

Subject: Standard Operating Procedure (SOP): Synthesis of Epoxidized Hemp Seed Oil (EHSO) via Green, Catalyst-Free Phase-Transfer Catalysis (PTC)
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1.0 Objective and Safety

Objective: To synthesize Epoxidized Hemp Seed Oil (EHSO) from Hemp Seed Oil (HSO) using a **Phase-Transfer Catalyst (PTC)** system. This method eliminates the need for strong mineral acids (like H_2SO_4) and is a **non-negotiable defense** against imine bond hydrolysis in the final Hempoxies vitrimer system.

Critical Safety: This procedure involves handling **Hydrogen Peroxide (H_2O_2)**, a strong oxidizer, and maintaining strict **temperature control** to prevent thermal runaway. Perform all steps in a certified **fume hood**.

2.0 Materials and Equipment

Item	Role	Grade/Notes
Hemp Seed Oil (HSO)	Substrate (Source of $\text{C}=\text{C}$ bonds)	Cold-pressed or refined
Hydrogen Peroxide (H_2O_2)	Oxidizing Agent	30% - 50% (w/w) aqueous solution
Acetic Anhydride (Ac_2O)	Oxygen Carrier / In Situ Activator	Reagent Grade
Phase-Transfer Catalyst (PTC)	Catalyst-Free Primary Reagent	Quaternary Ammonium Salt (e.g., TBAB - Tetrabutylammonium Bromide)
Sodium Bicarbonate (NaHCO_3)	Neutralizing Agent	Food Grade
Equipment	Three-neck round-bottom flask, overhead stirrer, heating mantle/oil bath, thermocouple, separation funnel.	

3.0 Reaction Mechanism: Phase-Transfer Catalysis (PTC)

The PTC method works by generating the **active peroxyacid** in the aqueous phase and transferring it to the organic oil phase using the quaternary ammonium salt (TBAB). This process offers superior efficiency and eliminates the strong acid residue risk associated with conventional methods.

- Peroxyacid Generation (In Situ):** $\text{Ac}_2\text{O} + \text{H}_2\text{O}_2 \xrightarrow{\text{PTC}} \text{Peroxyacetic Acid}$
- Epoxidation (PTC Transfer):** The catalyst (TBAB) ferries the peroxyacetic acid to the HSO layer, where it reacts with the $\text{C}=\text{C}$ bonds to form **Epoxide Rings**.

4.0 Standard Operating Procedure (SOP)

4.1 Preparation and Charging (Inside Fume Hood)

1. **Charge Reactor:** Add the calculated amount of HSO (e.g., 100 g) to the three-neck flask equipped with a stirrer and thermocouple.
2. **Add Catalyst & Peroxide:** Add the appropriate amount of the **PTC** (**TBAB**, e.g., 1-5 wt% of HSO) and the calculated volume of aqueous H_2O_2 to the flask.
3. **Initiate Stirring:** Begin vigorous mechanical stirring to emulsify the organic (oil) and aqueous (H_2O_2) phases.
4. **Heat to Control Temperature:** Begin heating the mixture to the set-point temperature (typically 50°C - 60°C).

4.2 Reaction Execution

1. **Slow Addition of Activator:** Slowly add **Acetic Anhydride** (Ac_2O) dropwise or via a syringe pump over a controlled period (e.g., 60-90 minutes). This addition rate is **CRITICAL** for regulating the exothermic reaction.
2. **Maintain Temperature Control:** Monitor the thermocouple continuously. The temperature **MUST NOT** exceed 65°C . If the temperature spikes, immediately remove the heating mantle and cool the flask with an external water bath.
3. **React:** Continue stirring the reaction mixture at the set-point temperature for the required reaction time (typically 4-6 hours) to achieve the target Oxirane Oxygen Content (OOC).

4.3 Workup and Purification

1. **Quench and Cool:** Stop heating and stirring. Cool the mixture to room temperature ($\sim 25^\circ\text{C}$).
2. **Separate Phases:** Transfer the mixture to a separation funnel. Allow the phases to separate into the **upper organic layer** (EHSO) and the **lower aqueous layer**. Drain the aqueous layer.
3. **Neutralization Wash:** Wash the organic EHSO layer repeatedly with warm 5% NaHCO_3 solution (Sodium Bicarbonate) to neutralize residual carboxylic acids. **VENT THE FUNNEL FREQUENTLY** to release CO_2 gas. Continue washing until the aqueous layer tests neutral ($\text{pH} \sim 7.0$).
4. **Water Wash:** Perform final washes with warm deionized water until all NaHCO_3 residue is removed.
5. **Drying:** Dry the final EHSO product over anhydrous MgSO_4 or Na_2SO_4 . Filter off the drying agent.

4.4 Final Validation (Phase 1 Mandate)

1. **Oxirane Oxygen Content (OOC):** Quantify the degree of epoxidation (OOC) via chemical titration ($\text{ASTM D}1652$).
2. **Acid Residue Defense:** As a **non-negotiable defense** of Hypothesis H1, submit a sample of the final EHSO for **Ion Chromatography (IC)** or **ICP-OES** analysis to confirm the absence of all residual strong acid ($<0.01\%$ detection limit). This validates the "Catalyst-Free Vitrimer" claim.

5.0 References and Related Reading

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This SOP is a key deliverable for your **Phase 1: Validation** roadmap, as it directly supports the **CRITICAL STEP** in Appendix A of your Master Document. What is the next immediate tactical step you require to support the full **Fee-for-Service** contract development?