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TECHNOLOGY OF STAGED HYDROGENATION OF FATS

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Abstract

Fats are an important component of a number of food products and affect their consistency, shelf life, taste and nutritional qualities. Stepwise hydrogenation is one of the main methods of modifying edible fats, allowing to influence their chemical structure and properties. The purpose of this work was to establish the main approaches to stepwise hydrogenation of edible fats, problems of the method, as well as the main areas of use and prospects for improving the technology.

Keywords: *unsaturated fatty acids, trans fats, nickel catalyst, oil and fat industry, fat modification*

Introduction

The most urgent task in the oil and fat industry is the development of combined fat and lipid-protein products that meet the requirements of modern nutrition science. Satisfaction of the need from the point of view of nutritional physiology, creation of edible fats, including specialized lipids with optimal physicochemical characteristics, minimum content of trans-isomerized acids and preservation of the main biological components in the native state, is an urgent task. At the same time, it is important to develop methods for obtaining, establishing industrial production processes and introducing edible fats using local raw materials. The purpose of this study was to analyze the methods for obtaining technologically and physiologically functional baking and confectionery fats by combining non-selective and selective stepwise hydrogenation, as well as methods for their application. The objectives of the study included the analysis of general technological approaches to stepwise hydrogenation, the role of catalysts and their selectivity in this process, the problem of formation of trans-isomers of fatty acids, as well as the possibilities of using target hydrogenated fats.

Materials and Methods

This study examined the production of target edible fats using the stepwise hydrogenation method, as well as their potential use. The work considered various aspects of edible fat hydrogenation and their use. This included studying the hydrogenation process itself, the influence of various factors on the reaction results, determining the optimal conditions and properties of the obtained edible fats. The materials used were data from open sources, including scientific articles, books and publications related to the topic of edible fat hydrogenation. A search of sources was conducted using the electronic databases Google Scholar, Scopus and Web of Science to identify relevant studies. The search strategy used a combination of keywords related to the topic, such as "target edible fats", "stepwise hydrogenation" and "application of edible fats".

Results and discussion

Hydrogenation is a process used to change the functional properties of liquid lipids. There are three types of hydrogenation: full hydrogenation, partial hydrogenation, and partial hydrogenation without solidification. This process is aimed at converting oil into solid or semi-solid (plastic) fats. During hydrogenation, unsaturated fatty acids (FA) are converted into saturated fatty acids and trans fatty acids (TFA), while simultaneously increasing the oil's resistance to oxidation. The data obtained indicate that excessive moisture in the oil can negatively affect the process and lead to hydrolysis and the formation of free fatty acids. To mitigate this negative effect, the researchers recommend drying the oils before or after placing them in the autoclave, since these compounds can be saponified under hydrogenation conditions at high temperatures and using a nickel catalyst. Initial stage of the process hydrogenation involves heating the oil to 140 °C, which is the initial temperature for the reaction reported in all studies analyzed. It was found that the specific reaction temperature may vary depending on the type of fat and the desired level of inhibition of trans fatty acid formation.

The analysis revealed that the most common definition of oil hydrogenation is the saturation of double bonds in unsaturated fats using nickel as a catalyst. This process involves a complex set of reactions in addition to the actual saturation. The equipment for stepwise hydrogenation has a relatively simple design. The main design features identified in all the studies analyzed include a vessel capable of withstanding a gauge pressure of 35–40 kPa, a stirrer, a heating and cooling mechanism, a hydrogen inlet, a pipeline, a pump for feeding the feedstock, and a sampling pipe for monitoring the reaction. This equipment allows for the control of three main parameters: pressure, temperature, and stirring speed.

The hydrogen pressure in the reaction, according to the analyzed data, is measured in the main reactor space and is controlled by an inlet valve. The headspace can also be vented to remove gaseous impurities such as methane, nitrogen, carbon dioxide, and carbon monoxide. However, this venting process results in some loss of hydrogen gas. Sánchez et al. reported that venting increases the flow of hydrogen through the reaction mass, resulting in increased mixing (Sánchez, M. A., Torres, G. C., Mazzieri, V. A. and Pieck, C. L., 2017). Several factors influence the mixing in the reactor. The main ones are the type and speed of the stirrer blades. In addition, the overall mixing effect is influenced by the design and number of heating and cooling coils, the presence of baffles, and the rate at which hydrogen enters through the perforated distribution ring at the bottom of the reactor. Heating of the oil in batch hydrogenation is typically achieved using high-pressure steam coils. The analyzed data showed that temperatures in the range of 140 to 225 degrees Celsius have been used for nickel-catalyzed hydrogenation. Jang et al. reported that higher temperatures could be achieved by initiating the reaction at a standard starting temperature and providing exothermic heat of reaction to raise it to the desired level (Jang, E. S., Jung, M. Y. and Min, D. B., 2005).

To initiate the hydrogenation process, the oil is pumped into the converter while a vacuum is created in the headspace, after which it is heated. At the same time, the catalyst is weighed and mixed in a catalyst mixture tank to form a slurry with a small amount of oil. Once the desired gassing temperature is reached, the catalyst is pumped into the reactor and thoroughly mixed with the oil. Hydrogen is then added to achieve the desired pressure. The reaction is initiated and the temperature is gradually increased to the operating temperature. To maintain the desired temperature, the reaction mass is cooled if necessary. The progress of the reaction is monitored by observing changes in the refractive index. It has been found that most researchers point to the need for preliminary staged treatment of the oil before the hydrogenation process. The raw material should be cleaned, bleached and have a low soap content. According to Allen, the amount of soap substances in the fat should be less than 25 mg / kg. In addition, the oil must be dry to ensure optimal hydrogenation results. As for the hydrogen used in the process, the gas must also be dry and have a low amount of impurities. Modern hydrogen production plants using hydrocarbons can produce extremely pure hydrogen. On the other hand, older plants may produce hydrogen that contains some methane, carbon dioxide, and potentially significant amounts of nitrogen if the feed gas contained a high content of these gases. Some hydrogenation plants have been designed to extract hydrogen from stored liquid hydrogen, which serves as a reliable source of backup gas in case of a gas plant shutdown. According to Žula et al., liquid hydrogen has a high purity (Žula, M., Grilc, M. and Likozar, B. Hydrocracking). In general, both the oil and the hydrogen used in the hydrogenation process must meet certain criteria for purity and dryness to ensure the efficiency of the process.

It is worth noting that in the process of partial hydrogenation, a significant amount of trans-fatty acid isomers (TJK) is formed.

It has been found that the degree of unsaturation of the oil and various process conditions influence the formation of trans fatty acid isomers during hydrogenation. Table 1 provides an overview of how these factors affect TFA production. Since hydrogen plays a critical role in the trans isomerization process, it is important to supply sufficient hydrogen to the catalyst. This can be achieved by increasing the pressure or improving the mixing conditions. In addition, oils rich in unsaturated fatty acids require more hydrogen compared to highly saturated fats.

Table 1. The influence of process conditions and fat saturation on the hydrogenation process

Change parameter	Positive influence	
	Hydrogen concentration on nickel catalyst	**Education of TJK**
Temperature increase	–	+
Intensification of mixing	+	–
Increasing the catalyst content	–	+
Increased catalyst activity	–	+
Increased pressure	+	–
Increased content of unsaturated fatty acids	–	+

Conclusions

The study found that the most important characteristics of a catalyst for fat hydrogenation are its activity, durability, selectivity, and stability of isomer formation. It was found that catalyst selectivity is a key factor in obtaining target edible fats by stepwise hydrogenation. It was found that different researchers use different definitions of this term. The most successful definition of selectivity is the rate of various reactions during hydrogenation. The work demonstrated that reuse of the catalyst can lead to a decrease in selectivity. Thus, to obtain the most important components, its reuse should be avoided. The problem of forming trans-isomers of fatty acids, which reduce the food quality of fats, was identified as one of the main disadvantages of the stepwise hydrogenation technology. The main factors that contribute to the formation of trans-isomers of fatty acids were high temperature, catalyst specificity, and the use of raw materials with a high amount of unsaturated fatty acids.

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