# TECH NOTE

# LRS-9550 Water Quality Guidelines

## PURPOSE

The LRS-9550 High Power Test System uses high performance water-cooled cold plates to achieve fixture temperatures of as low as 25°C under full thermal load. Good water quality is critical in water-cooled systems to prevent corrosion and scale buildup, which can degrade performance and cause cooling system failures. This technical note provides water quality guidelines designed to maximize lifetime of the LRS-9550 cold plates.

**Figure 1. LRS-9550 High Power Test System**

## BACKGROUND

Water cooling is well suited to high heat flux applications, such as those served by the LRS-9550. While water has the advantage of removing large quantities of heat, water-cooled systems are susceptible to damage from corrosion and mineral buildup. Corrosion can lead to leaks, while buildup can clog cold plates, increase pressure drop, and decrease the heat transfer properties.

The LRS-9550 has been carefully designed to mitigate corrosion risks. The cold plates in the LRS-9550 system are anodized to protect the aluminum structure. The anodization process used on the cold plates has been proven in a rigorous one week salt spray test. Additionally, all components in the fluid path have been carefully selected to be corrosion resistant, and to avoid galvanic (dissimilar metal) corrosion effects.

However, the buildup of mineral deposits (commonly referred to as scaling or fouling) on heat transfer surfaces is an issue that depends less on system design and more on circulating water quality and operating conditions. One of the most common components of scale buildup is calcium carbonate ($CaCO_3$). Calcium carbonate is present in most groundwater throughout the world, and is measured by the parameter "water hardness". The higher the concentration of calcium carbonate, the "harder" the water. While most compounds become more soluble in water at higher temperatures, calcium carbonate becomes less soluble as the temperature increases (Cho, 1998). When water containing calcium carbonate is heated in a cold plate or heat exchanger, the solubility can decrease until the water becomes saturated, at which point the calcium carbonate will begin to precipitate onto the high temperature surfaces.

## FACTORS THAT AFFECT SCALE DEPOSITION

Scale deposition is a complicated problem and many parameters can affect deposition. Factors that influence deposition include pH, hardness, alkalinity, suspended solids, fluid temperature, heat exchanger surface temperature, pressure, flow velocity, flow separation, and recirculation (Cho, 1998). Scale deposition rates increase as fluid velocity decreases, hardness increases, alkalinity increases, fluid temperature increases, and heat exchanger surface temperature increases (Quan, 2008). Cooling systems are typically either open loop or closed loop (recirculating). In open loop systems, scale deposition rates are somewhat constant over time assuming other system parameters are constant. Closed loop systems are desirable because water quality can be controlled. However, evaporation can increase the concentration of minerals in the water and if the evaporative losses are replaced with additional mineral containing water then the scale deposition rate could accelerate over time. Of all the water quality parameters that affect scale deposition, the most influential is hardness (Rafferty, 2000).

## PREDICTING SCALE DEPOSITION

Scale deposition is a serious and costly problem in many industries and much research has been done in the areas of scale prevention and prediction. In order to evaluate water quality for scaling potential, several multi-parameter indices have been developed. One of the most commonly used is the Langelier Saturation Index (LSI). The LSI is mainly based on temperature, water hardness, and pH but also takes into account alkalinity and total dissolved solids. LSI is defined as follows:

$$LSI = pH-((9.3+((\log(S)-1)/10)+((-13.12*\log(T)+34.55))-(((\log(H))-0.4)+(\log(A))))$$

where,

$pH$ = pH of water
$S$ = total dissolved solids (ppm)
$T$ = temperature (K)
$H$ = hardness (ppm as $CaCO_3$)
$A$ = alkalinity (ppm as $CaCO_3$)

An LSI value of zero indicates little potential for either scale formation or corrosion. A negative LSI indicates little or no scale potential; however corrosion becomes likely with LSI values less than -2. Positive LSI values indicate the possibility of scale formation, with values greater than 1 representing serious scaling potential (Rafferty, 2000). Using the Langelier Saturation Index it is possible to develop a specification for cooling water that will help to minimize the risk of scale buildup.

## WATER QUALITY GUIDELINES

To maximize cold plate performance and longevity, ILX Lightwave recommends that cooling water adhere to the following specifications:

**Table 1. Water quality guidelines**

| Parameter | Specification |
|---|---|
| Hardness | <100 ppm* |
| Alkalinity | <100 ppm |
| Particulate | <100 microns |
| Chloride | <25 ppm |
| Sulfate | <25 ppm |
| pH | 7.0 – 8.5* |
| Additives | Up to 30% Inhibited Glycol (PGW or EGW) |

* See graph below for recommended pH and hardness values

** Gycol adds freeze protection and corrosion protection but can cause up to a 5% decrease in thermal performance

# TECH NOTE

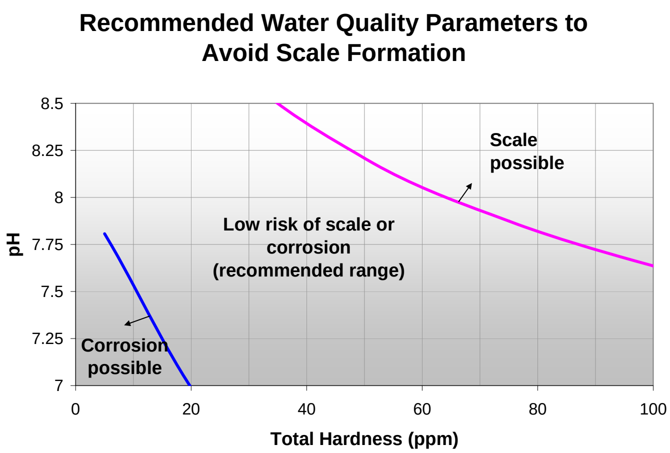


**Figure 2. Recommended pH and hardness values**

The chart in figure 2 is based on the Langelier Saturation Index and assumes operation of the cold plates under full thermal load.

## SCALE DEPOSITION TESTS

While the Langelier Saturation Index can predict the potential for scale formation, predicting the rate of scale deposition and resulting affect on performance is much more difficult from an analytical perspective. To help determine scale deposition rates and affect on performance of the LRS-9550 cold plates a series of accelerated scale deposition tests were performed. A water quality survey was done to identify well water locations in the Bozeman, MT vicinity which exhibited high LSI values and therefore high scaling potential. Two such locations were identified. The parameters of the test locations are given in table 2.

| Parameter | Location A | Location B |
|---|---|---|
| Hardness (ppm) | 256 | 350 |
| Alkalinity (ppm) | 186 | 313 |
| Total dissolved solids (ppm) | 385 | 450 |
| pH | 7.77 | 7.68 |
| LSI (at max thermal load) | 1.14 | 1.40 |

**Table 2. Water parameters of test locations**

Figure 3 shows the two locations plotted on the graph from figure 2. Note that both samples are well outside of the recommended range for water quality. The ILX facility water and two typical customer sites are also provided for reference.

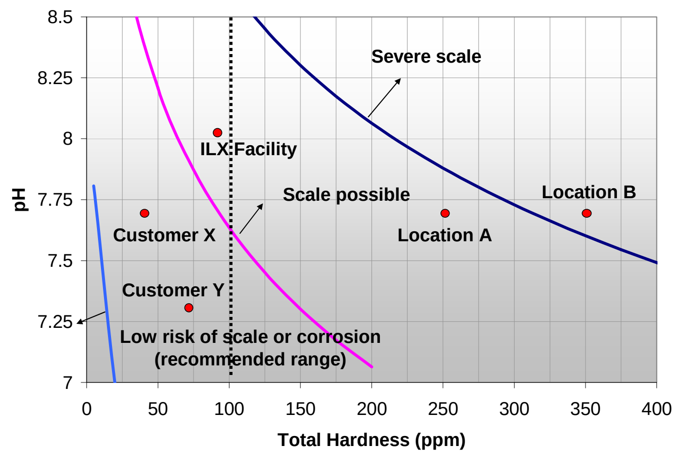


**Figure 3. Test locations plotted on graph from Figure 2**

One quarter-size LRS-9550 test cold plates were set up to run for 4 weeks at locations A and B. Each cold plate was outfitted with a 650W thermal load which represents the maximum load each cold plate would experience in typical use. The flow rate was controlled with an inlet pressure regulator. Inlet temperature was not controlled but remained nearly constant over the 4 week test period. Accelerated scale deposition was induced by reducing flow rate by a factor of 3.5 from typical operating conditions. Cold plate performance was characterized pre and post test by measuring thermal resistance as follows.

$$R = (T_{cp} - T_{water})/(P) \quad (°C/W)$$

where,

$T_{cp}$ = cold plate temperature (°C)
$T_{water}$ = inlet water temperature (°C)
$P$ = thermal load (W)

The results from the test are given in Table 3.

**Table 3. Results of accelerated scaling tests**

| Parameter | A | B |
|---|---|---|
| Baseline thermal resistance (°C/W) | 0.0261 | 0.0225 |
| Final thermal resistance (°C/W) | 0.0304 | 0.0273 |
| % increase in thermal resistance | 16.3% | 21.1% |

## ESTIMATED COLD PLATE LIFESPAN

The results from the accelerated scale test were used to estimate cold plate lifespan. Cold plate end of life was defined as a 5 °C increase in minimum achievable temperature at full power. The acceleration factor was estimated based on data from Quan et al. Quan found that rate of scale deposition changed with velocity as described by the equation below.

$$R_2 = R_1((0.2^{\log_2(V1/V2)})^{-1})$$

where,

$R_1$ = accelerated degradation rate observed in test
$R_2$ = predicted degradation rate under normal use
$V_1$ = flow velocity in accelerated test
$V_2$ = flow velocity in normal use

Based on the 3.5x decrease in flow velocity, the resulting acceleration factor in rate of scale deposition is 17.9x. Applying this factor to the test data and end of life criteria, lifespan estimates of 2.13 and 2.37 years were calculated for locations A and B respectively. These life estimates correspond to respective LSI indices of 1.14 and 1.40 which are indicative of serious scaling potential. Under conditions with LSI closer to zero, longer life spans can be expected.

## DESCALING

While scale prevention is always desirable, there are commercial solutions available for removing scale buildup in cooling systems. A commercial de-scaling solution (Rydlyme®, www.rydlyme.com) was tested on a third cold plate. This plate was subject to scaling in an identical fashion to the first two test plates. Pre and post test characterization showed a 32% increase in thermal resistance after scale deposition. A 1:1 solution of Rydlyme® and distilled water was circulated through the cold plate for a period of 8 hours. After the Rydlyme® treatment, 65% of the increase in thermal resistance was reversed. These results suggest that commercial de-scaling treatments can recover a majority of performance losses that occur with scale buildup. De-scaling an LRS-9550 system in the field would require the use of a portable recirculating tank and pump. These systems are economical and are available through Rydlyme® and other suppliers.

TECH NOTE

## CONCLUSIONS

While the water-cooled LRS-9550 provides excellent thermal performance, it can be susceptible to scale buildup over time if water quality is not given careful attention. The water quality guidelines outlined in this technical note help to ensure a long life for the high performance water-cooled cold plates. Based on empirical data, cold plate life spans of greater than 2 years are expected with marginal quality water, and much longer when the water quality guidelines are followed. If during the life of the system scaling does occur, commercial de-scaling solutions can be effective in restoring much of the performance losses that can occur due to scale buildup.

## REFERENCES


Cho, Y.I.; Fan, C.; Choi, B.G. (1998). Use of electronic anti-fouling technology with filtration to prevent fouling in a heat exchanger. *International Journal of Heat and Mass Transfer*, *41*, 2961-2966.

Quan, Z.; Chen, Y.; Ma, C. (2008). Experimental Study of Fouling on Heat Transfer Surface During Forced Convective Heat Transfer. *Chinese Journal of Chemical Engineering*, *16(4),* 535-540.

Rafferty, K (2000). Scaling in Geothermal Heat Pump Systems. *Geo-Heat Center Bulletin*, March 2000.