Gas Forge Construction Project

November 2008

1) Overview.

The intent of this document is to provide guiding instructions, diagrams, a materials list and parts sources for the construction of a basic propane forge. We developed this document as an instructional aid for a gas forge building workshop held by the Maritime Blacksmiths Association in November, 2008.

Burner. The burner used in this project is a normally aspirated (ie not forced-air) burner of the type described by Michael Porter in his book "*Gas Burners for Forges, Furnaces & Kilns*", published by Skipjack Press (2004). Anyone following the instructions in the present document is strongly advised to read the relevant chapters in Porter before attempting to construct the burner. The forge in which the burner operates is adapted from a number of designs and descriptions available on a wide variety of blacksmithing Internet sites as well as in Porter's book. The specific burner (Section 2) and forge design (Section 3) presented here are the collected results of the authors' experiences to date in constructing several versions of these units. However we fully expect that, as a result of the workshop and further experimentation of members on their own forges, better and more efficient ways to make these units will follow.

How does the burner work? This burner type belongs to a large family collectively called "jet ejectors" which use the Venturi effect to make a combustible mix of air and fuel. In the unit described here, the jet effect is caused by a stream of gas that emerges at high velocity from a narrow orifice (here a MIG wire-feed tip with an orifice of 0.035 in). This orifice is aimed down the centre of a long narrow tube, the burner body, and the high-velocity gas flow creates a small local drop in pressure that draws air into the body through side openings, the air intake slots (see assembly diagram). The air and gas become thoroughly mixed as they travel together down the body to the nozzle. This is a short extension of the body with an expanded inside diameter, where the mixture is ignited.

The flame characteristics and the amount of heat delivered by this type of burner are determined by, among other things, the proportion of air to gas in the mixture. This is set by several factors including the pressure of gas feeding the orifice, the diameter of the orifice itself, the length of the body, the degree of expansion of inside diameter in the nozzle, the length of the nozzle and the amount of air entering the intake slots. All of these factors can be easily altered in this design. The parts shown here were chosen to make a burner that ignites easily right away and gives a useful range of heats when supplied with propane from a standard regulator. The procedures for finding the best settings for adjusting the burner are discussed in Section 2 (IV). Some alternatives to the chosen parts sizes, and the effects of altering these parts, are discussed in Section 2 (V).

Forge body. The forge is a rolled 14 ga mild steel shell with open ends, lined with high-temperature refractory blanket that is coated with refractory compound to contain and apply the heat of the burner to the work being heated.

2) Burner construction

I) Components.

The assembly diagram, Figure 1, shows the burner components described below, and how these components go together.

Body. This is made from a 1 ft length of 3/4 in black iron pipe, Schedule 40. The functions of the body are to support and position the accelerator tube and jet orifice, allow air in to mix with the ejected gas, and to provide a smooth-bore passage for the air-gas mixture to the nozzle where the mixture ignites. The body also supports the nozzle and the choke that controls air intake volume.

Nozzle. Stainless steel thin wall seamless tube with an inside diameter selected for a clearance fit on the outside diameter of the body. This provides an enlarged region at the forge end of the body where the air-gas mixture expands slightly to make burning more efficient. The length of nozzle extending past the end of the body is adjusted for optimal ignition by sliding the nozzle tubing along the body, then clamping in place with a setscrew.

Choke. Made from the same tubing as the nozzle, the choke is flared at the air intake end to funnel air smoothly into the burner body. To start a burner from cold, the choke is moved up the body to cover the air intake slots. As the burner warms up the choke is moved down the body to uncover more of the intake slots.

Accelerator tube and gas feed. The brass accelerator tube places the injector jet in the centre of the body bore in alignment with its long axis, and can be moved along this axis to position the orifice relative to the air intake slots for best gas-air mixing. The accelerator tube also supports and anchors the gas shutoff valve, its fittings and the supply tubing. A collet attached to the intake end of the burner body is tightened to clamp the accelerator tube into the body. This collet allows the accelerator position to be adjusted easily yet provides high clamping force to keep the gas feed assembly locked securely in place once the best orifice location has been found.

II) Materials list, burner assembly

Item	Description
body	Schedule 40 black iron pipe, 3/4 in, 1 ft long (1)
choke	stainless steel tube, 1.055 in ID (clearance fit on body), 0.095-0.100 in wall thickness, 4 in long (1)
nozzle	stainless steel tube as choke, 4 in long (1)
setscrew	stainless steel, 1/4 - 28 TPI thread, 1/4 in long (1)
thumbscrew	stainless steel 1/4 - 28 thread, 1/2 in long
accelerator tube	brass round bar, 1/2 in diameter, 4 in long (1)
jet orifice	MIG wire-feed tip, long type Tweco, 0.035 in orifice diameter (1)
accelerator collet	brass 45° flare tubing connector, 1/2 in tube to 1/2 in male NPT (Fairview # 48-8D) (1)
collet clamp nut	brass 45° flare tubing nut, 1/2 in tube (Fairview # 40-8) (1)
bushing	1/4 in NPT male to 1/8 in NPT female, brass (Fairveiw # 110-BA) (1)
elbow	90° elbow, black iron, 1/4 NPT (Fairview # BI-100-B) (1)
nipple	black iron, 1/4 NPT 2 in long (Fairview # Bl-113-B2) (1)
ball valve	1/4 female NPT to 1/4 female NPT gas specification (Fairview # BV-2103-B) (1)
gas fitting	brass 45° flare tubing connector, 3/8 in tube to 1/4 in male NPT (Fairview # 48-6-B) (1)
Miscellaneous	Soudotec # 6020FC flux-coated silver brazing rod, 1 mm diameter

Suppliers:

Fairview Fittings
40 Gloster Court
3B 1X9
902-468-1634

Soudotec silver brazing rod
BOC Gases/Linde Canada Ltd
10 Thornhill Drive
Dartmouth NS
902-468-6595

III) Steps in construction

The steps in building each component are described below. The diagrams show the construction details and limits for important dimensions. In most cases the actual dimensions are not critical, as long as parts that are intended to go together make a reasonable fit.

Body. Cut 1 ft of 3/4 in black iron pipe, turn the ends square, chamfer the edges and smooth the outside surface with strips of emery cloth so that the stainless steel tubing for the choke and nozzle are a sliding fit along the body with no interference. Mark the locations of the holes for cross-drilling, drill and cut the air slot openings between the holes as indicated in Figure 2. The edges of each slot should be chamfered inside and out, and the chamfer should be deepened with a round file into channels at the outsides of the slot ends nearest the collet and at the insides of the opposite ends of the slots so that air flows smoothly into the body when the choke restricts the intake. Check the bore of the body to make sure it is smooth; any roughness in the bore will cause turbulence in the air-gas mixture that could lead to an uneven flame.

Nozzle. Cut 4 in of stainless steel tube, turn the ends square and chamfer the edges just enough to remove any burrs. In some designs the end of the nozzle is flared (as in the Zoeller burner) but this has not been necessary for the "Porter" design used here. Ensure that the inside surface of the tubing is free of nicks and irregularities since these will concentrate heat while the burner is running; the resulting hot spots will shorten the life of the nozzle. Drill a #3 hole near one end of the nozzle and tap (1/4 X 28 TPI) for the clamping screw, deburring afterward. It is best to use a stainless steel setscrew for clamping.

Choke. This is made of a 4 in long piece of the same stainless tubing used for the nozzle, and is treated in the same way. However, the end of the choke opposite the clamp screw has a flare for approximately 1 in along its length, with the inside diameter of the flare 1 3/8 in at the open end. Opinions vary on the best flare expansion; we followed Porter's guidelines for the advanced burner and this has worked well on our prototype. There are several ways to flare the tubing; we used a cone die on a hydraulic press. When the flaring is done, smooth and chamfer the flared end and polish the inside surface. Check the fit of the choke over the body since some distortion can result from the flaring process.

Accelerator tube. The accelerator tube (Figure 2) is made from 4 in of 1/2 in nominal diameter brass rod that is faced square on both ends then through-bored to 3/16 in with an aircraft-type long twist drill. Taper the end of the tube that will receive the MIG tip at 10° to obtain a diameter of 5/16 in at the threaded end, bore with a #3 drill and tap 1/4 – 28 TPI for 1/4 in depth. The end that fits into the bushing is turned down to 0.405 in diameter for a length of 1/2 - 5/8 in, then tapered 2 ° for about 3/8 in. Thread this end with a 1/8 in tapered pipe thread die.

Collet and nut. Clamp the hex of the flare connector in the chuck with the flare portion sticking out, screw the flare nut on and bore to 31/64 in diameter, and ream to 0.500 in diameter with a chucking reamer. This will give a light slip fit of the accelerator tube in the connector when the flare nut is loose. Cross-cut twice at right angles into the flare connector to make the collet slits (see Figure 1). Cut off all but 5/16 in of the pipe thread from the other end of the flare connector and turn the outside diameter of this section to make an easy fit into the air intake end of the burner. The collet is attached to the body by brazing with a rod containing high silver content for strength (see materials list); this rod is used in preference to welding because the brazing process requires only moderate heat, reducing the risk of overheating the brass collet and damaging it.

IV. Setup, adjustments and running.

1) Setup. Assemble the burner components as shown in Figure 1, with the accelerator body clamped in the collet to position the tip of the jet about 1/4 in back from the nozzle end of the air intake slots. Check that the gas jet is centred in the bore of the burner body by connecting a water hose to the gas supply fitting and turning on the pressure. If the water jet is slightly off axis this should not be a problem, but if it hits the side of the bore, adjust the jet direction by gently bending the MIG tip. Close the choke by sliding it toward the valve so that only about 1/4 in of the air intake slots are exposed. The nozzle should be extended about 1 1/4 in past the end of the body. With these initial settings the burner should ignite with about 3 lb of propane. When first ignited the burner will burn very rich (high fuel to air proportion). Wait 2-3 min to let the burner warm up, then move the choke gradually down the body to let more air in so the mixture becomes leaner. Leave about 1/4 in of the intake slots covered by the choke.

2) Adjustments. The position of the jet tip, the choke position (and thus the amount of air entering the burner), the propane feed pressure and the amount of nozzle extension can all be adjusted to "tune" the burner. All of these adjustments are interactive (that is, adjusting one factor will slightly affect the settings of all the other factors) so the best adjustment procedure is to make several rounds of small changes in each factor in turn. Never adjust more than one factor at a time; changing two or more factors at once can rapidly make things worse. Porter's book has a thorough discussion of the adjustment process so only the main points will be covered here. Adjustments should be done with the burner outside, but it is important to ensure that the flame can be seen, so mount the burner horizontally in a vice in a shady spot.

The flame shape and color are the major indicators of correct adjustment. At a fixed gas pressure of about 3 lb and with the choke mostly open and the burner warm, move the nozzle back and forth slightly to get a primary flame that has a medium blue corona (the outer edge of the flame) and a clear inner cone next to the nozzle; this is a neutral flame. The flame front (the end of the color) should be blunt (Porter likens the shape to the end of a baseball bat). Green indicates a reducing flame (too rich) and dark blue indicates an oxidizing flame (too lean). Adjust the choke a bit at a time to balance the flame as well as possible between oxidizing and reducing. If a neutral flame cannot be produced by small choke adjustments, try altering the gas pressure slightly. Once the choke setting is optimal, unclamp the collet and try moving the accelerator slightly into or out of the body to adjust the position of the jet relative to the air flow. Then readjust the nozzle and choke settings and the accelerator position, one at a time, to see if the flame can be improved. The burner should be useable at this stage.

3) Running the burner. The nozzle will get red to orange hot in the forge; this is normal. If gas pressure is changed to alter the amount of forge heat, only the choke should need adjustment. Normally, reducing the gas pressure would require that the choke covers slightly more of the air intake slots. If an idler circuit with a needle valve is used to cut down the gas consumption between heats, the valve will have to be set to give a flame that burns just above the threshold for ignition instability (seen as a pulsing or uneven flame) at the specific gas pressure. If running at consistently higher pressures, it may be necessary to switch to a larger jet orific

3) Forge Body Construction

I) Components

Gas forges can be constructed of many different materials in many configurations. The MBA Project forge was designed to be easily assembled in quantity and economical to build.

Its volume is optimal for the 3/4 inch jet ejector burner. It will accept a 9 x 9 piece of steel and with insulated doors should easily reach welding heat. The 13 inch diameter x 9 inch long shell is 14 gauge steel, light enough to be portable and stiff enough to retain its cylindrical shape.

The forge is insulated with high temperature ceramic blanket insulation. It is rated to 2600 degrees F and is applied in two one inch layers. The 8lb density material conforms to the cylindrical shape resulting in a strong, self supporting arch structure.
The soft insulating firebrick floor protects the fibre blanket, has low thermal mass and so heats quickly.

The 3000 degree F mortar lining helps protect the insulation from abrasion and overheating.

The forge ends are designed to be closed with ceramic blanket held in place with firebrick or just the brick. The opening(s) can be configured for the size and shape of the steel you are heating. You should never completely seal both ends as this will create too much back pressure for the burner. At least sixteen square inches of opening should be maintained.
The burner holder allows for some adjustment, usually you will want to aim the flame at the centre of the forge floor.

II) Materials list, forge body

Item	Description
Forge shell	42 inch x 9 inch 14 gauge steel (1)
Burner holder	4 inch x 1 ½ inch schedule 40 black iron pipe (1)
Legs	8 inch x 20 inch 14 gauge steel (2)
Shelf	4 x 1/8 inch flat bar 18 inches long (2)
Insulation	1 inch thick 8 lb density 2600 degree F ceramic fibre blanket 9 1/4 inches x 38 inches (1) 9 1/4 inches x 32 inches (1)
Floor	Insulating kiln brick 9 x 4 ½ x 1 ½ (1)
Mortar	Vesuvius 3000 degree F

Suppliers

ceramic fibre blanket and kiln brick
Atlantic Pottery Supply
15 Canal St
Dartmouth NS B2Y 2W1
466-6947

The Pottery Supply House
Oakville ON
1-800-465-8544
www.pshcanada.com

III) Steps in construction

Cut the 1 ½ inch pipe at 79 degrees. Drill three #3 holes 120 degrees apart, one inch from the squared end. Tap for ¼ x 28

Cut a 1 3/8 inch hole in the centre of the sheet of 42 inch x 9 inch 14 gauge steel. Roll to13 inches in diameter. Weld seam.

Bend 90 degrees the 8 inch x 20 inch 14 gauge steel at the 4 inch and 16 inch marks making a "] " shape. Weld the shelf to form the assembly as illustrated.

The shell is rotated so the burner hole is 80 degrees from the horizontal.

Weld the leg assemblies on the ends of the shell leaving four inches of clearance from the bottom of shell to the bench.

Weld the burner holder to the shell.

Insert the 9 1/4 inch x 38 inch fibre blanket keeping it tight to the shell. The ends of the blanket will overlap slightly. Force them flush locking the blanket in place. Roll the 9 1/4 inch x 32 inch fibre blanket and insert. Unroll the blanket pushing it tightly into place. The blanket should stick out of the ends of the forge slightly.

Saw, using a hacksaw, your firebrick into two pieces 9 x 4 ½ x 1 ½ inches. Shred some insulation and bed the brick in the bottom of the forge so that it is level with the shelves.

Using a 1 3/8 inch hole saw, carefully cut the insulation down through the burner holder hole.

Butter the inside of the forge with refractory mortar about 1/8 inch thick. Let dry at least overnight before firing it at low heat with the burner in place and the end open at first.

4) Propane forge safety guidelines

by Bruce Freeman, with contributions by Robert Grauman .

Facts about Propane

1. Propane is a liquid in the cylinder, but is burned as a gas, expanding 270 times its volume.
2. Propane gas must be tapped from the top of the cylinder.
3. As the propane vapor (gas) is pulled off, evaporation of more liquid propane within the cylinder cools the cylinder (refrigeration effect).
4. As the liquid propane cools, the pressure of the vapor above it drops.
5. Overheating liquid propane will cause dramatic, and potentially catastrophic increase in the pressure of the vapor above it. Most commercial cylinders have a pressure relief device. If this opens the cylinder will not explode. but it could vent the entire contents of the cylinder.
6. Liquid propane is not only flammable. it's an effective solvent. (The gas is not a solvent.)
7. A propane cylinder could leak, and it's best to assume it does leak.
8. Propane + air in a confined space (i.e., indoors) is a recipe for an explosion.
9. Propane is colourless, is denser than air and can settle in basins or run along the ground to a source of ignition, then flash-back. It could also drain into a sewer and cause an underground explosion hazard. It can fill up a basement, ignite from a furnace or other appliance, and demolish a house. The pungent odor of propane comes from an additive Meracaptan making gas leaks easier to detect.

Facts about Regulators and Hoses

1. Every regulator has a diaphragm. a poppet valve and several fitting. Any of these could leak.
2. In particular, the poppet valve, the diaphragm and the pressure gauge contain mechanical parts. Any mechanical part is subject to failure with use, sometimes suddenly.
3. Regulators are pressure-control components, not shut-off valves. A separate shut-off valve should be located immediately upstream of a regulator. (This is always the case anyway when the regulator is directly connected to a propane cylinder, but should also be the case if the regulator is mounted remote from the cylinder on pipe or tubing.)
4. Regulators are typically designed to handle only gases. Solvents can harm internal components and cause dangerous breakdowns (eg. of the diaphragm or poppet valve). Use regulators and hoses that are rated for propane; many acetylene regulators and hoses will break down if used with propane, check with your supplier.

Facts about Refractories

1. Refractory will melt if heated beyond its rating. The insulation in your forge is rated to 2600 degrees F and the mortar lining is rated to 3000 degrees F. Your forge may exceed these temperatures under some conditions.

2. Any refractory that may have become wet should be heated slowly to dry it before it is exposed to full heat.

Facts about Combustion Gases

1. The two major combustion products propane are carbon dioxide (CO_2) and carbon monoxide (CO).

2. Carbon dioxide, is colorless, odorless, tasteless and is only slightly poisonous. It is the waste product of animal metabolism, so animals have a pretty high tolerance for it.

3. Carbon monoxide is a colorless, odorless, tasteless yet highly toxic gas.

Carbon monoxide forms when there is not enough oxygen present during the combustion process.

A concentration of as little as 0.04% (400 parts per million) carbon monoxide in the air can be fatal. The gas is especially dangerous because it is not easily detected by human senses.

When carbon monoxide is inhaled, it takes the place of oxygen in hemoglobin, the red blood pigment that normally carries oxygen to all parts of the body. Because carbon monoxide binds to hemoglobin several hundred times more strongly than oxygen, its effects are cumulative and long-lasting, causing oxygen starvation throughout the body

Early symptoms of carbon monoxide poisoning include drowsiness and headache, followed by unconsciousness, respiratory failure, and death. First aid for a victim of carbon monoxide poisoning requires access to fresh air, administration of artificial respiration and, if available, oxygen, and, as soon as possible, medical attention.

Therefore we suggest the following safety measures:

In General

1. Never allow a propane cylinder to tip while in use, as liquid propane may enter the regulator, possibly damaging the regulator and rendering it unsafe, and definitely resulting in a surge in propane flow.
2. If your propane cylinder cools so much that you can't get the pressure you need, place it in a tub of cold water (be mindful that the cylinder will float once enough propane has been consumed, remember to never allow a propane cylinder to tip while in use). Never apply artificial heat. A freezing propane cylinder is too small for the job, and you should consider using a larger one, or two cylinders in parallel, using an R V tandem valve for this application.
3. Never allow the heat from the forge to heat the propane cylinder.
4. The regulator and hose are vulnerable components and should be treated gently, protected from heat and harm (watch where you wave that hot iron) and inspected before use. Solvents, sunlight, and other deteriorating influences can also affect the hose.
5. Place the forge on a non-combustible surface. Keep combustibles away.

6. Buy and install a Carbon Monoxide detector.
7. Have a dry chemical fire extinguisher ("ABC") handy.
8. Never leave a hot forge unattended, even if the fuel is shut off.
9. Never store a propane cylinder indoors.
10. Preferably operate a propane forge outside. If that is impossible or impractical, operate the forge only where very substantial ventilation is provided. This means, either no walls (roof only) or forced ventilation. This precaution is necessary both to reduce the chances of fire from a propane leak and to prevent CO poisoning. If you ever suffer a headache while working with any combustion equipment, shut it down and get out of there!

Suggested Procedure for Lighting a Propane Forge

1. Inspect your propane cylinder (especially the valve), your regulator (especially the connector to the cylinder and its O-ring) and your burner (especially the hose) for any signs of wear or problems. Do not install the regulator if you see any sign of problem.
2. Install the regulator by hand, without tools, until the nut (left-hand thread, remember) is fully seated. Immediately tighten the nut with a wrench. (If you wait, you might forget and have a very serious propane leak when you turn on the propane.) Do not over tighten the nut, as this will only ruin the connectors.
3. Make sure the forge is safely situated (no combustibles nearby), the burner is properly and firmly installed, and all is well before lighting the forge.
4. Before lighting the forge, ensure that there is proper ventilation. If you are outside or only under a canopy, no problem. If you are inside, provide forced ventilation. At a minimum, this should consist of a high-powered roof or window fan (preferably blowing out) and an open door or large window, turn on the fan before or immediately after lighting the forge. (The noise of a fan may interfere with your ability to judge the burning conditions of the burner. If so, be sure to turn the fan on within a minute or so of lighting the burner.)
5. Recheck the regulator connection to the cylinder, and recheck that the knob is loose (set to zero pressure). To check for any leaks apply a little soapy water to the fitting – bubbles appearing will indicate a leaky valve or fitting. Then light a propane torch and hold it near the burner opening inside the base of the forge (off to one side so you don't blow it out when you turn on the propane to the forge). [Some folks roll up some newspaper, light the paper and place it in the forge, then slowly turn on the gas. Be careful, the pressure of the gas can blow the burning paper right out of the forge. First turn on the propane at the cylinder valve, and then slowly turn the regulator knob to bring the pressure up to an appropriate value. The forge should light easily and stay lit. If it doesn't something is wrong.
6. If you even think anything has gone wrong, turn off the propane at the cylinder valve.

Use and Adjustment of the Forge

1. After the forge is lit and the flame is stable, make any adjustments necessary to the pressure to get a good stable burn.
2. I f you haven't already done so, turn on your exhaust fan.

3. If there is a flame shooting out of the forge (i.e., between the bricks typically used as a front door), you have incomplete combustion in the forge. With the forge burner adjusted to this mixture, your forge cannot give you maximum heat and, in addition, formation of toxic carbon monoxide may be greatly increased. Adjust the choke and regulator until the flame recedes into the forge.

4.If you find that your steel is scaling excessively when heating, try closing the choke slightly to reduce the air flow and bring the forge atmosphere closer to neutral.

5 Don't completely close up front and back, too much back pressure will reduce the venturi effect reducing the amount of oxygen available for combustion

Shut-Down of the Forge

1. Always shut down the forge by turning off the fuel at the cylinder, then backing off the regulator knob (as a safety precaution.) Close the choke completely. Close the ball valve at the burner.
2. Remove the back and front doors (i.e., the firebricks) and set these aside on noncombustible surfaces. Remember that they are easily hot enough to start a wood fire.

3. When finished a forging session, remove the regulator from the cylinder and take the cylinder to its outside storage area at once. Make sure you replace the plastic plug in the propane cylinder.

4. Allow the forge to cool for at least a half an hour before you leave the area. This is to prevent accidental fires from going undetected.

5. Be gentle with the refractory. Repair mortar chipped as you go. The soft firebrick will not last long with heavy use, replace it before it no longer protects the blanket insulation on the forge floor.

6. Flux will quickly damage the bottom of the forge unless it is protected with a more flux resistant refractory such as kiln shelf or hard firebrick.

Acknowledgements

Propane Gas Forge Use and Safety

NJBA Newsletter

by Bruce Freeman, with contributions by Robert Grauman .