Quenching of Heavy Gauge Loads

When quenching heavy gauge aluminum parts (1/4" or thicker) there are several very important issues to consider: The load configuration, the quenchants used for the quench, agitation rate, total load weight and the density of the load on the racks. Last but not least the alloy processed has an extreme say in the probability of a successful quench and a part with acceptable properties after the heat treat process. This paper specifically discusses the design and implementation of quench tanks and racks associated with the quench of heavy gage and densely loaded parts. The paper will be an guideline for anyone implementing or upgrading heat treat facilities where a quench tank is used.

Basic tank design

The basic quench tank design takes following considerations into account:

Heat load
Agitation
Cooling/Heating
Filtering

These considerations are discussed below in order.

Heat load.

Per most of the Aluminum spec's the tank shall be sized so the temperature rise does not exceed 10^0F during a quench. In the following example the parts are 5000 lbs of Aluminum racked on a 1500 lbs steel rack. The temperature of the water quench is 160^0F. The parts and rack are heated to 1000^0F in the furnace.

The definition of a BTU (British Thermal Unit) is the amount of heat it takes to heat one lbs of water 1^0F. The basic formula for finding the amount of water in a quench tank to keep the temperature rise at 10^0F is shown below.

$$\frac{\text{BTU given away by the parts and rack}}{(10^0\text{F})\text{Allowed temperature rise.}}$$

In our example the parts are 1000^0F hot at the start of the quench and is quenched in 160^0F water. The BTU's given to the water is shown below.

Heat load calculation:

Aluminum:	(Start temp-End temp)x specific heat x load weight	=BTU
Steel	(Start temp-End temp)x specific heat x load weight	=BTU
	Total	

Example:

Aluminum:	(1000-160)x .22 x 5000	=924,000 BTU
Steel	(1000-160)x .15 x 1500	=189,000 BTU
	Total	1,113,000 BTU

The water volume will now be calculated by dividing the total BTU's with the allowed temperature rise.

Water volume in gallons:

$$\frac{\text{Total BTU}}{\text{Temperature rise x 8.34 lbs}} = \text{Gallons}$$

Example:

$$\frac{1{,}113{,}000}{10 \text{ x } 8.34 \text{ lbs}} = 13{,}345 \text{ Gallons}$$

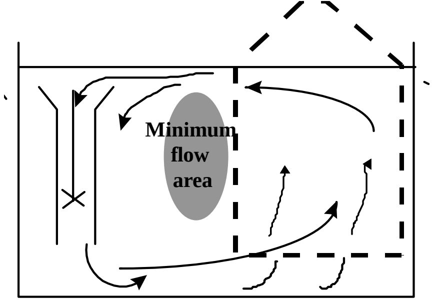
As shown in the example the tank volume must be a minimum of 13,345 gallons of water to ensure that the quench temperature does not rise more than the specified 10^0F.

Agitation

Agitation and design of agitation systems has been covered in several papers.[*] The specifications for agitation design has over time been done as changeovers of tank volumes (Gallons per hour), description of surface movement (Babbling brook) or measured flow past the parts in feet/sec. The best way to specify the quench flow is a calculated or measured flow past the parts. The maximum flow that should be specified for aluminum batch quenching is in the area of .8-1.2 feet/sec past the parts. Any flow higher than that will not add to the cooling of the parts. However this amount of water might be impossible to move. It will in some cases mean the complete tank volume must be changed over every 1-3 minutes. This is not practical. Many tanks are successfully producing heavy gage parts with measured flows in the area of .25-.4 feet/sec.

To produce quality parts the basket or rack must be placed in an area of the tank where there is directional flow up past the parts. (see figure 1)

Figure #1
Basket Location in Quench Tank



The type of agitation that are most effective for tanks that are used for heavy gauge loads are educter agitation and draft tube agitation. The educters (Figure 2) take up less space in the tank but requires more horse power per gallon of water moved due to the required pumping compared to the agitators that use high efficiency airfoil propellers or marine propellers. (Figure #3)

Figure #2 Eductor.
Flow are 4 times the pumped volume.

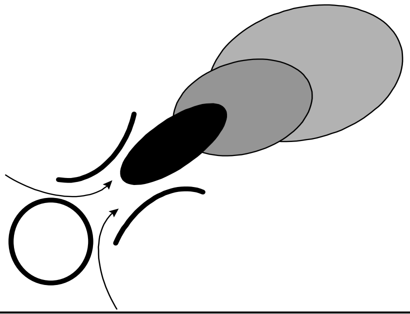
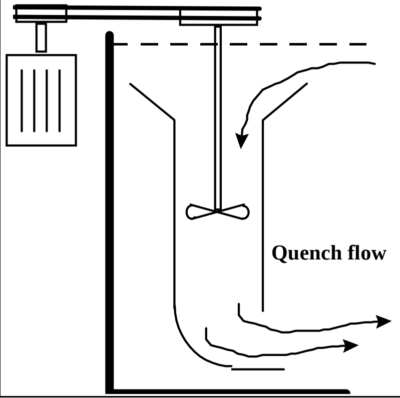


Figure # 3
Draft tube.



With the proper designed draft tube setup an additional benefit can be obtained by the natural inducted flow in the tank. See figure #1

The measurements of the flow will normally be taken with an empty tank. When the parts displaces space and volume in the tank the speed of the quench around the parts goes up. In addition to this the thermal action of the rising heated quench from the contact with the parts will add to the velocity of the quench past the parts.

Cooling/Heating

The quench tank must be equipped with a mean of initial heat up if the tank are used for quenching in hot water. The heating can be done with steam, natural gas or electric. The most commonly used heating media is a submerged burner tube fired by natural gas or electric heating elements submerged directly in the tank. A heat up time of 6-8 hours is normally used. During production the heat is provided by the parts that are quenched. The controls for the heating is a on/off system. There are no requirements for PID control due to the very slow response time on the tanks. It shall be noted that the agitation must be interlocked with the heaters to ensure that there is good flow across the heaters and temperature uniformity is achieved in the tank during the heatup.

Caution: For temperatures above 160^0F tanks and piping must be insulated or guarded to protect personnel.

The cooling of the tanks is done by the use of heat exchangers or chiller. The heat exchangers can be water/water or water/air. Water air exchangers are placed either inside or outside of the buildings. For exchangers placed outside provisions shall be made for freeze protection in the winter and

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[*] Quench Tank Agitation Design Using Flow Modeling. N. Bogh ASM Heat treating Conference 18-20 April 1994.

if located inside it is recommended to duct the exhaust to the outside to prevent and significant heat load being added to the factory.

The sizing of the systems will depend on how fast the tank are required to recover to the start temperature.

BTU's removed per hour/12000= Tons of cooling

Example:
In the previous example we determined that the parts gives 1,113,000 BTU to the water. This heat load will now be removed in two hours

1,113,000 BTU /2 hours/12,000=46.375 tons of cooling capacity required.

Filtering:
Several systems are in production supporting the manufacturing of forged parts. One of the release agents used in this process is graphite. The graphite adheres to the parts and is washed off in the quench. Filters are employed to remove dirt from the tank to maintain a quench that is reasonable clean. The filters must be sized to allow for maintenance. If they are too small the changing/cleaning will be to big a burden and if they are too big the equipment cost will be absorbent. It is important to get a good picture of the dirt loading in the tank before the design is decided for the filtering system. Bag filters or cartridge filters are the most common used filter types.

Hoist/elevator design
The quench delay time begins when the furnace door starts to open and ends when the last corner of the load is completely immersed in the quench bath.[**]
The exception to this rule is a down draft bottom opening furnace where it has been verified that the metal temperature does not drop below solution temperature before the loads starts to move. In that case the quench delay start when the load emerges from the zone and stops when the load is fully submerged in the tank.

Maximum quench delay, wrought alloys. (For immersion quenching)[*]
Table 1.

Nominal thickness (Inch)	Maximum time (Seconds)
Up to 0.016 incl.	5
0.017 to 0.031 incl.	7
0.032 to 0.090 incl.	10
0.091 and over.	15

As shown in the table above the speed which the parts must be quenched at increases significantly for the thinner gauge parts. This has a very significant effect on the design of the heat treating equipment and the hoist and quench tank in particular. In this paper it is assumed that the parts are 0.091" and over.

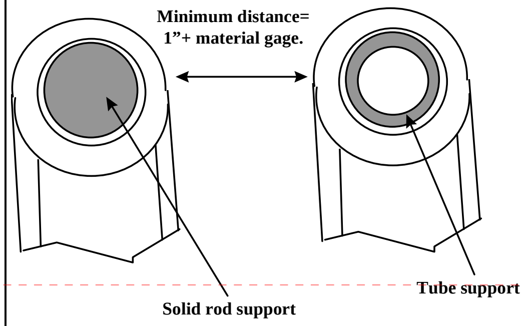
The elevator/hoist must be designed to transfer the parts into the water at a speed that satisfy the over all quench delay requirement. However care shall be taken to ensure that the speed does not create a splash problem. This is particularly an issue on the horizontal quench systems. Air hoist are used for loads up to 3000 lbs and for larger loads hydraulic cylinders are employed.

Load configuration.
The load configuration is probably the most important aspect of heat treating heavy gauge loads. The load must be configured to allow the air to heat the parts during the heat cycle and the parts must be spaced so the quench has access to all surfaces and can remove the heat quickly. The tendency to pack same size and configured parts tightly on the racks can have very detrimental effect on the process.

The rule of thumb is that there must be a minimum of 1 inch plus the thickest part of the material between each part to achieve good heat transfer.

Care must be taken when racking the parts. As show in figure #4 it can significantly change the process when different approaches is used for hanging the same part. The main concern in the example shown in figure 4 is the fact that the steel rod has a different cool down rate than the aluminum and the part might have a "soft" spot where the rod is in contact with the part due to slow cooling and slow heat up during the solution heat treat cycle. The use of thin wall tubing/pipe for hanging the parts is preferred compared to solid rod.

Figure # 4
Parts supported by rod or pipe.



Comment [NB1]:

[**] MIL-H-6088F Table VI footnote 1/
[*] MIL-H-6088F Table VI

Rack

The configuration of the rack must not restrict the airflow or the quench flow to the parts. The rack's shall be designed and constructed with the rack weight as low as possible compared to the parts. The continuous heating and cooling of the fixtures/rack is a waste in BTU for heating the racks and cooling capacity for removing the heat from the quench.

The rack shall be fabricated of materials that can endure the repeated heating and cooling cycles without any detrimental effect on the rack. (Warpage or cracking.) The racks shall be pinned and bolted together to allow the rack to expand and contract without restriction. Welding shall be eliminated as much as possible since they have a high tendency to crack. The use of tubing especially 4130 steel tubing has been very successful throughout the aluminum aerospace industry with racks in production that have thousands of cycles without any repairs or distortion.

Conclusion

This paper has examined the basic design criteria for a quench tank system. The paper is a guideline for all systems however specific details is dependent on the type of parts that are heat treated and the type of equipment employed. A delicate review of the process, parts and racking methods in the facility combined with close coordination of design is a must for a successful rebuild of existing or implementation of a new quench system.