PRIMJENA METODE TAGUCHI KOD ODREĐIVANJA UČINKOVITOSTI RAZLIČITIH MATERIJALA U ZADRŽAVANJU TOPLOTE U TERMOS-BOCI

APPLICATION OF THE TAGUCHI METHOD IN DETERMINING THE EFFICIENCY OF DIFFERENT MATERIALS IN RETAINING HEAT IN A THERMOS BOTTLE

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REZIME
Prijenos toplote je ključni proces koji se javlja u svakodnevnom životu, bilo da se radi o očuvanju toplote hrane ili različitim industrijskim procesima. Ova pojava uključuje tri osnovna mehanizma prijenosa: provođenje, konvekciju i zračenje. Kako bi se smanjio gubitak toplote ili zadržala hladnoća, koriste se različiti izolacijski materijali. U ovom radu istraživano je koliko su različiti materijali učinkoviti u izolaciji termos-boce. Eksperiment je obuhvatio tri vrste izolacijskih metoda: standardnu vakuumsku termos bocu, vakuumsku bocu s dodatkom kamene vune i vakuumsku bocu s dodatkom kartona. Analizirana je sposobnost svakog modela da zadrži početnu temperaturu tekućine na tri različite temperature (5 °C, 40 °C i 90 °C) tokom vremenskih intervala od pola, jednog i dva sata. Cilj istraživanja bio je utvrditi optimalne uvjete za očuvanje toplote koristeći metodu Taguchi za analizu i optimizaciju faktora.

Professional paper

SUMMARY
Heat transfer is a key process that occurs in everyday life, whether it involves maintaining the warmth of the food, or various industrial processes. This term includes three primary mechanisms of transfer: conduction, convection, and radiation. To minimize heat loss or retain coldness, different insulating materials are used. This paper examines the effectiveness of different materials in insulating a thermos bottle. The experiment involved three types of insulation methods: a standard vacuum thermos bottle, a vacuum thermos bottle with added mineral wool, and a vacuum thermos bottle with added cardboard. The ability of each model to maintain the initial temperature of the liquid was analyzed at three different temperatures (5 °C, 40 °C, and 90 °C) over time intervals of half an hour, one, and two hours. The objective of the study was to determine the optimal conditions for maintaining heat or coldness, using the Taguchi method for factor analysis and optimization.

1. INTRODUCTION

A thermos bottle is a specialized container designed to preserve the temperature of liquids. Its main function is to keep the liquid inside either warm or cold for an extended period, thanks to a special insulating layer. The working principle of a thermos bottle is simple. It consists of an inner and outer layer, with a vacuum or another insulating material in between. The vacuum acts as a barrier to heat transfer. The inner layer of the thermos is often coated with a reflective material (such as silver) that reflects heat rays back towards the liquid, further aiding in heat retention. In summary, the vacuum or insulating layer prevents heat transfer through conduction and convection, while the reflective surface minimizes heat loss through radiation.

2. DESIGN OF EXPERIMENT

The aim of the experiment is to determine which insulation method is the most effective in retaining heat or coldness in a thermos bottle over time. The experiment compares the heat retention capability of a standard vacuum thermos bottle with two modified versions that use additional insulating materials. The experiment is designed using the Taguchi method to optimize factors and minimize temperature changes. The considered factors are the insulation method, duration, and the initial temperature of the liquid.

2.1. Experiment plan

To conduct this experiment, an L9 orthogonal array was used, resulting in nine different combinations of factors. For each combination, temperature changes were measured at three different time intervals. The Signal-to-Noise (S/N) ratio, with the 'smaller-is-better' criterion, was applied to analyze the effectiveness of each insulation method in minimizing temperature changes.

Table 1. *Factors and their levels*

Factor	Level 1 (-1)	Level 2 (0)	Level 3 (1)
Insulation method	Vacuum	Vacuum + mineral wool	Vacuum + cardboard
Initial temperature [°C]	5	40	90
Time [h]	0.5	1	2

The first of the three methods uses a standard vacuum thermos bottle as the reference value. The second method involves additional insulation with mineral wool, known for its excellent thermal insulation properties, while the third method employs cardboard as an extra layer of insulation to enhance heat or cold retention. To test heat retention, water at different temperatures was used: cold water at 5 °C to simulate the storage of cold beverages, warm water at 40 °C to assess moderate temperatures, and hot water at 90 °C to evaluate the thermos bottle's ability to retain high temperatures.

Temperature readings will be taken at specified time intervals using a precise digital thermometer. The experiment will be conducted in a controlled environment, recording temperature changes after 0.5, 1, and 2 hours to assess the insulation performance. Additionally, a stopwatch will be required for accurate time measurement, and a measuring jug will be used to ensure a consistent liquid volume of 500 ml in each sample.

2.2. Results

After the measurements were conducted, the temperature change was calculated for each experiment. The temperature change is equal to the difference between the initial and measured temperatures.

$$\frac{S}{N} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad \text{... (1)}$$

As previously mentioned, the 'smaller-is-better' criterion was used in the calculation of the S/N ratio, as a smaller response value — i.e., a smaller temperature change — is desired.

The calculation follows the formula where y_i represents the result for each experiment and *n* is the number of repetitions.

***Table 2**. Calculation of the S/N ratio*

Experiment	Insulation method	Initial temperature	Time	Average	S/N ratio
1	-1	-1	-1	29.89	-14.75
2	-1	0	0	1497.70	-31.75
3	-1	1	1	6373.69	-38.04
4	0	-1	0	34.42	-15.37
5	0	0	1	1428.93	-31.55
6	0	1	-1	7242.26	-38.60
7	1	-1	1	47.16	-16.74
8	1	0	-1	1539.26	-31.87
9	1	1	0	6967.18	-38.43

3. ANALYSIS OF MEASUREMENT RESULTS

Calculating the average S/N ratio for each factor level simplifies the analysis by reducing variability. Instead of analyzing each individual experiment, it becomes possible to observe the general trend for the levels of each factor.

***Table 3**. Average S/N ratio – insulation method*

Insulation method	
Average S/N – Level 1	-28.184
Average S/N – Level 2	-28.506
Average S/N – Level 3	-29.013

Table 3 indicates that the combination of vacuum and cardboard provides the highest S/N ratio, suggesting that this insulation method offers better heat retention compared to the other methods. Although the temperature loss with this method is minimal, there is still space for optimization. One potential improvement involves using sleeves made from thermal insulating materials, which not only enhance insulation but also protect the bottle from physical damage and make it easier to transport.

***Table 4.** Average S/N ratio- initial temperature*

Initial temperature	
Average S/N – Level 1	-15.670
Average S/N – Level 2	-31.726
Average S/N – Level 3	-38.358

According to Table 4, the S/N ratio suggests that the thermos bottle performs better at higher temperatures. One reason for this is the reflective surface inside the thermos, which effectively retains heat by reflecting thermal radiation. However, in case a liquid is cold, it cannot reflect it, since coldness is not a physical entity; instead, heat from the external environment easily penetrates inward. Specialized thermos bottles designed for keeping liquids cold are available on the market, and the need for such bottles was validated by this experiment. These bottles often replace the silver coating with a copper layer and feature an outer coating with an anti-condensation finish. The caps of these thermos bottles are also slightly different from those designed for retaining heat at higher temperatures.

Table 5. *Average S/N ratio – time*

Time	
Average S/N – Level 1	-28.409
Average S/N – Level 2	-28.518
Average S/N – Level 3	-28.777

The S/N ratio presented in Table 5 shows that the thermos bottle performs better over longer periods. The greatest temperature change occurs during the initial minutes of the process. This is primarily due to the first contact between the liquid and the thermos wall, during which heat is transferred between the liquid and the bottle. Additionally, air entering through the thermos opening comes into contact with the liquid, contributing to the temperature change. One of the simplest optimization suggestions would be to reduce the size of the thermos opening, thereby minimizing environmental influence and limiting contact with air.

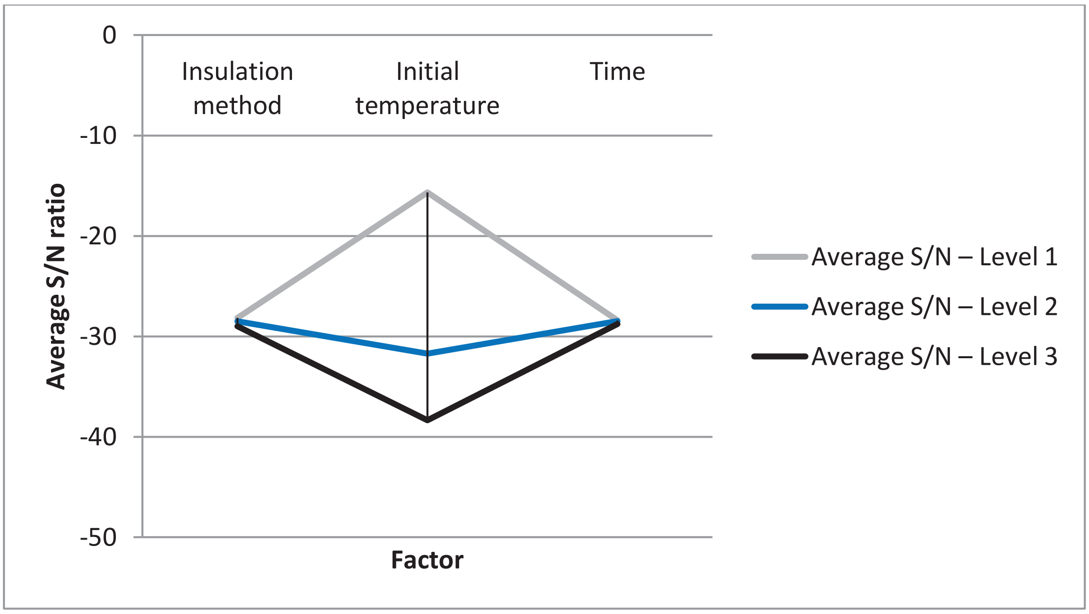

Figure 1. The graph shows the results - average S/N ratio for each level of the three factors analyzed

4. CONCLUSION

Based on the conducted experiment and statistical analysis, it was determined that different insulation materials have a measurable impact on a thermos bottle ability to retain heat or coldness. The standard vacuum thermos bottle proved effective, while the addition of cardboard provided slightly improved insulation results. The experiment also revealed that thermos bottles retain temperature more effectively with higher initial liquid temperatures and over longer time periods. The greatest temperature loss occurred during the initial minutes of the process, after which the cooling rate significantly slowed. This highlights potential directions for product optimization.

Furthermore, it was concluded that the development of various thermos bottle models and their components, such as additional insulation layers or innovative design solutions, is feasible using the Taguchi method. This method facilitates systematic analysis and optimization of key factors, offering an efficient approach to improving thermos bottle performance. Optimizations, such as reducing temperature loss or enhancing insulation durability, can be achieved through this approach.

The findings of this research emphasize the critical role of insulation material selection in temperature preservation, providing practical guidelines and directions for further studies in thermal insulation and thermos bottle design.

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