TYRELL CHEMICAL

REPLACING 3M NOVEC FLUIDS (HFEs) IN HEAT TRANSFER APPLICATIONS

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Heat Transfer Fluid Types

Replacing 3M NOVEC fluids for your heat transfer applications requires an understanding of not only the basic chemistry of your fluid replacements, but also the production processes that is employed when producing your replacement fluid.

What is in this Paper?

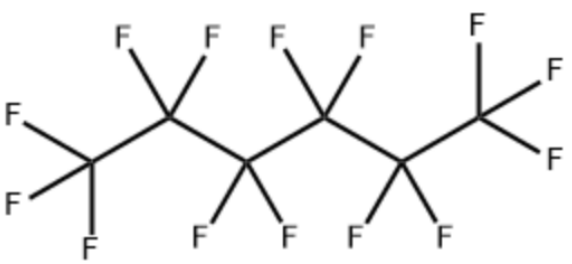
In this paper, we will examine the problems and solutions for meeting the goals of your heat transfer applications and how the production processes is a crucial component when replacing 3M Novec fluids.

The Evolution of Heat Transfer Fluids

Fluorinated Heat Transfer Fluids have undergone significant evolution over the years in a desire to be more sustainable for the environment. Traditional perfluorochemicals (PFCs) began to be replaced by Perfluoropolyether (PFPE) and then replaced by hydrofluoroethers. (HFE).

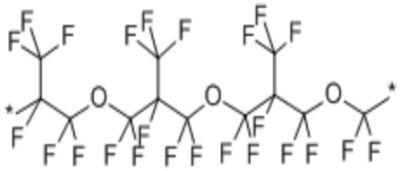
PFCs

Perfluorocarbons (PFCs) are a class of synthetic organofluorine compounds where all the hydrogen atoms in a hydrocarbon are replaced by fluorine atoms. The key material in PFCs are Fluorspar. PFCs consist of Carbon-Fluorine (C-F)bonds in long-chain form molecules. While PFC's are inherit chemicals they have higher GWP levels yet still have zero Global Warming potential



Perfluoropolyether's (PFPE's)

After CFCs and PFCs were in use for many decades, PFPEs were developed in an attempt to make a class of synthetic, inert fluorinated polyether's. Their molecular structure consists of carbon, fluorine, and oxygen atoms arranged in a polymer chain. They are known for their exceptional stability and unique properties due to the strong carbon-fluorine and carbon-oxygen bonds. They are characterized by thermal stability, low volatility, low surface energy and high dielectric strength.

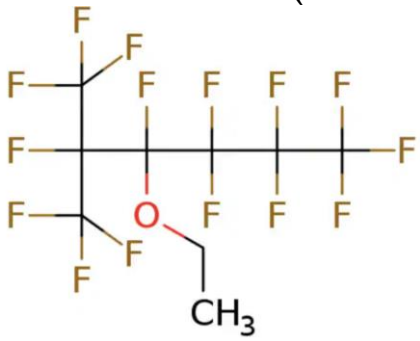


PFPEs include an oxygen atom in order for the chain to break apart in the environment. Therefore, short-chain molecules are released into the environment instead of long-chain fluorine-carbon bonds.

Tyrell Chemical offers a range of PFPEs with boiling points from 50c to 270c.

Hydrofluoroethers (HFE's)

Hydrofluoroethers are a class of synthetic organic compounds that contain carbon, hydrogen, fluorine, and oxygen atoms connected by ether linkages. They are **not considered fully fluorinated** molecules as compared to PFPEs. They were primarily developed as environmentally friendlier replacements for ozone-depleting substances. They have high thermal stability, low toxicity, low global warming potential and zero Ozone depletion. HFE's from an environmental standpoint are superior to PFPE's when produced using the synthesis method. (More on this later)



Fluorspar is the base material used when producing all Fluorinated Heat Transfer Fluids

The Production of Hydrofluoroethers (HFE's)

How are Heat Transfer Fluids produced?

How are Heat Transfer Fluids produced?

Fluorinated HTFs can be produced by Electrochemical Fluorination (**ECF)** or **Telomerization**, i.e. the synthesis method (used by Tyrell). 3M has traditionally produced HFE's with Electrochemical Fluorination which involves passing electric current through a solution of hydrogen fluoride and some organic precursors to replace hydrogen atoms with fluorine, producing fully or partially fluorinated compounds. Electrochemical Fluorination was a foundational technology for 3M, enabling the large-scale production of perfluorochemicals with diverse and valuable applications. Telomerization on the other hand, is a polymerization production process where a telogen reacts with a monomer to produce short-chain polymers.

The Downsides of ECF production

ECF has several major drawbacks in producing HTFs when compared to telomerization. The first drawback for ECF is control of the molecular chain length. Telomerization provides a defined chain length offering better control, selectivity (uniformity) , and versatility as well as having a lower energy input.

The major drawback in ECF is concerns over PFOAs. The ECF production process has a tendency to produce PFOA as a byproduct due to poor chain length control, incomplete fluorination, and/or side reactions.

PFOA

PFOA is a persistent, bio accumulative PFAS. PFOA is not an intended component of ECF production, but as a byproduct, it is unavoidable.

The Benefits of Telomerization

Telomerization on the other hand, is a polymerization production process where a telogen reacts with a monomer to produce short-chain polymers.
Telomerization produces chemicals with Short Chain Polymers which are better for the environment than long chain because the extra Oxygen molecule (s) enable the chemical to breakdown faster in the environment.

Where are we headed?

Over the past ten years the industry, sometimes by country, has changed the definition of PFAS chemicals. The industry's desire to produce PFAS free, more environmentally friendly chemicals, necessitates changes. Changes, both with production processes as well as chemical formulations, which include additional chemicals to the production process. Creating chemicals which are completely PFAS free may not be possible for chemicals required in complex industries such as semiconductor manufacturing, high temperature CPU cooling and many others.

Chemical producers will likely not perfectly replicate all of the performance matrix of the PFAS chemicals we are replacing. Tyrell's boutique production capabilities allow us to create custom blends of the chemicals in our product line to optimize for certain factors such as vapor pressure and temperature operating range.

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Tyrell Chem: Building the world's most effective HTF's

Tyrell Chemical uses only the Telomerization process on production of HTFs , therefore, avoiding the environmentally contaminating ECF process. Tyrell's boutique production capabilities allow us to create custom blends of the chemicals in our product line to optimize for certain factors such as vapor pressure and temperature operating range.

Tyrell Chemical Novec replacements have been designed to replace the Novec HFE product lines across a range of requirements. Tyrell manufacturing capacity is 50 MT per month. Tyrell operations are ISO14001 and ISO9001 certified.

Fluorinated Liquid Production Reactor

Fluorine Liquid Production Evaporator

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