carbon, or of malleable iron, this is accomplished by using a cyanide made especially for the purpose. This is known as "50 per cent. fused cyanide of potassium."

Hardening Steel.

Having considered the nature of steel, methods of heating for different purposes, and the means of cooling by the various baths, we will proceed to the consideration of hardening articles of various types. As it would be impossible to consider all the articles that require hardening in the various shops throughout the country, such examples have been selected as are representative of the articles that are commonly hardened.

Uniform heats are the secret of success when hardening steel. A greater part of the trouble experienced by men not skillful in this branch of the business arises from this fact not being observed. The writer cannot resist the desire to caution the reader against trouble arising from this cause, and hopes he will be pardoned if he apparently repeats this warning oftener than may seem necessary.

When hardening steel, avoid too rapid cooling of the surface, as it is then rigid and inflexible, while the inside of the piece is still undergoing the change in structure incident to hardening. As a consequence, if the outer surface is hard and inflexible, and the internal portion is undergoing changes in size and structure, the outer surface will crack from the enormous strain brought to bear on it. It is advisable when hardening

small articles to heat the contents of the bath somewhat, to avoid the sudden cooling mentioned.

As stated, when the surface becomes hard before the center has ceased changing its size and structure, there is a tendency to crack the surface from the internal strains.

To overcome this tendency, the piece should be heated to a degree that allows the surface to yield somewhat and conform to the strains in the piece. The amount of heat necessary to produce this result has been ascertained to be at the temperature of boiling water (212 degrees). An experienced hardener can determine the necessary amount of heat very nicely by the sense of feeling, heat the steel until, when touched with the moistened finger, the peculiar snapping sound is heard. This is the same as the housewife tells when her irons have reached the proper temperature for ironing linen.

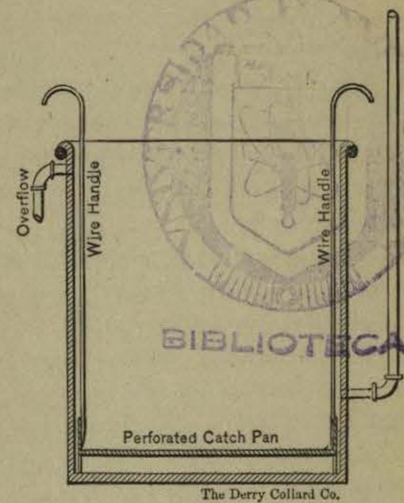

Figure 45. Bath for hardening in hot water.

When pieces are hardened in large quantities, it becomes very costly practice reheating each piece over the fire, guaging the heat by the sense of feeling. A good plan in such cases is to have a tank of the description shown in Fig. 24. A steam pipe is connected with the tank, as by this means it is possible to heat the water to any desired degree to the boiling point. A perforated pan is provided to catch the work as it is dropped into the tank. Occasionally the pan may be removed from the tank by means of the wires shown, the pieces emptied out and the pan returned.

As the pieces are removed from the hardening bath, they may be dropped into this tank, and the tendency to crack overcome. For certain articles the brittleness is reduced sufficiently, making it unnecessary to draw the temper any more.

The use of extremely cold baths is not as a rule advisable. Results fully as satisfactory so far as the hardened surface is concerned, are obtained if the bath is warmed somewhat, and the danger of cracking is greatly reduced.

It is claimed that when articles made of steel and heated red-hot are plunged in a cooling bath, the outside surface becoming chilled and consequently contracted, causes by this process of contraction an immense pressure on the internal portion of the steel which is red-hot; this pressure has the effect of raising the temperature of the interior of the steel still higher, with the result that it expands still more. This extra expansion is, of course, communicated to the hardened (and consequently unyielding) surface, and this being unable to stand the immense strain, either cracks or bursts.

If the contents of the bath are heated to some extent, the surface is not chilled below a temperature that allows it to yield somewhat, allowing it to con-

form in a measure to the internal pressure, which is relieved as that portion cools and contracts.

The pliability of steel when warmed is illustrated in the case of such tools as taps, reamers, or drills, which become crooked when hardening. In order to straighten, it is necessary to apply a certain amount of heat. Place the tool between the centers of a lathe, with the convex side toward the operator, a piece of stock is then put in the tool post of the lathe, having one end against the bowed side, as shown in Fig. 46. The article is now heated until oil placed on the surface commences to smoke; pressure is applied by means of the cross feed screw and until the article is slightly bowing in the opposite direction.

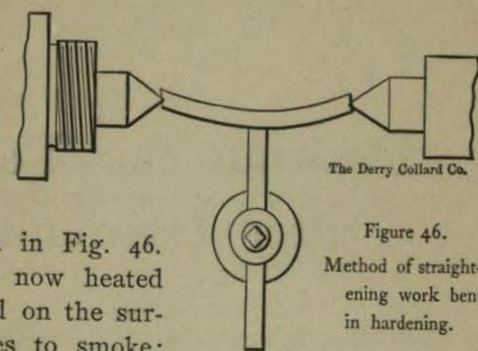

Figure 46.
Method of straightening work bent in hardening.

The piece should now be suddenly cooled while in this position. If it is not straight, the process should be repeated. Now, it is safe to spring the steel when warm, but when it is cooled, even after heating, as described, it will break if any great amount of pressure is applied. Should it spring somewhat when cold, it will return to its original shape when the pressure is removed, thus proving that hardened steel, when heated to a certain degree, is somewhat pliable. It is for this reason the surface of a hardened piece is reheated to "remove strains," as it is familiarly termed, or it is made pliable by heat, and in this condition conforms to the immense strain incident to hardening.

In the case of the article heated and straightened by pressure, it is necessary to cool the piece uniformly. Should one side be cooled and the opposite side left hot, the piece would probably crack from the unequal contraction. By carefully following this plan it will be possible to save many tools that would otherwise have to be thrown away—or which, if used, would not be satisfactory.

Drawing the Temper after Hardening.

When a piece of steel is hardened it becomes brittle. When the design of the piece is such that the working surface has sufficient backing, it is safe and advisable to keep the article as hard as when it comes from the bath. But in the case of tools having slender cutting edges, as taps, screw threading dies and milling machine cutters of the ordinary styles, it becomes necessary to reduce the amount of brittleness in order that it may stand up when in use. This is done by reheating the piece somewhat.

The process of reheating also has the effect of softening the steel to a considerable degree. It is not generally desirable to soften it, but it is necessary to do so in

order to reduce the brittleness. This reheating is generally termed "drawing the temper." Unfortunately, the word temper is understood as having more than one meaning, and as a consequence people are sometimes puzzled to know exactly what one means when the term is used. By some it is understood as the double process of hardening and drawing the temper. To others it simply conveys the idea of drawing the temper of a hardened piece, and will be so used by the writer in connection with treating steel by heat, although the steel maker's definition of the word temper will be used occasionally to designate the percentage of carbon the steel contains.

When steel is heated, the amount of heat it absorbs may be determined by the surface colors, provided it has been brightened previous to heating. It is customary after hardening to brighten the surface with a stick whose surface has been coated with glue and then covered with emery, or a piece of emery cloth may be attached to a stick or held on a file. After brightening, the piece may be subjected to heat. As the steel becomes heated various colors will appear on the brightened surfaces. The first color visible is a faint straw color, then straw color, light brown, darker brown, brown with purple, light blue, darker blue. If heated to a black, the hardness is reduced to a point that makes the steel practically soft.

The amount of heat necessary to give steel in tempering, depends on the make of the steel, how hot it was heated when hardening, and for what purpose it is to be used. The method ordinarily practiced has been briefly described above.

When work is done in large quantities, the temper is sometimes drawn by placing the articles in a pan having a long handle, as shown in Fig. 47. A quantity of clean sand is put in and the pan held over a fire, moving it back and forth, thus keeping the sand and work in motion. The surface colors can be closely watched and excellent results obtained. If there are any sharp edges or cutting teeth that will be harmed by striking against the other pieces, it is not advisable to use this method unless extreme care is exercised, but a pan of sand may be placed over the fire and a few pieces of work, having edges as described, placed in it and kept in motion by a stick, being careful not to hit them together.

An excellent furnace, which is illustrated in Fig.

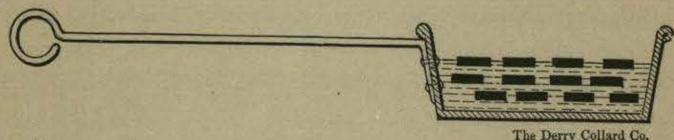

Figure 47. Pan for drawing temper.

48, can be procured, which gives very satisfactory results. The pieces to be tempered are placed in the pans, D D, which rotate at the speed of two or three revolutions per minute, the pans being hung loosely from rods connected with spokes around the driving block in the center, which receives motion from the worm and gear, A B, connected with power. The door, C, is closed and the furnace is charged with work, and may be opened for observation. When opened, the door forms a shelf or rest for the pans.

The thermometer indicates a degree of temper somewhat different from the actual heat in the furnace, but if the temperature indicated is observed when the desired temper is obtained, the operation may be repeated with satisfactory results.

This furnace is designed for tempering small articles, but the writer has used it with excellent results on punches used for punching rectangular holes 2 inches by ⅝ inch, the shanks being 1¼ inches in diameter and 5 inches long. The action of the furnace depends on the heated air, with temperature so regulated that articles of irregular shape can be exposed to it long enough to impart the proper temper to the heavier parts without drawing the temper too low on

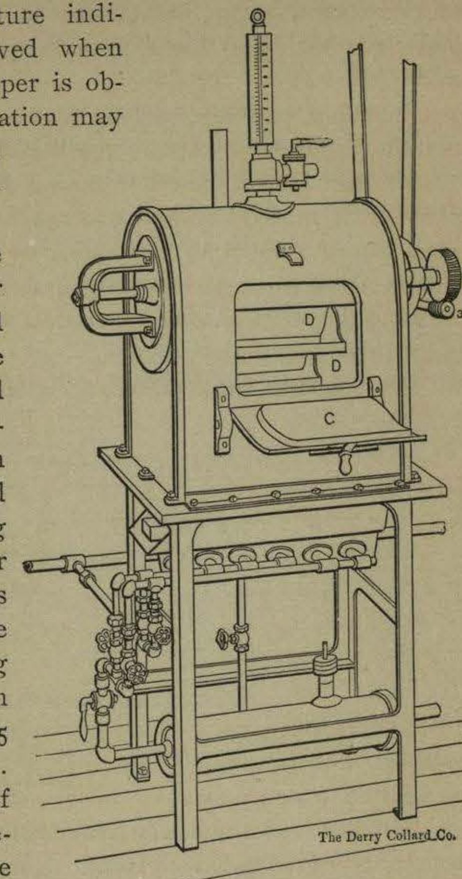

Figure 48. Revolving furnace for tempering small pieces.

the lighter parts of the same piece. By means furnished of regulating the heat generated, the injection of the heat evenly throughout the furnace is easily secured, and the overheating of any part of the piece prevented.

A common method when drawing the temper of articles which are of a uniform thickness, is to heat a flat piece of iron to a red heat, lay the pieces on this, moving them around and turning them over occasionally to insure uniform heating. When the desired temper color shows, the piece is immediately immersed in oil to prevent its softening more than is desired. This method is open to objections when articles having heavy and light portions, which must be heated alike, are to be tempered, because the lighter parts, heating more quickly than the heavy ones, will become too soft before the heavier portions reach the desired temper.

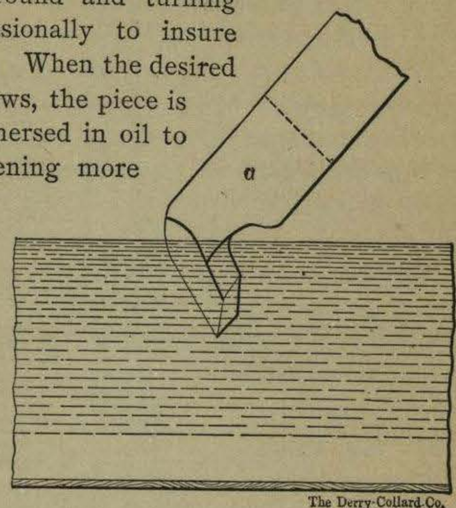

Figure 49. Hardening a diamond pointed lathe tool.

When tools having heavy parts adjoining the cutting portion are to be hardened, and it is not necessary to harden the heavy parts, as a diamond point lathe tool or similar article, it is the general practice to heat the tool for a distance on the shank—say as far back as

the dotted line in Fig. 49—to a red heat. Plunge the cutting blade into the bath, being careful not to dip the portion marked *a* into the bath. Work up and down to prevent a water line, and move around to avoid steam. When the cutting part is sufficiently hardened, remove from the bath, and allow the heat from the heavy portion to run into the hardened part until the desired color shows, when it may be quenched to prevent its running any lower.

When work is tempered in large batches, a very satisfactory method consists in putting the articles in oil and heating to a proper degree, gauging the heat by means of a thermometer.

A very satisfactory tempering furnace is shown in Fig. 50. Illuminating gas is used as fuel. The burning gas circulates around the kettle holding the oil, thus heating it very uniformly. The work is held in a perforated pail or basket, somewhat smaller than the inside of the kettle. The degree of heat to which the oil is brought is shown by the thermometer.

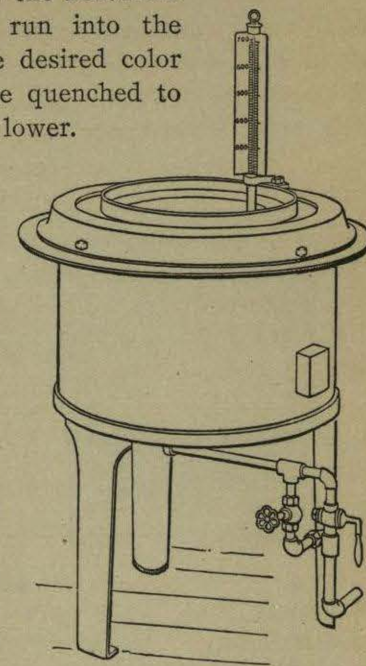
Figure 50. Oil tempering furnace.

If not situated so that a furnace of this kind is accessible, a kettle may be placed on a fire in a blacksmith's forge and built up around with bricks, leaving a space up around the kettle for coals. Now fill the space with charcoal. As this catches fire, it heats the oil in the kettle. The articles to be tempered may be placed in the perforated sheet iron pail, at least two inches smaller than the inside of the kettle. The pail should have a flange at the bottom, as shown in Fig.

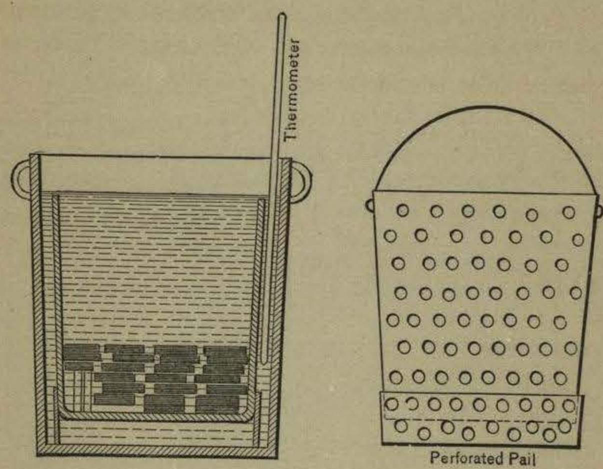

Figure 51. Oil tempering in a kettle.

51, or it should be blocked up 1½ inches or 2 inches from the bottom of the kettle, to allow the oil to circulate freely beneath it.

If the pail were to rest directly on the bottom, the pieces of work at the bottom of the pail would soften too much from coming in contact with the kettle, which is acted on by the direct heat of the fire. The thermometer should be placed between the pail and the

kettle, as shown. It is advisable to stir the oil in the kettle occasionally, in order to equalize the heat. When the thermometer shows the desired degree of heat, the pail containing the work may be removed, set to one side, where no current of air can strike it, and allowed to cool off.

When pieces of hardened steel are placed in a kettle of oil and heated, the temper colors do not show, so it becomes necessary to gauge the heat by a thermometer. The temper colors are significant of a certain amount of heat which the steel has absorbed.

Faint straw color.........	430	degrees	Fahr.
Straw color.............	460	"	"
Light brown..............	490	"	"
Darker brown...........	500	"	"
Brown with purple spots..	510	"	"
Light purple.............	530	"	"
Dark purple..............	550	"	"
Light blue...............	570	"	"
Darker blue.............	600	"	"
Blue, tinged with green...	630	"	"

Knowing the proper degree of heat to which a piece of steel should be subjected, it becomes possible to draw the temper on any number of pieces exactly alike, and much more uniformly than though they were gauged by color. As stated, 430 degrees of heat represents a faint straw color, while 460 degrees a full straw, a difference of only 30 degrees, yet when tested with a file by one accustomed to this work, there is a vast difference in the hardness of the two. While the difference in the two colors is slight, yet difference in the ability of the two pieces to resist wear in the case of cutting tools is quite noticeable. The average man does not detect a difference of 10 degrees by observing colors, consequently he is liable to have a product varying in efficiency if he attempts to draw the temper by observing the color. But if he gauges the temper by a thermometer he can get his product within a limit of 1 degree or 2 degrees every day, and at a much less cost than if he were to draw to the color, provided the work is done in large quantities.

At times a tool as it comes from the bath is too brittle to stand up well, yet when the temper is drawn to the first color discernible, *i. e.*, a light straw—it is too soft to do its maximum amount of work. Now, in a case of this kind the temper may be drawn to 200 to 250 degrees, or any temperature that proves exactly right.

The writer has in mind tools which, if left dead hard, would crumble away on certain projections when used; but if they were heated to the faintest straw color, would not do the amount of work required of them. But if they were taken from the hardening bath and placed in a kettle of boiling water (212 degrees) and left there about five minutes, would show excellent results when used. Other tools showed best results when heated to 300 degrees and some to 350 degrees. These facts are given the reader in order that he may understand that there is a method whereby the amount of brittleness in a piece of steel may be reduced to a point where it will stand up to its work and yet not soften it as much as is necessary when it is drawn to the first temper color discernible.

The colors visible on the brightened surface of a piece of heated steel are supposed to be due to a thin

coating of oxide, formed by the action of the air on the heated surface. If a piece of steel is heated in oil away from the air, these colors will not present themselves, provided the steel is left in the oil until the temperature is below the point necessary to show the faint straw color (430 degrees).

It is necessary, in order to gauge the temper to which steel is drawn if gauged by temper colors, not only to have the piece bright, but it must be free from grease or oil, as the presence of oil will cause the colors to show differently than if the surface were clean.

It is the custom in some shops to polish the hardened pieces and then draw the temper leaving the temper color as a finish. Now, if the work has been polished on a greased wheel, a certain amount of the oil is taken into the pores of the steel. When it is heated in tempering, this oil comes to the surface of the steel and produces a peculiar appearance. The surface appears streaked. If it is wiped with an oily piece of waste or cloth, this streaky or mottled look disappears. Many hardeners always wipe a piece of steel being tempered with some substance having oil or vaseline on it; the appearance of the temper color is slightly changed by so doing, but allowance is made for this.

When drawing the temper of articles which are small or thin, it is not advisable to heat by rapid methods, heating until the desired color appears and then quenching in cold water to keep it from running too low. The cold water, on account of the sudden chill which it gives an article heated to 430 to 500 or more degrees, has a tendency to make it more brittle than it would be if it were drawn to the proper temper color and allowed to cool off slowly, or plunged in warm oil or hot water. In the case of large, heavy pieces, or where brittleness would do no particular harm, this precaution need not be observed so closely. But on the other hand, if brittleness did no harm, it would not be necessary to draw the temper, because few tools are ever too hard for the purpose for which they are intended. For, as previously explained, the process of hardening makes them too brittle to stand up well when they are in use, consequently they are tempered to reduce the brittleness to a point where they will stand up. But the process of tempering is also (unfortunately for cutting tools) a process of softening.

It should be the aim of the hardener at all times to harden steel at the lowest heat that will give the desired result, because in this condition the steel is the strongest possible, and consequently will not need the temper drawn as much as though it was given a higher heat and made brittle. Many times the writer has seen hardeners heat a diamond point turning tool to a temperature much hotter than was necessary when hardening, then draw it to a full straw color in order to reduce the brittleness so it would be able to cut and not flake off, or the surface cave in when the tool was cutting.

Now, the tool in this condition could not do anywhere near its maximum work in a given time. Neither would the life of the tool be as long as though it were hardened at the proper heat, and in this case it is doubtful if it would be necessary to draw the temper at all, provided it had not been improperly heated when forging. Many times tools of this description

can have the temper drawn sufficiently by immersing the tool after hardening in a dish of boiling water and leaving there a few minutes.

Examples of Hardening.

When hardening articles made of tool steel, it is necessary to consider, first, the nature of the steel used, the construction of the article, next the shape of the article, and the use to which it is to be put. It is also necessary to take into consideration the means of heating furnished by the shop, and the bath to be used in quenching the article after it is heated.

The operator should adapt himself so far as possible to circumstances as he finds them, although it is not advisable to attempt the impossible, because a failure is generally counted against the man making it, rather than to any lack of apparatus necessary to do a job successfully. By this is meant that it is not policy to attempt to heat a piece of steel for hardening in a fire that cannot be made to heat the piece the entire length under *any* conditions—that is, if it is necessary to harden it the entire length—because such an attempt must end in a manner disastrous to the steel. It is, however, the best plan to attempt to find some means whereby the piece may be heated properly by means of the apparatus at hand.

The writer remembers, when a boy, seeing a tool