The Cost of Coolers for cooling Superconducting Devices at 4.2 K, 20 K, 40 K, and 77 K

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This is another Report in a Series of Reports

- **The first report in this series was written by Strobridge, Mann, and Chelton of the National Bureau of Standards in 1966.**
- **The first report in the literature was written by Strobridge in *IEEE Trans. Nucl. Science* NS-2, No. 2, p 1104 (1969)**
- **Strobridge included cryogenic refrigeration at other temperatures in an NBS Tech. Note 655 (1974)**
- **Bryns, Green and St. Lorant published a report in *Advances in Cryogenic Engineering* 37, p 637 (1991)**
- **Bryns and Green updated the 1991 report in *Advances in Cryogenic Engineering* 43, p 1661, (1997)**
- **Green updated the 1997 report to include 4 K coolers in *Advances in Cryogenic Engineering* 53, p 872 (2007)**

Why was this report written?

- This report provides a budgetary cost for coolers currently being produced.
- Temperatures above 4.2 K are included because there is a need for coolers that operate at higher temperatures. The author decided to use 20 K, 40 K, and 77 K as benchmark temperatures.
- Cooler efficiency is included in this report along with cooler capital cost. Cooler efficiency is very important for some users.

What Assumptions were used?

- Cooler performance and costs are based on coolers using 60 Hz power. For the 90+ percent of the coolers, the compressors are water-cooled.
- The cooler costs are given in US dollars for coolers shipped to the United States.
- In most cases, the costs were provided by the cooler manufacturers. In other cases, costs were provided by the cooler customers.
- The technical data for the coolers came from the vendor web sites. Some vendors did not provide cost data.
- Coolers have a maintenance interval of at least 10000 hr.

Calculation of Cooler Efficiency

The efficiency is calculated for a rejection temperature of 300 K for all of the coolers. For single-stage coolers, the author used the following equation to estimate the cooler efficiency η;

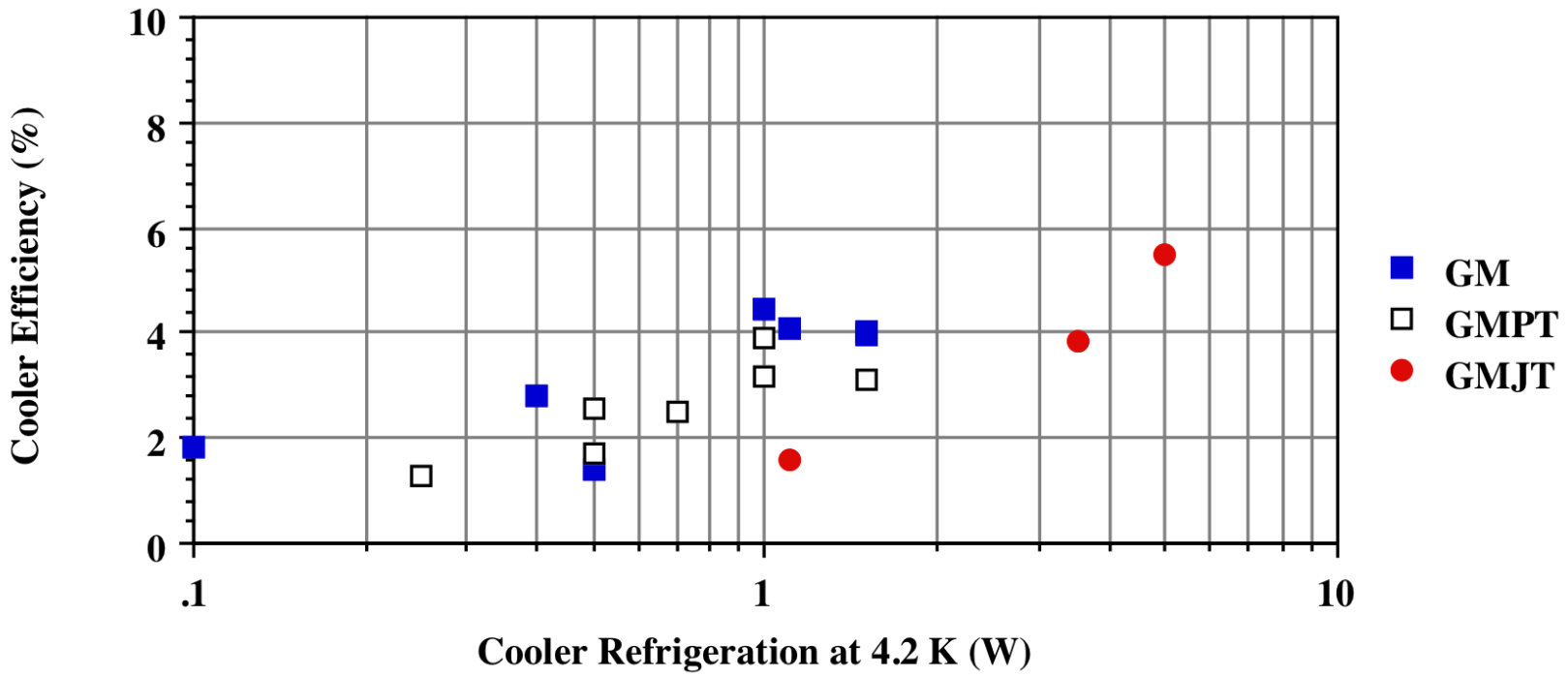
$$\eta = 100\left[\frac{Q1\dfrac{300 - T1}{T1}}{P_{COM}}\right],$$

where $Q1$ is the refrigeration produced at temperature $T1$ and P_{COM} is the input power of the compressor selected by the manufacturer. For two-stage coolers, the author used the following equation to estimate cooler efficiency η;

$$\eta = 100\left[\frac{Q1\dfrac{300 - T1}{T1} + Q2\dfrac{300 - T2}{T2}}{P_{COM}}\right],$$

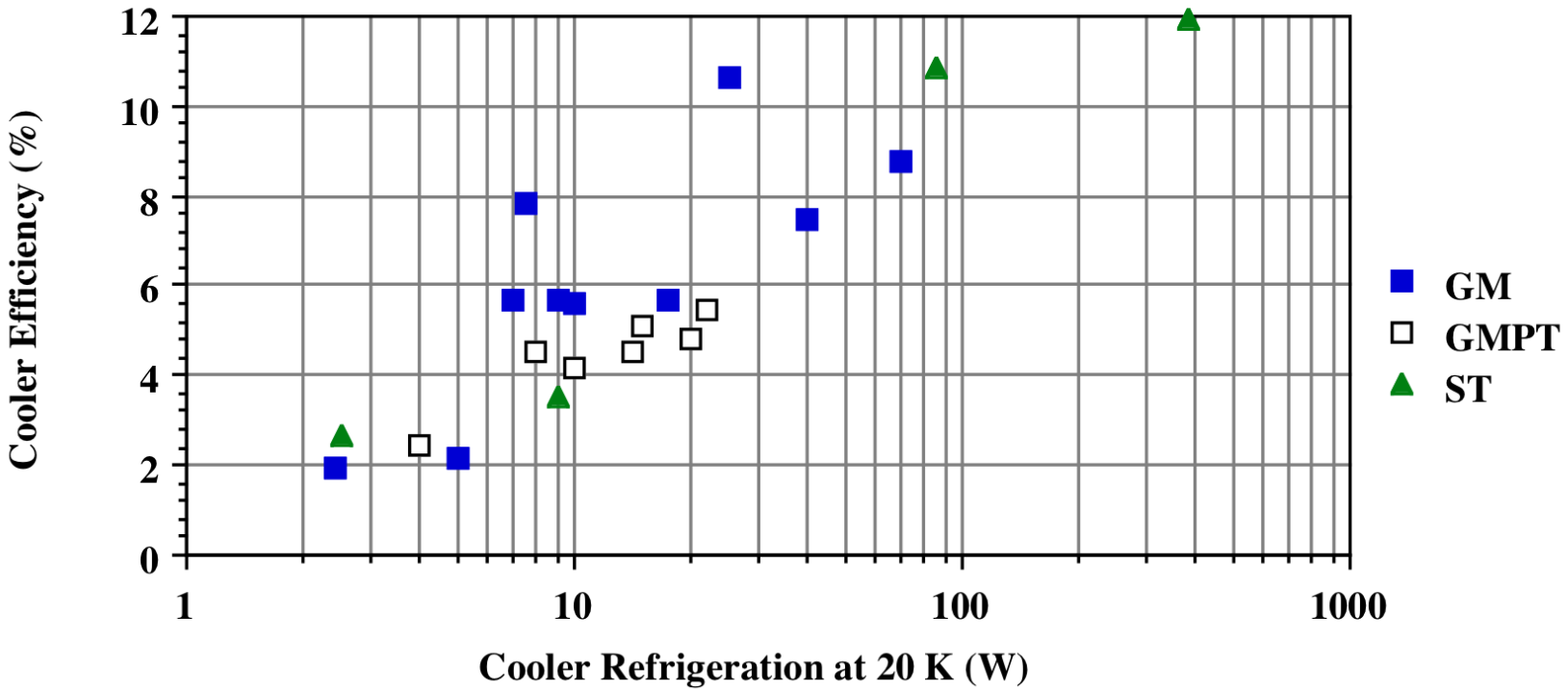
where $Q1$ the first stage refrigeration is produced at temperature $T1$ and $Q2$ the second stage refrigeration is produced at temperature $T2$ simultaneously.

Cooler Efficiency at 4.2 K



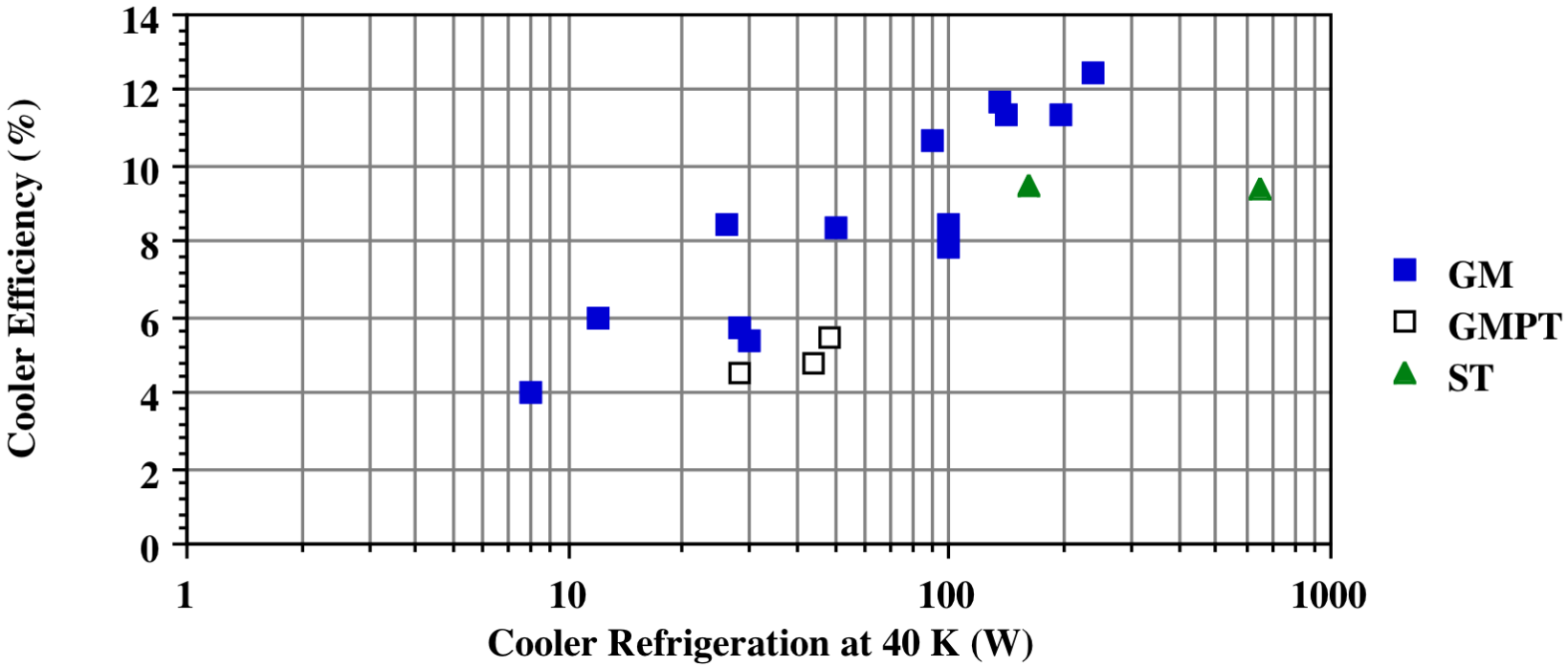
GM refers to a standard Gifford McMahon cooler. GMPT refers to a pulse tube cooler with a Gifford McMahon cycle. GMJT is a GM cooler with an added JT loop.

Cooler Efficiency at 20 K



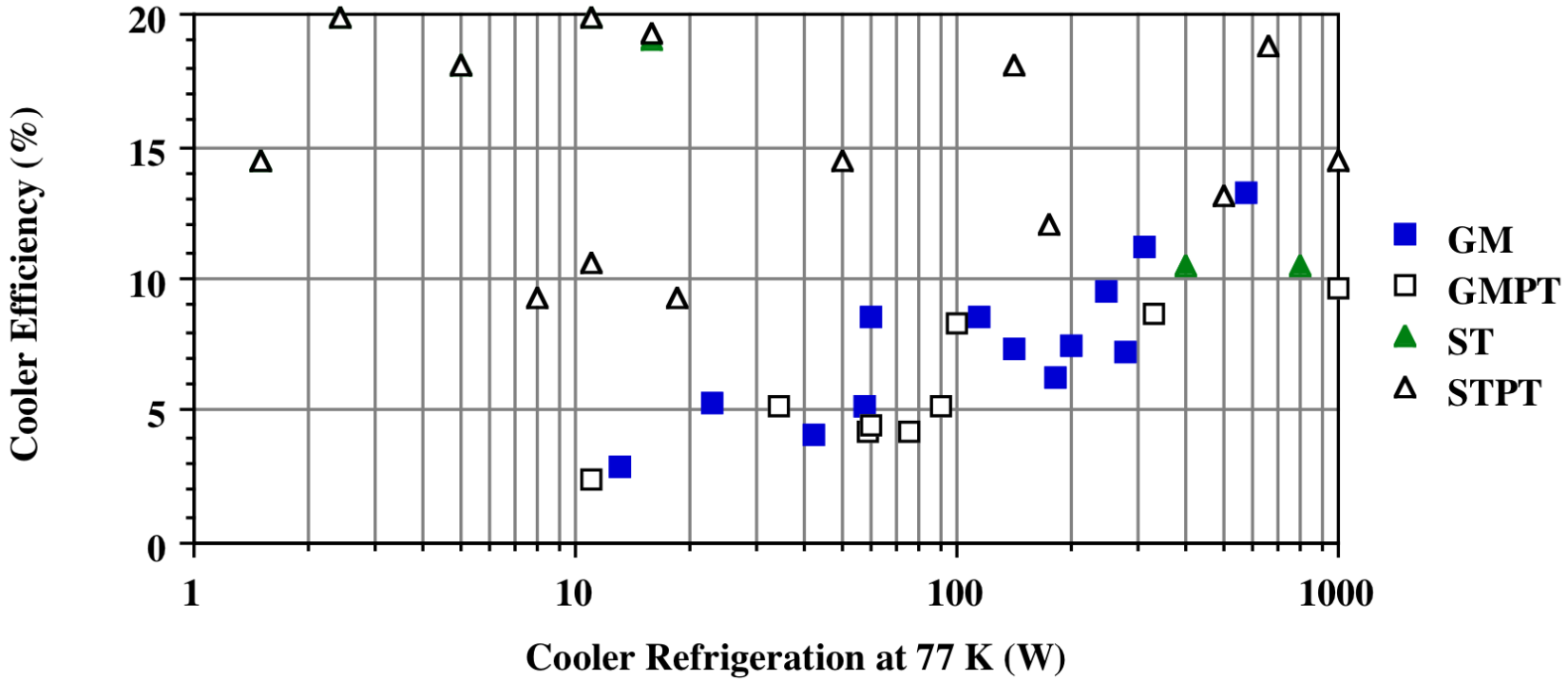
GM and GMPT are previously defined. ST is a cooler using a Stirling cycle.

Cooler Efficiency at 40 K



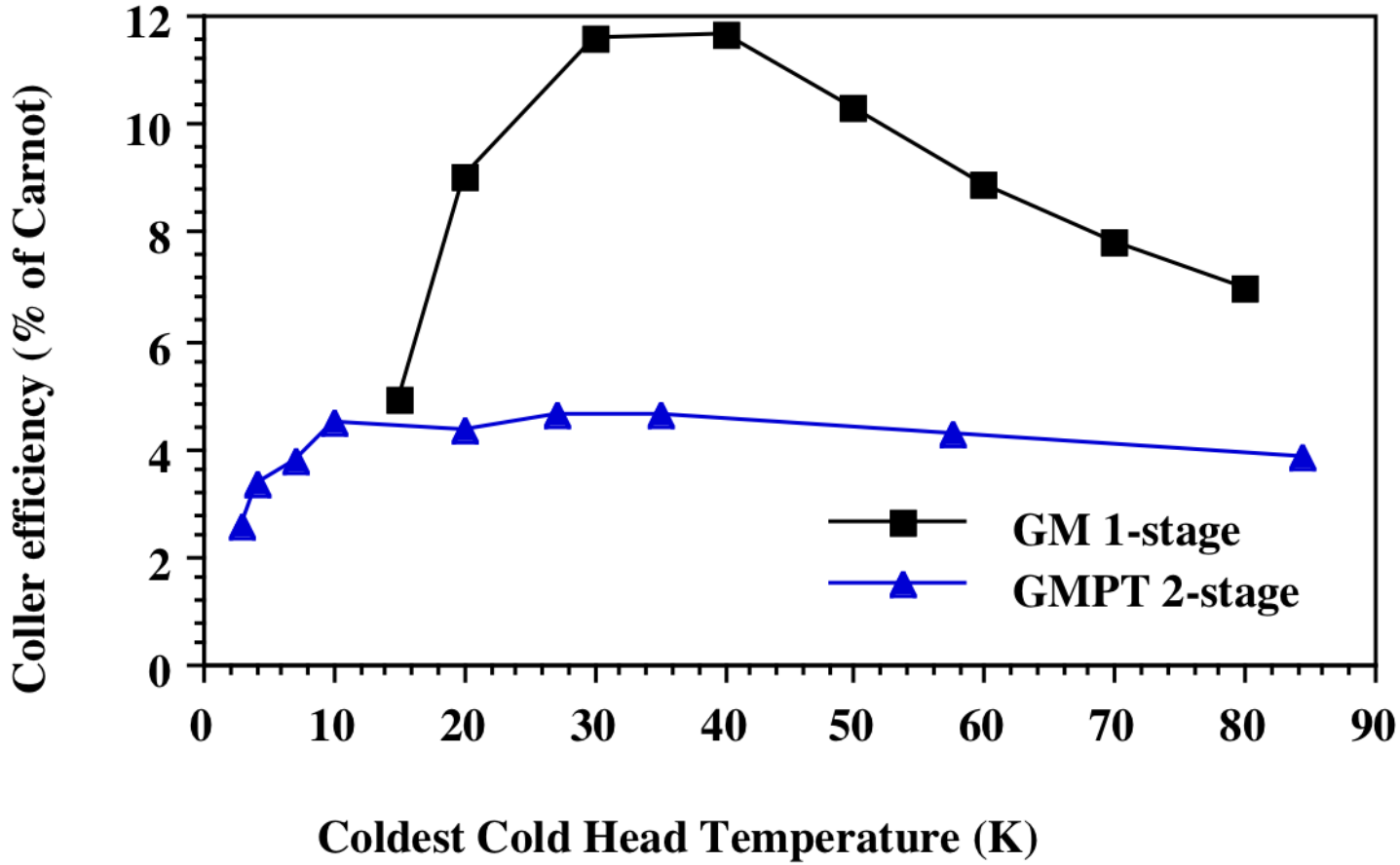
GM, GMPT, and ST are previously defined.

Cooler Efficiency at 77 K



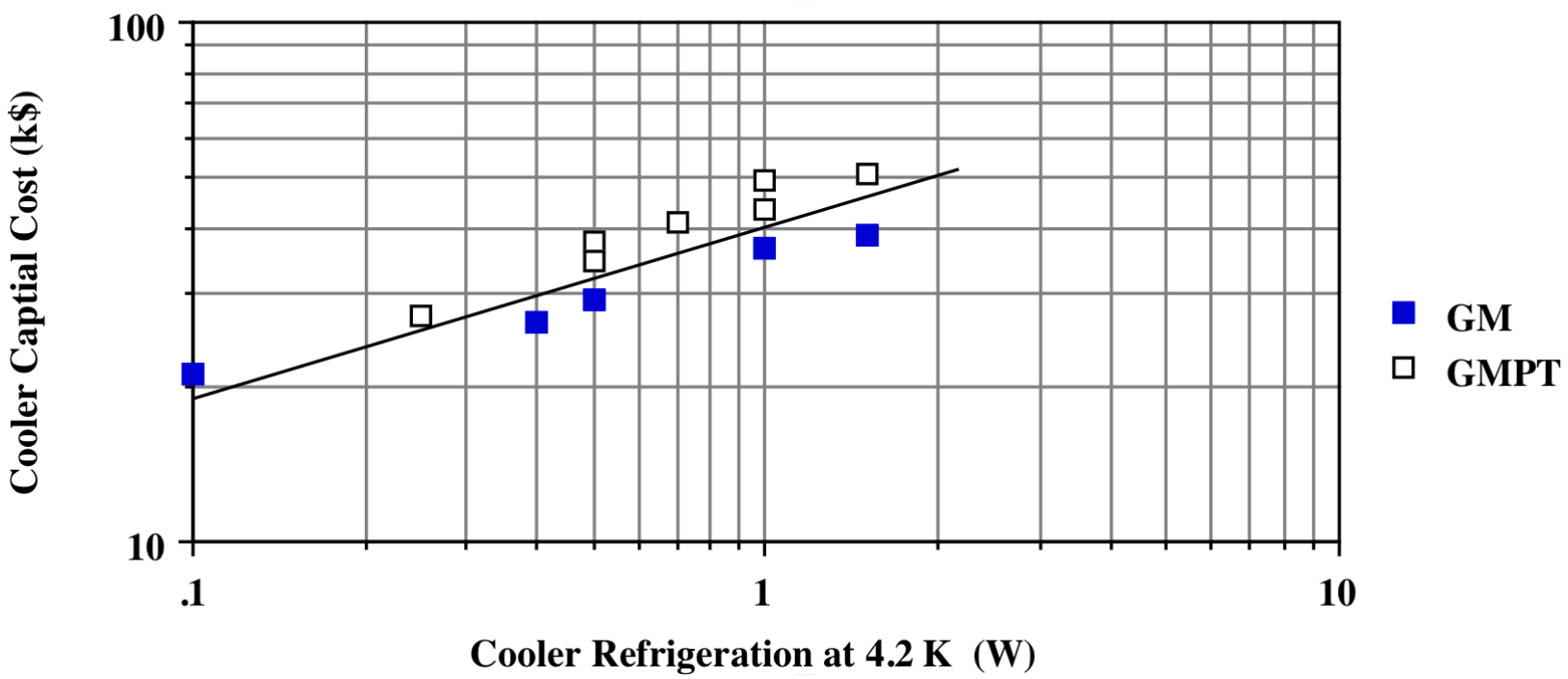
GM, GMPT, and ST are previously defined.
STPT is a Stirling cycle pulse tube cooler.

Efficiency of Two Coolers as a function of Temperature



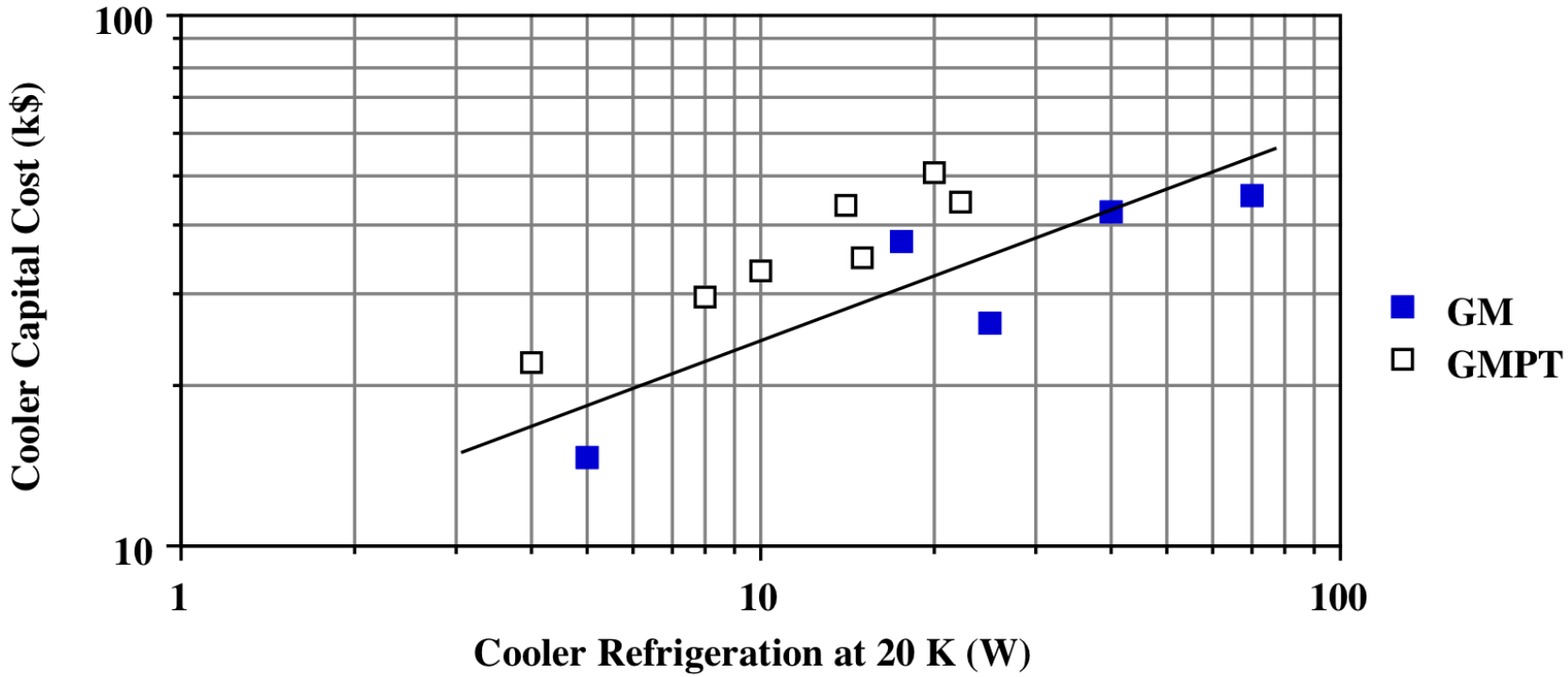
Each cooler has its maximum efficiency point.

Cooler Capital Cost at 4.2 K



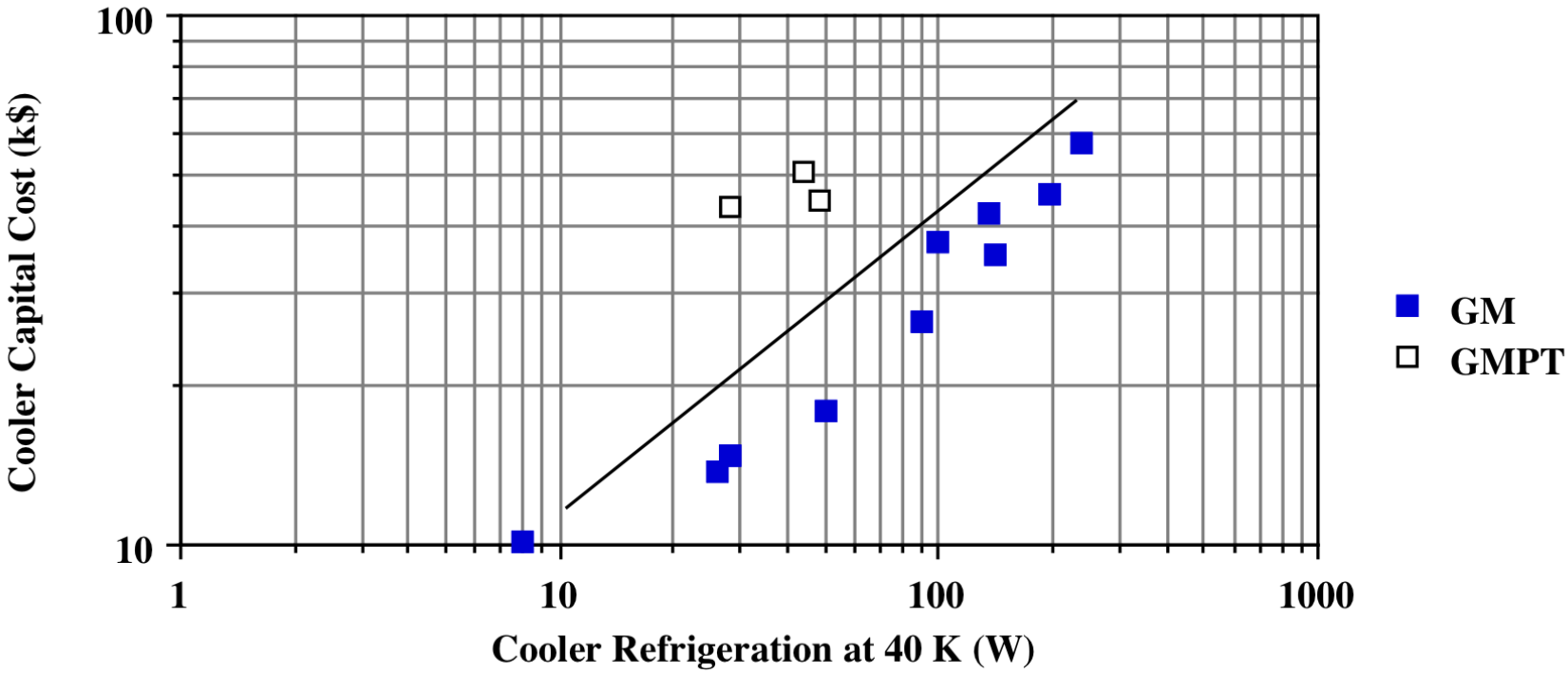
$$C(k\$) = 40\left[R(W)\right]^{0.32}$$

Cooler Capital Cost at 20 K



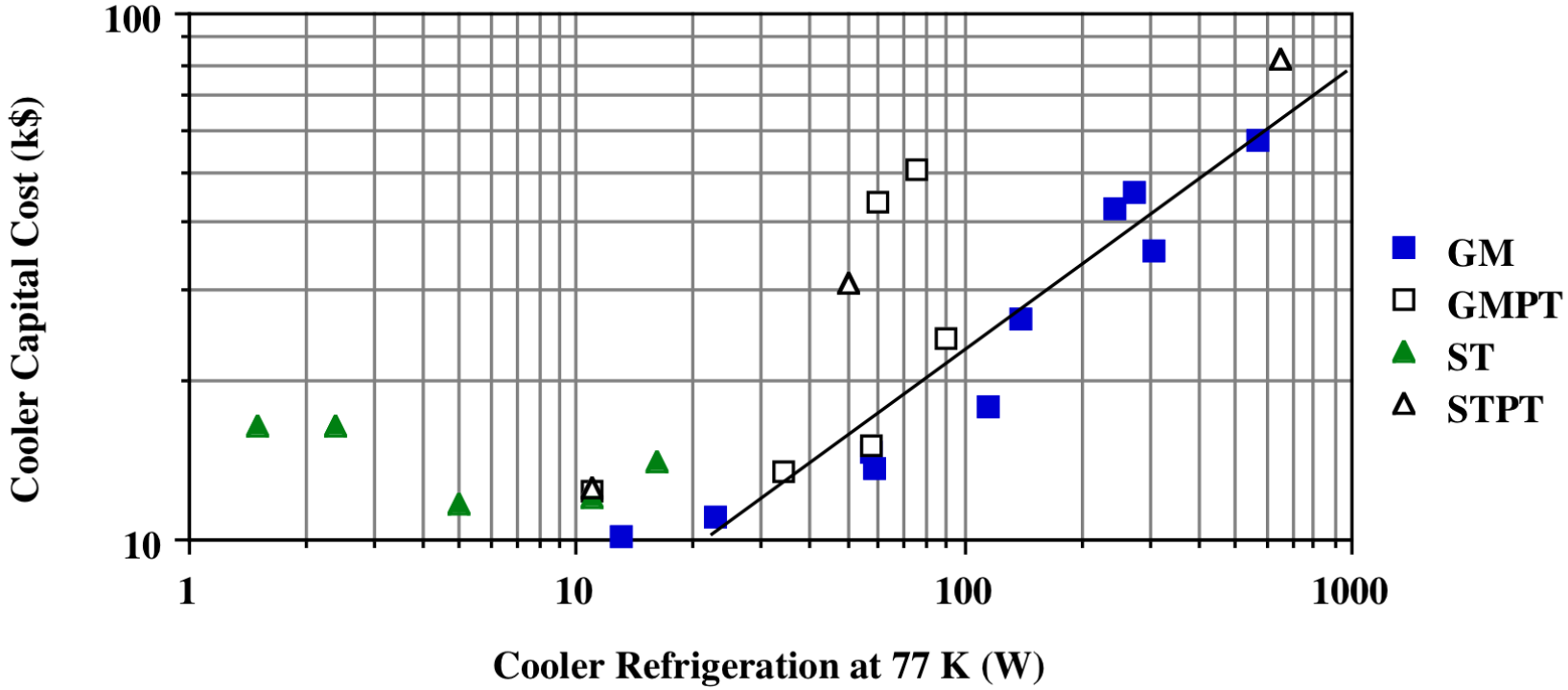
$$C(k\$) = 9.3\left[R(W)\right]^{0.41}$$

Cooler Capital Cost at 40 K



$$C(k\$) = 3.16\left[R(W)\right]^{0.56}$$

Cooler Capital Cost at 77 K



$$C(k\$) = 1.81(R(W))^{0.57}$$

There is a lot of scatter in the cost data at 77 K.

Other Cooler Selection Criteria

- **Cooler capital cost and efficiency are not the only criteria used for cooler selection.**
- **Other criteria may be more important that cost and efficiency. Other criteria may include;**

1) **Cost & frequency of cooler maintenance**
2) **Orientation of the cooler cold head**
3) **Magnetic field at the cold head or compressor**
4) **Cooler cold head or compressor vibration**
5) **Other criteria**

Some Conclusions

- **GM coolers are more efficient than GMPT coolers. They are also more efficient than ST coolers. The GMJT have the same efficiency as a GM cooler, but a separate cooler is needed for 40 to 50 K cooling.**
- **The STPT coolers can be very efficient at 77 K.**
- **GM coolers are less expensive than all of the other types of coolers in all temperature ranges. This may be due, in part, because more GM coolers are produced than the other types of coolers.**
- **When selecting a cooler, one should look at other criteria besides cost and efficiency. For example, cooler maintenance may be a key issue.**