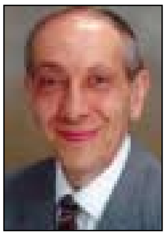
THE HEAT TREAT DOCTOR®

About the columnist . . .

Daniel H. Herring is president of The Herring Group Inc., Elmhurst, Ill., a business specializing in practical solutions to problems facing the heat treating and sintering industries (Web: www.heat-treat-doctor.com).



Dan Herring has spent more than 25 years working for furnace equipment manufacturers in a variety of roles, including senior management and new business development. Now an independent entrepreneur, Dan lectures, writes, teaches, and consults. A frequent speaker at local, national, and international conferences, he is dedicated to advancing the state of the art in thermal processing. He has published more than 100 technical papers, written three books, and contributes to Heat Treating Progress *and other industry publications.*

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How to Load Parts in Furnace Baskets

Because parts come in all shapes and sizes, standard heat treating furnaces have been designed to accommodate most any workload configuration (Table 1). A loading arrangement generally falls into one of two classes: weight limited or volume limited. In either case, when loading parts in furnace baskets or onto racks the goal is often to maximize loading efficiency. However, heat treaters must also be concerned with proper part spacing; that is, positioning parts within the load for optimal heat transfer, atmosphere circulation, temperature uniformity, and heat extraction during quenching to minimize distortion. Despite the almost limitless choices, some commonsense rules apply.

Furnace factor: How parts are loaded is very much a function of the style of furnace being used. Rectangular baskets designed for stacking or nesting (Fig. 1) are commonly used in integral quench furnaces. These are typically placed atop carrier grids. Pit furnaces use cylindrical baskets, often with solid sides (Fig. 2) to promote circulation. In some instances, parts are loaded onto fixtures consisting of multiple grids with a center post — a "Christmas tree" arrangement (Fig. 3). Parts loaded in pusher-style furnaces can be placed directly on the grid, in racks, or in segmented frames

Fig. 1 — Baskets of precision-machined AISI/SAE 8620 (UNS G86200) steel plates will be carburized and oil quenched in a batch integral quench furnace. The parts baskets are made of AISI 330 (UNS N08330), an austenitic Ni-Cr-Fe-Si alloy combining resistance to carburization and oxidation at temperatures to 2200°F (1200°C) with high strength. Photo courtesy Specialty Heat Treating Inc., Grand Rapids, Mich. (www.specialtyheat.com).

Table 1 — Common furnace workload sizes

Furnace style	Width, in.	Length, in.	Height, in.
Integral quench	24	36	18
	24	36	24
	30	48	30
	36	48	30
	36	48	36
	36	72	36
	48	72	36
Pusher	12	12	22
	22	22	24
	24	24	24
	24	36	24
	27.5	27.5	24
	30	30	30
	36	36	30
	Diameter, in.	**Depth, in.**	—
Pit	12–120	12–192	—

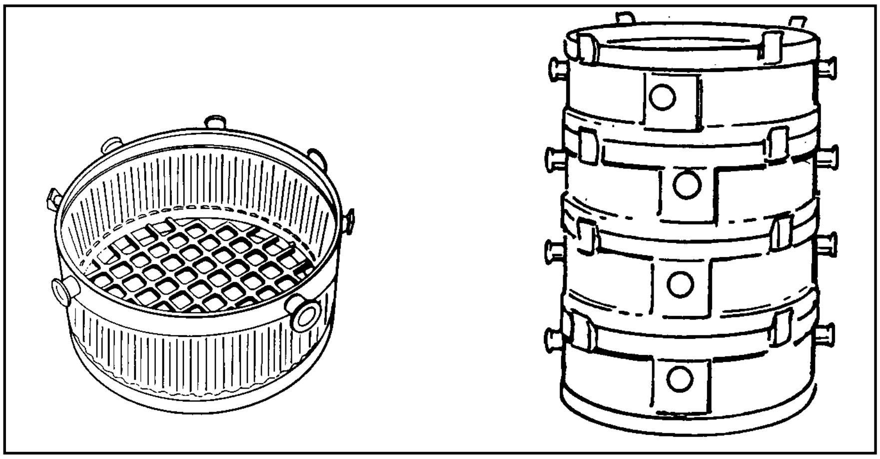

Fig. 2 — Circular basket for a large pit furnace, left. (Source: ASM Handbook, *Vol. 4,* Heat Treating*: ASM International, Materials Park, Ohio, 1991, p. 515.) Stack of fabricated baskets, right. (Source: Rolock Inc. advertisement,* Metal Progress, *Vol. 114, No. 4, September 1978, p. 8. Rolock went out of business in 2001. Many of the alloy components formerly made by Rolock are now fabricated by Alloy Engineering Co., Berea, Ohio.)*

Fig. 3 — Pit furnace lifting post fixture. The fixture is being inspected by Michael Haite (right, in white shirt), director of alloy fabricator AFE Klefisch, Hürth, Germany, and engineers of customer Timken România S.A., Ploiesti. Photo courtesy North American Cronite Inc., Div. AFE Technologies Corp., North Ridgeville, Ohio.

having crossmembers that can be added or removed as dictated by the geometry of the part to allow for hanging or support (Fig. 4).

Determining part spacing

The orientation of parts in the workload is very important when trying to minimize distortion in heat treatment. When loading baskets, imagine that each part occupies a cylindrical space encompassing both the part and a separation space or gap between it and adjacent parts (Table 2).

Table 2 — Typical part spacing requirements

Part diameter, in.	Horizontal spacing (inside), in.	Vertical spacing (inside), in.
≤1	0.25-0.75	0.5-0.75
1-2	0.5-1.5	0.75-1
2-3	0.75-2.25	1-1.5
3-4	2.25-3	1.5-2
≥4	≥3	≥2

An example is the load configuration for a part having overall dimensions of 1.5 in. diameter × 4 in. high. The part will fit inside a typical cylindrical envelope of 2.25 in. (1.5 + 0.75 in.) diameter × 4.75 in. (4 + 0.75 in.) high. Bear in mind that there are exceptions to every rule, and these part spacing recommendations are based on practical experience. Denser loading may be possible, but it is a good idea to have empirical test results and quality checks to prove that it can be done. An example: a load of 0.625 in. OD shafts placed into 24 × 36 in. baskets having openings that measure only 0.75 in. diameter.

The final part spacing selected is dictated by concerns for heating, soaking, and atmosphere flow; the volume and type of quench medium (brine, water, polymer, oil, salt, or air); and gross load weight. There are several industry-tested rules of thumb that can be used to help determine the proper spacing around parts, although trial-and-error is usually the best method. In general, the gap around a part should be no less than 25% and no greater than 75% of its envelope diameter.

Nesting: Note that both process and equipment variables also must be factored in. For example, large- and medium-sized bearing races of various diameters are commonly nested inside one another to produce an "optically dense" workload. This is done because the furnace space is volume limited, not weight limited. However,

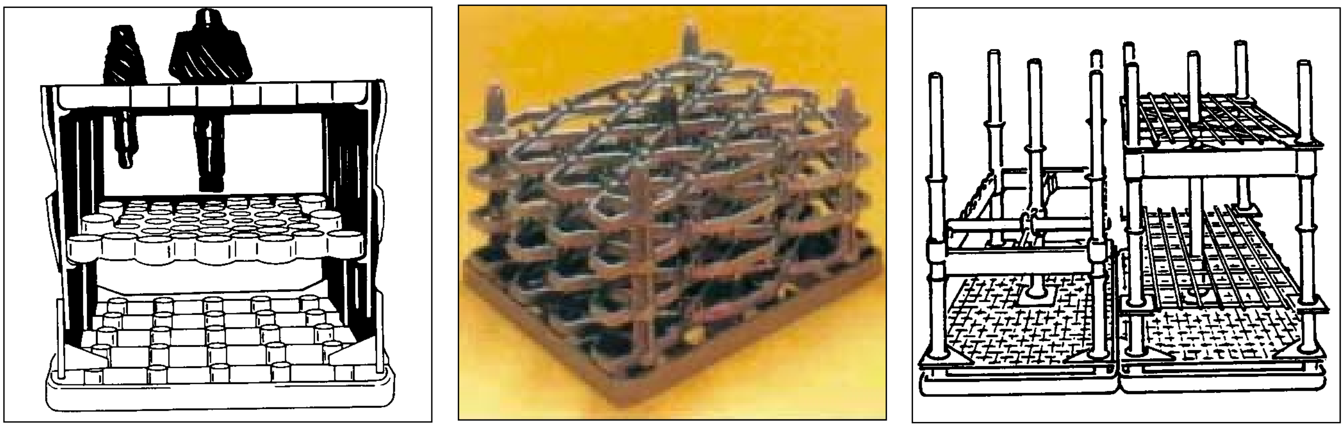

Fig. 4 — Tray/fixture assembly for carburizing pinions, left. (Source: ASM Handbook, *Vol. 4,* Heat Treating, *p. 515.) Heat treat fixture with grids and posts, center. (Source: North American Cronite Inc., Div. AFE Technologies Corp., North Ridgeville, Ohio.) "'Do-it-yourself' fixturing: the ultimate in adaptability," right. (Source: Rolock Inc. advertisement,* Metal Progress, *September 1978, p. 8.)*

Table 3 — Part-surface-area to load-size relationship

Load size (width × length × height), in.	Part surface area, ft^2
24 × 36 × 24	180–250
30 × 48 × 30	300–400
36 × 48 × 36	400–500
36 × 72 × 36	625–725

the cycle must be adjusted to allow enough time for the interior parts to be heated. In a case like this, the spacing given in Table 2 is often doubled. On the other hand, when processing similarly shaped parts made of thin-wall tubing, but not nesting them, the spacing is often reduced due to the relative ease of heating and cooling.

Random part loading: The most common reason to shovel- or random-load parts is to reduce labor costs. Small bearing races 1 in. in diameter could be stacked but instead are random loaded to a depth that will not prevent successful quenching, but will make it difficult to circulate furnace atmosphere throughout the load. To compensate, heat treaters push aside parts to create empty spaces, often at the center of the load. This preserves the economic advantage of random loading, since it would take much longer to stack the small parts to ensure proper atmosphere flow.

Rectangular-basket calculations

When loading rectangular baskets, there's a simple formula for determining how many circles of a given diameter (how many parts) can be placed into a rectangle of known size:

$$W / d \times L / d = N,$$

where W is the width of the rectangular space, L its length, d is the diameter of the part (including the separation space), and N is the number of parts that can be loaded into the rectangular space.

Example: (In this calculation all fractional parts are rounded down.) Consider a furnace with a workload size of 24 in. wide × 36 in. long × 24 in. high. Shafts with overall dimensions of 1.5 in. diameter × 4 in. long are to be loaded into four rod-frame mesh baskets, each 6 in. high. Parts will stand vertically inside an egg-crate-type separator system. Internal dimensions of each basket (inside the mesh liner): 22.5 × 34.5 × 5.5 in.

For loading purposes, consider each shaft to be inside a 2.25 in. (1.5 + 0.75 in.) circular envelope, with an overall height requirement of 4.75 in. (4 + 0.75 in.). Thus, we can fit 10 parts across (22.5 ÷ 2.25 = 10) and 15 down (34.5 ÷ 2.25 ≈ 15), or 150 shafts / layer. The total load is 600 shafts (150 shafts / layer × 4 layers / load).

The gross load should be checked against the furnace rating and the following "percentage rules" to ensure that the loading is reasonable:

- No more than 50 to 70% of the surface area of the bottom of the tray should be covered by the work area.
- No more than 70 to 80% of the overall height should be occupied.

In the previous shaft example, the 150 shafts in a layer will occupy 34% of the bottom area ($265\ \text{in.}^2 \div 776\ \text{in.}^2$) and 79% of the height ([4.754 × 4 in.] ÷ 24 in.).

- The quench chute area covered by the load, basket, and grid should be no greater than 50% (agitators) to 75% (pumps) of the total area. In critical quenching applications, these numbers will drop to 25–50% (maximum) of the total area.

Quench oil: The flash point of the quench oil should be taken into consideration to avoid localized or general overheating due to loads having either a large mass or high surface area. In addition, under certain circumstances such loads can cause an unexpected expulsion — a "burp" — of oil from the quench tank. This is believed to be due to the entrapment of gases formed by rapid oil volatilization when the load is first submerged.

Load configuration has been found to be an important contributor to this phenomenon. The rule of thumb is to reduce load size by 25% after each occurrence until no "burping" of oil is observed.

Finally, loads of high surface area, parts having cavities that nest, and load densities higher than normal will contribute to a large flame eruption on load transfer and quenching. (I have seen 20 to 30 ft flames exiting the front door of an integral quench furnace under these circumstances.)

Integral quench: Total surface area of the load is an important consideration in batch integral quench furnaces, especially those used for gas carburizing or carbonitriding. Volumetric considerations are important to ensure the availability of carburizing gas throughout the load. Several rules of thumb are given in Table 3. Powder metallurgy parts are also notorious for being difficult to carburize, carbon restore, neutral harden, and quench due to their surface porosity and relatively low density. Calculating the total surface area of a part can be challenging, but if done right can save a lot of guesswork (and rework) when trying to figure out why a seemingly light load will not carburize.

In the example that follows, 0.25 in. diameter × 0.75 in. long fasteners are to be randomly loaded in mesh baskets for hardening in a batch integral quench furnace. The furnace has a 30 in. wide × 48 in. long × 30 in. high work zone and a 2250 lb gross load capacity. The fasteners, which have a bulk load density of 225 lb / ft^3, will be loaded into five mesh baskets, each having an internal volume of 4.5 ft^3.

In this case, "packing density" is the major concern, and the overriding consideration is knowing when the center of the load of these tightly nested fasteners reaches temperature. In effect, this forces us to reduce furnace capacity because the area for flow of gases through the load is restricted, and heat-up takes longer. As the packing density increases, the "hour per inch of cross section" rule comes into play. A densely packed load of fasteners will *not* be at temperature in the middle of the baskets if the baskets are overloaded. In this example, loading should be limited to 1-2 in. deep, depending on the circulation efficiency through the load and other factors.

If this load were to be carburized, it should be spread out so that either parts are not touching or the depth of loading is no more than several layers. Care must also be taken to avoid losing too much heat when transferring small parts in shallow layers or thin parts. The solution is to add some type of heat "ballast": screens, extra baskets, or even plates set atop (and sometimes on the sides or ends) of the load to retain as much heat as possible during transfer.

Table 4 — Number of circles that can be placed within an enclosing circle[1]

R	N	R	N	R	N	R	N	R	N
2.00	2	6.76	34	12.80	130	18.75	290	26.65	600
2.15	3	6.86	35	13.06	135	18.90	295	26.86	610
2.41	4	7.00	36	13.26	140	19.05	300	27.07	620
2.70	5	7.00	37	13.49	145	19.35	310	27.28	630
3.00	6	7.08	38	13.72	150	19.65	320	27.49	640
3.00	7	7.18	39	13.95	155	19.94	330	27.70	650
3.31	8	7.31	40	14.17	160	20.23	340	27.91	660
3.61	9	7.39	41	14.39	165	20.52	350	28.12	670
3.80	10	7.43	42	14.60	170	20.81	360	28.33	680
3.92	11	7.61	43	14.81	175	21.09	370	28.54	690
4.05	12	7.70	44	15.01	180	21.36	380	28.75	700
4.23	13	7.72	45	15.20	185	21.63	390	29.14	720
4.41	14	7.81	46	15.39	190	21.90	400	29.52	740
4.55	15	7.92	47	15.57	195	22.17	410	29.90	760
4.70	16	8.00	48	15.75	200	22.44	420	30.28	780
4.86	17	8.03	49	15.93	205	22.70	430	30.65	800
5.00	18	8.13	50	16.11	210	22.96	440	31.02	820
5.00	19	8.21	55	16.29	215	23.21	450	31.39	840
5.18	20	8.94	60	16.46	220	23.47	460	31.75	860
5.31	21	9.25	65	16.63	225	23.72	470	32.11	880
5.49	22	9.61	70	16.80	230	23.97	480	32.46	900
5.61	23	9.93	75	16.97	235	24.21	490	32.80	920
5.72	24	10.20	80	17.14	240	24.45	500	33.14	940
5.81	25	10.46	85	17.30	245	24.68	510	33.48	960
5.92	26	10.73	90	17.46	250	24.91	520	33.82	980
6.00	27	11.15	95	17.63	255	25.13	530	34.15	1000
6.13	28	11.34	100	17.79	260	25.35	540	35.75	1100
6.23	29	11.60	105	17.95	265	25.57	550	27.30	1200
6.40	30	11.85	110	18.11	270	25.79	560	38.80	1300
6.44	31	12.10	115	18.27	275	26.01	570	40.20	1400
6.55	32	12.34	120	18.43	280	26.23	580	41.60	1500
6.70	33	12.57	125	18.59	285	26.44	590	42.95	1600

1. R = the ratio of the diameter of the load circle to that of the part circle. N = the number of part circles that can be inscribed in the load circle. (If appropriate, the separation distance has been added to the part circle diameter.)

Circular-basket calculations

For round or circular baskets, it's necessary to determine how many circles of a given diameter can be inscribed, or loaded, into a larger circle of known diameter. The method used involves calculating the ratio, R, of the diameter of the load circle, D, to that of the part circle, d, where, if appropriate, the separation distance has been added. In other words, R = D / d. N, the number of circles that can be inscribed, is related to R, and can be found using Table 4.

For example, to determine how many 0.5 in. diameter wires can be placed inside a 5 in. diameter pipe, first calculate R (5 ÷ 0.5 = 10), and then find N by interpolating between the N values (75 and 80) for the two R values nearest to 10 in Table 4 (9.93 and 10.20). In this case, N = 76.

In general, cylinders can be packed in rectangular containers more efficiently than in cylindrical ones because both the length and width of a rectangle can be varied, as opposed to only the diameter of cylinder. **HTP**

Selected references

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- "Densest Packing of Congruent Circles in an Equilateral Triangle," by H. Melissen: *The American Mathematical Monthly*, Vol. 100, No. 10, December 1993, p. 916–925.

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