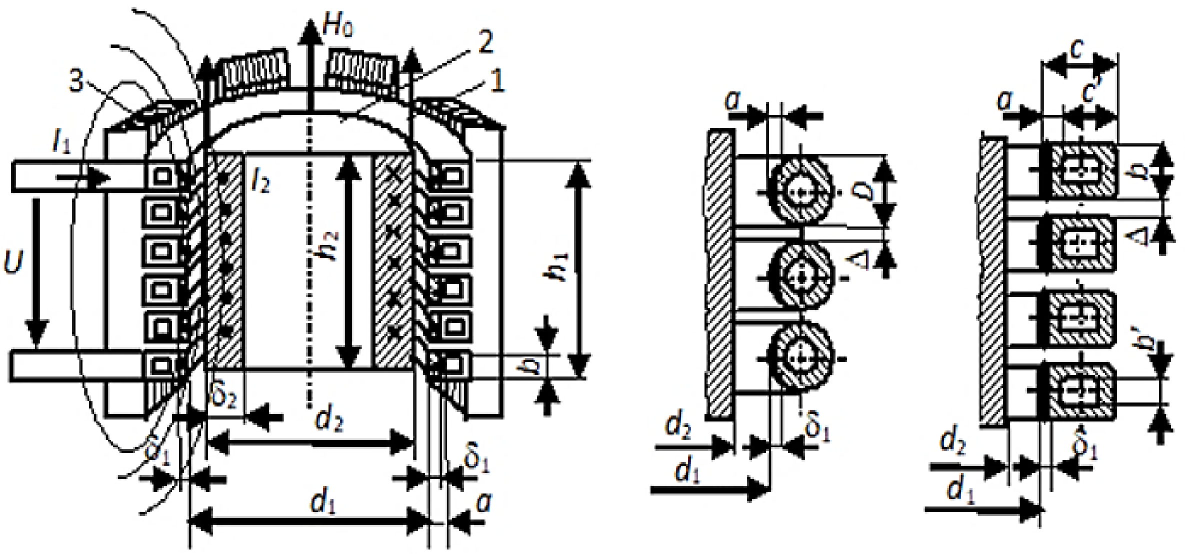
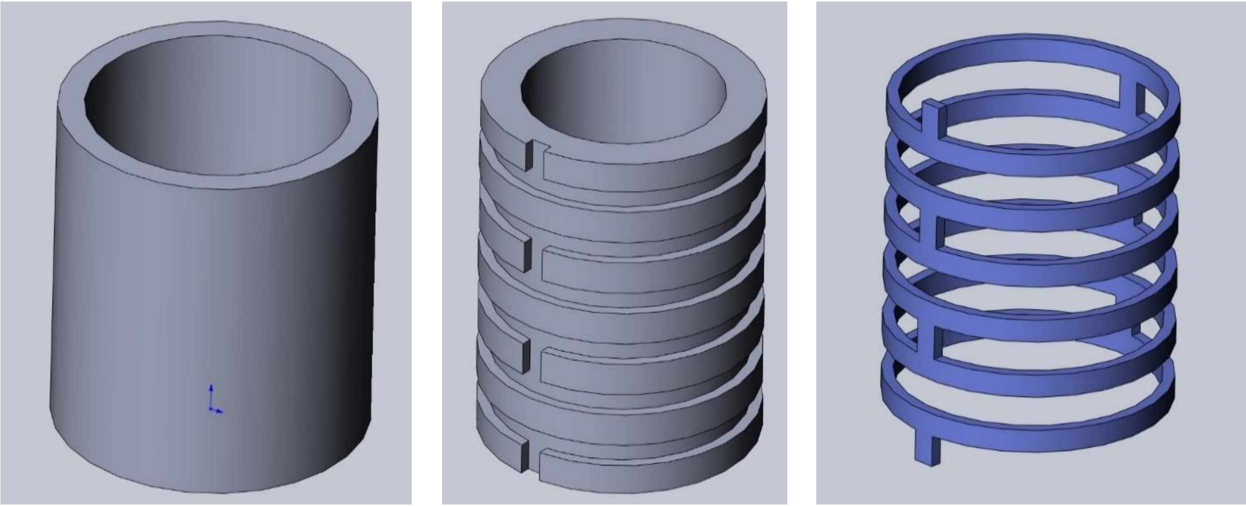



**Figure 2. The dimensions of the inductor and the workpiece [9]**

The sizing of the workpiece and water channel resulted in the workpiece being obtained and realized in SolidWorks, represented in Figure 3. It will be used for simulations in the 5$^{th}$ part of the study.



a) b) c)

**Figure 3. 3D representation of workpiece components at dimensioned inductive heater made in SolidWorks: a) outer cylinder; b) inner cylinder; c) the shape of the obtained water channel. (Developed by the author).**

- *The calculus of the electric parameters of the inductor and the workpiece.*

  Considering the dimensions of the workpiece shown in Figure 4 below, i.e. the distance from the boundary with the fluid to the outer wall of the workpiece is 5 mm, select the operating frequency of the inductor at a value that will not allow the depth of penetration to exceed 0.5 mm.

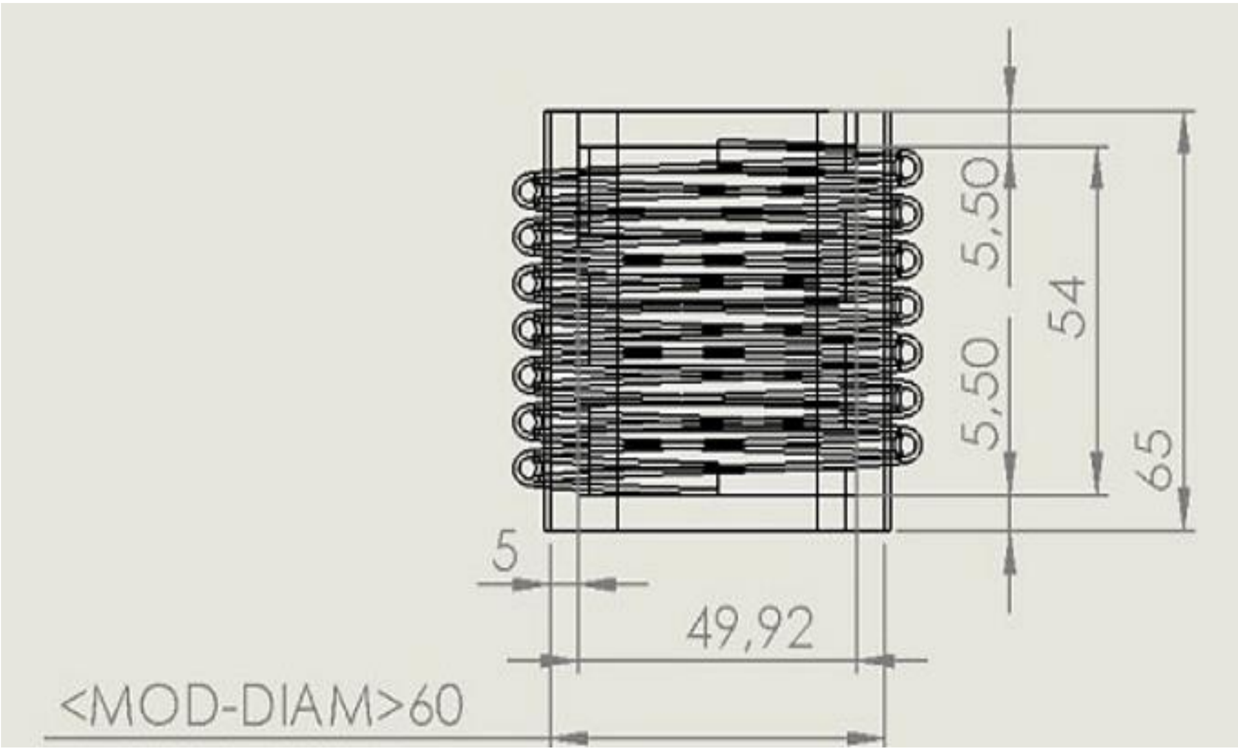



**Figure 4. View of inductive heater made in SolidWorks.**

**Figure 5** shows the calculation and construction of the characteristic δ(f) for the inductor and the workpiece.

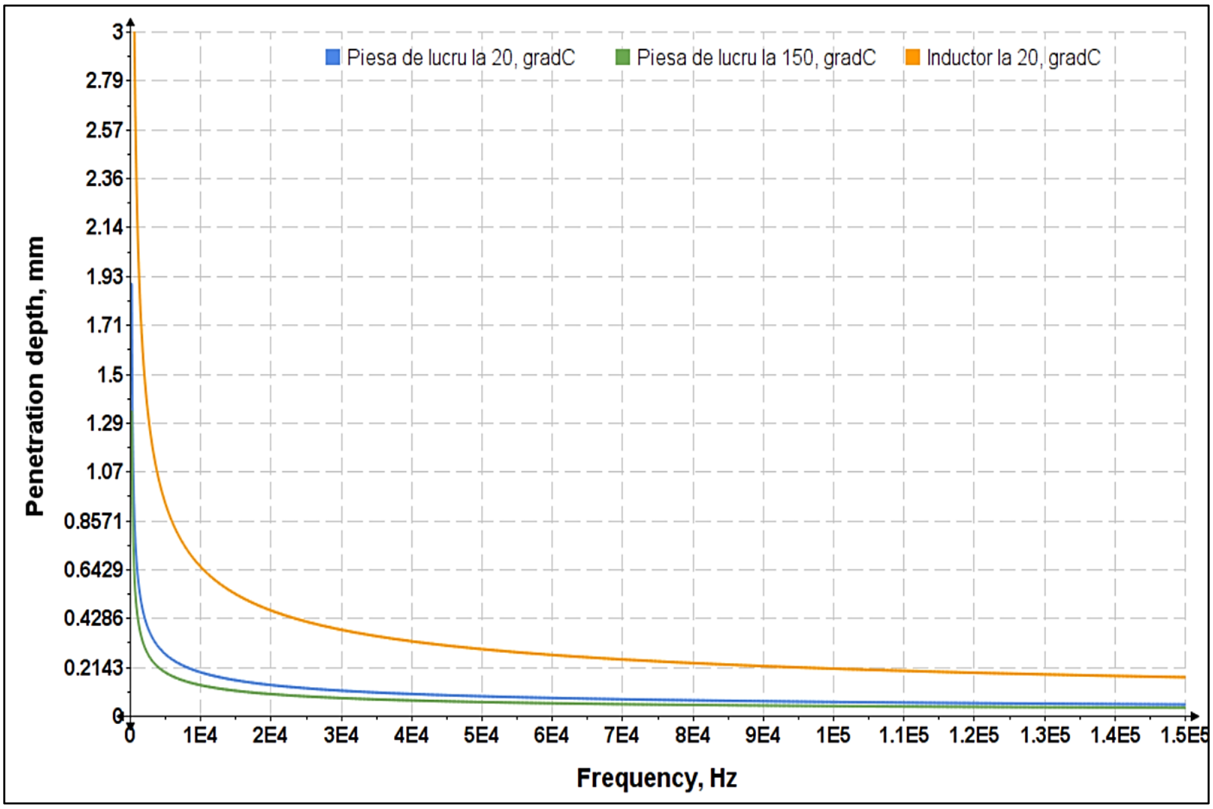



**Figure 5. Dependence of penetration depth on the inductor supply frequency**

- ***The penetration depth in the inductor at 20°C. Eq. (8)***

$$\delta_{1.20C}(f)=\sqrt{\frac{2\cdot\rho_{cup.20C}}{2\cdot\pi\cdot f\cdot f_0\cdot\mu_{cup}}} \tag{8}$$

- ***The penetration depth in the workpiece at 20°C. Eq. (9)***

$$\delta_{2.20C}(f)=\sqrt{\frac{2\cdot\rho_{ot.20C}}{2\cdot\pi\cdot f\cdot f_0\cdot\mu_{\mathrm{ot}}}} \tag{9}$$

- ***The penetration depth in the workpiece at 150°C. Eq. (10)***

$$\delta_{2.150C}(f)=\sqrt{\frac{2\cdot\rho_{ot.150C}}{2\cdot\pi\cdot f\cdot f_0\cdot\mu_{ot}}} \tag{10}$$

- ***We determine the thickness of the spiral wall according to the following recommendations a=(1.2, ... 2). Eq. (11)***

For the heater's operation, components F (corresponding to active power) and G (corresponding to reactive power) of the total energy absorbed at the body's surface shall be equal, and ε=a/δ shall be less than or equal to 1,57. The lower ε, the more efficient the power transfer will be. Penetration is minimal for ε=1.57

$$a_1=1.57\cdot\delta_1 \tag{11}$$

- ***The parameters of the inductor are calculated.***

To determine the inductor parameters, the number of turns (N) is determined. Then, the parameters for a single turn are selected, considering the turns linked in parallel. The internal resistance and reactance of the single-turn inductor can be calculated with Eq. (12) using the given relationship, with a filling factor of gu=0.8.

$$R_{1.1} = \rho_{cup.20C} \cdot \frac{\pi \cdot d_1}{h_1 \cdot \delta_1 \cdot g_u}; X_{1.1} = R_{1.1} \tag{12}$$

- ***The related resistance and reactance of the load, if we have Kr2=Kx2=1 and the number of turns N=N0=1, can be calculated with the formulas in Eq. (13)***

$$\begin{gathered} R_2' = N_0^2 \cdot \rho_{ot.20C} \cdot \frac{\pi \cdot d_2}{h_2 \cdot \delta_2} \cdot K_{r2}; X_2' = R' \\ R_2 = \rho_{ot.20C} \cdot \frac{\pi \cdot d_2}{h_2 \cdot \delta_2} \cdot K_{r2} \end{gathered} \tag{13}$$

- ***Air reactance can be calculated with the formulas in Eq. (14).***

$$\begin{gathered} X_{II} = \frac{2 \cdot f_{ind} \cdot \mu_0 \cdot \left( \frac{\pi \cdot d_1^2}{4 \cdot h_1} \cdot \alpha_1 - \varsigma \cdot \frac{\pi \cdot d_2^2}{4 \cdot h_2} \cdot \alpha_2 \right) + X_{1.1}}{p^2} \\ unde: \varsigma = \left( \frac{\alpha_m}{\alpha_1} \right)^2 = 0.94; p = \varsigma = 0.94; \mu_0 = 4 \cdot 10^{-7} \frac{H}{m} \end{gathered} \tag{14}$$

- ***Parameters of the inductor system are determined with Eq. (15)***

$$R_1 = R_{1.1} + \varsigma \cdot R_2; X_1 = X_{1.1} + \varsigma \cdot \left( X_2 - X_{II} \right) \tag{15}$$

➢ *Determination of the power absorbed by the inductor.*

The necessary calculations a presented in Table 6 below

- ***Determination of inductor electrical efficiency with Eq. (16)***

$$\eta_e = \frac{\varsigma \cdot R_2}{R_1} \tag{16}$$

- ***Determination of inductor power factor with Eq. (17)***

$$\cos \varphi = \frac{R_1}{\sqrt{R_1^2 + X_1^2}} \tag{17}$$

- ***Calculating power converted into heat for heating the workpiece with Eq. (18).***

$$P_{2.ot} = \frac{m_{ot} \cdot c_{p.ot} \cdot 100K}{\eta_t} \tag{18}$$

- ***Determining active power absorbed from the network without reactive power compensation with Eq. (19).***

$$P_{in} = \frac{P_2 + P_{2.ot}}{\eta_e} \tag{19}$$

- ***Determination of the apparent power of the inductive heater with Eq. (20).***

$$S_{in} = \frac{P_{in}}{\cos \varphi} \tag{20}$$

- ***Determination of inductor's required salination value with Eq. (21)***

$$NI_1 = \sqrt{\frac{P_{in}}{R_1 \cdot \eta_e}} \tag{21}$$

- ***Determination of inductor supply voltage with Eq. (22)***

$$U_{in} = N_i \cdot \frac{S_{in}}{NI_1} \tag{22}$$

- ***Determination of the inductive heater supply current with Eq. (23)***

$$I_1 = \frac{NI_1}{N_i} = 177.39\left[A\right] \tag{23}$$

As a result of the dimensioning, the inductive heater (figure 6) containing the inductor (8) was obtained, which consists of 7 turns made of a copper tube, parameters of which are dimensioned to travel the current of over 178 A with a frequency of about 100 kHz. The inductor is wrapped around the workpiece, which consists of two pieces in the form of tubular rings made of represented ferromagnetic material: outer cylinder (5) and inner cylinder (7)

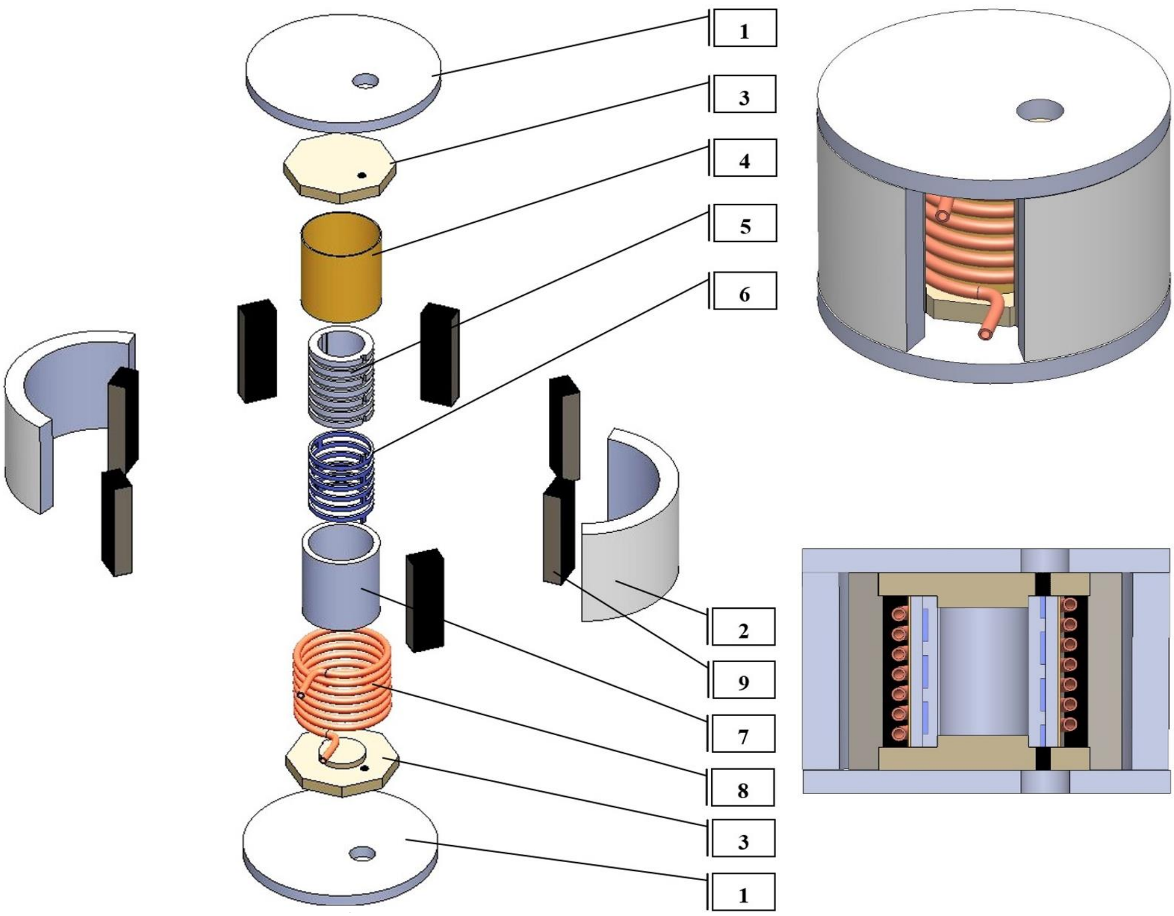



**Figure 6. The final representation of the inductive heater with all parts included [13].** ***1,2*-thermal protection elements; *3*-side positioning shields; *4*-insulator; *5*-outer cylinder; *6*-the profile of the water channel; *7*-inner cylinder; *8*-inductor; *9*-sheets of electrical steel**

On the outside of the inner tubular ring, cuts of such shape and length are made so that when assembling these tubular rings, a channel is obtained for the passage of the fluid to be heated. The shape of the channel obtained in the figure is represented by Figure 6. To ensure much higher flow rates and temperatures of the heated fluid than those dimensioned, both in the hot water generation regime of about 90℃ and the steam generation regime of 120℃, the inductor can be forcibly cooled by pumping a caloportor agent inside the copper tube, thus ensuring the stability of the heater. To avoid short circuits, the inductor is isolated from the workpiece using an insulator (4) with high thermal resistance, and its turns are removed from each other. To reduce magnetic field losses outside the inductor, sheets of electrical steel (9) are added and kept spaced away from the inductor utilizing side shields (3). These shields position both the sheets of the magnetic circuit and the working core. To decrease heat losses in the environment, the inductive heater is also provided with thermal protection made by thermal protection elements (1) and (2) of the heater made of a material with high thermal resistance and low thermal conductivity coefficient. [15]

### 4. Simulations of the inductive heater in MatLab Simscape

The results that have been obtained need to be simulated, and for that purpose, the MatLab Simscape library is being considered. The simulations will determine if the designed inductive boiler meets the necessary characteristics, the most important of which is the preheating time. To maximize the efficiency of the new boiler, it is essential to get the preheating time to be less than 8 seconds. Such a short time would make the preheating time so insignificant that the coffee machine would have enough time to get the hydraulic system ready for work within the grinding and dozing phases of the production process. [14-16]

Figure 7 presents the simulation diagram constructed in MatLab Simscape.

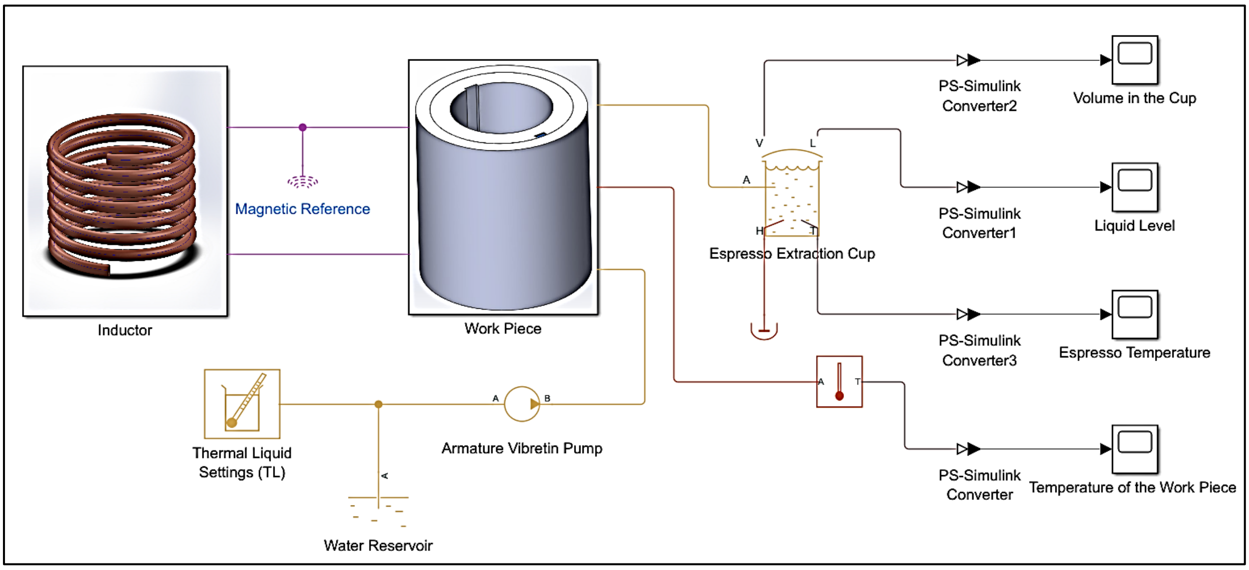
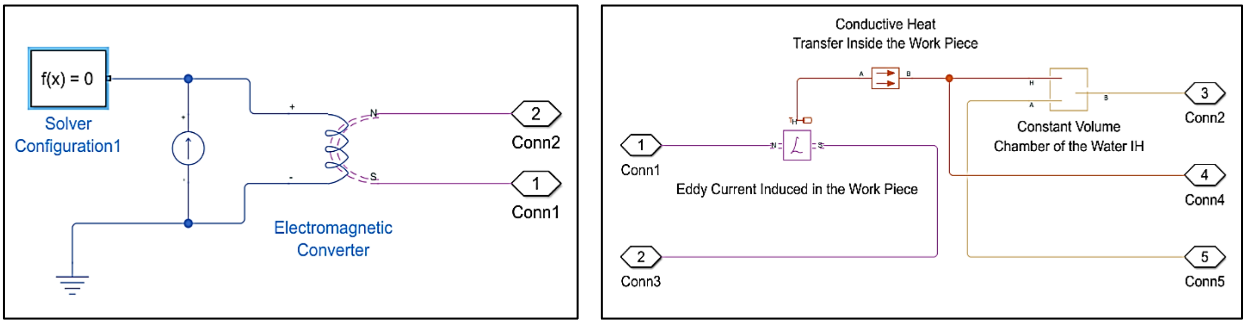



**Figure 7. The simulation diagram of the inductive heating boiler (Developed by the author)**

The simulation diagram contains two subsystems: one is the inductor modeling subsystem, and the other is the workpiece modeling subsystem. These subsystems relate to each other using the magnetic field (Figure 8 a, b). The same diagram has a thermal liquid settings block that is used to specify the water properties in various thermal conditions, the water reservoir for modeling the water source that is pushed through the hydraulic system by the armature vibrating pump. The pump forces the water through the workpiece of the induction heating boiler, and the boiler's output relates to a block that simulates the espresso extraction cup. This block has several ports beside port A for the hydraulic connection. Some of the ports are the V port – which is for measuring the volume of the water in the cup; the L port - which is for measuring the level of the liquid in the cup; and the T port - which is for measuring the temperature of the liquid in the cup. The H port in this diagram simulates the heat losses from that container.




a) b)

**Figure 8. The MatLab Simscape model subsystems: a) inductor module; b) workpiece module.**

Figure 9a shows the diagram for simulating the inductor module. It includes a current source block where the operating current and frequency are specified. The inductor block has all the necessary settings for correct operation. The workpiece diagram, presented in Figure 9b, consists of three blocks.

The "Eddy Current Induced in the Workpiece" block models the induced current that generates heat based on the workpiece's set parameters. The "Conductive Heat Transfer Inside the Workpiece" block simulates the process of conductive heat transfer, with parameters set for the layer. The inductor is designed to induce a current field in a minimal depth to achieve a high current density, resulting in a preheating time of under 8 seconds. Heat transfer from the induced current layer to the water takes some time. The "Constant Volume Chamber of the Water" block represents the water in the inductive heating boiler. Figure 10 below presents the simulation results with the inductor current set to 177 A and the frequency set to 100 kHz.

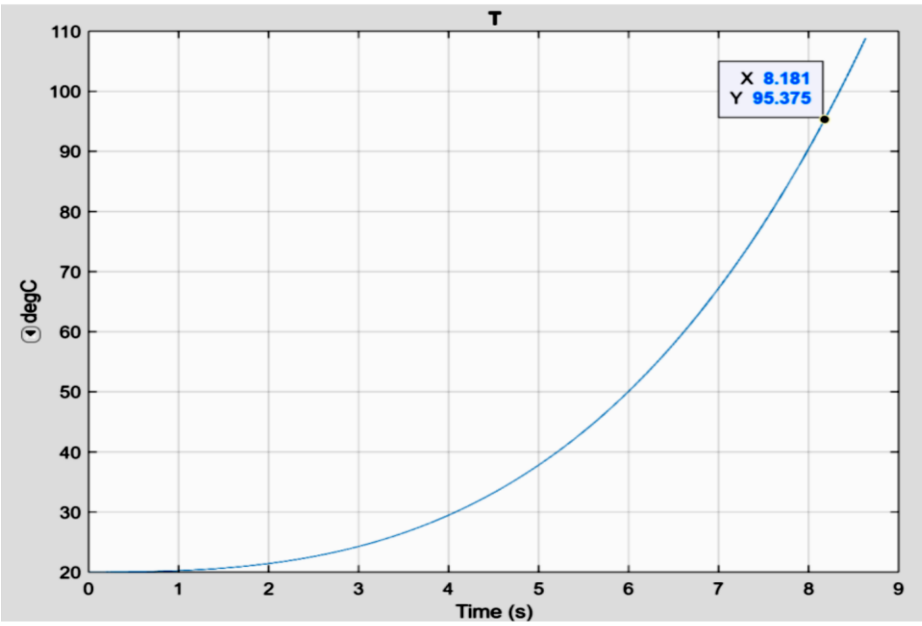



**Figure 9.The evolution of the temperature in the inductive heating boiler workpiece with inductor parameters at 177 A and 100 kHz**

It becomes evident that the set of parameters with the current at 177 A and the frequency at 100 kHz gets to the necessary temperature level in 8.3 seconds. The preheating time has to be shortened, and to do that, the following simulation will be performed with the current at 200 A, and the frequency remains constant. The results of that simulation are represented in Figure 10 below.

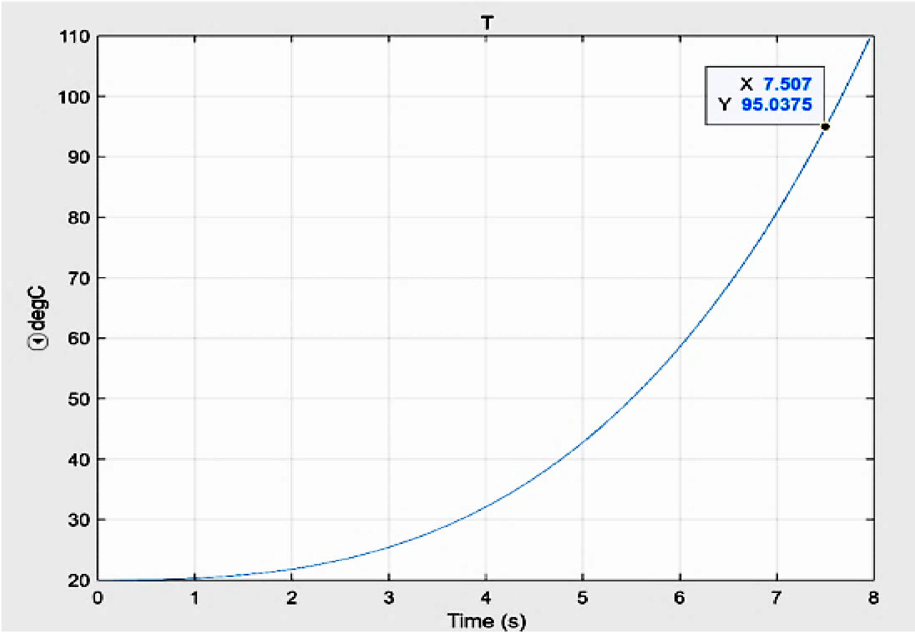



**Figure 10. The evolution of the temperature in the inductive heating boiler workpiece with inductor parameters at 200A and 100kHz**

This time, the necessary time was achieved, and the preheating process was finished in 7.5 seconds with the water temperature as high as 95˚C.

## 5. Discussion regarding the results

To carry out the analysis of the impact of innovations on the performance parameters of the coffee machine, the research will be divided into two parts as follows:

- *Determination of energy losses in the operation of resistive boilers* – At this stage, the consumption and energy losses in the operation of the resistive heater will be analyzed, and all phases of the operation process of such boilers will be considered. These include pre-heating, extraction process, and keeping the boiler at an optimal temperature during the waiting period for the next extraction step;
- *Comparative analysis of energy consumption between resistive and inductive heaters – here,* the performance of the two types of boilers will be compared, given the different times of thermodynamic processes, which are motivated by various physical processes, on which the operation of the respective types of boilers is based.

### 5.1. Determination of energy losses in the operation of resistive boilers

The determination of energy losses in the operation of the resistive heater will be carried out by numerical research, and the energy consumption used to pre-heat the respective boiler will be analyzed. For this, SAECO's resistive boiler will be considered. The required active power calculated for the preheating process of this boiler, having as input quantities the mass of the boiler, the mass thermal capacity of the boiler material, the temperature gradient of that process at which the active power required to heat the water inside the boiler during preheating will be gathered. The Eq. (24) determines the active power to pre-heat the resistive boiler.

$$P_{i.ap.al} = \frac{m_{ap.iboiler} \cdot c_{ap} \cdot \left(\theta_f - \theta_i\right)}{90\ s} + \frac{c_{al} \cdot m_{i.saeco} \cdot \left(\theta_f - \theta_i\right)}{90\ s} \tag{24}$$

The energy losses in the operation of the resistive heater are determined with Eq. (25)

$$P_{losses} = \frac{P_{i.ap.al}}{P_n} \cdot 100 - 100 = -28.63\% \qquad (25)$$

As can be seen from the above calculations, the resistive heater consumes about 29% more power than is required for the components subjected to heating, which proves that even during the lifetime of a boiler of this type, the energy consumption will be even higher.

### 5.2. Comparative analysis of energy consumption between resistive and inductive heaters

To capitalize on the impact of innovations on the performance parameters of the coffee machine, namely, to analyze the energy consumption in the operation process of the inductive boiler and compare it with the resistive boiler, a production process of a street trade point with an 8-hour work schedule and average productivity of 100 servings of coffee bean drinks will be analyzed. Considering that the basis of all coffee bean drinks is the portion of coffee with espresso extraction and to simplify the calculation process, these portions of drinks produced during a work day mentioned above will be equated to 100 servings of espresso.

**Table 2** provides input data for the performance analysis of the boilers concerned.

*Table 2*

**Datele de intrare pentru analiza performanțelor boilerelor comparate**

| Valoarea parametrului | Explicativa paramentului |
|---|---|
| $N_{p.zi.} = 100[\,portii\,]$ | - Numărul de porții produse pe durata unei zile de lucru |
| $D_{zi} = 8[h]$ | - Durata zilei de lucru |
| $P_{ir} = 1090[W]$ | - Puterea consumată de încălzitorul rezistiv |
| $P_{ii.i} = 1900[W]$ | - Puterea consumată de încălzitorul inductiv în procesul încălzirii |
| $P_{ii.ex} = 740[W]$ | - Puterea consumată de încălzitorul inductiv în procesul de extracție |

- ***The calculation of the total time of the extraction cycle by considering and evenly distributing the rest time on all extractions with Eq. (26)***

$$\begin{aligned} & if: \\ & N_{p.houe} = \frac{N_{p.day}}{D_{day}} \approx 12\left[{}^{extr}\!/_{h}\right] \\ & then: \\ & T_{c.pc} = \frac{3600}{N_{p.hour}} = 300[\sec] \end{aligned} \qquad (26)$$

- ***Calculation of the power consumption of the appliance in which the resistive heater is used***

**Figure 11** below shows the histogram of the distribution of the total energy consumption of the resistive heater for an extraction process, including pause.

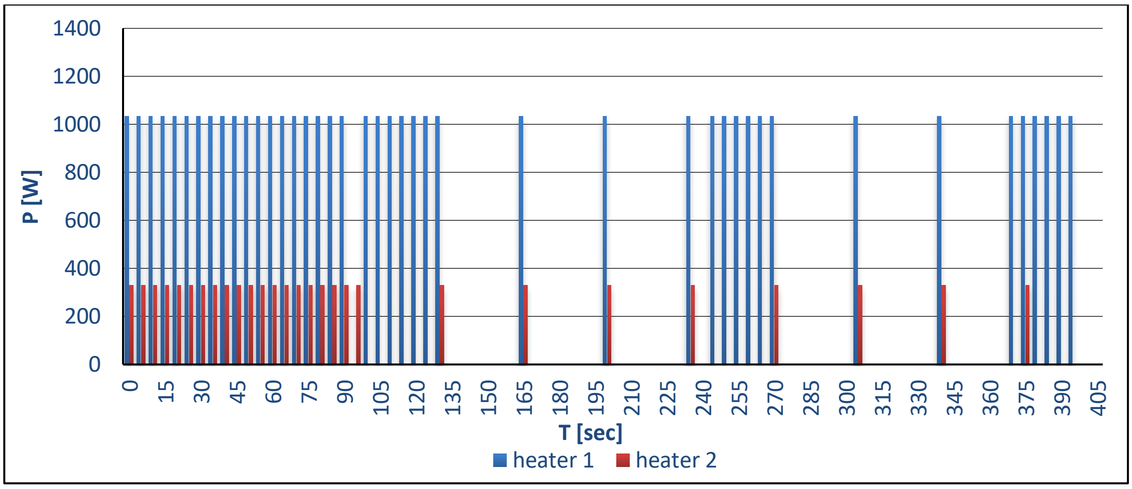



**Figure 11. Histogram of the distribution of the total energy consumption of the resistive heater for an extraction process, including pause [elaborated by the author]**

As can be seen from the histogram built on the experimentally collected database, in the first 90 seconds, the boiler preheats, after which the first extraction process takes place. During the break, the boiler must maintain its temperature; for these reasons, it needs to be periodically replenished. It was noted that in a time of 300 seconds, such connections were 8 in number.

- ***Calculation of total energy consumption for an extraction process, including pause, is done with Eq. (27)***

$$W_{day.ir} = \frac{\left(P_{preinc.ir} + P_{extr.ir} + 8 \cdot P_{ment.ir}\right) \cdot D_{zi} \cdot N_{p.hour}}{1000} \tag{27}$$

- ***Calculation of the cost of electricity consumed in a month using the resistive heater, and the electricity price is calculated with Eq. (28).***

$$E_{month.ir} = W_{day.ir} \cdot p_{ee} \cdot 31[days] \tag{28}$$

- ***Calculation of the energy consumption of the appliance in which the inductive heater is used.***

**Figure 12** shows the histogram of the distribution of total energy consumption when operating the coffee maker using the inductive heater.

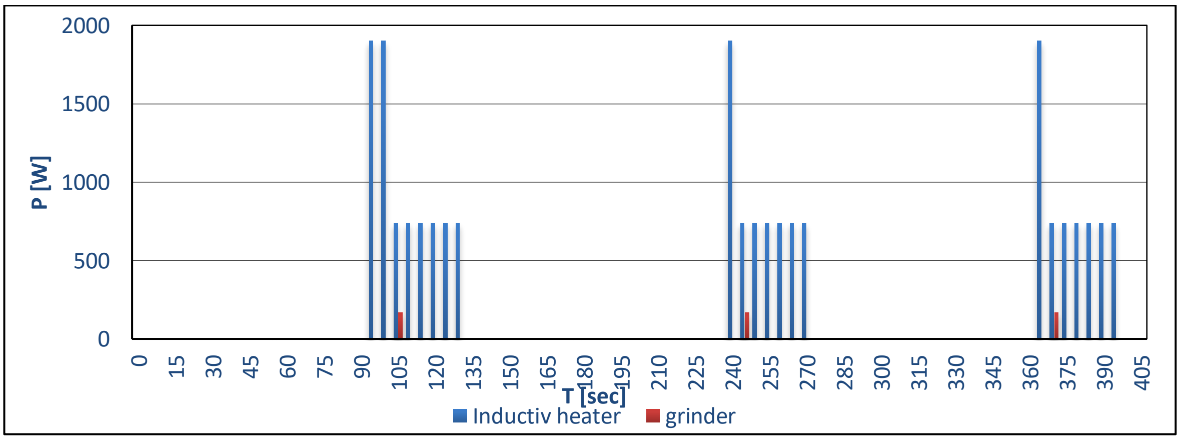



**Figure 12. Histograma distribuției consumului de energie al încălzitorului inductiv pentru un proces de extracție inclusiv pauza [elaborat de autor]**

As can be seen from the histogram built on the collected database, the preheating process of the inductive boiler takes only 8 sec with a consumption of 1900 W, and extraction requires a consumption of 740 W for 28 sec. Due to the performance of the inductive boiler, during the break, it is not necessary to maintain the temperature of the boiler, and its thermal protection gives us the possibility to reduce the time of returning the boiler to the optimum temperature at the next extraction by heating it only for 2 seconds instead of 7.5.

- ***Calculation of energy consumption for an extraction process including pause using inductive boiler is done with Eq. (29).***

$$W_{day.ii} = \frac{\left(P_{preheat.ii} + P_{extr.ii} + P_{re-heating.ii}\right) \cdot D_{zi} \cdot N_{p.hour}}{1000} \tag{29}$$

- ***Calculation of the cost of electricity consumed in a month using the inductive heater is done with the Eq. (30)***

$$E_{month.ii} = W_{day.ii} \cdot p_{ee} \cdot 31\left[days\right] \tag{30}$$

- ***Comparison of electricity consumption between the two types of heaters is calculated with Eq. (31).***

$$E_{-\%month} = \frac{E_{month.ii}}{E_{month.ir}} \cdot 100 - 100\% = -55.48\% \tag{31}$$

The implementation of the inductive heater at the selling points of itinerant trade with coffee drinks will increase energy efficiency by over 55% and this number will vary with respect to the change of workload.

## Conclusions

- ✓ The hydraulic systems of general-purpose installations, such as coffee machines, account for up to 97% of energy consumption in heat transfer processes in solids and liquids.
- ✓ The design methodology of the inductive instant boiler was presented.
- ✓ The simulation model was created in MatLab Simscape, which was used for parameter verification.
- ✓ The innovative inductive heating boiler reaches the operating temperature in 7.5$^{th}$ seconds.
- ✓ The optimal operating parameters of the heater are 200 A of current and a frequency of 100 kHz.
- ✓ The developed inductive heater increases the efficiency of coffee machines by about 29%, at the same time, their use in trade with coffee bean beverages as a finished product considering the schedule of a working day and the time required for the process of pre-heating and maintaining the appliance at the working parameters of the boiler (working temperature of the boiler) eliminated ensures an increase in efficiency of over 55%.

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