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KINETIC ANALYSIS OF AUTO-OXIDATION IN REUSED SUNFLOWER COOKING OIL AND DETERMINATION OF OPTIMUM PROCESS CONDITIONS

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Abstract

This study investigates the kinetic behavior of reused sunflower cooking oil to determine the optimum conditions for its processing and potential reuse. The feedstock, obtained from commercially available sunflower oil, was subjected to repeated heating cycles to simulate domestic cooking practices. The auto-oxidation reaction was monitored by evaluating the variation in the absorption coefficient at specific wavelengths, representing the extent of oxidative degradation. The kinetic parameters, including rate constant and activation energy, were calculated from experimental data using the Arrhenius equation. Results indicated that the oxidation rate increased with temperature and frequency of reuse, while controlled heating below 150 °C significantly reduced degradation. Optimum conditions were achieved at moderate temperatures (140–150 °C) and limited reuse cycles (up to 3), minimizing auto-oxidation and preserving oil quality. The findings provide a kinetic basis for improving the sustainability and safety of cooking oil reuse in domestic and commercial settings.

1. Introduction

Cooking oils are widely used in food preparation, but repeated heating during frying leads to significant physicochemical changes that degrade their nutritional and functional qualities. Sunflower oil, known for its high content of unsaturated fatty acids, is particularly prone to oxidation when exposed to heat, oxygen, and light. During repeated use, these reactions result in the formation of hydroperoxides, aldehydes, and other polar compounds, which compromise both flavor and safety.

Understanding the kinetics of oil oxidation is essential for establishing safe reuse conditions and preventing the formation of toxic degradation products. This research focuses on reused sunflower oil, examining its auto-oxidation behavior by tracking changes in its absorption coefficient—a sensitive indicator of oxidation level. The study aims to derive kinetic parameters and determine optimum temperature and reuse conditions that minimize degradation.

2. Materials and Methods

2.1 Feedstock Preparation

Commercially available refined sunflower oil was used as the initial feedstock. Samples were subjected to controlled heating at different temperatures (100 °C, 150 °C, 180 °C, and 200 °C) for specific time intervals to simulate reuse cycles (up to five times). Between each heating cycle, the oil was allowed to cool to room temperature to mimic real-life cooking practices.

2.2 Experimental Procedure

Auto-oxidation was monitored spectrophotometrically. The absorption coefficient was measured at 232 nm and 268 nm, corresponding to conjugated dienes and trienes formed during oxidation. Samples were collected at fixed intervals to determine the rate of change in absorbance, which was used to calculate the rate constant (k) for each condition.

2.3 Kinetic Modeling

The reaction rate was assumed to follow first-order kinetics with respect to the concentration of unoxidized oil:

$\frac{dA}{dt} = -\mathrm{k}[\mathrm{A}]$ ------------------------ (1)

where A represents the concentration of unoxidized oil and k is the rate constant. The Arrhenius equation was used to determine the activation energy (Ea) from the temperature dependence of k:

$k = Ae^{-\frac{E_a}{RT}}$ ------------------------ (2)

2.4 Determination of Optimum Conditions

Optimum processing conditions were identified as those minimizing the rate of oxidation while maintaining oil usability. These were determined by comparing rate constants and absorption changes across all temperature and reuse cycles.

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3. Results and Discussion

The absorption coefficient increased progressively with temperature and number of heating cycles, confirming enhanced oxidation at higher thermal exposure. The kinetic plots of ln [Ao/A] versus time yielded linear relationships, supporting first-order reaction behavior. The calculated rate constants increased exponentially with temperature, consistent with Arrhenius kinetics.

Activation energy for the oxidation process was found to be within the range of 35–45 kJ mol^{-1}, comparable to reported values for vegetable oil oxidation. At temperatures above 180 °C, a sharp rise in oxidation rate indicated accelerated degradation and polymerization reactions. However, at moderate heating (140–150 °C), oxidation was significantly slower, and the oil retained acceptable sensory and chemical properties after three reuse cycles.

These findings emphasize that maintaining lower processing temperatures and limiting reuse cycles can substantially reduce oxidative damage, thereby extending the safe usability of cooking oils.

4.1 Advantages and Limitations of the Study

Advantages

1. **Quantitative Kinetic Evaluation:**
   The study provides a detailed kinetic analysis of auto-oxidation in reused sunflower oil, allowing quantitative estimation of rate constants and activation energy—parameters often overlooked in similar works.
2. **Practical Relevance:**
   The experimental design simulates real domestic and commercial frying conditions, making the findings directly applicable for improving household and food industry practices.
3. **Sustainability Insight:**
   By identifying optimum reuse temperatures and limits, the study promotes more sustainable oil utilization, minimizing waste and reducing environmental disposal issues.

Disadvantages / Limitations

1. **Limited Range of Variables:**
   The study considers only temperature and reuse cycles; other influential factors such as light exposure, aeration rate, and presence of antioxidants were not included.
2. **Single-Oil System:**
   Results are specific to refined sunflower oil and may not directly apply to other edible oils with different fatty acid compositions or impurity levels.
3. **Laboratory-Scale Simulation:**
   The heating and cooling cycles, though representative, may differ slightly from actual frying conditions involving food materials, which can accelerate oxidation.

4. Conclusion

This study provides a kinetic understanding of auto-oxidation in reused sunflower oil. The reaction follows first-order kinetics, with the rate constant strongly dependent on temperature. Optimum conditions were achieved at 140–150 °C with a maximum of three reuse cycles, under which oxidative degradation remained minimal. These insights contribute to establishing guidelines for safe and sustainable cooking oil reuse in household and industrial applications.

5. References

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