Construction and Use of a Primitive Bellows for working Iron
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Ed (a hobby blacksmith) was recently asked by a local church if he could be a blacksmith at a historic village that they were trying to develop. The village was to represent Bethlahem at the time of Jesus. He has a portable coal forge that uses a two stage heart shapped bellows but knowing that such a bellows was developed in northern Europe about the 16th century and it would not be time appropriate for the Jesus period. But what type of bellows would have been used during the Roman era?

Figure 1

The earliest known air assist for metal working was the clay tipped reed blowpipe. The earliest depictions of blowpipes on Egyptian reliefs date from the 6th Dynasty of the Old Kingdom which is roughly 2200 BC. Figure 1 is a rendering from the tomb of that era showing copper smiths. On the left, material is weighed. In the center, six artisans use the blowpipes to force air into two side by side crucibles. Blowpipes were used worldwide for metal and glass production. The Aztecs and Incas were still using blowpipes when the Spaniards arrived in the Americas in the 16th century.

Although this method of stoking a fire was adequate for low melting temperature metals in small amounts, it would not have been adequate for working iron. Besides, we couldn’t find six people to work the blowpipes (dispite living in the state capitol with all of the politicians). Archaelogical research indicates that copper workers in the Middle East, were the first to develop the dish bellow.

Figure 2

The tomb of the governor of Thebes, Rekh-Mi-Re, dated about 1300 BC is the earliest depiction of a dish bellows.
The above hieroglyphic relief from the governor’s tomb shows two men on the lower left of the picture using the dish bellow with goat skin bellows and the attached strings for raising the goatskin to fill the bellows with air. The man on the lower level bending over is standing over a dish bellows that shows the strap attached to the top of the bellows. Above the bending man is another man use the bellows. Dish bellows allowed two men to provide more air than six men could with blowpipes.

Dish bellows came in three types. In the first, the leather goatskin has a valve that opens on the upstroke to allow air to enter but closes on the down stroke as the air is forced out of the bellows and through the tuyere into the furnace fire. The second type has a gap between the bellows and the tuyere and air is sucked into the bellows through this gap. A third type has the two bellows attached to a single tuyere. Dish Bellows have been found at numerous Bronze Age archaeological sites but seems to be far less numerous in Iron Age sites. These bowls are often mistaken for crucibles by archaeologists. They typically are 0.3 to 0.6 meters (12 to 24 inches) in diameter and 0.13 to 0.23 meters (5 to 9 inches) tall (Davey). Experiments with pot bellows have shown that copper may be melted if two bellows are pumped at 60 strokes per minute for thirty seconds (Yamauchi). While copper may be melted at 1083°C (1981°F), iron requires temperatures of 1260°C (2300°F). It is questionable if the pot bellows can be used to achieve the higher temperatures required for working iron.

Figure 3

Dish bellows are still found in some areas of Africa as is shown in Figure 3. However, this application is not ergonomically for two modern smiths in their 50s. We needed something that we could stand up at.

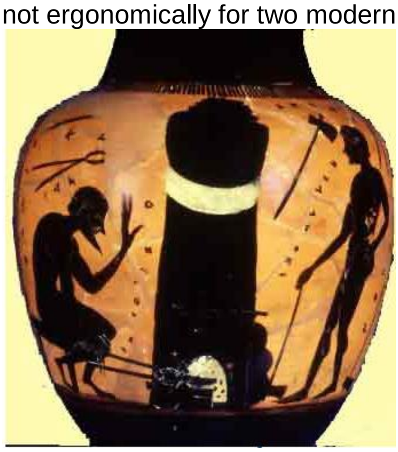

Figure 4

The Greek poet, Homer, was familiar with working iron in the 8th Century BC when he wrote in the Odyssey "…As when a man who works as a blacksmith plunges a screaming great ax blade or adze into cold water, treating it for temper, since this is the way steel is made strong,…" (Yamauchi)

A Greek vase from the fifth century BC Bronze Age, See Figure 5, shows a metal smith with a type of bellows that appears to have a bottom board that the apprentice works by raising with a cord. This is an ergonomic advancement and offers the potential for have a top or bottom board to work the bellows. The use of the board also allows for larger bellows air capacity which is a major factor in achieving higher temperatures. This Greek vase shows a set of tongs above the seated man and a sledge hammer above the standing man. Both of these tools are more in typical of iron working than copper or bonze work which usually cast.

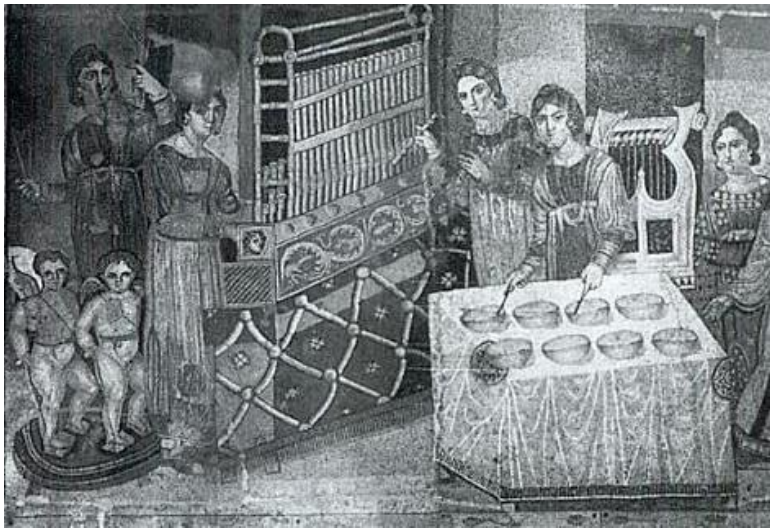

Figure 5

The Hama mosaic, recently discovered from 4th century AD in Syria, shows women playing a pipe organ powered by two angels using foot bellows that seem to have wooden tops. Like the Greek image, the wooden bellows top would hint at bellows with increased air capacity, necessary for higher temperature fires. This mosaic shows another variation of bellows and if they were used for music, they would also have been available for metal working. This mosaic also hints at the early development of pipe organs like those found in nearly all Christian churches.

Figure 6

Figure 6 shows a demonstration of scholars using a portable small Viking style furnace. This was certainly after the Roman period and it shows definite improvements in technology. This type of bellows used boards for both the top and bottom. The size of the boards would determine bellows capacity. This design of single acting bellows has an air intake on the top board and both bellows flow into a single pipe that goes to the tuyere. These bellows also point to future improvements such as the two stage bellows documented in the 16th Century.

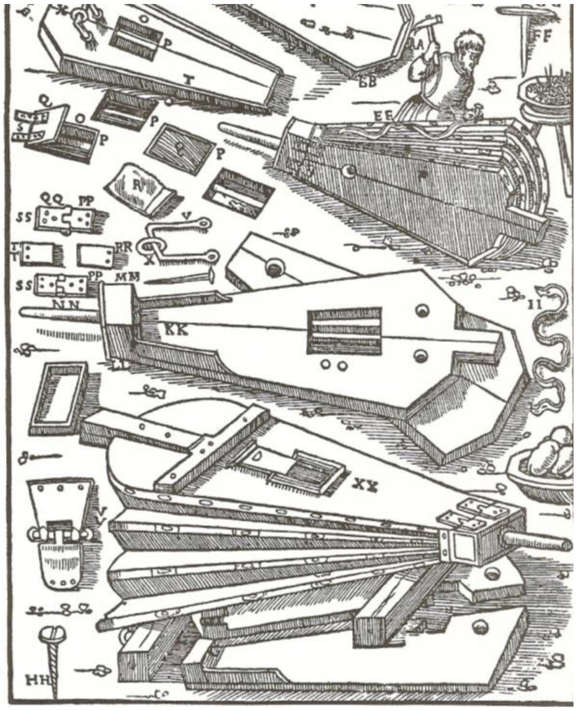

Figure 7

Figure 7 shows a worker building a set of bellows like most Americans are used to seeing. This print is from Georgius Agricola that was printed in 1556. A less accurate sketch of similar bellows appears in The Pirotechnia of Vannoccio Biringuccio who died in 1539. These bellows were two stages in that a lower bellows supplied air to an upper bellows which used the weight of the upper board to force air into the tuyere. Americans are used to seeing bellows of this type six to ten feet in length which supply an enormous amount of air to a fire. Practical experience has shown that these larger two stage bellows can go through charcoal or coal at a ravenous rate.

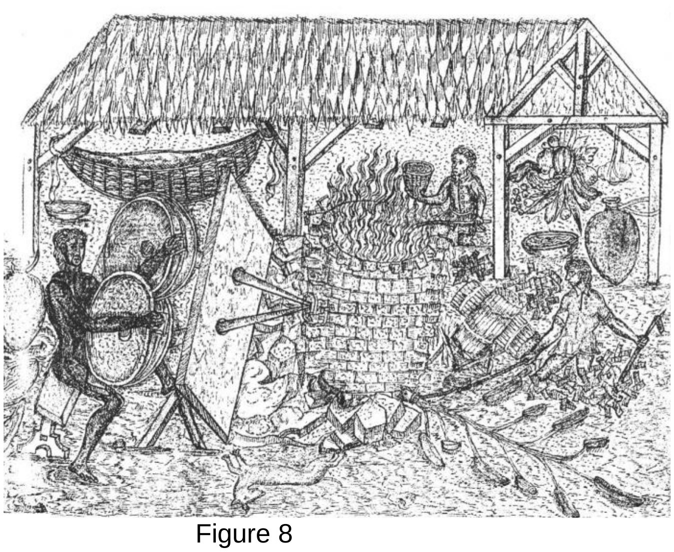

Figure 8

Figure 8 shows a Spanish forge in the new world that was used for melting gold and other metals for the King. This sketch is from the 16th century book, Historie naturelle des Indes. The Spanish were still using smaller bellows just one step removed from the pot bellows. This drawing indicates that each bellow was had its own air pipe to the tuyere. Because French and Italians were already a more efficient design, I can only image why the Spanish kept using the older technology.

The Spanish Mission San Juan Capistrano in San Antonio, Texas (see Figure 7) has a reconstructed bellows similar to the one shown in the 16th century sketch. These bellows were installed by Balcones Forge, the central Texas blacksmith society. These bellows were based on research presented in the book, Southwestern Colonial Ironwork. These bellows have a much longer stroke than is found in pot bellows which greatly improves their efficiency. These San Antonio bellows are only 16 inches in diameter which is smaller than those shown in the 16th century sketch but they can heat small pieces of iron to a welding heat.

Figure 9

Ed, who did all of the fabrication work, decided to combine the bellows design of San Juan Capistrano with the vertical motion approach shown in Figure 4. He needed to modify the bellows air passage, plenum, to fit the existing portable firebox (he uses it with his portable heart shaped double acting bellows but that might be another article). He also needed to make sure that both the firebox and the bellows would fit with the existing brick pit furnished by the church.

Bellows Construction

Figure 10 – The Bellows installed

Figure 11 – Bellows in Ed's garage

The bellows, as built consists of three major components and structural supports. The four major components are the 1) bellows, consisting of the lower and upper boards, the 2) cross plenum connecting the two bellows, 3) the running plenum connecting the cross plenum to the forge firebox, and 4) supporting structures. The bellows includes the upper and lower bellows boards, the bellows bag, and the lifting handles attached to the top board. Supporting structures included the rear legs that supported the cross plenum and the front legs that also acted as the hinges for the lifting handles. An additional piece was the plate that mated the running plenum to the existing wooden forge box. Remember that this design required local building materials and a design that could be completed quickly with a minimum of equipment.

The materials used included
7pieces 1” x 6” x 8’ pine boards
3 pieces 1” x 8” x 8’ pine boards
3 pieces 2” x 4” x 8’ pine boards
4 pieces 1/8” diameter x 48” long metal rod for stays
2 pieces ¾” diameter x 12” long dowel rod for hinges
2 pieces 1/8” x 5” x 7” hardboard for intake valves
2 pieces 1/8” x 4” x 5” hardboard for check valves and plenum end
3 pounds paraffin (use bee’s wax, canning paraffin, or candles, whichever is cheapest in your area)
3 inch hole saw for a power drill
400-500 Brass Tacks for attaching the canvas or leather.
32 ounces Waterproof Carpenters Glue
1 Pint Stain/Finish of builders choice
½ sheet of ½ inch thick plywood or particle board (to make four 16” diameter pieces)
9’ x 6’ of 8 ounce (minimum weight) canvas drop cloth (or you can use pliable leather)
Woodscrews as desired for extended use.
Small hand power drill
Hammers (claw, ball peen, and tack)
¾” diameter wood drill
3/8” diameter wood drill
Screw driver if wood screws are used
Cheap paint brush
Disposable tin or tray for melted paraffin
3/8” x ¾” x 3’ foam insulation tape

The Bellows bottom plate was a piece of ½ inch thick plywood or particle board some 16 inches in diameter. This might be adjusted down one or two inches to ensure that only one sheet of particle board is used or it might be adjusted up several inches if more air flow is desired. Several inches from one edge of each bottom plate drill a three inch diameter hole. This is the intake air hole. One the opposite side of the bottom plate from the intake air hole drill two three inch holes. The holes in this construction were slightly overlapped but they can be unconnected. These are the air discharge holes. The discharge holes must be located where they can discharge into mating holes on the cross plenum box. One can either cut these holes in the bellows bottom plate and then use those holes as patterns when cutting the holes in the cross plenum or then can attach the bottom plate to the top of the cross plenum and cut the holes through both boards at the same time.

The intake valve should be placed on the top side of the bellows bottom plate so it will be inside the finished bellows. When the top bellows plate is pulled upward, the valve should open to allow air to enter the bellows. As the top bellows plate is lowered, the valve should close to trap air in the bellows. The actual design of these valves in period pieces is not known so they were made by placing a 1/8 inch thick 4 x 7 inch piece of hardboard over the hole. The valve is secured in place by a piece of leather or canvas that is glued to the top of the hardwood and to the top surface of the bellows bottom plate. The hinge should be on the side of the intake valve towards the center of the bellows bottom plate. This plate needs to be light so it does not restrict air flow. Experiments might be made to see if a single piece of leather without the wooden block might work. If canvas is used, it will not be painted with paraffin.

The bellows top plate will be the same diameter as the bottom plate. This plate will be attached to the lifting handles as part of the final assembly.

The bellows bag should allow for 16-24 inches of lift as measured from the center of the bellows. This bag will be one layer for leather bags but a canvas design may be either one or two layers. For cost, the bellows were made of canvas. Two layers were used. One-eighth (1/8) inch diameter metal rods for the two stays on each bellows. Plates cut slightly smaller than the endplates might be used for the stays if the stay plates have large interior holes so air flow inside the bellows is not restricted. If plates are used for stays, they should be tacked to the bellows material as is shown on the San Juan bellows above. Stays may not be required but they do make for a more picturesque bellows.

If the bellows are made of canvas, the canvas might be painted with paraffin to make it more air tight and more insect resistant. It will be easier to do all of your sewing and tacking before painting with paraffin. Whether painted or not, two layers of canvas will be more efficient in trapping air than a single layer of canvas. The paraffin should be melted in a double boiler. Once melted, the canvas may be painted on the canvas using a normal hair or nylon paintbrush. if the canvas is painted,



(Left) Inside of bellows showing stay pockets on the inner bag. (Center) Assembled bellows and lifting handle. (Right) Cross plenum showing twin three inch diameter holes for air discharge from the bellows. Note the dowels holding the supporting legs in place.

Upholstery tacks come in a variety of lengths from 3/8 inch to 7/8 inch in 1/16 inch increments. A number three (3) tack is the shortest length and a number 18 is the longest length. These tacks are sold by the pound so you get more tacks if you order the shorter lengths of tacks. Tacks come in a variety of head styles and colors. For spacing the tacks, I recommend the "Quick Nail Spacer" that holds 5 tacks. It is a $7.00 tool that allows the tacks to be started on an even spacing. After the bellows bag is sewn and stay hoops have been sewn in place, tack the bellows bag to the two end plates. If using stay plates with a leather bellows, tack the lower bellows plate and then tack in each bellows stay before adding the top plate.

The cross plenum connects the two bellows to the running plenum so air is carried from the bellows discharged holes to the forge. The cross plenum was constructed using four pieces of 1" x 8" board set edge to full side so no cutting or beveling has to be completed. The pieces would be dowelled with 3/8" dowel rods and glued together. For extra strength, the sides might be screwed together. Stock eight foot boards were used but two pieces were cut short to make endplates for the cross plenum. The endplates might be held in place by dowels and glue. Air leakage here did not seem to affect our operation but a silicone seal here could make the cross plenum more air tight. Using the bellows bottom plate as a guide, mating three inch diameter air transfer holes are cut in the top of the cross plenum. The bellows were made portable so 3/8" dowels (pins) were installed to locate the bellows bottom plate with the cross plenum. We found during operation that we needed screws between the cross plenum and the bellow bottom plate to keep the bottom plate from lifting off the cross plenum when the handles were lifted. If the bellows does not have to be portable, the bellows bottom plate might be fastened to the top of the cross plenum. A 6" x 6" opening in the center of the front side of the cross plenum was cut for placement of the running plenum.

The running plenum connects the cross plenum to the forge box. This was made using four pieces of 1" x 6" x 8'. Like the cross plenum, this was set with the edge to the full side of each board for ease of construction. Because this rig was to be portable, the running plenum was pushed into the cross plenum some six inches. This was no problem as there was plenty of air gap for the air to enter the running plenum. To seal the interior gap a 3/8" x ¾" segment of insulating foam tape sealed the gap between the two plenums. For period pieces, leather stripping might be used to seal this gap. If the bellows does not have to be portable, a silicone seal on the inside of the cross plenum might also be used for sealing this gap.

The handle for the bellows was attached to the supports for the front of the running plenum using ¾" dowel rods as hinges. The bellows were put at the far end of the handles from the dowel rod hinges. Ideally the handles should be just below knuckle height when in the down position. With this set of bellows, we were handicapped by a slight slope at the forge location so we were standing downhill from the forge by several inches.



(Left) Running plenum with faceplate for interface to forge box. This shows the cross support for the front of the running plenum and the "U" shaped legs that also support the handle hinge dowels. Support structures will have to vary with each application. (Center) 3/8" dowels holding cross plenum to rear support legs. (Right) Bellows as installed.

The roman anvil is described as being square. It was probably similar to small portable anvils that have a spiked bottom for installation on any handy stump. A square anvil was made for this project by cutting the horn and heel off a 55 pound (cheap) anvil.

Bellows Operation

The event that we were invited to covered the Saturday and Sunday of two weekends. The village was the prime money making event for the Church food collection program. The entry fee was a can of food. I was not able to attend the first weekend. Because of the cold, attendance was scant. However, Ed was able to set up this forge and bellows and was able to operate it by himself.

We deviated from the image of the blacksmith at the time of Christ in that we both wore safety glasses. We both have prescription bi-focal glasses. This disagrees with the description of a blacksmith by the Roman poet Virgil, who said that blacksmiths wore an eye patch over one eye to protect one eye from sparks.

We didn’t want to use coal since that fuel was not common to Palestine during the Christ time period. At the local grocery store B&B lump hardwood charcoal and Kingsford briquettes were located. We know that briquets were not invented until the patent of Ellsworth B.A. Zwoyer of Pennsylvania in 1897. However, it was Henry Ford who made the product popular in the 1920 by making briquets from scraps of wood used in building his automobiles. The operation was eventually turned over to a Ford distributor and distant Ford cousin, E. G. Kingsford.

In the course of the two weekends, this forge was used at a leisurely pace as a lot of time was spent answering questions for the spectators. However, five sickles and four chisels were produced and heat treated. The sickles were produced from flat stock 1/16” x 1” x 12”. First one end was pointed and then pounded into a handle that already had a predrilled hole. The sickle was then slightly pointed in its length and then curved on the square anvil. We both spoke of how much easier and quicker this construction would have been on a modern anvil with its horn. The chisels were made from auto spring steel and then heat treated with a water quench. The chisels were said to be Roman tribute to be used to work local limestone. We demonstrated their use to several groups of spectators.

Because of the downward slope at the site of the bellows, we were standing in a hole so the handles of the bellows were about six inches too high. This height made prolonged high speed operation of the bellows very strenuous. Once we got the fire going, a rhythm of 25 to 30 beats a minute worked well for most blacksmith forming operations. This was not a hard beat to maintain, at least in the short bursts when we had spectators present. It only took a few minutes of use to pick up the click of the intake valve when the bellows arm was raised.

On the last Sunday, we decided to try making a weld with this bellows. We know that the fire box is more than capable as it has welded chain links several times in demonstrations. We first put two pieces of 1/16” x 1” x 24” pieces in the hardwood charcoal fire to heat them up for the weld. After about 10 minutes of pumping at 50-60 beats a minute, I took the two pieces out of the fire and they were loosely welded to each other on the corner where they touched. However, when we broke them apart and tried a hammer weld it did not take. We then realized that we did not have brushes or flux to assist our welding effort. We tried twice more to make a weld with no success. We then thought of making a sand flux which Ed was able to do using one of the chisels and our block of sandstone. The sand was poured on both sides of both strips as they were reinserted into the fire. On the fourth try, with the sand flux, we got a solid but not pretty weld. At the end of the weld experiment, we took the biggest clinker that either of us has ever seen out of the fire.

The bellows were left with the church as they would like to make their own firebox to use with this forge. I am sure that both of us will be working with them on this project in the future.

Summary of Fuels

My favorite fuel of the weekend was Cumberland Elkhorn Coal and Coke. This is a standard blacksmith coal that we buy in fifty pound bags from a local farm store or from Centaur Forge. Although we get some smoke with this fuel, I always say that it is the smell of industrial progress. It packs well and makes its own coke so it can be used for welding. This brand does not have a lot of trash so we got almost no popping or spitting. This is the fuel I first learned to blacksmith with and I still prefer it.

Ed like coke better as a fuel. He has to ignite the coke with coal but once the coke “lights off’ it makes a hot, smokeless fire. It packs well and it ideal for welding.

One of the local grocery stores offers lump charcoal. Since this is imported from Argentina, Ed and I wondered what the carbon footprint of this fuel was. It lit easily but gave off a lot of sparks. In fact, there were so many sparks that it was very hard to tell when the metal was ready for welding. We considered this the poorest of the four fuels that we tried but half or three quarters of a bag would last about an hour. This was working out to about 9 pounds per hour. This fuel packed poorly which could be because of its inconsistent size. However, we were able to weld with this fuel even though we only had sand rubbed from sandstone for flux. We also noted that after we had made our weld, the forge had the biggest clinker that either of us had ever seen.

Ed also brought along some Kingsford charcoal briquets. They have a good heat to weight ratio and have almost no sparking issues. They light easily and have almost no smoke. They pack fairly well and they do provide enough heat for welding once the briquets began to break down. We noticed no problem with clinkers using briquets.

Vocabulary

Charcoal – fuel made from a control burn of wood. This fuel has much better heat to weight ratio than wood and was the preferred fuel source for blacksmiths before coal became popular.

Coke – fuel made from a control burn of coal. This fuel has the best heat to weight ratio of the four fuels we tried. This is a popular blacksmith fuel if it can be found. It is required for industrial steel smelting.

Plenum – a space or passage used to transfer air at pressures greater than atmospheric pressure.

Tuyere – an opening through which air enters a forge or blast furnace

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http://www.aiarch.org.au/bios/cjd/12_Davey&Edwards.pdf	Figure 1, Egyptian Relief
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