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Water Chiller and Heat Exchanger Test Results

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The test has been conducted to verify performance of water chiller and acid heat exchanger procured to used in BCP facility being constructed at ANL. There were two major things to verify. The first was the heat exchange efficiency. The second was the time constants of the cooling process and equilibrium temperatures in the process tank.
The scheme of the test is shown in the picture below. In the scheme, WC stands for Water Chiller, HE is Heat Exchanger, FM – Flow Monitor, PD – Differential Pressure Detector; all the rest is self-explanatory.

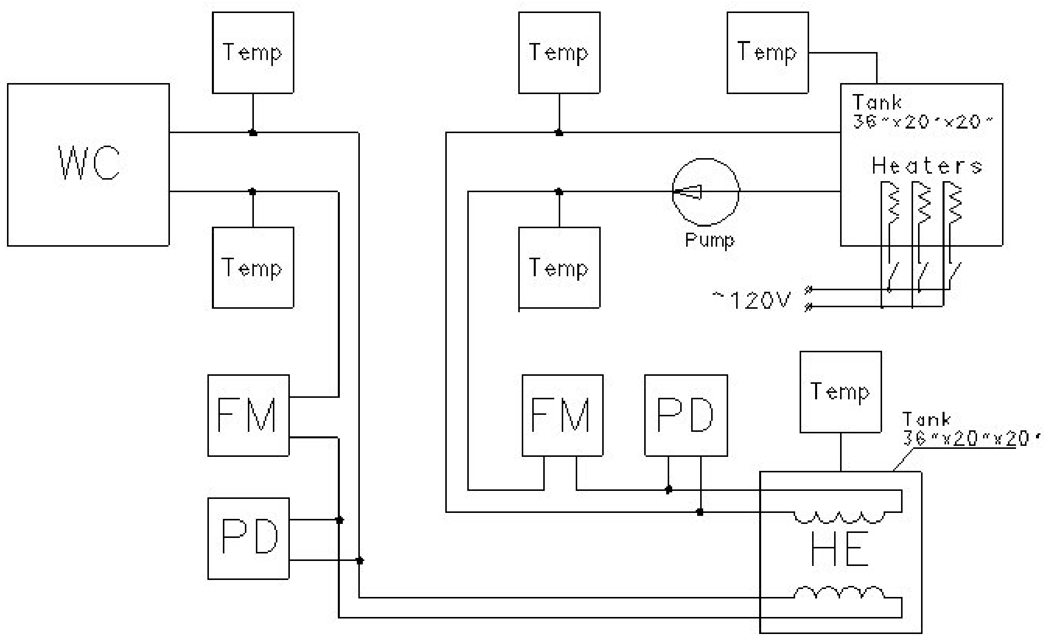

Fig. 1. Hydraulic scheme of the test

There were two heat exchangers to check. One HE was of immersion type, the other was plate type; both made by George Fisher, Inc., Tustin, Ca.
The water chiller was filled with propylene glycol, that allows setting the chiller temperature down to 5°C with the cooling power of 4.3 kW at 5°C. At 10°C the cooling power is 5.8 kW, and at 20°C it is 7.0 kW. Cooling fluid flow was measured to be near 5 GPM.

I. Immersion Heat Exchanger

The HE consists of the primary and the secondary circuits mounted in a HE tank filled with water (XXXXX). Capacity of the tank is 60 gallons, and amount of liquid in the tank

was about 50 gallons. The primary heat exchanger has two parallel branches and is made of copper piping. The total surface area of the piping is 12.5 sqft. The secondary heat exchanger is immersion type GF PVDF heat exchanger. According to GF specifications, the surface of the heater is 23.6 sqft, and nominal power is 2 kW considering acid temperature of 14°C with the flow rate of 6.65 GPM and the cooling water temperature on the level of 10°C with the flow rate of 3.4 GPM. In the test, water was used instead acid. It was pumped through the HE circuit by a Little Giant immersion pump with the rate of 6.5 GPM, which is close to HE specifications. To increase heat exchange rate, water in the HE tank was circulated by two small immersion pumps. The heat generated during the process was imitated by heaters placed in the "process" tank. There were three heaters, 1 kW each. Temperatures, water flow rates and other parameters of the hydraulic circuit were measured using appropriate gauges as shown in Fig. 1.
The test was staged as following:

A. Primary HE test.

At different WC temperature settings (5°C and 10°C), cooling power was measured by evaluating tank water temperature drop rate (**P1 - method 1**)

$$P1 = c*m*dT/dt \qquad /1/$$

and by calculating water heating power (**P2 - method 2**).

$$P2 = c*dm/dt*(Tin-Tout), \qquad /2/$$

Where Tin and Tout are water temperatures at the input and output of the heater.
Mass of water inside the tank was about 195 kg. Table 1 below presents main results of the test at different settings of the WC.

Table 1

WC set (°C)	5	10
P1 (kW)	5.3	6.1
P2 (kW)	5.3	5.3
Ploss (W)	260	170

The heat leak was estimated by measuring tank temperature rise without cooling. Thermally insulated tank had a heat leak of 260 W at 5°C and 170 W at 10°C with ambient temperature of 22.5 °C. This results in the heat transfer coefficient

$$q = Ploss / ((Tenv – Tbath)*Sbath) \qquad /3/$$

of 7 $W/(m^2K)$. Here Sbath is the surface the tank exposed to air. For the tank that was not thermally insulated, the heat transfer coefficient was calculated to be 15 W/m^2K, which is well compared with the value of the coefficient used for practical thermal calculations. If two tanks are used in the heat exchange process, the heat loss can be as much as 500 W or even more.
Typical temperature history during the test is shown in the figure 2 below.
The blue curve represents the tank temperature, the black one is the chiller output coolant temperature, and the red one is the input chiller coolant temperature.
During the first hour and a half, the water is cooled from 26°C to about 10.5°C. After all the temperatures are settled (7500 sec or about 2 h), the chiller was turned off, and we observed slow temperature rise. The temperature rise rate increases significantly when 1-kW heater is on.

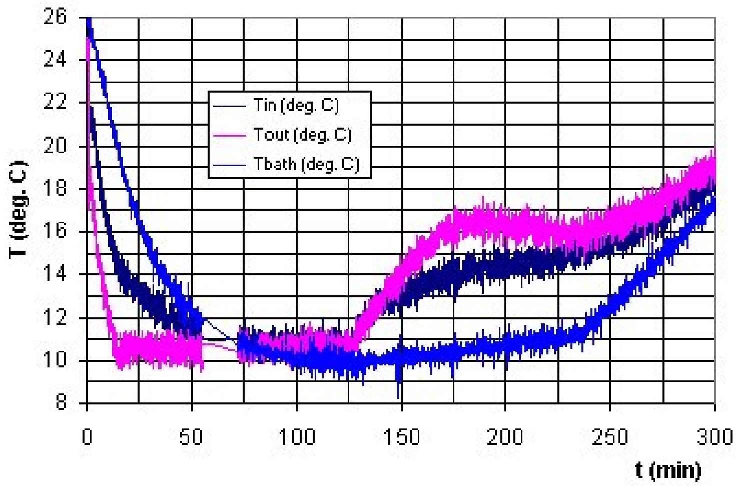

Fig. 2. Typical test history

The results of the first part of the test are:

1. Maximal cooling power is defined by the water chiller and is about 5.2 kW. This value was obtained by two methods: measuring the tank water heating time, and measuring the input and output coolant temperature difference.

The result is that the cooling rate does not depend much on the initial temperature setting.

2. Minimal temperature in the tank is close to the chiller output water temperature.

3. It takes about 2 hours to cool the tank filled with water (250 liters)

4. The heat transfer coefficient was estimated on the level of 15 W/m^2K if tank is not thermally insulated. It is about 7 W/m^2K if the tank is insulated. Maximal heat loss expected at coolant temperature of 10 C is about 250 W for non-insulated tank and about 125 W if the tank is insulated.

5. Mixing water in the tank significantly (almost twice) improves heat exchange rate.

B. Secondary HE test

During the second part of the test, the efficiency of the acid heat exchanger was checked. Heaters were used to model heat generated during the process. At each temperature setting of the WC (5°C and 10°C), the equilibrium temperatures of water in the process tank and in the heat exchange tank were measured at different levels of input power. The results are shown on the graph in figure 3.

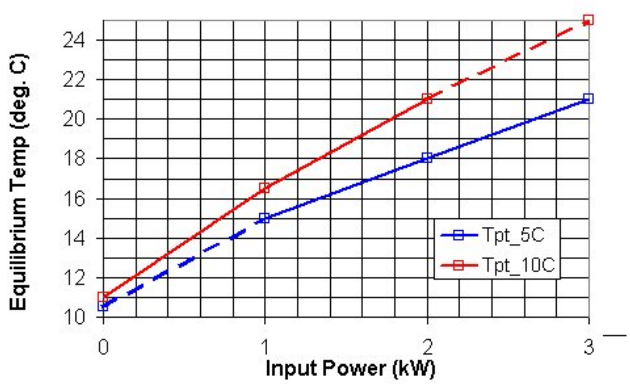

Fig. 3. Dependence of the process tank water temperature on the heating power.

Typical thermalization time is about 2 hours as one can see in the temperature history graphs below.

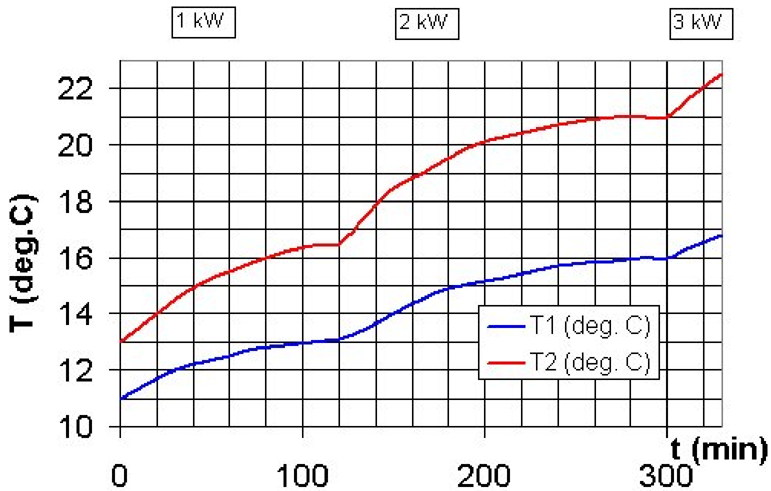

Fig. 4. Tank 1 (HE) tank and tank 2 (process tank) temperature history at 10°C WC output setting

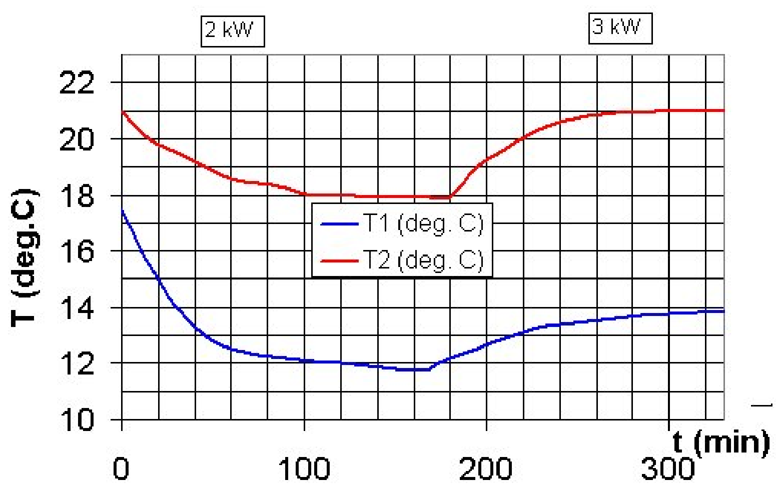

Fig. 5. Tank 1 and 2 temperature history at 5°C WC output setting

In the case of 10°C WC temperature setting, the water in the two tanks was cooled first without using heaters. Temperature in both tanks reached 10.5°C. Then the 1 kW heater was activated in the process tank (T2) that brought the temperatures to the higher level (Fig. 4). After equilibrium was reached, two 1-kW heaters were activated, and so on. At the level of 3 kW, maximal temperature in the process tank T2 was higher that the maximal allowed process temperature of 20°C.

In the case of 5°C WC temperature setting, two 1-kW heaters were activated that brought the tank temperatures to the equilibrium (Fig. 5). 3 kW of input power resulted in maximal temperature of about 21°C.

The expected heat generation while processing TESLA type cavity is 650 W. Even using the 10°C WC temperature setting, it is possible to keep the process temperature on the level of 15°C.

Obtained data allow calculating the heat transfer coefficients defined as

$$k = P/(S(Tbath-Tav)) \qquad /4/$$

for both the primary and secondary heat exchangers. Tav in /4/ is the average temperature of water on the HE piping, and P is heat transfer power. Substituting /2/ for P, it is possible to obtain:

$$k = c/S*dm/dt*(Tin-Tout)/(Tbath-Tav) \qquad /5/$$

where S – the surface area of a heat exchanger

For the primary, copper-made HE, calculated heat transfer coefficient of about 550 W/m^2/K, which is close enough to the used value of 600 W/m^2/K.

For the secondary HE which is made of PVDF, the calculated heat transfer coefficient ranges from 100 to 200 W/m^2/K. Reference value of the coefficient provided by GF is 200 W/m^2/K.

It was impossible at this test to measure this value with better precision because of a significant noise during temperature reading. Eliminating this noise and automating data acquisition will be the next step towards the system mockup at FNAL.

II. Plate Heat Exchanger

For the plate HE, the set of measurements is very similar to what was done with the immersion HE. The only difference was that there was no HE water tank, so one expect slightly higher efficiency of the system. It is demonstrated by Fig. 6 that shows dependence of the equilibrium temperature in the process tank on the heating power.

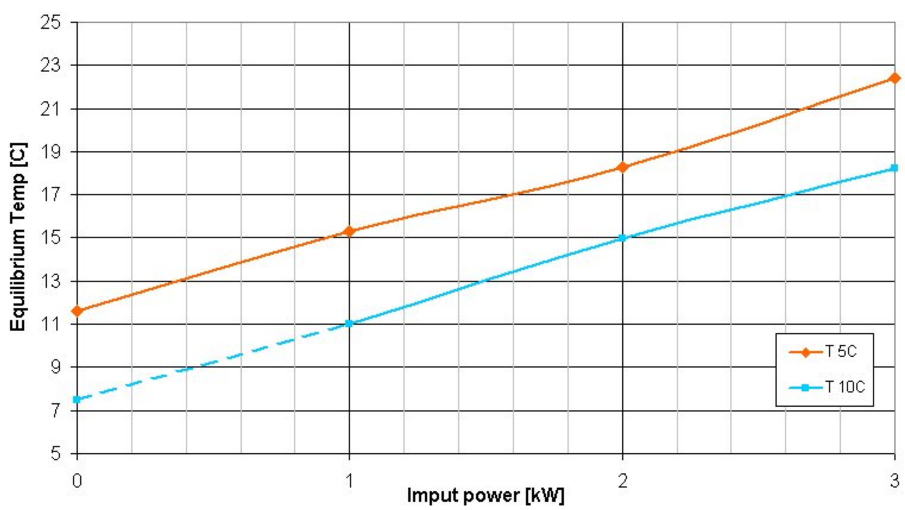

Fig. 6. Dependence of the process tank water temperature on the heating power.

It is possible to see that at the 5°C temperature setting of the WC, process tank temperature does not exceed 20°C even if heating power is 3 kW. Heat balance calculations similar to what was made for the immersion HE result in the maximal cooling power of the HE of about 2.5 kW at 5°C of WC setting (4 kW of WC cooling power). Typical cooling time is about 2 hours, like it was for the immersion HE. Fig. 7

gives a summary temperature map of the test with the three temperature plateaus corresponding to different heating power in the process tank: 1, 2, and 3 kW. It can be compared with Fig. 5 where only two power settings were realized before temperature was out of the allowed range.

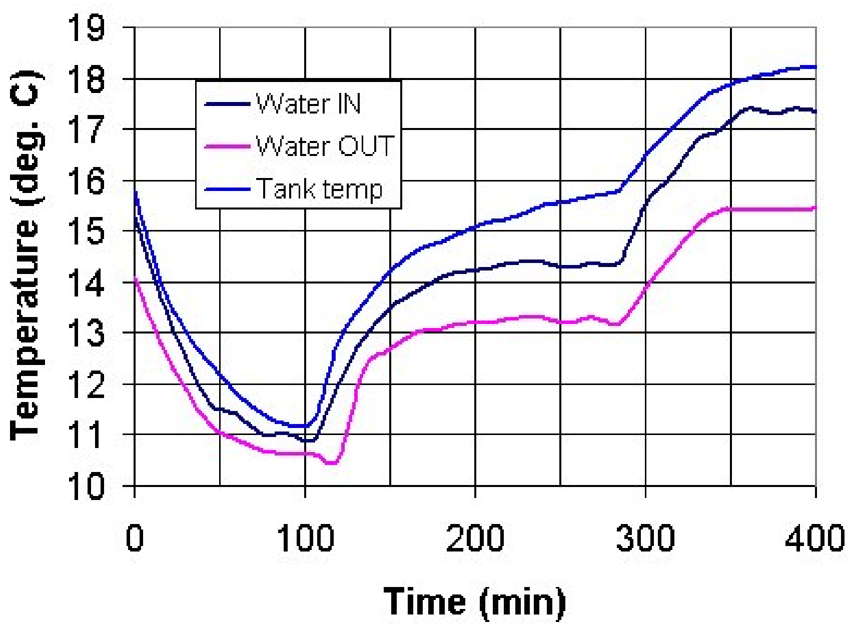

Fig. 7. Process tank temperature history in the case of the plate HE and WC temperature setting of 5°C

Summary.

Immersion and plate HE were tested to find that both of them can be used as part of the chemistry room equipment setup to provide needed cooling rate of the acid at the preparation stage and at the etching stage.
Although thermal efficiency of the plate type heat exchanger was better, the immersion type was chosen for use in the system because it provides better interface for possible leak control, does not have any sealing O-rings, and is robust enough not to be afraid of possible mechanical damage.