TECHNICAL BULLETIN:

Green Chemistry as it relates to HRC® and 3D-Microemulsion®

The Concept of Green Chemistry

The term "green" is used to describe processes, products, or activities that have little or no detrimental effects to the environment and human health and safety. In recent years, the American Chemical Society (ACS) and the United States Environmental Protection Agency (US EPA) have emphasized the importance of green chemistry for the chemical industry. From the EPA website on this subject, the concept is briefly defined as follows:

"Green chemistry, also known as sustainable chemistry, is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle, including the design, manufacture, and use of a chemical product"

- US EPA website: www.epa.gov/gcc/

To further define the concept of green chemistry, both the US EPA and the ACS have cited the book "Green Chemistry, Theory and Practice" by Anastas and Warner,[1] which defines twelve principles of green chemistry. In the context of these twelve principles, we have determined the 3D-Microemulsion, HRC, HRC-X, and HRC-Primer products (HRC product family) to be significanty green chemical technologies. The twelve principles of green chemistry are outlined below with descriptions of how the HRC product family complies on nearly all accounts.

Twelve Principles of Green Chemistry[1]

And how they are reflected in the HRC family of Products

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.

   The HRC™ family of products (HRC™, 3D-Microemulsion, HRC-X™, HRC Primer™) are manufactured in such a way that there is no waste resulting from their production. Water is the sole byproduct of the manufacturing processes.

2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.

   HRC™, 3D Microemulsion™, and related products are formulated from agriculturally derived chemicals with little or no toxicity, including lactic acid (and its polymeric forms), potassium phosphates, oleic acid, and glycerol.

3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.

   As mentioned in #1, all of the HRC family of products contain nearly 100% of the ingredients that are used in their synthesis. The only residuals from their manufacture are the water removed from esterification reactions and residual lactic acid that can be reused in subsequent batches.

4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.

   The HRC family of products are each produced from over 95% renewable feedstocks derived from agricultrual products. These include primarily lactic acid, fatty acids, and glycerin.

5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.

   The syntheses of the glycerol polylactate (HRC) and the HRC-Advanced molecule (3D Microemulsion) involve esterification reactions that are catalyzed by acids. An added benefit of the chosen catalysts is that they become active ingredients in the final formulation.

6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.

   HRC products are synthesized with a building-block type approach, where structures are built upon only with molecular fragments that are included in the final product. No protecting-groups or temporary modifications are made. This minimizes waste and maximizes energy efficiency.

7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.

   See #6. Only water is a by-product of the syntheses of HRC products, making them 100% atom-economical.

8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.

   The reaction ingredients, and ultimately the constituents of the final products act also as solvents for the reactions to occur. These environmentally friendly, renewable materials allow for a process that has no waste and uses no solvent that need be removed, recycled, or destroyed.

9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.

Aside from the esterification reaction steps (which require elevated temperature and reduced pressure), the HRC products formulations are made and blended at ambient temperature and pressure to minimize associated energy costs.

10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.

    By design, Regenesis products are made to have little or no detrimental impact on groundwater quality or the environment. The biodegradation of HRC and related products is their intended use- a mechanism for destruction of harmful contaminants in groundwater. The degradation of the HRC products themselves produce innocuous materials including lactic acid, acetic acid, hydrogen (in very low concentrations), fatty acids, carbon dioxide, and water.

11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.

    Water, the sole byproduct of HRC products syntheses, is monitored through the course of esterification reactions as an indicator of completeness of the reaction process. The weight measurement of water allows the minimization of wasted energy by allowing the operator to conclude the manufacturing run immediately when the reaction is complete.

12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment

    As viscous liquids, the HRC family of products are very easily handled and have no toxic or harmful volatile constituents. They are considered non-hazardous materials by the DOT and carry little or no environmental risk upon accidental release to the environment.

References

1. Originally published by Paul Anastas and John Warner in **Green Chemistry: Theory and Practice** (Oxford University Press: New York, 1998). Taken from: http://www.epa.gov/greenchemistry/pubs/principles.html