biology and life sciences forum

Proceeding Paper

Effect of Nanofluids on Heat Transfer in Milk and Tomato Juice Production: An Optimization Study with ANCOVA †

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† Presented at the 4th International Electronic Conference on Foods, 15–30 October 2023; Available online: https://foods2023.sciforum.net/.

Abstract: Recently, researchers have developed new heat transfer fluids that have high thermal conductivity, heat capacity, and low viscosity for food applications. Because the thermal conductivity of nanoparticles is higher than base fluids (water, ethylene glycol, and so on), nanofluids (NFs) are characterized by high performance in heat transfer operations. In this study, the aim was to determine the effect of NFs used in heat transfer equipment on the heat transfer coefficient using Analysis of Covariance (ANCOVA), which is an optimization test. For heat transfer modeling of tomato juice, the effect of alumina content in NFs on Reynolds Number (Re) and overall heat transfer coefficient was evaluated. For heat transfer modeling of milk, the effect of carbon nanotube content in NFs on Peclet Number (Pe) and convective heat transfer coefficient was assessed. As a result, it was determined that Re and alumina content to be crucial in the heat transfer of tomato juice within their *p*-values. However, in milk production heat transfer, carbon nanotubes had no crucial importance.

Keywords: nanofluids; heat transfer; tomato juice; milk

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Citation: Ozcakir, G. Effect of Nanofluids on Heat Transfer in Milk and Tomato Juice Production: An Optimization Study with ANCOVA. *Biol. Life Sci. Forum* **2023**, *26*, 68. https://doi.org/10.3390/Foods2023-14963

Academic Editor: Cristina A. Fente

Published: 13 October 2023

1. Introduction

Due to high consumption worldwide, fruit juice production has gained importance as one of the agriculture-based sectors. Evaporation is a kind of heat treatment used to obtain safe and stable juice. Besides that, it can be possible to adjust the desired concentration level of a juice via an evaporator [1]. Except for evaporation, there are many application areas of heat transfer in the juice sector such as refrigeration, pasteurization, and sterilization [2].

Nanofluid is a colloidal suspension composed of metallic or non-metallic nanoparticles which disperse uniformly in a base liquid. These particles can be effective at larger sizes to increase the thermal conductivity of the fluid. The reason for decreasing particle size to the nanoscale is to prevent sedimentation and provide a large surface area per volume. Using nanofluid in heat transfer operations can provide many advantages to an industrial food producer. Thanks to high thermal conductivity and heat transfer coefficient, the process becomes feasible in terms of economy and time. It can be used in smaller process equipment as a low amount of fluid can be used. Nanofluids have a few drawbacks to solve. These need more pump power because of their low viscosity making them more stable [2].

In the current literature, there are several optimization studies about NFs. Chang et al. (2006) carried out a study about the optimization of TiO_2 NF synthesis parameters. They used the Robustness Design method for optimization [3]. Salameh et al. (2021) combined fuzzy modeling and particle swarm optimization to determine the optimum heat transfer operating parameters for Al_2O_3/SiO_2 NF. In summary, they achieved specific values of density, viscosity, specific heat, and thermal conductivity [4]. Mohammadi et al. (2019) worked with water–Fe_3O_4 NF to obtain the maximum heat transfer rate. They used Taguchi as an optimization method. They tested the effect of different mass flowrates and nanoparticle concentration to reach the optimum values [5].

Nanofluid utilization in beverage production is a novel topic in the literature. Jafari et al. (2017) synthesized Al_2O_3 containing NF to reduce the process time during pasteurization in tomato juice production [6]. Saremnejad Namini et al. (2015) used the same NF type for the production of watermelon juice. At this time, researchers investigated color and vitamin changes during the process when NF was used in the heat transfer [7]. Taghizadeh-Tabari et al. (2016) assessed TiO_2-containing NF to increase the heat transfer rate during pasteurization in milk production [8]. This study aimed to display the effect of NFs in liquid food production via computational optimization.

2. Material and Methods

Optimization was done on SigmaPlot 14.0 software for one-way Analysis of Covariance (ANCOVA). The importance of the independent variables for heat transfer determined in relation to the *p*-values means that if a variable had a below-selected *p*-value, it was not the effect of this variable on heat transfer. Data for the analysis were obtained from the literature, which are presented in Tables 1 and 2. Normality and Equal Variance tests were made using Shapiro–Wilk and Levene, respectively.

Table 1. Data for heat transfer in tomato juice production [9].

Alumina (wt./v. %)	Reynolds Number (Re)	Overall Heat Transfer Coefficient ($W/m^2/K$)
0	200	1700
0	250	2150
2	200	1800
2	250	2250
4	200	2000
4	250	2500

Table 2. Data for heat transfer in milk production [10].

Carbon Nanotube (wt./wt. %)	Peclet Number (Pe)	Convective Heat Transfer Coefficient ($W/m^2/K$)
0	574	700
0	1000	1040
0.35	574	800
0.35	1000	1220
0.55	574	880
0.55	1000	1340

For tomato juice production, independent variables (alumina amount in the NF and Reynolds Number) were connected with the dependent variable (Overall Heat Transfer Coefficient). The alumina content of the NF was selected as factor for this analysis.

For milk production, independent variables (Carbon Nanotube amount in the NF and Peclet Number) were connected with the dependent variable (Convective Heat Transfer Coefficient). The carbon nanotube content of the NF was selected as factor for this analysis.

As a result of the analysis, Degree of Freedom, Sum of Square, mean square, F- and *p*-values were determined. Adjusted means graphs were drawn. Regression equations were obtained.

3. Results and Discussion

3.1. Tomato Juice Production

In Table 3, the ANCOVA results for heat transfer in tomato juice production are shown. The Reynolds number was assumed as the covariate. As can be shown in the results, all of the parameters had a crucial effect on heat transfer. Because the *p*-value of both the alumina amount and Reynolds number were below 0.05. However, it was concluded that

Re had more importance than alumina amount. Same conclusion was obtained the study by Vahidinia and Miri in 2015. They determined that an increasing Re had a positive effect on heat transfer when it was used alumina contained NF [11]. Since its *p*-value was near zero. For ANCOVA analysis of tomato juice, the R^2 value was found as 0.998. In Figure 1 the possible overall heat transfer coefficient ranges when the appropriate amount of alumina in NF was used is shown. Table 4 displays the equations used to compute the overall heat transfer coefficient for NF contained in alumina in tomato juice heat transfer.

Table 3. ANCOVA calculations for heat transfer in tomato juice production.

Variance Source	Degree of Freedom	Sum of Square	Mean Square Value	F-Value	*p*-Value
Alumina (wt./v. %)	2	110,833.333	55,416.667	133.000	0.007
Re	1	326,666.667	326,666.667	784.000	0.001
Residual	2	833.333	416.667	--	--
Total	5	438,333.333	87,666.667	--	--

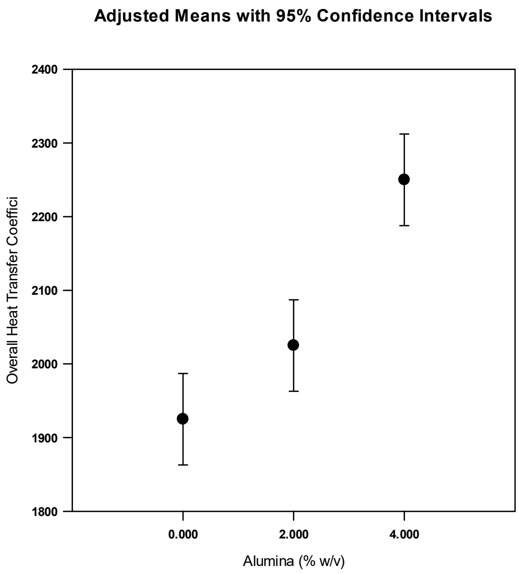

Figure 1. Adjusted means with 95% confidence intervals for heat transfer in tomato juice production.

Table 4. Resulting ANCOVA equations for heat transfer in tomato juice production.

Alumina (wt./v. %)	Equation
0	Overall Heat Transfer Coefficient = −175.000 + (9.333 × Re)
2	Overall Heat Transfer Coefficient = −75.000 + (9.333 × Re)
4	Overall Heat Transfer Coefficient = 150.000 + (9.333 × Re)

3.2. Milk Production

In Table 5, the ANCOVA results for heat transfer in milk production are displayed. At this time, the Peclet Number was chosen as the covariate. The results show that only the Peclet Number had a significant effect on heat transfer. Because the *p*-value of the Carbon Nanotube amount was higher than 0.05,it was not a surprising result. Sarafraz and Hormozi in 2016 concluded that carbon nanotubes content in NFs has a negligible effect on the friction factor, especially in the case of high Re (over 8000). It is known that the friction factor affects heat transfer P [11]. Furthermore, researchers determined that the optimum carbon nanotube amount is 1% [12]. The reference study values in this work were lower than this value (Table 2). In the ANCOVA analysis of milk, the R^2 value was 0.988. Figure 2 shows the ranges of the convective heat transfer coefficient using the appropriate amount of Carbon Nanotube in the NF. Table 6 shows the equations used to calculate the convective heat transfer coefficient for Carbon Nanotube containing NF in milk heat transfer.

Table 5. ANCOVA calculations for heat transfer in milk production.

Variance Source	Degree of Freedom	Sum of Square	Mean Square Value	F-Value	*p*-Value
Carbon Nanotube (wt./wt. %)	2	58,133.333	29,066.667	15.571	0.060
Pe	1	248,066.667	248,066.667	132.893	0.007
Residual	2	3733.333	1866.667	--	--
Total	5	309,933.333	61,986.667	--	--

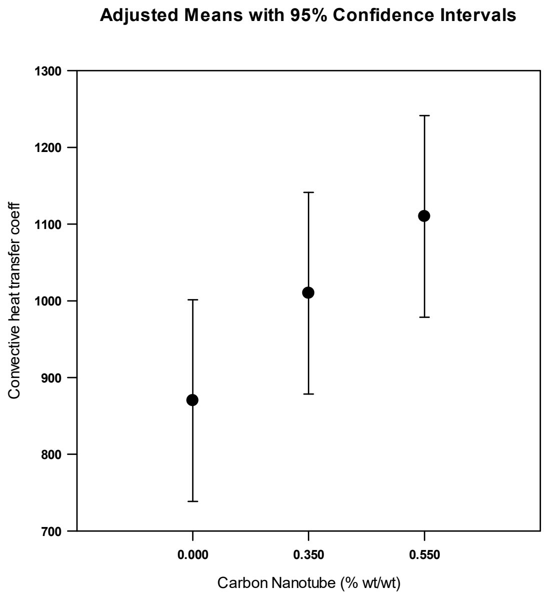

Figure 2. Adjusted means with 95% confidence intervals for heat transfer in milk production.

Table 6. Resulting ANCOVA equations for heat transfer in milk production.

Carbon Nanotube (wt./wt. %)	Equation
0	Convective heat transfer coefficient = 118.717 + (0.955 × Pe)
0.35	Convective heat transfer coefficient = 258.717 + (0.955 × Pe)
0.55	Convective heat transfer coefficient = 358.717 + (0.955 × Pe)

4. Conclusions

The aim of this work was to display the effect of parameters, one of which was the amount of nanomaterial in NF, on heat transfer in the production of milk and tomato juice. The experimental data were obtained from the scientific literature and utilized in the analysis of covariance. After the analysis, the most effective parameter in heat transfer in liquid food production was determined, as well as the equations defining the relationship between the covariance, the factor, and the dependent variable. It was concluded that the amount of alumina was an important parameter used in tomato juice production in terms of its *p*-value. It may be appropriate to work with high percentage Alumina to achieve a high heat transfer rate. For 4% w/v alumina NF content, almost 2200–2300 overall heat transfer coefficient in the heat exchanger can be achieved. It was determined that the Peclet

Number is more important for heat transfer than the content of carbon nanotube in NF in milk production. When working with high heat transfer, it is crucial to work with high carbon nanotube content NF for milk production. This is one of the disadvantages of using NF using in heat transfer in the production of food juice sin terms of the production costs of nanomaterials.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/Foods2023-14963/s1. Presentation Video: Effect of Nanofluids on Heat Transfer in Milk and Tomato Juice Production: An Optimization Study with ANCOVA.

Funding: This research received no external funding.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The author declares no conflict of interest.

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