Enzymatic Interesterification: Process Advantages and Product Benefits

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INTRODUCTION

There are many reasons for changing the melting properties of fats and oils (and mixtures of these) ranging from increasing or decreasing the melting point (or cloud point) of an oil, to altering the melting profile of an oil mixture.

Basically, five different methods of changing the melting properties profiles of fats and oils exist - blending, fractionation, chemical interesterification, enzymatic interesterification and hydrogenation. In this presentation, we will only discuss the last three methods which have one thing in common; they all change the composition of the fat molecules during the process.

Interesterification or ester-ester exchange is a process during which the fatty acids of triglycerides exchange positions from one glyceride to another, thereby altering the overall chemical composition and physical properties of the interesterified fats. Interesteri- fication is thus an efficient way for changing and controlling the melting characteristics of oils and fats.

Hydrogenation alters the fat composition by addition of hydrogen atoms to the double bonds.The hydrogenated fat is made less unsaturated and thereby more hard during the process.

We will show how enzymatic interesterification has been developed and made cost-efficient, so that it now can compete with chemical interesterification and hydrogenation, both on process benefits, product quality and on the overall process costs (capital an operational).

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DEVELOPMENTS WITHIN ENZYMATIC INTERESTERIFICATION

Enzymatic interesterification has been used by scientists in laboratory scale columns, producing up to a few kilos of product per hour, for more than 20 years. But due to normally high enzyme prices,market penetration has been limited to specialty products.

A quantum leap in lipase immobilization technology was obtained with the development of the granulation technology. The technology led Novozymes to develop a low cost silica granulated lipase for bulk fat modification. This granulated lipase product enables lipases to be used for production of bulk fats such as margarine, shortenings and vanaspati by interesterification.

Although the granulated lipase product can be used in both batch and continuous fixed bed operation, we will only discuss the use of graulated lipases in fixed beds.

FROM LABORATORY TO PRODUCTION SCALE

In order to turn enzymatic interesterification into an industrial process for bulk fat modification, it was necessary to scale up the process from the laboratory scale to produce industrial amounts of interesterified fat. In scaling up, it is not sufficient to only get enough product out of the column. It is also necessary to focus on the reaction kinetics and the physical parameters of the immobilized lipase to design a good reactor.

To establish the basis for a good design, studies of the reaction kinetics, particle stability, pressure drop and film diffusion resistance were undertaken to characterize the immobilized lipase product.

Besides being well suited for the observed kinetics, the reactor should be simple, inexpensive, mobile, easy to operate, robust and capable of being plugged in between existing feed and product tanks in the oil mill.

Based on our studies and considerations, we developed a Plug & Play Reactor for production scale.

A fixed bed reactor was chosen as the reactor type. All the listed criteria were met. The reactor was additionally designed so that it could be easily filled with the granulated lipase on arrival, and thereafter be plugged in (either alone or

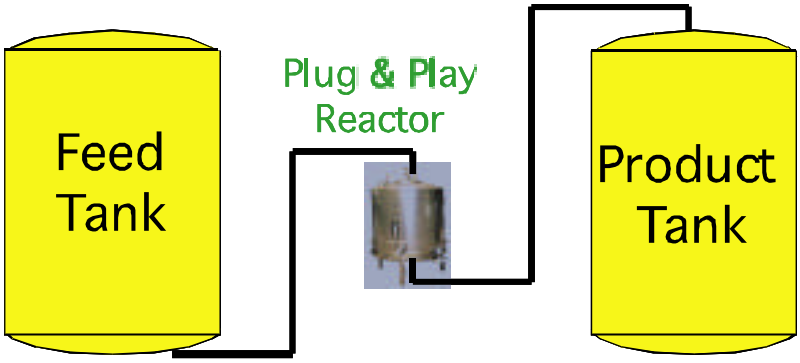


Figure 1. The Plug & Play Reactor.

several in series) between two existing tanks at the oil mill *(Figure 1).*

PARTIAL HYDROGENATION

In hydrogenation, the double bonds are broken resulting in a harder oil. Hydrogenation is carried out with hydrogen at high temperature/pressure, catalyzed by a nickel catalyst. By controlling the degree of hydrogenation, it is possible to control the melting profile of the fat. The process requires very pure hydrogen which can be obtained by different methods in a separate hydrogen plant. Hydrogen is the highest variable cost in the process. The overall reaction takes approximately 2 hr. After the reaction, addition of citric acid is required to eliminate nickel soaps, filtration, bleaching and deodorization done *(Figure 2).*

The disadvantages of the process are the use of hydrogen, chemical catalyst (nickel) and the formation of *trans* fatty acids. *Trans* fatty acids are believed to have a negative impact on health when consumed in large amounts. The content of *trans* fatty acids often increases to 15%-25%, and under certain circumstances as high as 50%.

Fully hydrogenated fats do not contain *trans* fatty acids, because all the double bonds in the fat molecules have been eliminated.However, the melting profile, which makes, *e.g.* a margarine pleasant to eat has to be adjusted for. One way to achieve a more suitable melting profile without producing *trans* fatty acids, is to mix a fully hydrogenated fat with a naturally liquid oil or to interesterify the mix to get the specific melting profile of the end product.

CHEMICAL INTERESTERIFICATION

Interesterification adjusts the melting profile of a blend of saturated and unsaturated fats. In contrast to hydrogenation and (as shown later) enzymatic interesterification, there is no possibility of a partial reaction in chemical interesterification. This is because the chemical interesterification occurs very rapidly – once started, equilibrium is reached within minutes. The reaction will therefore be completed and the properties of the interesterified product can only be controlled by the composition of the fat ingredients. Although the reaction time is short, washing, bleaching and deodorization are required after chemical interesterification. The most common chemical catalysts are sodium methylate (methoxide) or sodium ethylate (ethoxylate). The catalyst shifts the fatty acids of the triglycerides around randomly. No *trans* fatty acids are produced, but the catalyst requires thorough purification downstream after the interesterification to give the required quality (*Figure 3*).

The drawback of chemical interesterification is, that the catalysts are very reactive and must be handled with extreme care to prevent contact with the skin or eyes. In contact with water, the catalysts may explode.

The process is carried out at harsh conditions, and the by-products formed need to be removed by bleaching and washing.

All three positions of the tryglycerides are shifted randomly,which creates a less natural fat compared to the enzymatic method. The process produces wastewater, and the oil loss is 5-10 kg t^{-1} due to the post-treatments needed. And, as mentioned, the level of interesterification cannot be controlled. The reaction goes all the way to complete randomization in a few minutes.

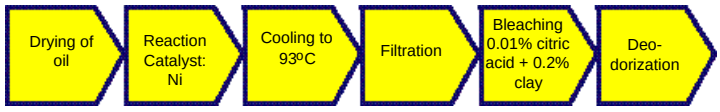


Figure 2. Batch process.

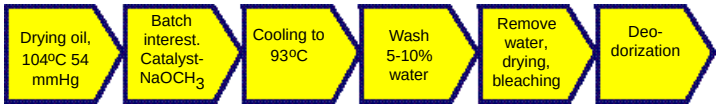


Figure 3. Batch process.

ENZYMATIC INTERESTERIFICATION

The catalyst in enzymatic interesterification is a 1,3-specific lipase.

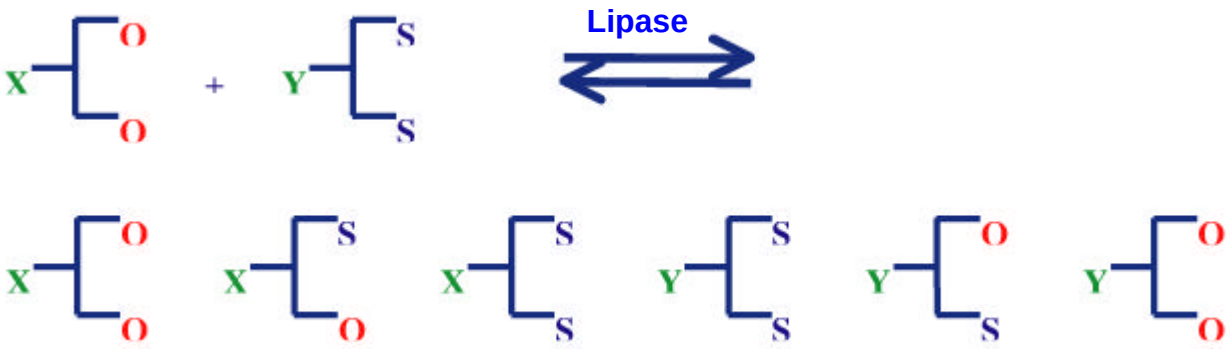


Figure 4. Interesterification using a 1,3-specific lipase.

Using a 1,3-specific lipase, only the fatty acids in the 1,3-positions are shifted around, while the 2-position is left untouched. Preservation of the 2-position means that a more natural fat is produced. This is in contrast to chemical interesterification where all three positions are juggled randomly around.

In *Figure 4*, an example of enzymatic interesterification of two triglycerides using a 1,3-specific lipase is shown. Once the lipase is added to this mixture, the fatty acids on the outer positions (1- and 3-positions) are exchanged, leaving the fatty acid in the 2-position untouched. Interesterification of these two triglycerides result in a mixture containing six triglycerides whereas random chemical interesterification produces a mixture of 40 triglycerides (not shown).

It is important to understand that even though different mixtures of triglycerides are obtained using either chemical or enzymatic interesterification (using a 1,3-specific lipase), it is still possible to obtain the desired modification of the melting curves for the interesterified fat.

Examples of the melting profile modification, obtained with chemical and enzymatic interesterification of a mixture of palm stearin and coconut oil (60/40) is shown in *Figure 5*, which gives the solid fat content.

Very similar melting profiles are obtained with the chemical and enzymatic interesterified products, and both reactions give the desired low melting points at 35°C-40°C. A margarine produced from these interesterified mixtures will have good mouth feel because of the improved melting properties.

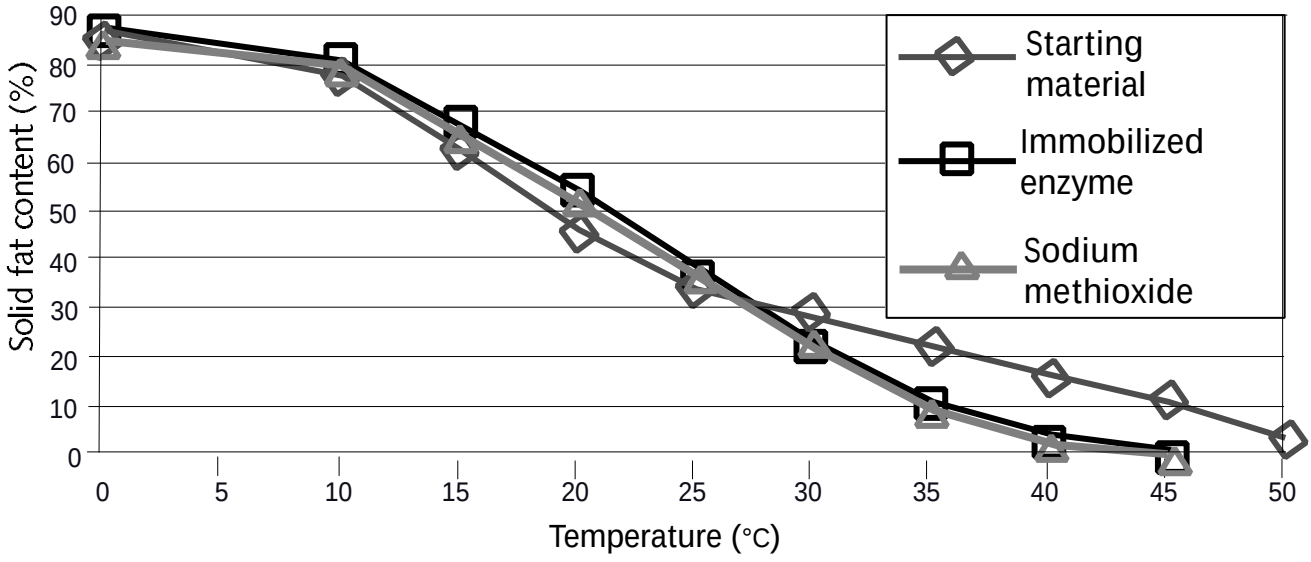


Figure 5. Melting properties of a palm stearin/coconut oil mixture.

The enzymatic process is much simpler than the chemical and there is no requirement for any post-treatment of the interesterified oil afterwards. Due to the harsh conditions required for the chemical catalyst, unwanted by-products are inevitable and post-treatment necessary.

No chemicals are used in the process and no *trans* fats are formed (*Figure 6*).

The benefits of enzymatic interesterification are low investment costs (less expensive equipment needed), simple and easy continuous process, no *trans* fatty acids produced, more natural fat produced, production of a large variety of end-products, environmentally friendly production, and no use of chemicals/solvents.

Figure 6. Continuous or batch processes can be applied.

COSTS OF PROCESSES

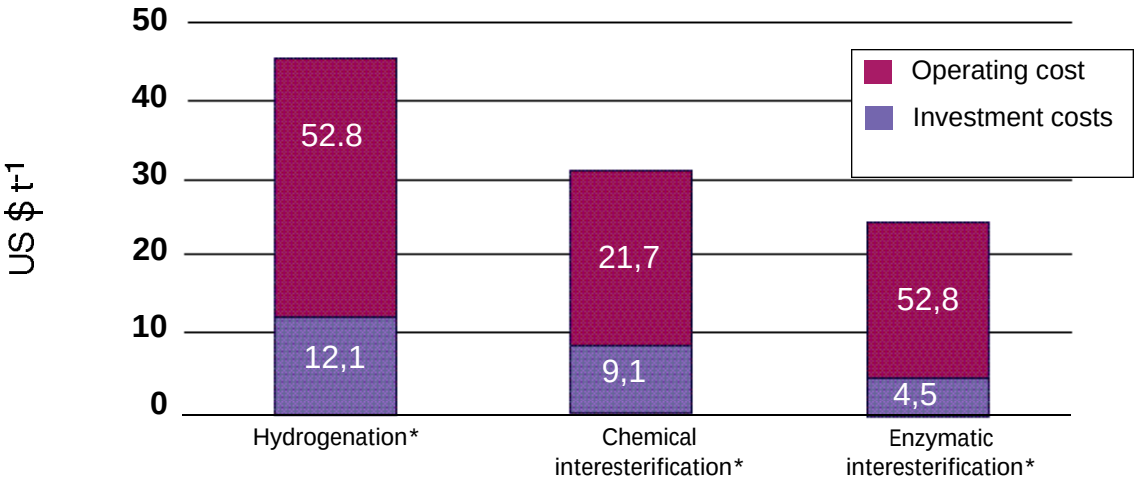
As shown in *Figure 7*, enzymatic interesterification has truly become cost-efficient to chemical interesterification and hydrogenation.

It is fairly easy to do a direct comparison between chemical and enzymatic interesterification. When comparing partial hydrogenation with interesterification, it needs to be taken into consideration whether the hard fat fraction is an expensive fully hydrogenated fat or an inexpensive tropical fat.

CONCLUSION

Enzymatic interesterification of fats and oils provides a safe, easy and cost-efficient alternative to chemical interesterification and hydrogenation. The process gives a more natural product, free of *trans* fatty acids.

The process can easily be implemented in existing factories fo continuous operation. As no chemicals are used and the operating conditions mild, the only post-treatment needed is deodorization.



Note: *Data from M. Kellens (2000). Edible Oil Processing (Hamm and Hamilton eds.). p. 155.

Figure 7. Comparing the operation and investment costs of the three methods.