General Electric soon cleared a cornfield near the Mohawk River in New York and built on it a manufacturing plant to make the methyl silicones. This is what Chemical Engineers do.

Building a manufacturing plant might seem to be a simple activity. Wouldn't GE just increase the size of Rochow’s equipment; make a bigger chemistry set to make the silicones? Let's look at the steps:

- Buy some HCl and methyl chloride.
- Mix Si and Cu, heat the mixture and flow the two gases, HCl and CH₃Cl over the Si and Cu catalyst.
- Take the product (CH₃)₂SiCl₂(9), and react it with water.
- Collect the methylsilicone polymer.

But the commercial manufacture of the silicones required far more than Rochow’s experiments. It required the work of many men and women called Chemical Engineers.
Making Silicone Polymers

The reaction of silicon with methyl chloride has a high activation energy. This means that a great deal of energy must be supplied -- in the form of heat -- to achieve the activated complex that proceeds to products.

\[ 2\text{CH}_3\text{Cl} + \text{Si} \rightarrow (\text{CH}_3)_2\text{SiCl}_2(9) \]

But then the reaction itself is highly exothermic and if left unattended, the process temperature will rise, the rate will increase and even more heat will be generated in a "runaway" process. Additonally, if the temperature of the reaction mixture rises as result of the heat generated in the exothermic synthesis, a series of alternate products is formed. These are called "impurities" among chemists. They represent synthesis of unwanted byproducts.

So GE's engineers faced a situation in which the temperature must be nearly 300 degrees Celsius to start the reaction, but heat must be removed efficiently to operate the synthesis of (9) most efficiently.
A sketch of the reactor in which methyl chloride and Si were contacted reveals the kind of "units" that the GE engineers combined into the methylsilicone manufacturing unit.

A "superheater" heats the methyl chloride before it reaches the reactor. The silicon is fed into a reactor that is stirred or "fluidized" by passage of hot gas through the bed of copper-containing silicon. A "heat transfer coil" removes excess heat by transferring it to a cooler, circulating fluid. The engineers stopped silicon powder from being carried through the reactor by collecting it in two different types of filters. A "condenser" cools the gases from the reactor to a liquid that contains all the products.

But a chemical reactor is not sufficient equipment to isolate a usable chemical product in the purified state from all other substances. Experiments led to a material balance for the preparation of \((\text{CH}_3)_2\text{SiCl}_2\). GE's engineers isolated the following products in the order of their abundance:

- \((\text{CH}_3)_2\text{SiCl}_2\) boiling point 70.0 degrees Celsius
  - \(\text{CH}_3\text{SiCl}_3\) boiling point 65.7 degrees
  - \(\text{HSiCl}_3\) boiling point 31.8 degrees
  - \((\text{CH}_3)\text{HSiCl}_2\) boiling point 40.7 degrees
  - \((\text{CH}_3)_3\text{SiCl}\) boiling point 57.3 degrees
  - \(\text{SiCl}_4\) boiling point 56.7 degrees
Isolation of (9) from this complicated series of materials required a difficult "distillation" carried out in the system seen at left.

The reaction products of silicon and methyl chloride enter a series of "columns" on the left. The columns separate the products by boiling point, isolating pure compounds wherever practical.

Compound (9) is the highest boiling of the products and is purified by removal of all the other, lower-boiling materials. They achieved purity of greater than 99.9% of (9).

One of the other products, HSiCl₃ boiling point 31.8 degrees, is purified in the process and we will see how this compound is important in the late-century world of the computer revolution. General Electric chemists and engineers worked under the lash of time as they tried to convert (9) to useful products. The lash was the lash of wartime. It was 1943, 1944, 1945 and the new materials would be critical for the armies, navies, air forces in Europe and Asia.

The chemists knew that Rochow's reaction of (9) with water:

\[ n(9) + nH_2O \rightarrow n[(CH_3)_2SiO]n + nHCl \]

could give a polymer, a molecule in which the number of repeated units,
n, was very high, only if \((9)\) was close to 100 % pure. That is, \((9)\) could have no other chemical impurities in the sample. In addition they would have to deliver the wate in small and very controlled amounts. If they used an excess of moles of water over that of \((9)\), they would not get long chains. And GE’s chemists knew they must find a way to “cure” the long chain silicone if it were to have reliable rubber properties.

GE’s engineers solved the purification problem with the distillation. Rochow and the other GE chemists applied the two skills that chemists must master: hard intellectual work and careful observation, to solve the other two.

Remember that inorganic salts are often most stable as hydrate; molecules containing water of crystallization. One chemist realized these small amounts of water could be easily measured out by weighing the hydrate salt, they mixed \(\text{FeCl}_3(\text{H}_2\text{O})_6\) with \((9)\) and supplied exactly the correct amount of water. The resulting polymers had thousands of units bonded in a row \((n=>1000)\). Another one of GE’s scientists examined many agents to cause the rubber to cure after articles were first made. He found a compound called benzoyl peroxide cured the rubber.

The scientists were in the war effort; they worked seven days a week, they made silicone rubber gaskets for battleship searchlights that would prevent the lenses from shattering from the vibration when the warships loosed their 16 inch shells.
In less than sixty years manufacturing grew to more than 1 billion kg. of silicone resins made by Rochow’s process.

Problem

The automobile represents engineering solutions to the problem of converting the energy from the burning of hydrocarbons to moving a mass in a desired direction at a convenient acceleration and velocity. Sit in groups of three and discuss the engineering inherent in the chemical reactor called the automobile engine:

1. When we burn gasoline in an automobile engine we carry out an exothermic process that gives heat and energy. Gasoline and air are mixed in a cylinder and a spark ignites the mixture.

   a. Initially in the cylinder the concentration of gasoline and air is high, the temperature is low. But as gasoline and air burn, the temperature rises but the concentration of fuel and air drop. Draw on a chart as shown below your best estimate as to the rate of burning and mixture temperature after the spark ignites the mixture.

   b. What do we do with the energy? Be specific.

   c. What do we do with the heat? Be specific.

   d. Why does an automobile have a radiator?

   e. How does the radiator operate?