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THE METHODOLOGY OF MULTIPLE CRITERIA DECISION MAKING FOR SELECTING THE HEATING MEDIUM FOR MULTIFUNCTIONAL STERILIZER

Summary

This paper deals with designing a device for food processing industry, i.e. a multifunctional sterilizer (MFS) to be used for extending the shelf life of food, such as meat, fish, fruit and vegetables, packaged in containers of various capacities made of popular materials such as glass, tin and thin film. Having analyzed the existing solutions regarding the choice of the heating medium used in sterilization systems, the authors showed that when selecting a new sterilizing device many criteria need to be accounted for, some of them being rather contradictory. Thus the authors suggest to apply a multiple criteria decision making approach which is used in other areas of research. For that purpose, a coherent group of criteria for different types of heating medium was suggested. Based on the decision maker's preference model, a final ranking list was prepared using the method based on the prevalence relationship – Electre III. The obtained results were subsequently summed up.
***Key words**: food sterilization, choice of the heating medium, multiple criteria decision making*

METODYKA WIELOKRYTERIALNEGO WSPOMAGANIA DECYZJI W ZASTOSOWANIU DO WYBORU MEDIUM GRZEWCZEGO DO WIELOFUNKCYJNEGO URZĄDZENIA DO STERYLIZACJI (WUS)

Streszczenie

Artykuł dotyczy projektowania maszyn dla przemysłu spożywczego, tj. wielofunkcyjnego urządzenia do sterylizacji (WUS). Urządzenie takie, zgodnie z założeniami konstruktorów, przeznaczone zostanie do utrwaleniu żywności w opakowaniach o różnej pojemności, wykonanych z powszechnie stosowanych materiałów opakowaniowych, jak: szkło, blacha, cienka folia, zawierających produkty mięsne, ryby, przetwory owocowo-warzywne. Dokonując analizy istniejących rozwiązań medium grzewczego do WUS autorzy wykazali, że przy doborze do nowo zaprojektowanego urządzenia wskazane jest uwzględnienie wielu, często przeciwstawnych kryteriów. Stąd też autorzy zaproponowali, znane z innych obszarów badawczych, podejście oparte o metodykę wielokryterialnego wspomagania decyzji (WWD). W tym celu dla rozważanych wariantów medium grzewczego zaproponowano spójną rodzinę kryteriów. W oparciu o model preferencji decydenta skonstruowano ranking finalny z wykorzystaniem metody opartej o relację przewyższania – Electre III. Uzyskane wyniki podsumowano.
***Słowa kluczowe**: sterylizacja żywności, dobór medium grzewczego, wielokryterialne wspomaganie decyzji*

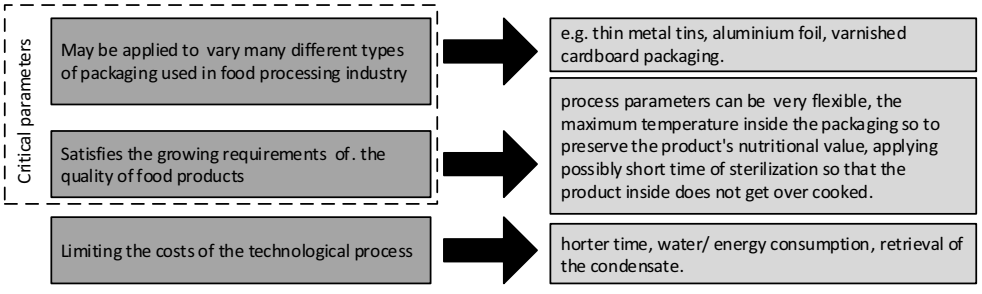
1. Introduction

Thermal sterilization of food products is currently the most popular method of preserving food and thus extending its shelf life. It is vital that certain parameters are observed in sterilization process as they influence the quality of these products (taste, vitamin content), as well as consumer's safety [3].

When using the sterilizing media a number of factors must be considered. The authors believe that there are two critical heating media for the MFS (fig. 1) which limit the number of types of containers used in food processing industry and deteriorate the quality of food products.

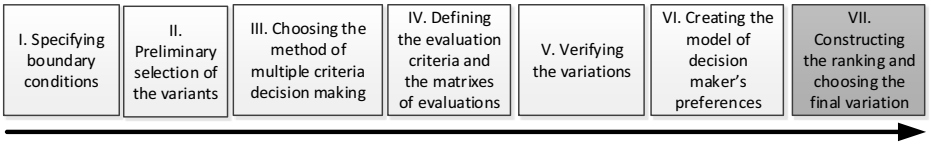
2. Definition of the decision problem

In view of the principal research problem, i.e. designing a multifunctional sterilizer, the following decision problem was defined: how to choose the heating medium for the multifunctional sterilizer which, in specified conditions, addresses the needs of both players - the producer as well as the user. The formulation of the decision problem and the potential number of variations led the authors to assume that this issue must be solved according to multiple criteria problems of variations ranking (the so called ranking problems). Thus a multiple criteria decision making analysis (MCDA) needs to be applied [2, 10, 11, 12].



Source: authors' own diagram / Źródło: opracowanie własne

Fig. 1. Boundary conditions when choosing sterilization heating medium
Rys. 1. Warunki brzegowe przy wyborze medium grzewczego do sterylizacji



Source: authors' own diagram / Źródło: opracowanie własne

Fig. 2. The procedure of selecting the heating medium for the MFS
Rys. 2. Procedura wyboru medium grzewczego do wielofunkcyjnego urządzenia do sterylizacji

3. Case study

3.1. Procedure of choosing the heating medium

As it was essential to carry out a preliminary selection of variations as well as potential ranking methods, the authors proposed a seven stage procedure of selecting the heating medium for the MFS as presented in fig. 2.

At Stage I it is necessary to define the boundary conditions which all the potential variations of the heating medium should fulfill. This allows for selecting a set of potential variations or alternatives (Stage II) which shall be evaluated at a later stage. Before the evaluation is carried out, however, it is necessary to choose the method that assists the decision making process (Stage VII). The next stage involves defining the criteria which shall serve as a basis of the construction of variation evaluation matrix (Stage IV). The data from this stage shall be used for verifying the variations from the point of view of occurrence of situations of dominated options of the heating medium. At the penultimate stage (VI), the decision maker's preferences model shall be created. Its structure depends on the method chosen at Stage III of multiple criteria decision making analysis. The end result of the work is the final ranking.

3.2. Choice and characteristics of the MCDM method

Based on the analysis of the available methods at the first stage, five methods were selected, i.e. AHP, UTA, Electre III, Promethee and MUZ. Having considered the advantages and disadvantages of each of the above methods, ELECTRE III was used for creating rankings [8, 9]. The method originates from the so called European school of MCDM. In this method, the key to the construction of model of preferences involves comparing pairs of all decision variations. The comparison leads to partial structuring of the pairs according to the preferences of the decision maker which are defined as indifference thresholds q_j, preference thresholds p_j, veto thresholds v_j and the values of weights of particular criteria k_j. The result may be presented in the form of rank of matrix and /or graph of prevalence. In the final ranking, between the variations the following interdependencies might occur: indifference – I, prevalence – P, reversed prevalence– P*, incomparability – R.

3.3. Criteria of evaluation of variations

In the case under discussion, the following family of criteria evaluating the variations of the heating medium for the MFS were assumed:

– The degree of shortening sterilization time (K1) – a maximized criterion expressed as percentage [%]. The time of sterilization is mostly affected by how fast heat penetrates towards the centre of the packaging based on the principle of thermal conductivity. The time of heating in typical sterilizers where water is the heating medium amounts to max. 30% of the total sterilization process. It must be noted that the shortened time of heating the content of the packaging results in achieving lower temperature than if the heating time was longer. The rate of shortening sterilization time was estimated based on the instruments using a similar technology.

– Thermal energy consumption (K2) – a minimized criterion expressed as a percentage [%]. This criterion was defined on the assumption that the same number of packaging shall undergo sterilization. In this criterion it was assumed that for the medium with which most thermal energy was used, the value is 100%.

– The level of impurities in the condensate (K3) – a minimized criterion expressed on a point scale [pt.]. This criterion allows for considering a potential condensate retrieval and returning it to the boiler. The following point scale was assumed:

a) Relatively pure condensate (may be retrieved and returned to the boiler) – 1 point,

b) The condensate polluted with the remains of products left on the packaging (cannot be returned to the boiler) – 2 points,

c) The condensate polluted with the remains of products left on the packaging and mixed with untreated water used for flooding the sterilizer (cannot be returned to the boiler) – 3 points.

– Water consumption (K4) – a minimized criterion expressed as a percentage [%]. In this criterion, the consumption of water was considered, for instance water used for preliminary flooding the sterilizer or the treated water used by the boiler. In this criterion, the medium for which the most water was used for sterilization was assigned the value of 100%. It was also assumed that the same number of packaging undergoes sterilization.

The above criteria consider the economical aspect (K1, K2, K3, K4), the technical aspect (K1) as well as the environmental aspect (K2, K3, K4).

3.4. The variations of the heating medium for the MFS

The selection of the media considered in the procedure of creating final ranking was carried out at Stage II – preliminary selection of the variations- and Stage V – verification of the variants. Thus from among six preliminary solutions (hot air, steam, steam saturated with air sent directly to the MFS, microwave heating, hot water heated directly with steam, hot water heated indirectly with steam) due to boundary requirements for the multiple criteria evaluation, the following three were chosen:

– W1_pw: a mixture of saturated steam with air supplied directly for the MFS.
– W2_gwi: hot water heated directly with steam,
– W3_gwp: hot water heated indirectly with steam.

The matrix of evaluation of the three variations under discussion was presented in Table 1. Having verified the variations, the authors concluded that the W2_gwi variation was dominated. Consequently, only variations W1_pw and W3_gwp were considered at further stages of the analysis.

Tab. 1. The matrix of evaluation of the three variations of heating media for the MFS
Tab. 1. Macierz ocen wariantów mediów grzewczych wielofunkcyjnego urządzenia do sterylizacji

Criterion	Direction of preference	Variation		
		W1_pw	W2_gwi	W3_gwp
K1: The degree of shortening sterilization time [%]	max	10	0	0
K2: Thermal energy consumption [%]	min	87	100	100
K3: The content of impurities in the condensate [pt.]	min	2	3	1
K4: water consumption [%]	min	50	100	50

Source: own work / Źródło: opracowanie własne

Table 2. The model of decision maker's preferences for the situation of choosing the heating medium for the MFS
Tab. 2. Model preferencji decydenta dla problemu wyboru medium grzewczego do wielofunkcyjnego urządzenia do sterylizacji

Criterion	Weight k_j	Thresholds		
		indifference q_j	preference p_j	veto v_j
K1: The degree of shortening sterilization time [%]	3	5	10	-
K2: Thermal energy consumption [%]	5	5	15	-
K3: The content of impurities in the condensate [pt.]	5	0	1	3
K4:water consumption [%]	4	10	15	-

Source: own work / Źródło: opracowanie własne

3.4. The model of decision maker's preferences

According to the assumed algorithm, at Stage IV the so called decision maker's preferences model was constructed. It was agreed that it would be formulated from the point of view of the MFS user. It was assumed that the threshold of veto did not need to be considered, i.e. it was not obligatory while defining the final ranking. This approach is well grounded especially when the number of variations is small [5, 6] which does not mean that this threshold must be considered in more complex problems [5, 6]. The model of decision maker's preferences is presented in Table 2.

3.5. Final results

The Diviz v. 1.13.2 software [1] was used for obtaining the final ranking as it allows for designing each stage of the Electre III method. Based on the proposed criteria and variations as well as the model of decision maker's preferences, the final ranking of two variations of heating medium, W1_pw and W3_gwp, was obtained by way of intersecting the ascending and descending distillation (fig. 3).

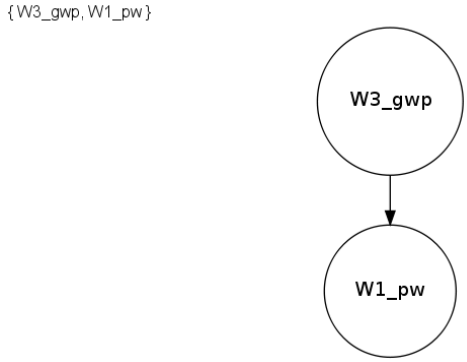


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Fig. 3. Final ranking of the variations of the heating medium for the MFS obtained using the Electre III method
Rys. 3. Ranking finalny wariantów medium grzewczego wielofunkcyjnego urządzenia do sterylizacji uzyskany metodą Electre III

4. Summary and conclusions

Based on the obtained final rankings, it is obvious that from the point of view of a multiple criteria evaluation the best medium for the MFS is hot water heated indirectly with steam (variation W3_gwp). This medium has the best values with respect to criterion K3. As far as the K1 and K2 are considered, it is worse than W1_pw.

Since the final differentiation of the processed foods influences changes in the values of particular criteria, it is advisable that - besides medium W1_pw based model - various users should carry out research into the W3_gwp medium, i.e. a mixture of saturated steam with air supplied directly to the MFS.

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