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Proceeding Paper

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

Gamze Ozcakir

Department of Chemical Engineering, Faculty of Engineering, Bilecik Seyh Edebali University, TR 11100 Bilecik, Turkey; gamze.ozcakir@bilecik.edu.tr

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Abstract: Today, 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) have 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 with Analysis of Covariance (ANCOVA) which is an optimization test. For heat transfer modeling of tomato juice, it was evaluated the effect of alumina content in NFs on Reynolds Number (Re) and overall heat transfer coefficient. For heat transfer modeling of milk, it was assessed the effect of carbon nanotube content in NFs on Peclet Number (Pe) and convective heat transfer coefficient. As a result, it was determined that Re and alumina content have crucial importance on heat transfer of tomato juice regarding their *p*-values. However, in milk production heat transfer, carbon nanotubes had no crucial importance.

Keywords: nanofluids; heat transfer; tomato juice; milk

1. Introduction

Regarding high consumption worldwide, fruit juice production has gained importance as one of the agriculture-based sectors. Evaporation is a kind of heat treatment 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 its high 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 to feasible regarding economy and time. It can be used in smaller process equipment due to it can be enough to use a low amount of fluid. Nanofluids have a few drawbacks to solve. These need more pump power because of their low viscosity making them more stable [2].

In current literature, there are several optimization studies about NFs. Chang et al. (2006) carried out a study about synthesis parameters optimization for TiO_2 NF. They used Robustness Design Method for optimization [3]. Salameh et al. (2021) combined fuzzy modeling and particle swarm optimization to determine optimum heat transfer operating parameters for Al_2O_3/SiO_2 NF. As a conclusion, they reached specific values for density, viscosity, specific heat, and thermal conductivity [4]. Mohammadi et al. (2019) worked with water–Fe_3O_4 NF to obtain maximum heat transfer rate. They used Taguchi

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as an optimization method. They tested the effect of different mass flowrates and nanoparticle concentration to reach optimum values [5].

Nanofluid utilization in beverage production is a novel topic in literature. Jafari et al. (2017) synthesized Al_2O_3 containing NF to reduce process time during pasteurization for 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 it was used NF in the heat transfer [7]. Taghizadeh-Tabari et al. (2016) assessed TiO_2-containing NF to increase the heat transfer rate during pasteurization for milk production [8]. This study aimed to display the effect of NFs on 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 on heat transfer decided concerning *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 was obtained literature. One can see data in Tables 1 and 2. Normality and Equal Variance tests were made by using Shapiro-Wilk and Levene respectively.

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

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

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.

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

Alumina (wt./v. %)	Reynolds Number (Re)	Overall Heat Transfer Coeffient ($W/m^2/K$)
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 Coeffient ($W/m^2/K$)
0	574	700
0	1000	1040
0.35	574	800
0.35	1000	1220
0.55	574	880
0.55	1000	1340

3. Results and Discussion

3.1. Tomato Juice Production

In Table 3, it was shown ANCOVA results for heat transfer in tomato juice production. 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 whose Vahidinia and Miri in 2015. They determined that increasing Re had positive effect on heat transfer when it was worked with 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, it can be shown that the possible overall heat transfer coefficient ranges when it was used appropriate amount of Alumina in NF. Table 4, it was displayed equations to compute the overall heat transfer coefficient for Alumina contained NF 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	--	--

Table 4. Resulted 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)

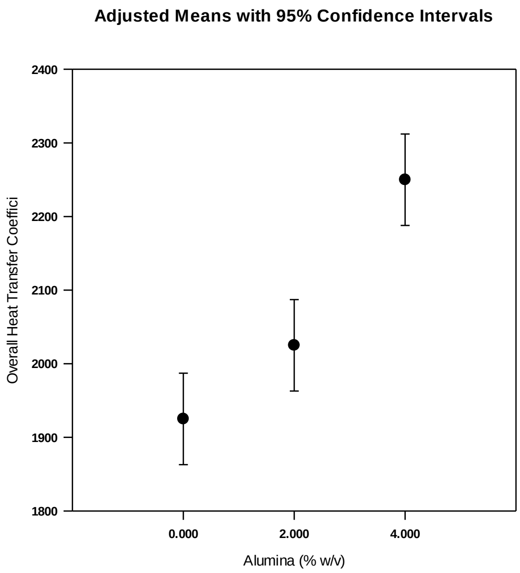

Figure 1. Adjusted means with 95% confidence intervals for heat transfer in tomato juice production.

3.2. Milk Production

In Table 5, ANCOVA results for heat transfer in milk production were displayed. At this time, the Peclet Number was chosen as the covariate. As can be given in the results, just 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 NF had ignorable importance on friction factor especially in high Re (over 8000). It is known that friction factor is effective on heat transfer [11]. Besides that, researchers determined that optimum carbon nanotube amount can be selected as 1% [12]. Reference study values in this work were lower than this value (Table 2). For ANCOVA analysis of milk, the R^2 value was found as 0.988. In Figure 2, convective heat transfer coefficient ranges were presented when it was used appropriate amount of Carbon Nanotube in NF. Table 6, it was shown equations 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	--	--

Table 6. Resulted 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)

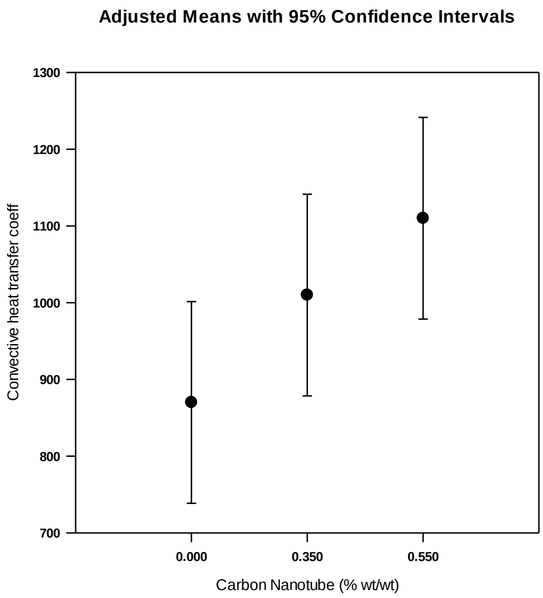

Figure 2. Adjusted means with 95% confidence intervals for heat transfer in milk production.

4. Conclusions

In this work, the aim was to display the effect of parameters one of which was nanomaterial amount in NF on heat transfer in milk and tomato juice production. The experimental data was obtained from the scientific literature and utilized in the analysis of covariance. After the analysis, the most effective parameter in heat transfer for liquid food production, and the equations which gave the relationship between covariance, factor, and dependent variable were determined. It was concluded that Alumina amount was an important parameter to work in tomato juice production regarding its *p*-value. It can be suitable to work with high percentage alumina to achieve high heat transfer rate. For 4% w/v Alumina content NF it can be reached nearly 2200–2300 overall heat transfer coefficient in heat exchanger. It was determined that Peclet Number had more importance on heat transfer than carbon nanotube content in NF for milk production. For working with high heat transfer, it is crucial to work with high carbon nanotube content NF for milk production. This is one of the drawback of NF using in heat transfer for food juice production regarding nanomaterial production costs.

Supplementary Materials: The following supporting information can be downloaded at: https://foods2023.sciforum.net/#session2774, Presentation Video: Effect of Nanofluids on Heat Transfer in Milk and Tomato Juice Production: An Optimization Study with ANCOVA.

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