EVALUATING TEMPERATURE UNIFORMITY IN PASTEURIZATION: CFD AND EXPERIMENTAL APPROACH FOR VISCOUS FLUIDS

Natalya Lysova[1], Federico Solari[1], Leonardo Restori[1] and Roberto Montanari[1]

[1]Department of Engineering for Industrial Systems and Technologies, University of Parma, e-mail: natalya.lysova@unipr.it

KEYWORDS

Computational Fluid Dynamics, viscous products, heat exchanger, virtual sensor, experimental validation, industrial process optimization.

ABSTRACT

Ensuring uniform temperature distribution during thermal treatments is crucial for food safety and quality, particularly in the case of high-viscosity products. This study investigates temperature uniformity in a tube-in-tube heat exchanger using a combined Computational Fluid Dynamics (CFD) and experimental approach. CFD provides detailed thermal profiles, while the experimental tests carried out using concentrated orange juice (40 Brix) allow to validate the simulation results and confirm the presence of significant temperature variations across the pipe section. The results highlight the need for more precise thermal control strategies to mitigate risks of localized undertreatment or excessive heating, which can lead to food safety concerns or product degradation. A virtual sensor approach based on simulation results is proposed to this end. This solution would allow estimating internal temperature distributions based on external sensor data, acting as an essential tool for real-time process optimization that could be integrated into Digital Twin frameworks. This approach would enhance pasteurization efficiency, reduce fouling, and ensure consistent product quality. Future work will extend the investigation and application of simulation-based virtual sensors to this and other heat exchanger designs, to enhance and support the implementation of Digital Twin technologies for advanced control of food processes.

INTRODUCTION

Thermal treatment is a fundamental process in the food industry, playing a crucial role in ensuring microbial safety while preserving the organoleptic properties of food products throughout their shelf life. Pasteurization and sterilization are the primary thermal processing methods, both of which rely on either direct or indirect heat exchange technologies.

The heat exchanger should be selected to maximize energy efficiency based on the type of product to be treated. Direct exchangers are the most efficient, but they can only be used with low-viscosity products without suspended solids and when treatment temperatures exceed 140°C. For lower treatment temperatures (typically used with high-acid products), plate heat exchangers are used. When the viscosity of the product is high, or when there are many fibers or suspended solids, tubular exchangers are to be preferred. Among them, tube-in-tube exchangers represent the most flexible, cleanable, and simplest solution, even though less energy-efficient, allowing for reduced fouling risk compared to plate heat exchangers. However, significant issues may persist, mainly related to non-uniform heating, which may result in localized undertreatment or excessive heating, with the former leading to safety issues, and the latter to browning and product degradation.

Typically, two main approaches have been explored to address these issues: the introduction of mixing devices at the exit of the heat exchanger, and the adoption of alternative, also non-thermal, pasteurization techniques. The incorporation of static or mechanical mixers can enhance uniformity and heat distribution; however, this method presents limitations when suspended solids are present, as excessive mixing may compromise their structural integrity and sensory attributes. Additionally, in the case of highly viscous products, the presence of additional components increases fouling issues generating the need for frequent and labor-intensive cleaning procedures. In contrast, alternative non-conventional heat treatments, such as Ohmic Heating and High-Pressure Pasteurization, have been investigated for their potential to enhance thermal uniformity and process efficiency on such kind of products (Pereira et al., 2010; Roobab et al., 2018). Other emerging techniques, including Pulsed Electric Field (PEF) and Ultraviolet (UV) treatments, remain impractical for viscous fluids due to insufficient penetration depth, as well as limited energy efficiency and cost-effectiveness.

Despite ongoing advancements in alternative pasteurization methods, traditional heat exchangers remain widely utilized, particularly for highly viscous food products. Enhancing the performance of these systems is imperative to achieve an optimal balance between microbial safety and the preservation of organoleptic properties (Lysova et al., 2024; Perone et al., 2021; Jha et al., 2019), but also to improve energy efficiency as some studies underline (Pereira et al., 2010). Notably, temperature distribution at the outlet of shell-and-tube heat exchangers has received limited attention in existing studies, especially concerning heat-sensitive food products. The focus has been mainly on the study of the cold spots during the treatment (Jha et al., 2019), geometry (Kola et al., 2021), and process parameters (Lysova et al., 2022), but without paying particular attention to the temperature distribution of the product leaving the exchanger. A more comprehensive understanding of temperature gradients within these systems can facilitate improved thermal cycle management, thereby minimizing peak temperatures and optimizing treatment uniformity according to product viscosity. Furthermore, an in-depth analysis of fluid velocity profiles as a function of rheological properties could enable more precise control over the thermal treatment, leading to enhanced energy efficiency, reduced fouling, and improved product quality. Some studies in this area include (Perone et al., 2021; Jha et al., 2019; Kola et al., 2021; Tancredi et al., 2020).

Computational Fluid Dynamics (CFD) analysis can be an excellent way to simulate and investigate efficiency problems without carrying out many tests on physical plants. Indeed, the simulations provide a detailed picture of the temperature distribution within the system so sensors can be strategically placed in areas with significant temperature gradients, and simulation results could integrate sensor data to gain a complete understanding of the thermal profile (Jha et al., 2019). Indeed, using the results of CFD simulations and data collected from real sensors, virtual sensors can be created to estimate temperature in inaccessible locations where physical sensors cannot be installed (Guzmán et al., 2019; Tancredi et al., 2022) or, in the case of highly viscous fluids, where fouling could occur, and their cleaning would be impossible. As an example, by combining physical sensor data with CFD simulations, temperature information can be derived at critical points, such as the temperature at the center of the flow (Yolmeh et al., 2017; Han et al., 2015; Liu et al., 2021; Kola et al., 2021).

Results from CFD simulations provide an accurate description of thermo-fluid dynamics in pasteurization processes, but their high computational cost prevents their direct use in real-time control. To overcome this limitation, reduced-order models (ROM) can be developed using dimensionality reduction techniques or methods based on parametric interpolation. ROM preserves the essential features of the system by significantly reducing the number of equations to be solved, thus allowing fast predictions (Lysova et al., 2022). This simplified model can be integrated into predictive control strategies (MPC) to optimize real-time operating parameters such as flow, temperature, or pressure. In addition, also ROM, as well as simulation results, can act as a virtual sensor (Lysova et al., 2024) to estimate process variables that are difficult to measure directly, improving plant monitoring and efficiency. To summarize, virtual sensors could be used to estimate physical quantities of interest at specific points where physical sensors cannot be installed.

In the future, these insights could contribute to the development of cost-effective, high-precision process control solutions, seamlessly integrating with existing industrial setups through the implementation of Digital Twin technologies. Such advancements would enable real-time monitoring and adaptive control of processing parameters, thereby optimizing heat exchanger performance and ensuring superior product safety and quality.

MATERIALS AND METHODS

Experimental setup

The pilot-scale processing system comprises a stainless-steel tube-in-tube heat exchanger having a maximum processing capacity of 2,500 l/h. In particular, the product flows upwards through the inner tube while heating water circulates counter-currently within the outer shell. The inner tube has an internal diameter of 38 mm, thus allowing the treatment of highly viscous products, as well as formulations containing suspended particulates having a maximum size of up to 10 mm. The heat exchanger consists of six horizontally aligned heating modules, each approximately 4 meters in length, arranged in a vertically stacked configuration.

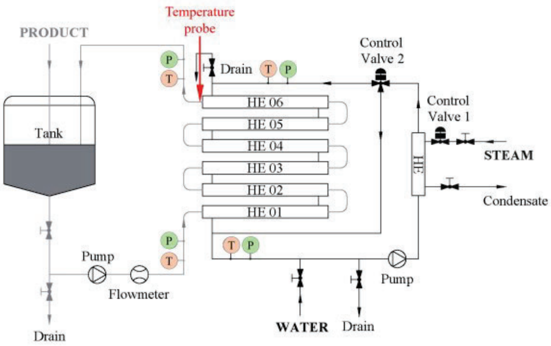

Figure 1: Schematic layout of the plant and position of the outlet temperature probe used

The inner pipes of successive modules are interconnected via 180° return bends, whereas the outer shell sections are linked through vertical flange couplings.

The heat exchanger is connected to a stainless-steel mixing tank where the product is continuously recirculated. The flow through the system is provided by a twin-screw volumetric pump having a maximum flow rate of 5 m^3/h. The flow rate is monitored using a mass flowmeter and can be adjusted by modulating the pump's operating frequency through an inverter.

Temperature and pressure measurements of both product and heating water are continuously monitored at the inlet and outlet sections of the heat exchanger. Temperature measurements are performed using resistance temperature detectors (T in Figure 1), whereas pressure is measured using flush diaphragm pressure transmitters (P). All the data acquired during experimental tests were recorded every 0.5 seconds with a LabView NI 9208 module.

Water temperature is adjusted via indirect steam heating in a dedicated heat exchanger, while the flow rates of both steam and water are regulated by two control valves (denoted as Control Valve 1 and Control Valve 2 in Figure 1). These valves can be adjusted both automatically, using a Proportional-Integral (PI) control system to maintain product and water temperatures near

predefined setpoints, or manually, by specifying a fixed valve opening percentage.
The facility is integrated with auxiliary subsystems supplying steam, electrical power, water, and compressed air to the various operational units. Process control is implemented via a Programmable Logic Controller (PLC), with parameter adjustments accessible through a Human-Machine Interface (HMI) on the control panel.

Product and rheology

The tests were carried out by using the tubular heat exchanger to heat orange juice. The circulated juice was obtained by diluting a concentrated product, initially stored in 20 L bag-in-box containers, from an initial concentration of 60 Brix degrees to 40 Brix. In particular, 100 L of juice at 60 Brix was diluted to 40 Brix by adding 50 L of water. Before beginning the experimental campaign, the two fluids were accurately mixed to ensure homogeneity. To reproduce the tests via simulation, and gain valuable insights about the experimental outcomes, the rheology of the fluid was characterized using a rotational Anton Paar MCR 102 rheometer at different shear rates ranging from 10 to 300 s^{-1}, capturing the significant shear rate ($\dot{\gamma}$) values usually encountered in pipe flow applications (Steffe, 1996). The obtained apparent viscosity (η) data were fitted with a power law model, to obtain the consistency (K) and behavior (n) indices characterizing the non-Newtonian behavior of the fluid according to the relation (Equation 1) described in Steffe (1996).
The analysis was performed at three temperatures, i.e., 298.15 K, 323.15 K, and 348.15 K, to capture the temperature-dependent behavior of the apparent viscosity. These tests were then used to calculate the value of the activation energy E_a of the Arrhenius equation, where η_α is the apparent viscosity at the reference temperature T_α=348.15 K, and R is the universal gas constant (Equation 2).
At T_α the following indices were obtained: K= 0.018 Pa s^n, n=0.6354. Since n<1, a non-Newtonian shear-thinning behavior emerges, as it is common in the case of food fluids and fruit juices. Moreover, the value of $\frac{E_a}{R}$ was calculated equal to 3898 K.

$$\eta = K\dot{\gamma}^{n-1} \qquad (1)$$

$$\frac{\eta}{\eta_\alpha} = \exp\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_\alpha}\right) \qquad (2)$$

Experimental campaign

The experimental procedure was designed to validate the temperature profile of the product at the outlet of the heat exchanger. To this end, the tank was filled with 150 L of fruit juice at 40 Brix, at an initial temperature of approximately 25°C. The heating water was brought to an initial temperature of 75°C, then the product circulation was activated. The product inlet and outlet temperature, as well as the water inlet temperature and the product flow rate, were continuously monitored throughout the entire product heating phase.
Regarding the product inlet and outlet temperature, two PT100 RTD sensors, having a measuring range between -50°C and 100°C were used. According to the technical characteristics of the sensor, the active part of the stem in temperature detection is 2 cm at the end of the probe. In light of this, to track the temperature profile of the product at the outlet of the heat exchanger, the temperature was measured at two different points by changing the position of the temperature probe. In the first position the 2 active centimeters of the stem were placed exactly at the center of the section (1 cm above the axis and 1 cm below the axis); in the second position they were placed at the bottom of the section (avoiding direct contact with the wall so as not to influence the measurement with metal temperature).
The test ended when the product temperature approximately reached the water temperature.
Some operating snapshots that occurred during the tests were then reproduced with fluid-dynamic simulations, and the results were compared in terms of the temperature profile of the product exiting the heat exchanger.

Simulation settings

The CFD simulations of the plant operation were carried out with ANSYS Fluent using the model presented and validated in Lysova et al. (2022). Specifically, the geometry reproduced half of the heat exchanger, exploiting its symmetry plane, and the mesh included 10 inflation layers, with a first layer thickness of 10^{-4} m, on each side of the heat exchange surface. Simulation settings are summarized in Table 1.
Regarding the definition of the treated product, the apparent viscosity was described using the results of the rheological characterization performed, while the physical properties were retrieved in the literature (ρ [kg/m^3] = 1336 – 0.5286·T (Garza and Ibarz, 2010); λ [W/m K]=0.1064 + 0.0012·T (Zhang et al., 2011); c_p=3114.4 [J/kg K] (Moresi and Spinosi, 1980)).
The simulated operating point was defined to reproduce a condition encountered during the experimental campaign, in order to validate the obtained results (product entering at 300.15 K and water at 333.15 K).
To evaluate the temperature profile calculated, and compare it with experimental data, the temperature was calculated across a vertical line, passing through the center of the pipe in the same position as the temperature probe in the real plant (Figure 2). To reproduce the readings of the probe in the central position, the average of the values of the central 2 cm of the pipe was calculated, while for the bottom section, the lower 2 cm was considered, starting 0.5 mm from the wall to reproduce the experimental set-up.

Table 1: Simulation settings

General settings	Solver	Pressure-based Steady-state
	Gravity	-9.81 m/s^2 in the y direction (see Figure 2)
	Turbulence model	k-ω SST
Boundary conditions	Product inlet	Velocity inlet 0.55 m/s 300.15 K
	Water inlet	Velocity inlet 1.3 m/s 333.15 K
	Product and water outlets	Pressure outlet
	Faces on the cutting plane	Symmetry condition
	Walls (all)	No-slip condition
	Interface between water and product	Coupled two-sided steel wall with 1.5 mm thickness

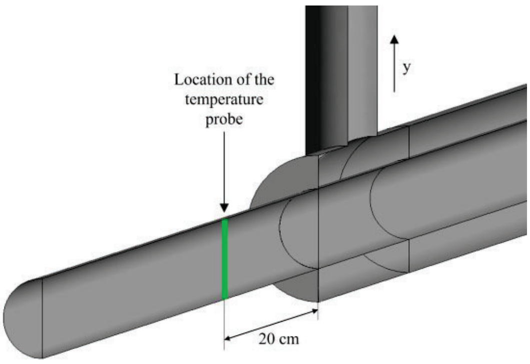

Figure 2: Line where the simulation results were evaluated, corresponding to the position of the temperature probe installed on the plant

RESULTS AND DISCUSSION

Figure 3 presents the temperature profile calculated across the line presented in Figure 2. As expected, it can be clearly seen how there is variability across the pipe section, with higher values near the pipe walls, and lower values in the pipe center where the heat is transmitted more slowly. This behavior is due to the high concentration of the product, and therefore higher apparent viscosity, as discussed in (Lysova et al., 2024). Moreover, the top section of the pipe presents higher temperatures compared to the bottom.

The simulation was run reproducing the conditions of the experimental campaign, in order to validate the obtained results and the hypotheses about the temperature profile of the viscous product. The comparison between the simulated (in green) and experimental (in black) results can be seen in Figure 4. The error in the values is 0.23 K for the bottom measurement and 0.21 K for the central measurement, equal to 1.31% and 1.22% of the measured temperature increase in that location, respectively. Apart from the considerations about the error, which may be linked to the definition of the product characteristics and the experimental measurements, it can be observed that the trend of the temperature differences between the two locations is confirmed. This highlights the necessity of deeply investigating the heating of viscous products, without relying on a single value measured by a sensor.

To this end, the simulation results were used to investigate the temperature profile in the final section of the heat exchanger (Figures 5 and 6). In the sections where the product is still in indirect contact with the heating medium, the non-uniformity in the temperature appears particularly pronounced. Proceeding towards the outlet, as the heating ceases, the differences decrease. The heat transfer and gradual changes of the temperature profile are shown through contour plots in Figure 5, and plotted more in detail in Figure 6, where the values calculated across the pipe section at several locations, starting from the end of the heating zone, are presented.

In Figure 6a it can be seen how the non-uniformity in the temperature is particularly relevant in the heating section (0 cm plot) and in the immediately adjacent locations (5 and 10 cm plots).

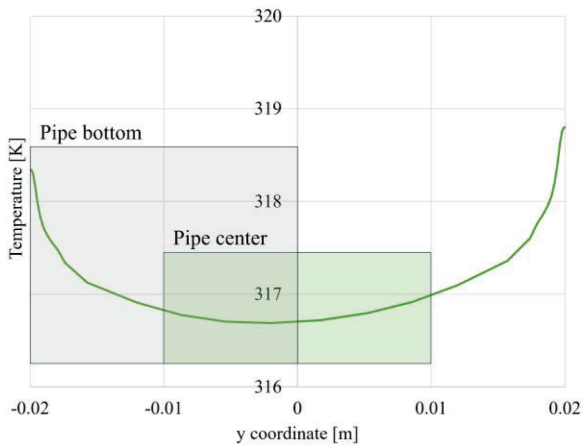

Figure 3: Temperature profile at the probe location. Highlighted in green are the data corresponding to the measurement in the pipe center, while in grey those related to the measurement of the bottom section.

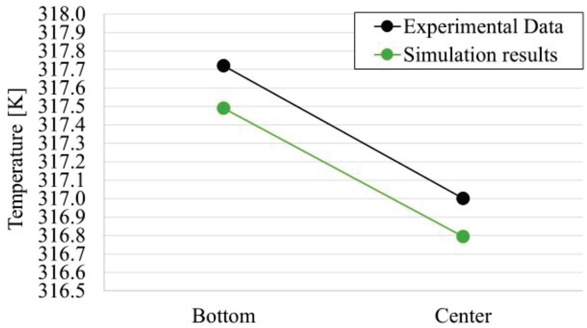

Figure 4: Comparison between the simulation results and the experimental measurements

On the other hand, the plot reported in Figure 6b shows the heat penetration from the near wall region towards the center of the pipe as the fluid moves away from the heating medium.
In particular, it is evident how the temperature in the center of the pipe increases while that in the near-wall region gradually decreases, reaching an almost uniform distribution after 0.5m.

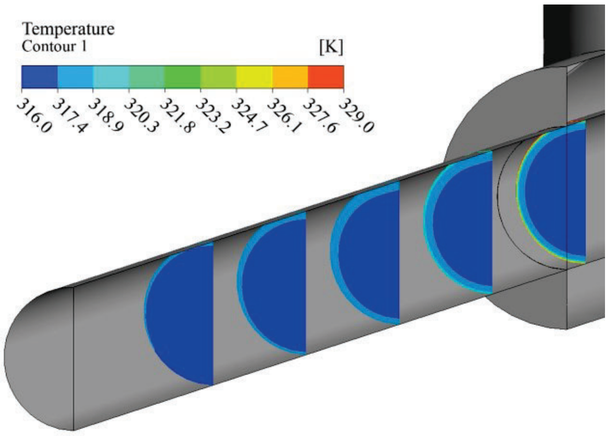

Figure 5: Contour of temperature calculated on 5 planes. The central plane is relative to the position of the probe, while those that precede and follow it are placed at a 5 cm distance between each other

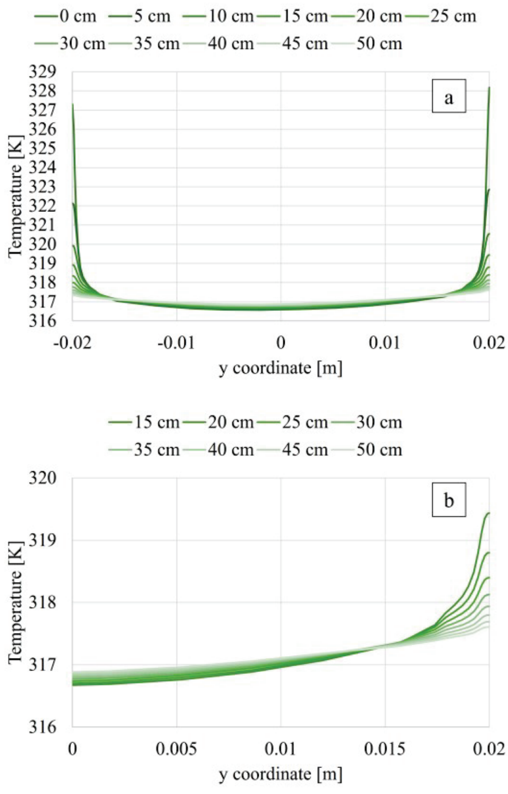

Figure 6: Temperature profiles at different distances from the end of the heating zone a) across the whole pipe section and b) across the upper half

CONCLUSIONS

During the thermal treatment of fluid foods, especially those characterized by high viscosity, and therefore by reduced convective motions, the temperature distribution within the product during, and immediately after the heat treatment, suffers a certain degree of non-uniformity. This phenomenon impacts the performance of the process, both in terms of minimum and maximum thermal treatment achieved. The former could result in food safety issues, while the latter in problems related to fouling or food degradation.
In the present work, the fluid dynamics simulation capability in predicting the temperature profile at the outlet section of a heat exchanger was investigated. The results were validated through experimental tests conducted on an industrial-scale tube-in-tube heat exchanger using concentrated orange juice at 40 Brix. Experimental and numerical results agreed in predicting temperature variations across pipe sections located in the proximity of the outlet of the heat exchanger (i.e. the temperature in the near-wall regions was consistently higher than the temperature at the center of the section). Simulation results demonstrate that this difference is even more pronounced inside the heat exchanger, where the product is in direct contact with the hot surfaces, which are heated by the heating medium.
These results suggest the potential for the development of simulation-based virtual sensors based on the data measured by the physical sensor installed at the exit of the heat exchanger and the operating conditions. These virtual sensors would allow the real-time estimation of the temperature at each point within the heat exchanger, even where the installation of physical sensors would be very impractical, if not impossible. Moreover, the insights obtained through dedicated simulation campaigns, combined with the development of virtual sensors, would allow for the process to be adjusted to avoid localized time-temperature combinations that could cause fouling and/or sensory and organoleptic product degradation at any point of the heat exchanger.
Future research activities will focus on the development, testing, and validation of virtual sensors based on simulation results and their integration in Digital Twins and advanced control frameworks of industrial plants. In particular, the sensors will be developed using statistical techniques to interpolate simulation data calculated across a significant operating range. Finally, to test and confirm broader applicability, the described methodology will be applied to different viscous fluids (e.g., tomato paste or dairy products) and different kinds of heat exchangers (e.g., concentric channel, shell and tube, and plate heat exchangers).

REFERENCES

Bottani, E., Vignali, G., & Carlo Tancredi, G. P. (2020). A digital twin model of a pasteurization system for food beverages: tools and architecture. *2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, 1–8. https://doi.org/10.1109/ice/itmc49519.2020.9198625

Garza, S., & Ibarz, A. (2010). Effect of Temperature and Concentration on the Density of Clarified Pineapple Juice. *International Journal of Food Properties*, 13(4), 913–920. https://doi.org/10.1080/10942910902919596

Guzmán, C. H., Carrera, J. L., Durán, H. A., Berumen, J., Ortiz, A. A., Guirette, O. A., Arroyo, A., Brizuela, J. A., Gómez, F., Blanco, A., Azcaray, H. R., & Hernández, M. (2018). Implementation of Virtual Sensors for Monitoring Temperature in Greenhouses Using CFD and Control. *Sensors*, 19(1), 60. https://doi.org/10.3390/s19010060

Han, H.-Z., Li, B.-X., Wu, H., & Shao, W. (2015). Multi-objective shape optimization of double pipe heat exchanger with inner corrugated tube using RSM method. *International Journal of Thermal Sciences*, 90, 173–186. https://doi.org/10.1016/j.ijthermalsci.2014.12.010

Jha, A., Moses, J. A., & Anandharamakrishnan, C. (2019). Optimizing Beverage Pasteurization Using Computational Fluid Dynamics. Preservatives and Preservation *Approaches in Beverages*, 237–271. https://doi.org/10.1016/b978-0-12-816685-7.00008-2

Kola, P. V. K. V., Pisipaty, S. K., Mendu, S. S., & Ghosh, R. (2021). Optimization of performance parameters of a double pipe heat exchanger with cut twisted tapes using CFD and RSM. *Chemical Engineering and Processing - Process Intensification*, 163, 108362. https://doi.org/10.1016/j.cep.2021.108362

Liu, S., Huang, W., Bao, Z., Zeng, T., Qiao, M., & Meng, J. (2021). Analysis, prediction and multi-objective optimization of helically coiled tube-in-tube heat exchanger with double cooling source using RSM. *International Journal of Thermal Sciences*, 159, 106568. https://doi.org/10.1016/j.ijthermalsci.2020.106568

Lysova N, Solari F, Vignali G. Optimization of an indirect heating process for food fluids through the combined use of CFD and Response Surface Methodology. Food and Bioproducts Processing 2022;131:60–76. https://doi.org/10.1016/j.fbp.2021.10.010.

Lysova, N., Solari, F., Bocelli, M., Rizzi, A., & Montanari, R. (2024). Exploring the impact of the process parameters on the thermal treatment of viscous food fluids in a tube-in-tube heat exchanger. *Procedia Computer Science*, 232, 2347–2357. https://doi.org/10.1016/j.procs.2024.02.053

Moresi, M., Spinosi, M. (1980). Engineering factors in the production of concentrated fruit juices 1. Fluid physical properties of orange juices. *International Journal of Food Science & Technology*, 15(3), 265–276. Portico. https://doi.org/10.1111/j.1365-2621.1980.tb00939.x

Pereira, R. N., & Vicente, A. A. (2010). Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Research International*, 43(7), 1936–1943. https://doi.org/10.1016/j.foodres.2009.09.013

Perone, C., Romaniello, R., Leone, A., Catalano, P., & Tamborrino, A. (2021). CFD Analysis of a Tubular Heat Exchanger for the Conditioning of Olive Paste. *Applied Sciences*, 11(4), 1858. https://doi.org/10.3390/app11041858

Roobab, U., Aadil, R. M., Madni, G. M., & Bekhit, A. E. (2018). The Impact of Nonthermal Technologies on the Microbiological Quality of Juices: A Review. *Comprehensive Reviews in Food Science and Food Safety*, 17(2), 437–457. Portico. https://doi.org/10.1111/1541-4337.12336

Steffe, J.F., 1996. ch.1, Introduction to Rheology. Rheological Methods in Food Process Engineering. Freeman Press, pp. 1–91.

Tancredi, G. P. C., Vignali, G., & Bottani, E. (2022). Implementation of a remote control and system monitoring via a Digital Twin on an industrial pilot plant. *IFAC-PapersOnLine*, 55(10), 1128–1133. https://doi.org/10.1016/j.ifacol.2022.09.541

Yolmeh, M., & Jafari, S. M. (2017). Applications of Response Surface Methodology in the Food Industry Processes. *Food and Bioprocess Technology*, 10(3), 413–433. https://doi.org/10.1007/s11947-016-1855-2

Zhang, M., Zhao, H.-Z., Zhang, L.-J., Yang, L., Zhong, Z.-Y., & Chen, J.-H. (2011). Experimental Study on Thermal Conductivity of Orange Juice Using Probe System. *International Journal of Food Properties*, 14(1), 134–144. https://doi.org/10.1080/10942910903147965

AUTHOR BIOGRAPHIES

NATALYA LYSOVA is a Ph.D. Candidate in Industrial Engineering at the University of Parma, where she graduated in Engineering for the Food Industry in 2021. Her doctoral research project is titled "Virtualization approaches for industrial plants control and design". In her research activities, she aims to leverage numerical techniques for the analysis, design and optimization of industrial systems, plants, and devices. Her e-mail address is: natalya.lysova@unipr.it. ORCID: 0000-0001-6066-6398

FEDERICO SOLARI is a researcher and lecturer at the Department of Engineering for Industrial Systems and Technologies of the University of Parma since September 2021. He graduated (with distinction) in Mechanical Engineering for the Food Industry in 2008 and got his Ph.D. in Industrial Engineering in 2014, both at the University of Parma. He authored 57 publications indexed on Scopus. His main research topics are industrial plant logistics, industrial plant analysis and design, supply chain management, advanced industrial plant design also using simulative techniques. In his research activities, he explores the use of simulation and advanced numerical techniques for the design, control and maintenance of industrial plants and processes. His e-mail address is: federico.solari@unipr.it and his Web- page can be found at ttps://personale.unipr.it/it/ugovdocenti/person/102724.

ORCID: 0000-0001-8365-965X

LEONARDO RESTORI is a Master's student at the University of Parma. After a Bachelor's Degree in Mechanical Engineering, he is now concluding his studies in Engineering for the Food Industry and this work will be part of his dissertation.

ROBERTO MONTANARI is a Full Professor at the Department of Engineering for Industrial Systems and Technologies - University of Parma. He is the Holder of the course in Industrial Plants – Bachelor of Engineering Management, and the course in Simulation of Production Systems – Master Degree in Engineering for the Food Industry. His e-mail address is: roberto.montanari@unipr.it and his Web- page can be found at https://personale.unipr.it/it/ugovdocenti/person/19786.