ing, and while the steel must be subjected for a period of time to heat that insures its being of the same temperature in the middle of the piece as it is at the surface, yet we must be careful not to overdo it.

Steel kept at a red heat for a long period of time, even if it is not overheated, will betray the fact when the temper is drawn after hardening, if it does not at any other time. A piece of steel which is kept hot for too long a period when annealing, may apparently harden all right, but when the temper is drawn the hardness apparently runs out—i. e., when the piece is heated to a straw color it may be filed very readily, whereas a piece from the same bar not annealed, or which was *properly* annealed and then hardened and drawn to the same temper color, would show all right —i. e., a file would just catch it.

Uniform temperature when heating for annealing is as desirable as when heating for hardening. If a large block is unevenly heated, its corners and edges are hotter than the main part of the block. Violent strains are set up at these points, so it will be readily apparent that uniform heating during the various processes is one of the secrets of successful hardening of tool steel.

There are other methods of annealing steel, methods whereby the surface does not become oxidized by the process of heating, as when heating drill rods, etc., but as these methods are not likely to be used by mechanics in every day shops, their consideration would be entirely out of place at this time.

Lastly, remember that any process of annealing that takes from the steel any of its hardening properties should never be used, no matter how soft it will

make the steel. It is better to work a piece of steel which is hard, than to unfit it for doing its maximum amount of duty when finished; but *it is* possible to anneal most steel so that it will be workable and yet harden in a satisfactory manner; in fact, in a much more satisfactory manner than if not annealed.

When annealing high carbon steel, and it is desirable to retain the full amount of carbon in the steel, it is advisable to pack in the annealing box with charred leather, instead of wood charcoal.

When it is desirable to harden the surface of low carbon steel harder than it would naturally be, it may be machined nearly to size, packed in a box with charred leather and run for a length of time sufficient to give the desired results. After machining to shape, it may be hardened in the ordinary manner.

Hardening Baths.

When steel is heated to the proper hardening heat it is plunged into some cooling bath to harden. The rapidity with which the heat is absorbed by the bath determines the hardness of the steel. Knowing this, it is possible by the use of baths of various kinds to give steel the different degrees of hardness and toughness. A bath that will absorb the heat contained in a piece of steel the quickest, will make it the hardest, everything else being equal. A bath of mercury will cause a piece of steel plunged in it to be harder than if it were plunged in any of the liquids commonly used for this purpose, but as such a bath would be extremely expensive, it is but little used. Clear cold water is the one more commonly used than any other, and for most cutting and similar tools gives good satisfaction, although many old hardeners claim better success with water that has been boiled, or that has been used for some time, provided it is not dirty or greasy.

A very excellent bath that is used very extensively is made by dissolving all the salt possible in a tank of water, or what is known as a "saturated solution." Salt water, or "brine," as it is commonly called, is used in most shops on certain classes of work, and in some shops it is used altogether where a bath of water is desired.

Different kinds of oil are also used to accomplish various results. When small or thin cutting tools requiring a hard cutting edge are to be hardened, a bath of raw linseed oil, or neat's foot oil, is used.

When toughness is the desired quality, as in hardening a spring, a bath of tallow, sperm oil or lard oil is used. But the nature of steel of different makes varies so much that no one bath answers best for all purposes, or for the same purpose, when applied to steels of different makes. Sometimes it becomes necessary to use a bath containing two or three ingredients in order to accomplish the desired result.

I have in mind a manufacturing concern who made a great many heavy springs. Until they changed the make of steel they had been using for years they had excellent results from hardening in lard oil, but *after* changing they could do nothing with this bath. After considerable experimenting they were advised to use the following mixture: Spermaceti oil 48 parts, neat's

foot oil 45 parts, rendered beef suet 4 parts, resin 3 parts. They had very good results with this bath until a drummer came along with good cigars and a steel two cents a pound cheaper, and then trouble was the result.

By the way, I have visited and known of several shops where a few good cigars or an occasional wine supper, which some glib-tongued salesman was willing to put up for the man who did the buying, caused more trouble than a little in the hardening department. But to return to the hardening of the springs. When the new steel came, the springs would not harden sufficiently in the mixture mentioned. They were finally advised to try a bath of boiling water, and this worked very nicely.

Very small cutting tools, as taps, reamers, counterbores, etc., harden nicely in a bath made by dissolving one pound of citric acid crystals in one gallon of water. This proportion may be used in making a bath of any size.

The following is recommended when it is desired to have the tools hard and tough:

Salt....................	½ teacupful.
Saltpetre.................	½ ounce.
Pulverized alum......	1 teaspoonful.
Soft water...............	1 gallon.

The following bath gives excellent results, but care must be exercised in its use, as it is deadly poison. To six quarts of soft water put in one ounce of corrosive sublimate and two handfuls of common table salt. When dissolved it is ready for use.

Sulphuric acid is added to water in various proportions, from one part acid to ten parts water, to equal parts of acid and water. Some even use clear acid, and although excellent results, so far as the hardened surface is concerned, may be obtained by the use of this acid, steel makers do not advocate its use, claiming that the after-effects are injurious to the steel, that is, it "*rots*" the steel, and the writer's experience substantiates the claims of the steel makers. I do not advocate the use of any of the acids which act directly on steel, provided any other form of bath will give satisfactory results.

There are many other compounds used with success in various shops. Some of these will be mentioned in connection with hardening various tools. As a rule, tool steel that is fit for use for cutting tools will harden in a satisfactory manner in clear water. If the outline is irregular or it is desirable that it should be extra hard, a bath of brine answers admirably. Articles of an irregular shape made of steel liable to crack when hardened should be dipped in water or brine (that is, warmed somewhat), the temperature of the bath depending upon the liability of the piece to crack.

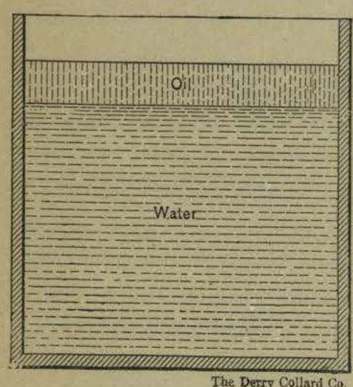

Figure 30. Oil and water bath for hardening.

Tools, as milling cutters, made from high carbon steel, are many times hardened to advantage in a bath

of water having one or two inches of oil on the surface, as shown in Fig. 30. The article is brought to the proper temperature in the fire and immersed in the bath, passing it down through the oil into the water. Enough oil adheres to the red hot steel, especially in the corners of the teeth or projections, to prevent the water acting as suddenly as it otherwise would, thus doing away in a great measure with the tendency to crack.

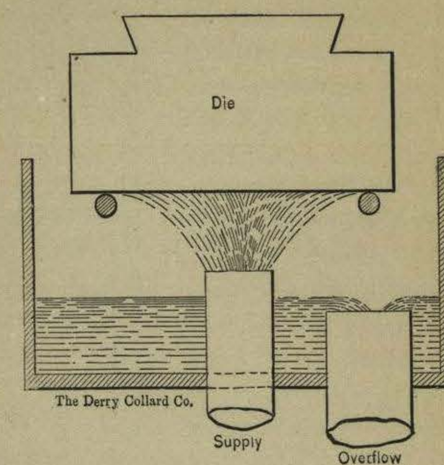

Figure 31. Hardening with jet from bottom.

It is a good plan when hardening large pieces of almost any shape to first dip in water or brine and allow them to remain in this liquid until the surface is hard, then remove and instantly plunge into a tank of oil, allowing them to remain in the oil until cold. This works especially well in the case of such tools as milling machine cutters, punching press dies, etc., where it is not necessary that the hardened surface be very deep.

The depth to which a piece is hardened depends on the length of time it is left in the water. For this purpose old hardeners allow the article to remain in the water until it ceases to "sing." This is the peculiar noise occasioned by putting a piece of red hot steel in water. When the piece stops singing it is removed from the water and plunged in oil and left until cold.

When pieces are to be hardened, and it is necessary to harden the walls of a hole or some depression, as the face of an impression die, or forming die, or any similar piece, it is necessary if good results are desired, to have a bath which has a stream or jet coming up from the bottom, as shown in Fig. 31. If clear water

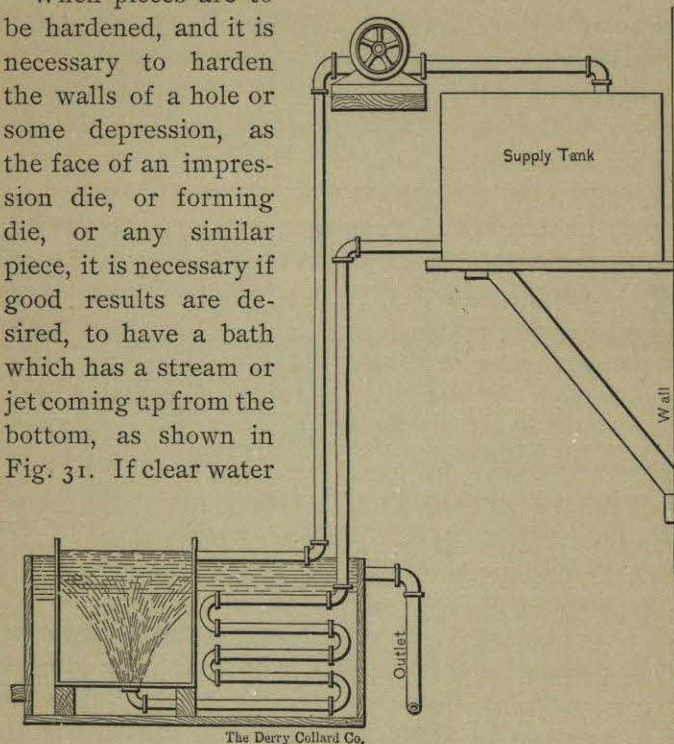

Figure 32. Continuous brine bath.

is used in the bath, the inlet pipe may be connected with some constant supply, but if brine or some solution is used, it becomes necessary to have a supply tank having a pump as shown in Fig. 32. The contents of

the bath are pumped into the supply tank and run down the supply pipe as shown.

At times it is desirable to have a tank in which there is no gush or jet of fluid, but where the contents of the bath are kept in motion in order to force the steam away from the surface to be hardened. There are several ways of accomplishing this. Fig. 33 shows a bath having a pipe coming up from the bottom, the jet striking the plate which spreads the fluid. It then comes to the surface through the perforated plate shown.

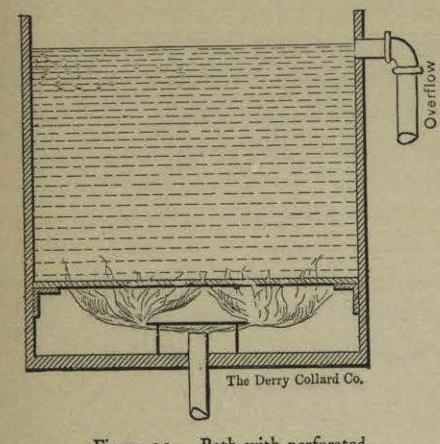

Figure 33. Bath with perforated bottom plate.

Fig. 34 shows a bath in which the contents are kept in motion by some mechanical means contained in the tank. Such a bath may be made by following the suggestions contained

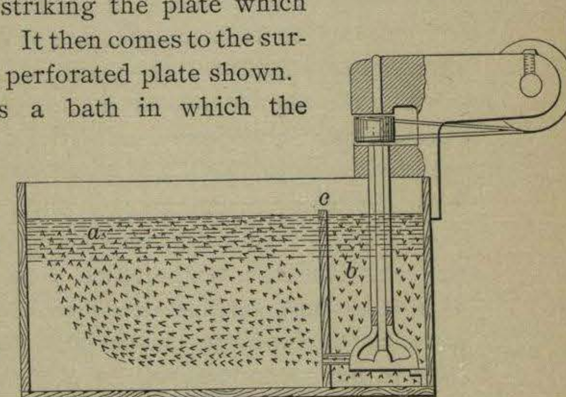

Figure 34. Bath with agitator.

in the illustration. A tank of any convenient size may be made having a partition as shown. The portion of the tank marked *a* is intended to be used for the immersion of the articles being hardened, while *b* contains a pump, Archimedian screw or some similar device for forcing the water into the side *a*.

If a pump is used, the water is forced through the pipe shown. If an Archimedian screw is used, the partition shown should not extend way to the bottom, the water being forced under it. In either case it returns to *b* over the top of the partition *c* as shown, thus insuring a rapid circulation of fluid. This form of bath is especially to be desired where brine or some favorite hardening solution is used. It is also possible to heat the contents of the bath when it is considered advisable, as in the case where articles are to be hardened that are liable to crack in contact with extremely cold liquids. Much more uniform results may be obtained, especially when small, thin pieces are hardened, if a uniform temperature can be maintained in the bath.

In order to keep the contents of the bath at somewhere near a uniform temperature, a small coil of steam pipe may be placed in the tank, and a thermometer may be so placed as to readily show the condition of the bath. While it may seem unnecessary to be so particular about the temperature (and it is unnecessary on most work, as an experienced hardener can determine the temperature very closely by the sense of feeling), yet there are jobs where it is essential that a certain uniform temperature be maintained in order to get uniform results. I do not mean by this that it is practical to attempt to keep the temperature within a few degrees of a given point, but it can be

kept somewhere near in order to get the best results possible.

Sometimes it is necessary to harden the walls of a hole that does not go way through the piece, as a die used for compression work or some forms of dies for striking up cylindrical pieces. Fig. 35 shows a sectional view of a die having a hole part way through it as described. Now, if a piece of work of this description were hardened in a bath where the contents were not agitated, it is doubtful if the walls of the hole would be hardened in the least. The steam generated would blow the liquid out of the hole, and none could enter until the steel was cooled to a point where it could not harden.

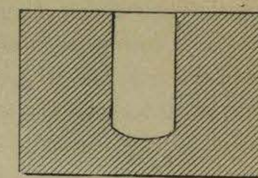

Figure 35. Die with hole.

Better success would follow if it were dipped in a bath having a jet of water coming up from the bottom of the tank, but in this case it would be necessary to invert the piece in order to get the liquid to enter the hole, and if it were dipped in this position, it is probable that enough steam would rise to keep the contents of the bath from affecting the walls near the bottom.

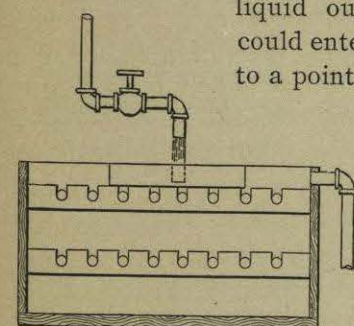

Figure 36. Method of cooling holes in dies.

Now, in order to get satisfactory results when hardening work of this character, it will be found best to have a bath so constructed that the liquid can run into the hole by means of a faucet or pipe, as shown in Fig. 36. If the hole is deep and there is danger of the steam preventing the liquid effectually working at the bottom, a pipe may be run nearly to the bottom, as shown in the sectional view of Fig. 37. The pipe must not be as large as the hole, or the results will not be satisfactory.

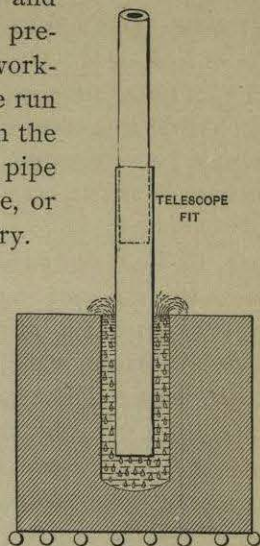

Figure 37. Cooling a deep hole in a die.

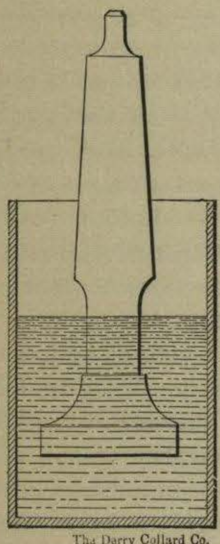

Figure 38. Cooling a shank mill.

Sometimes it is necessary to harden several pieces of a kind whose outline betokens trouble if dipped in a cold bath, and yet it seems necessary to use a cold bath in order to get the desired result. Take, for instance, a shank mill of the shape shown in Fig. 38. If this mill is heated to the proper degree of heat and plunged in a dish containing just enough water or other liquid to harden the teeth before the water gets hot, the teeth

will harden in a satisfactory manner, and the water will heat so as to do away with any danger of cracking the cutter from internal strains. The size of the dish will determine the depth of the hardening. When one piece is hardened the dish may be emptied and filled with cold water for the next.

The writer has seen this scheme used with excellent results, not only on milling cutters, but on broaches, small dies, etc., that showed a tendency to crack when dipped in a large bath of cold fluid. Of course, it should be borne in mind that the dish selected for the bath must be large enough to hold a sufficient amount of liquid to harden the piece the necessary amount before it becomes too hot, but it is also essential that it should not be so large that the contents will not heat, because then there is no difference in its action from that of a large bath.

Generally speaking, however, it is *advisable* to use a *large* bath, having the contents at a temperature of about 60 degrees Fahr., as then the process of contraction, which takes place when the piece is cooling, is uniform.

Delicate articles, however, require a bath having the contents heated somewhat above the temperature mentioned, the temperature depending on the character of the article and the nature of the steel.

It should be borne in mind that a tank or dish of *dirty* water makes a very undesirable bath; neither should one be used having dirt in the bottom, because as the contents are agitated, the dirt rises, preventing the liquid acting in a satisfactory manner.