

SUMMARY

PHD THESIS

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Determinants of the progress of the commercialization process of innovative oxygen scavengers

Nowadays, when we observe an increase in the pace of life, the consumer expects food products that are distinguished by high quality, attractive appearance, low processing and high sensory and nutritional values. In order to meet these customer expectations, food producers are looking for new methods of securing food. As a result, the interest in innovative packaging methods has increased, which includes not only the packaging materials themselves, but also packaging technologies, modifications of the atmosphere inside the packaging, as well as packaging structures.

It can therefore be seen that the packaging of products is gaining more and more new functions. It is no longer only a form of protection against harmful external factors, but also fulfills information, marketing, ecological and logistic functions. Despite these new aspects of the use of packaging, the overriding goal of product packaging remains unchanged: to maintain the best possible quality of the product for as long as possible. In other words, protection against physical factors (temperature, pressure, sunlight, oxygen or mechanical deformation), chemical (water, air pollution, etc.) and biological factors (i.e. pathogenic microorganisms and pests).

This high quality and food safety, which are the overriding goal of packaging, largely depends on the quality of raw materials as well as the method and conditions of packaging. However, even the use of high-quality ingredients and ensuring good packaging conditions do not guarantee a food product with a long shelf life. An additional problem for food producers is the offer of chemically unpreserved products,

as consumers are increasingly turning to low-processed and preservative-free products. In recent years, there has been a trend to move away from chemical food preservation and an interest in alternative methods that fit in with a healthy diet.

In order to meet these expectations, food producers are forced to look for new solutions ensuring food safety, maintaining the best quality with the longest possible shelf life. The solution is modern food packaging methods. An example of an innovative and at the same time very effective method that extends the shelf life are oxygen absorbers. Oxygen absorbers do not require specialized packaging equipment. The basis of their action is an active substance, e.g. iron, enzymes or polymers, absorbing oxygen, which is the most often undesirable factor in food storage.

The above challenges of the packaging industry and the need to search for new technologies and the creation of the ZEVIFOS oxygen absorber by scientists from the Poznań University of Economics and Business, prompted the author of this paper to analyze the topic of oxygen absorbers and undertake research on the possibility of commercializing such a solution on the domestic market. The cognitive value of the work is the analysis of the innovation maturity potential and the assessment of the possibility of introducing the ZEVIFOS oxygen absorber based on zero-valent iron to the market, both in terms of technology and business, using selected methods. It should be emphasized that the work analyzes in detail the product itself and its properties in order to assess its value and possibilities of use, which is necessary in the process of commercialization of innovations. The dissertation in terms of literature and research is part of the area of quality sciences. It deals with the issues of methods of extending the quality and freshness of food, as well as the development of product and technological innovations in this area.

The aim of the work is to define the conditions for the commercialization of technology, including the outline of exemplary commercialization paths and the valuation of intellectual property, which is the ZEVIFOS absorber. The absorber is currently in the prototype stage, tested both in laboratory conditions and in a near-real environment.

The characteristics of the research object are of key importance in the commercialization process and constitute its first stage. We then use the concept of the subject of commercialization. It is important for further proceedings and the development of a scheme of possible commercialization paths. The specificity of the subject of commercialization and its legal conditions impose certain possibilities of selecting variants of entering the market for a given innovation.

The ZEVIFOS nanocomposite oxygen absorber was developed at the Department of Commodity Science and Ecology of Industrial Products at the Faculty of Commodity Science, currently the Institute of Quality Sciences of the University of Economics in Poznań. The creator of the technology is a team led by prof. dr hab. Zenon Foltynowicz, while the owner of the technology is the above-mentioned university, which is the same potential seller or licensor of the ZEVIFOS absorber technology.

The ZEVIFOS oxygen absorber is in the form of a composite in which the active substance is zero-valent iron (nZvi) and the matrix is a selected polymer. The ZEVIFOS oxygen absorber is primarily characterized by its high efficiency in absorbing oxygen from the product packaging. This effectiveness will be discussed in more detail in this paper. What distinguishes the mentioned ZEVIFOS oxygen absorber is, among others, no need for a catalyst, and no need for moisture in the product to initiate the oxygen adsorption reaction. For other iron oxygen absorbers, the humidity level necessary to initiate the oxygen adsorption reaction was set at 75% relative humidity. This makes it possible to use the absorber for products with very low humidity, where oxygen is a factor that reduces the quality of the stored product. However, then, it is necessary to adjust the size of the nano-iron particles in order for the oxygen adsorption process to be effective. The absorber can also take any form, e.g. a sachet, or be an integral part of the package, e.g. in the form of a laminate covering the inner layer of the package, or as part of a cap or cap. This form of using the absorber undoubtedly minimizes the risk of accidental consumption with a food product. The ZEVIFOS absorber can be used in

refrigerated conditions, which is confirmed by tests. It is also possible to dye it with selected colors.

Based on the literature studies cited in the theoretical chapters of this work, the following research thesis was formulated: Quality of the Poznań University of Economics. In order to determine the determinants of the readiness of the ZEVIFOS oxygen absorber for the commercialization process on the Polish market, the following three research questions were developed, to which answers will be provided in the course of the research:

Question 1: Does the ZEVIFOS oxygen absorber prototype demonstrate good oxygen removal capacity from food packaging and can be an alternative to chemical food preservation?

Question 2: Is the ZEVIFOS oxygen absorber technologically mature for commercialization?

Question 3: Is the ZEVIFOS Oxygen Absorber ready for commercialization?

In order to answer question 1, tests of the effectiveness of oxygen adsorption by the ZEVIFOS oxygen absorber were planned, using a product that is recommended for the use of oxygen absorbers. In this case, it was decided to have coffee. The conducted research showed an improvement in the quality of coffee samples stored with an oxygen absorber, compared to samples without an oxygen absorber. In order to answer also question 1, consumer research was carried out in 2015 and 2022 on the perception and knowledge of oxygen absorbers. These studies were also to determine the possibilities of using oxygen absorbers as an alternative to chemical food preservation, as well as to determine the cost of the oxygen absorber acceptable to producers and possible threats that may occur in the commercialization of this solution. The results of consumer research show that the percentage of people who had contact with the oxygen absorber in the product packaging has increased over time. This proves that these solutions are popularized in the world. The vast majority of respondents indicate that oxygen scavengers are a good alternative to chemical food preservation. The key aspect for the

commercialization of the solution, which is the oxygen absorber, turns out to be the cost of its implementation. The respondents were largely interested in the possibilities of such an absorber, but only if the price of the product with the absorber differed slightly compared to the analogous product without the absorber.

In order to be able to answer question 2, regarding the technological maturity of the ZEVIFOS oxygen absorber for the commercialization process, an analysis of the basic parameters of the ZEVIFOS oxygen absorber against the background of world leaders was carried out, as well as commissioned safety studies, consisting in verification of general and specific migration in three model fluids, in accordance with applicable standards. The analysis of the ZEVIFOS oxygen absorber, compared to the market leaders, showed the performance parameters of oxygen adsorption at the same level as the oxygen absorbers of the world leaders. What's more, the ZEVIFOS oxygen absorber is also versatile in use. It can be price competitive with a larger scale of production, although even when calculating the cost of production on a laboratory scale, its cost is not the highest in relation to the above competition. Additional advantages that speak for the potential success of the ZEVIFOS absorber are the possibility of tinting to the desired color and the possibility of shaping. One should not forget about its effectiveness in cooling conditions, which is rare among competing oxygen absorbers. The migration safety studies performed have shown that neither global nor specific migration occurs when the ZEVIFOS Oxygen Absorber is stored in any of the three model fluids.

One of the elements of the evaluation of the technological maturity of the ZEVIFOS oxygen absorber was also the innovation analysis using the TRL method. The TRL method is also known as the Technology Readiness Level. As the name suggests, it is a method used to determine the technological readiness stage of a given project, idea, invention or technology. Technological readiness should be understood as the degree of development of the project being the subject of scientific research. The TRL method was chosen as the method of assessing the readiness of technology for the commercialization process due to its universality and the possibility of comparison with other innovations. It is the method most often used in the evaluation of research and

development investment projects, in particular research co-financed by the European Union. The performed analysis of the ZEVIFOS oxygen absorber using the TRL method determined the advancement of the project at TRL 6. This means that the technology was demonstrated in a near-real environment. The ZEVIFOS oxygen absorber has been tested on the packaging line, and the results of storage tests of products with an oxygen absorber show that it has fulfilled its function, significantly affecting the shelf life of the product.

The above-mentioned research on the analysis of the competitive environment for the ZEVIFOS oxygen absorber and the TRL innovation assessment method also allowed us to answer the third research question. In these analyzes, both business and technology readiness are assessed. An additional element assessing the business readiness of the ZEVIFOS oxygen absorber was the valuation of this product and technological innovation, carried out using the cost and profit method. Following the literature recommendations mentioned above, the most appropriate approaches for the valuation of an intangible asset such as ZEVIFOS Oxygen Absorber will be the cost method and the income method. The market-based approach cannot be used due to the lack of reference transactions with similar assets. It is also impossible to talk about an active market of similarly priced technologies due to the innovative solution, which is the aforementioned ZEVIFOS oxygen absorber.

The study also analyzed possible commercialization paths for this innovation and proposed the most optimal solution that takes into account the specificity of the research subject. Due to the wide range of industries that could potentially benefit from this product and technological innovation, the recommendation was directed towards granting a license or establishing a spin-off company. These solutions create many more opportunities to improve and develop the developed technology and can generate long-term income from its commercialization.

The aim of this dissertation was to indicate the indicators of the readiness of new oxygen absorbers for the commercialization process on the Polish market. The determinants of the readiness of new oxygen absorbers for the commercialization process on the Polish market, mentioned in the study, are the following points of the

commercialization model. Their definition makes it possible to assign and describe activities that have already been carried out and which are still to be performed in order to be able to carry out the commercialization process:

1. Research work
2. Creation of an idea or invention
3. Identification of the market potential
4. Business idea
5. Patent
6. Promotion of the technological offer
7. Sale or license of patent rights
8. Implementation of technological innovation into production
9. Profits from sales

A detailed description of the implementation of individual readiness determinants can be found in chapter 4. "Theoretical issues of the commercialization process". Summarizing the above considerations on the technological and business readiness assessment of the ZEVIFOS oxygen absorber, it was found that this product and technological innovation is ready for the commercialization process, both in terms of technology and business. Therefore, it was concluded that the thesis put forward in this dissertation is confirmed. Therefore, there are reasons for introducing an oxygen absorber based on zero-valent iron (nZVI, ZEVIFOS), developed at the Institute of Quality Sciences of the University of Economics in Poznań, to the Polish market.

Based on the conducted research, the following conclusions and proposals for actions for the future were formulated:

- The dynamic development of the packaging market in Poland and in the world in terms of value and innovation of the offer, creates opportunities for commercialization of new solutions in this field.

- The need for producers from the packaging industry to adapt to the legislative requirements and the necessity to extend the life cycle of products may favor the development of packaging innovation.
- Oxygen absorbers, in the face of the growing awareness of food producers and consumers, may be an alternative to chemical preservation of food, and also contribute to extending the shelf life of products, preserving their quality values, which may contribute to reducing food waste.
- The applied ZEVIFOS oxygen absorber technology, based on iron nanoparticles, results in a much higher rate of oxygen adsorption and thus creates its competitive advantage compared to market equivalents. It also makes it possible to use the oxygen absorber in products with low relative humidity and in refrigerated conditions.
- The ZEVIFOS oxygen absorber, which overcomes many of the limitations in the use of oxygen absorbers on the market, has a good chance of being commercialized or even replacing existing commercial oxygen absorbers. The possibility of using various polymer matrices creates a much wider spectrum of application forms, from a sachet inside a packaging with a product, to a laminate which is an integral layer of the packaging material.
- The evaluation of the technological and business readiness of the ZEVIFOS oxygen absorber confirms the rationale for the commercialization of this product and technological innovation. The conducted assessments confirm the high level of advancement of the technology to be implemented.
- In the opinion of people associated with the packaging and food industry, the greatest threats related to the commercialization of the oxygen absorber on the Polish market are related to the high cost of this innovation and the safety of this solution.
- The valuation of the ZEVIFOS oxygen absorber is an important aspect of a possible commercialization process. It is likely that the result of the valuation and the proposed commercialization paths will contribute to the implementation of implementation activities in this area.

- Based on the projection of the financial results of the commercialization of the ZEVIFOS oxygen absorber, it was recommended to implement this innovation in the food, packaging and pharmaceutical industries. The selection of the indicated industries was primarily influenced by the potential of using this technology and the market demand for packaging innovations.
- The recommended paths of commercialization of the ZEVIFOS oxygen absorber, due to the specificity of the technology itself and patent protection, are licensing or establishment of spin-off companies by the creators or the university.

In the course of the conducted research procedure, answers to the research questions were obtained. The technological and business maturity of the ZEVIFOS oxygen absorber is at a high level, and the technological and product solution itself can be successfully commercialized. The research results also allowed for making assumptions about the suitability and feasibility of using the ZEVIFOS absorber in individual industries. Before the possible commencement of the commercialization process, the potential risks presented in the SWOT analysis for the ZEVIFOS oxygen absorber should be analyzed in more detail. However, according to the author of the work, these are not strategic issues that could be a factor in commercial success. For each of the identified threats and weaknesses, you can prepare a preventive strategy that will reduce their impact on the market situation of the product.