

ALT2SEG

**Reciprocating
Steam
Engine**

Jemmett Engineering

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Hatch End

Pinner

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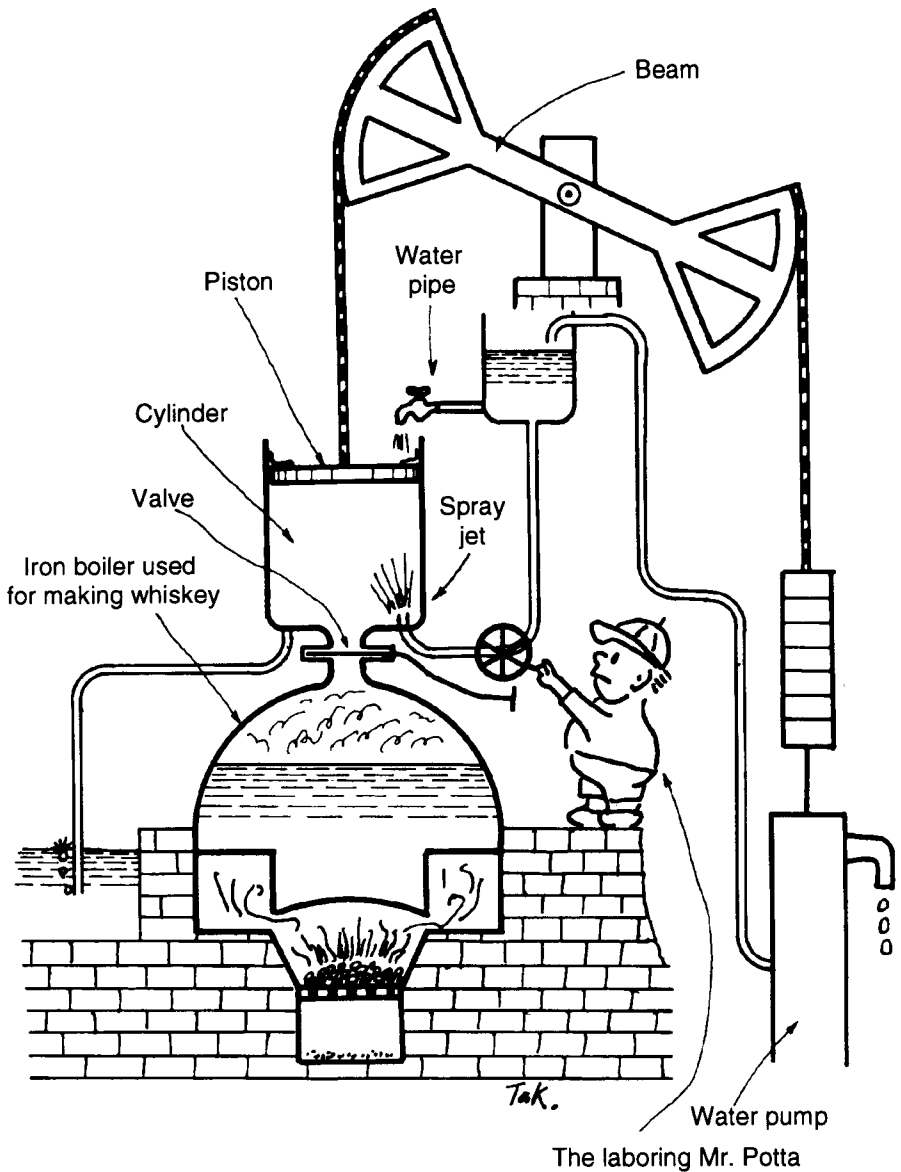
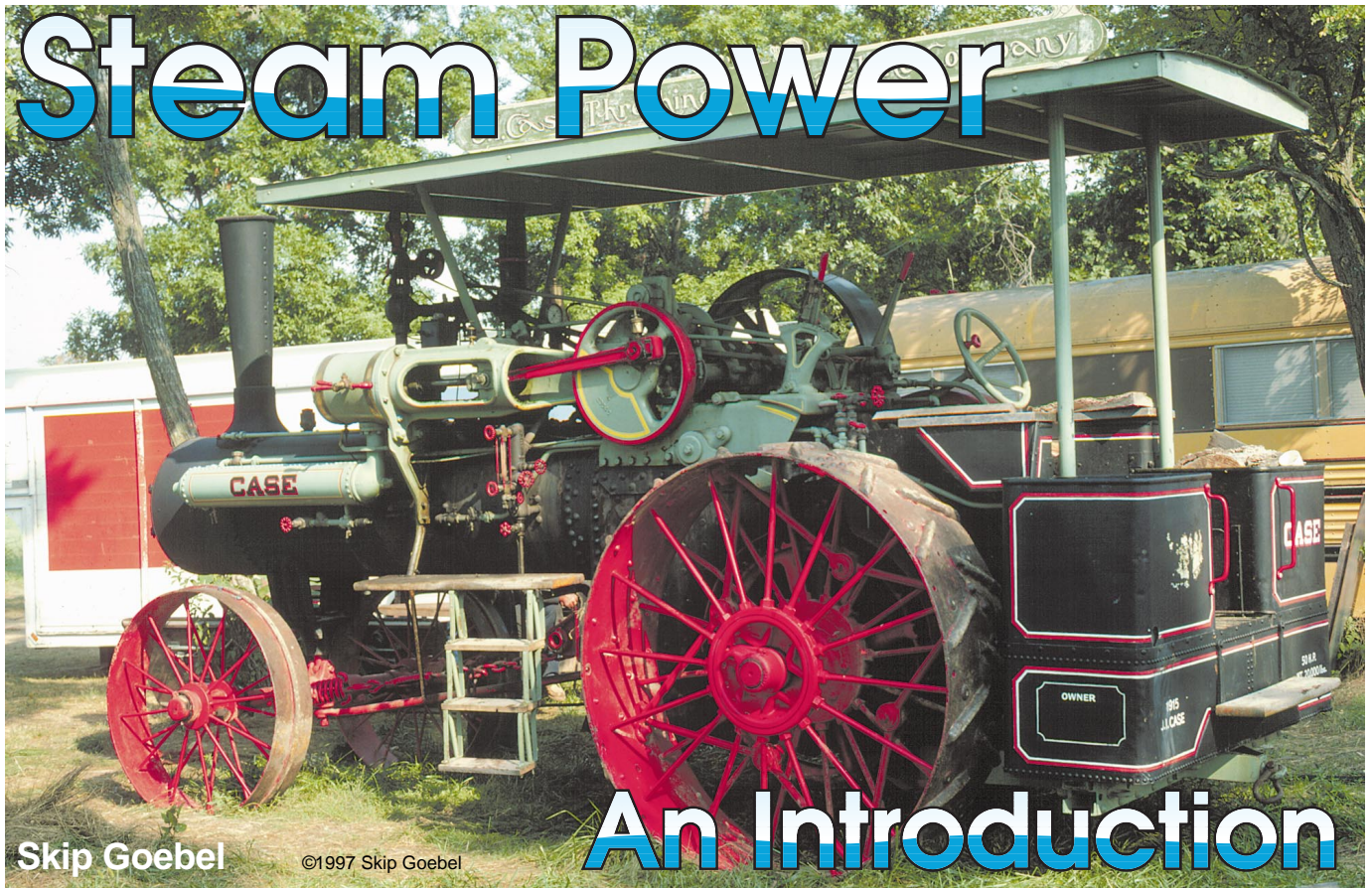


Fig. 2-1 Newcomen engine (1712): The engine was completed thanks to the Potta proposal.

Steam Power



Skip Goebel

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An Introduction

Human beings have a habit of continually seeking ways to improve their condition. Sometimes, they go full circle in their quest for comfort and revert back to the basics. In the realm of alternative energy, steam can be considered “basic.” It may not be the best or cheapest thing available but it certainly works. Fortunately, all the technology has been discovered, proven, and documented. When we are tired of all the other energy sources being absorbed into “the system” many self-sufficient folks will try their hand at steam.

What is Steam?

Steam is a gas, not a water vapor. It is clear, tasteless, and odorless, so if you can see it then that is actually only water vapor and not capable of doing any work. It takes a given amount of heat added to water under a given amount of pressure to convert from water to steam.

A simple and safe experiment to observe water and steam is to “can” some water. Put an oven thermometer in a canning jar with a small amount of water. Using a pressure cooker, evacuate all the air and seal the lid. Gently heat the water and notice at what temperature the water boils. Watch the volume changes closely. Then with the water around 120°, have some fun by putting an ice cube on top and watching the water continue to boil all the way down to about 60°. You’ll get an idea of how water changes states at different pressures and temperatures.

Steam System Sizing

The first step in a steam system, as with any system, is planning. First, determine your needs or task. Then work back to your source of power and then to your fuel source. It all ties together in a full circle and you can go around and around making refinements until you have a system that is suited to your needs.

The best tool there is to plan this way is a flow chart. The flow chart will give you a visual representation of what you are trying to accomplish and you can see how one aspect relates to another. The idea is to break down the entire system into as many individual elements as possible to determine what they require and how they relate to each other.

You can follow our example flow chart and make changes to suit to your needs. Starting at the top is the task, or actual needs. Determine exactly what you are

going to do: pump water, generate electricity, or even power a 30 foot boat. In this example, we will make 1000 watts of electricity in one hour. What ever you choose to do, you should know that there is a fixed set of values to move mass or create energy. In fact, energy is often considered a measurable force in the movement of mass. The key words here are horsepower, torque, foot pounds, watts, btus, etc. Steam is an excellent way to take potential energy or raw resources and convert them to kinetic energy, or "energy in motion."

Energy Required

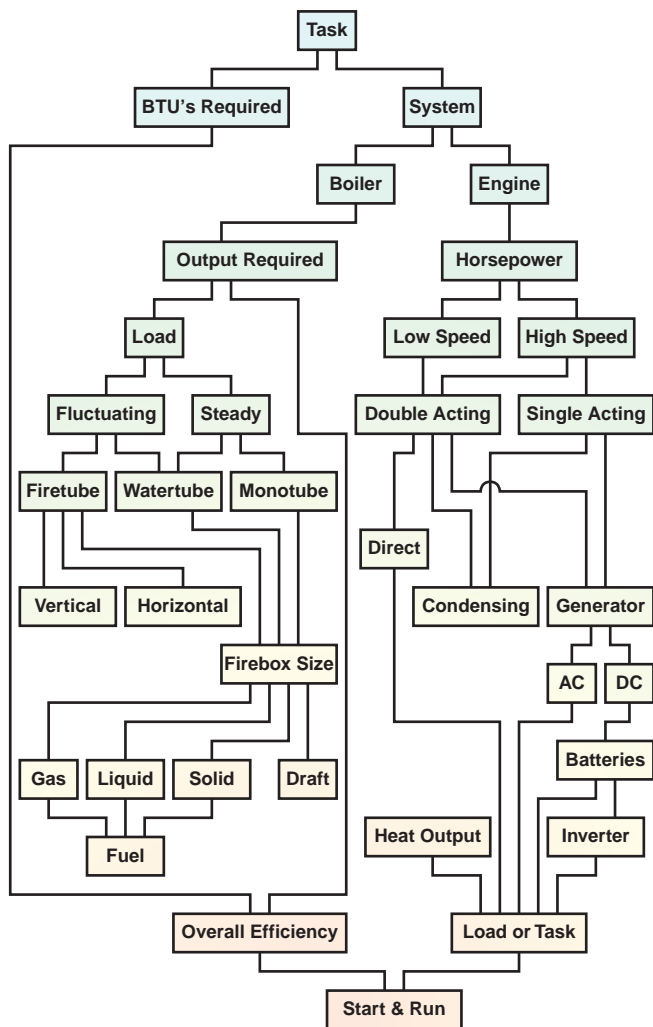
This leads to the next planning phase which is energy required. Looking at the illustration, we can learn some values and apply them to our application. Since we will be using steam, we will be creating a difference in heat values. The most common way to measure this is the btu, (British Thermal Unit). It is the amount of heat needed to raise one pound of water 1° Fahrenheit, with no time value. In mechanical form this translates to lifting 778 pounds of mass one foot. Also, 42.44 btus in one minute equals 1 horsepower at 100% efficiency.

I mention that because no system ever comes close to 100% efficiency. A good starting point is around 10%. We will benchmark our initial system plan for 10%. Since we wanted to make 1000 watts for one hour we will need enough btus for 10,000 watts. One watt equals 3.412 btus so we will need about 34,120 btus (3.412 x 1000 x 10). Look at the fuel values chart to determine how much fuel you will need. We will use wood for our example so we divide 34,120 by 6,000 (cheap Ozark wood) and we get 5.68 lbs. Please note

Below: A steam-powered lathe.



System Design Flow Chart & Interrelationships



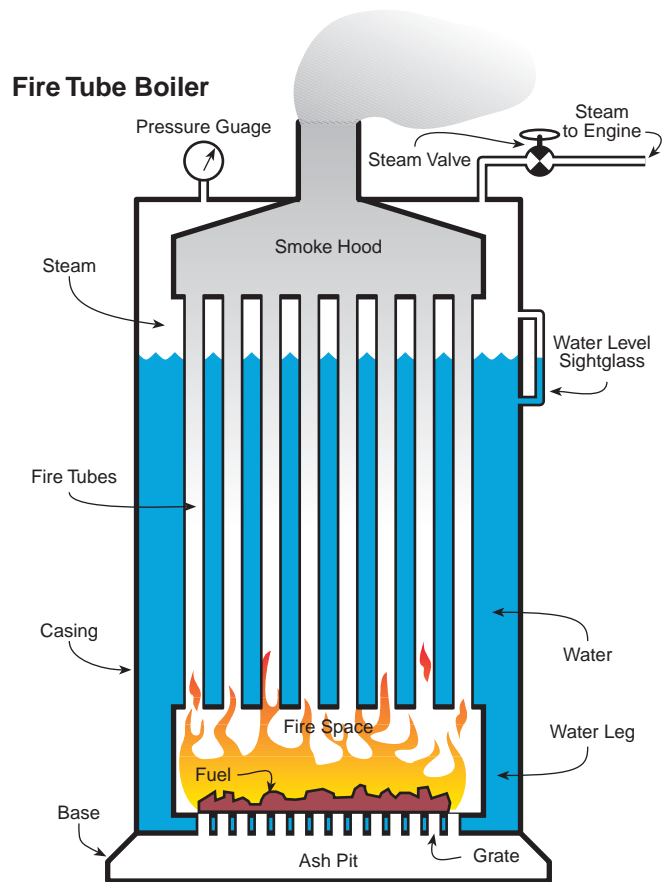
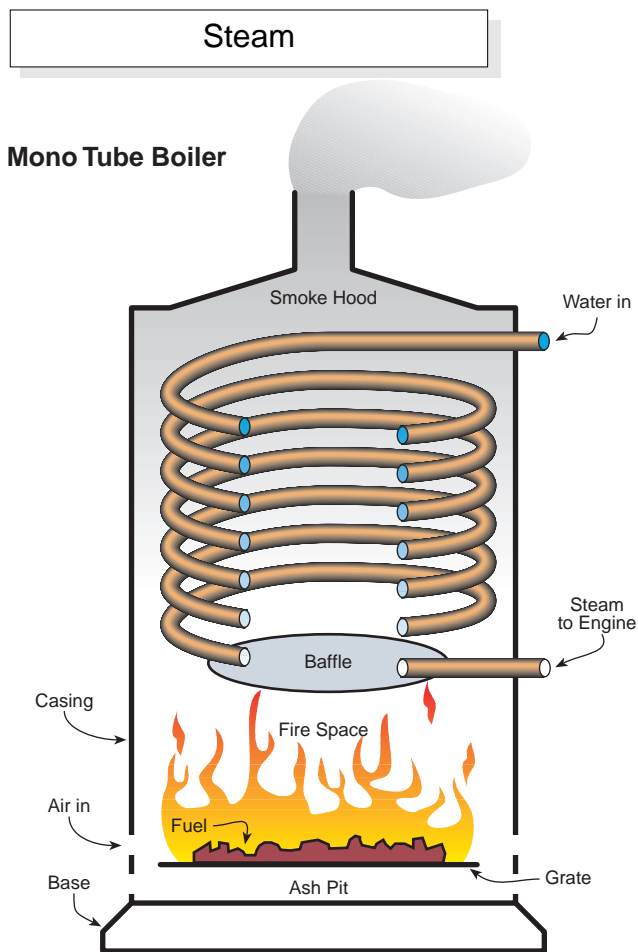
that this figure does not take into account warming up the system, shutdowns, or idle time. More on that later.

From here, we could follow the flow chart in two directions, costs / source of fuel or system. I'll start with the system. In our steam system, the two main categories are Boiler and Engine. Let's start with sizing the engine first.

Engine

If you are used to typical horsepower ratings such as the way manufacturers rate gas engines, you're in for a shock here. A safe bet is to figure one steam horsepower equals 3 gas engine horsepower. The truth is that one horsepower equals raising 33,000 pounds one foot in one minute or 550 pounds one foot in one second. Period. That's why we call steam "honest horsepower."

Generally speaking, 750 watts equals one horsepower so 1000 watts is roughly 1.34 horsepower. In real life you are going to need at least 2 or more horsepower as



Mono tube boilers consist of a series of coils of small diameter tubing connected such that water and steam travel through one long tube. Water and gasses move in opposite directions, known as contra-flow, so that the coolest water comes in to contact with the coolest gasses first. These boilers are the safest and most efficient of all designs, however they require the greatest skill to operate due to their small water reserves and sensitivity to changing fuel and load conditions.

Vertical Fire Tube Boilers are popular where horizontal space is limited. They are the easiest boiler type to construct. 50% to 70% of the heat energy is captured by radiance therefore a water leg often completely jackets the firebox. Combustion space is usually small requiring smaller pieces of fuel. A forced draft system is often utilized to combust greater amounts of fuel. Note that while they are not detailed in these diagrams, **SAFETY VALVES ARE A MUST!**

there are inefficiencies in all generators. So, how do you figure the horsepower of a steam engine? The standard horsepower formula in reciprocating (piston) steam engines is called PLAN. That stands for multiplying together:

- P = pressure (average or mean)
- L = length of stroke in feet
- A = surface area of the piston in inches
- N = number of revolutions per minute (rpm)

Our example engine has a 2 inch piston and a 3 inch stroke running at 1000 rpm and a 100 pound average or "mean" pressure. The area of piston (A) = $\pi r^2 = 3.14 \times 1 \times 1 = 3.14$ square inches. The stroke (L) is 3 inches so converting to feet = $3 / 12 = .25$ ft. The pressure (P) is 100 and the rpm (N) is 1000 so $100 \times .25 \times 3.14 \times 1000 = 2.37$ hp. 2.37 horsepower gives us a little extra hedge room and will suit our needs.

You can also find the torque by dividing the stroke in half and dividing by 12. Then multiply the pressure times the area of the piston times your stroke figure.

$3 / 2 = 1.5$, $1.5 / 12 = .125$. So $3.14 \times 100 \times .125 = 39.25$ ft. lbs. of torque.

Cogeneration

Now that we have an engine size, what is it going to do and how is it going to do it? What else can we do with the steam? Making both electricity and hot water are perfect examples for us to utilize here. In operations of less than 10 kw it is more practical to make DC instead of ac electricity because standard ac requires exactly 60 cps making engine speed critical. With DC we can work the engine hard for a brief time, storing the power, and go about our business for the day. Utilizing the exhaust steam gives us 55,000 to 60,000 btus to heat water with.

There is an abundance of low speed generators. Instead of using gears or belts we can direct connect to the engine, enhancing system reliability. Also, the regulators are small and efficient or even built in making a more compact power plant. For water heating, a 10 to 12 foot length of 1/2 inch copper tubing placed inside a water tank will work as a heat exchanger.

Some Quick Tips

Use an automotive in-line solenoid fuel pump to extract the condensate. It will maintain a small vacuum, adding power and efficiency. Use a windshield wiper gear motor direct-connected to a small high pressure pump to supply water to the boiler. Make a small, open tank called a "hotwell" to collect the condensate and provide a supply for the feed pump. A common float valve can be used as a bypass to regulate the system, but more on that later. Finally, check out the local battery company and ask if they have some phone company change-out batteries. A bargain might be found there.

You'll notice that on our flowchart the task is at the beginning and the end. We go from point 'a' to point 'b', so to speak, and work the details out in between. Also notice that you can connect each box or segment to any other box and see the relationship each has to the other. Study this to avoid expensive surprises later on.

Back to the System

We have our engine or work (or kinetic energy if you will) all figured out. Now we have to take potential energy (fuel) and convert it (reaction) and then transmit it (using steam) from the reactor to the engine. We call the apparatus that handles this a boiler. When your neighbor asks, "What is that?" Tell them, "That is my rapid oxidation reduction reaction hydro-morphosis energy transmission reactor." That will keep him a few feet away.

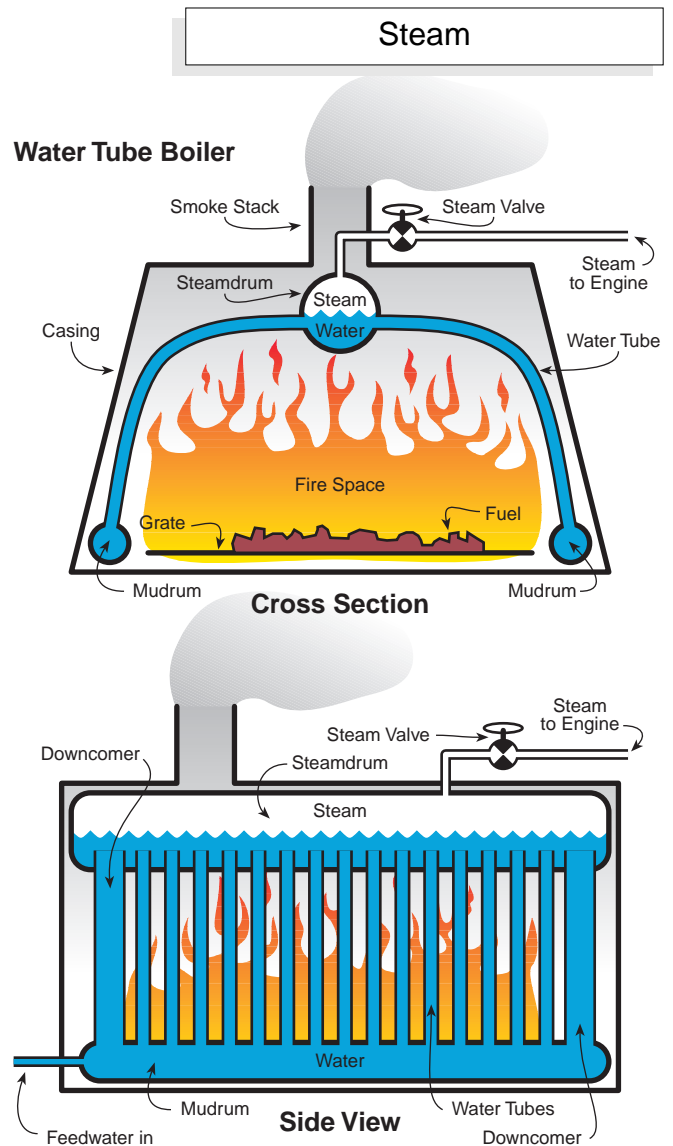
Safety Lecture

In round numbers, there is a stick of dynamite in a gallon of water. How close do you want to get? Steam, when superheated, is an invisible, super-radiant gas. It can burn to the bone. You can walk into a cloud of invisible superheated steam, take one breath and destroy your lungs. It takes about 3 minutes to die and there is nothing you can do about it. Period. If you think you are going to do this inside your house, send the kids to live with grandma, sell your Arizona swampland, and please put me in your will.

Boilers

Boilers are basically of either the pressure vessel or the mono-tube type. Solar should be put in a class by itself because most boilers are built around the chamber where combustion occurs.

Of the pressure vessel types, we generally classify them as fire-tube (combustion gases pass through tubes surrounded by water) or water-tube (combustion gases surrounded by water filled tubes). The generating section is where the water is close to the fire. Anywhere else the combustion gases transferring heat are usually known as ancillary sections and are where steam may be superheated, feed water preheated, or even the incoming combustion air heated.



Water Tube boilers usually have smaller diameter tubing than Fire Tube boilers and are therefore lighter. The relatively high amount of surface exposure for a small amount of water allows these types of boilers to come up to temperature more quickly, but limits residual capacity.

A boiler giving a steady steam supply with less fluctuations is determined by the amount of water it holds. Heat stored in the water is called latent heat. This is the left over energy that can still turn the water to steam after the fire out.

A fire-tube boiler generally holds the most water. It is known for steady steaming, ability to supply upon sudden demand, and also is the most dangerous! For the novice, this type of boiler has no place in the homestead so no more discussion on this one.

Safer, but still dangerous, is the water-tube boiler. They consist of a smaller pressure vessel that sits above the fire and has lots of small tubes attached that extend down and around the fire. Natural convection in the water makes it circulate thereby allowing the cold water to flow downward and warming water to travel upwards to release its steam in the main vessel. This boiler is the

Steam Table

lbs. Gauge (Absolute)	° F	Heat (BTUs)		Latent Heat (BTUs)	Volume of Steam (cu. ft.)	Weight in lbs. of Steam per cu.ft.
		Water > 32	Steam > 32			
-14 (.7)	90	58.0	1099.0	1041.0	470.00	0.0021
-10 (4.7)	155	125.0	1128.0	1003.0	85.00	0.0125
-4 (10.7)	196	164.0	1144.0	980.0	36.00	0.0280
0 (14.7)	212	180.0	1150.4	970.4	26.79	0.0373
5.3 (20)	228	196.1	1156.2	960.0	20.08	0.0498
10.3 (25)	240	208.4	1160.4	952.0	16.30	0.0614
15.3 (30)	250	218.8	1163.9	945.1	13.74	0.0728
20.3 (35)	259	227.9	1166.8	938.9	11.89	0.0841
30.3 (45)	275	243.4	1171.6	928.2	9.39	0.1065
40.3 (55)	287	256.3	1175.4	919.0	7.78	0.1285
50.3 (65)	298	267.5	1178.5	911.0	6.65	0.1503
60.3 (75)	308	277.4	1181.1	903.7	5.81	0.1721
70.3 (85)	316	286.3	1183.4	897.1	5.16	0.1937
80.3 (95)	324	294.5	1185.4	890.9	4.65	0.2151
91.3 (106)	332	302.7	1187.4	884.7	4.19	0.2336
99.3 (114)	338	309.0	1189.0	880.0	3.90	0.2500
125.3 (140)	353	324.6	1192.2	867.6	3.22	0.3107
151.3 (166)	367	338.7	1195.1	856.4	2.74	0.3654
175.3 (190)	378	350.4	1197.3	846.9	2.41	0.4157
200.3 (215)	388	361.4	1199.2	837.9	2.14	0.4680
255.3 (270)	408	382.5	1202.6	820.1	1.72	0.5820
305.3 (320)	423	399.1	1204.9	805.8	1.46	0.7080
355.3 (370)	437	414.0	1206.8	792.8	1.26	0.7910
435.3 (450)	457	435.0	1209.0	774.0	1.04	0.9600
485.3 (500)	467	448.0	1210.0	762.0	0.93	1.0800
1047 (1062)	550	542.0	1200.0	658.0	0.42	2.3600
2250 (2265)	650	670.0	1111.0	441.0	0.16	6.2000

most commonly used today and can be seen in everything from power plants to ships and heating boilers. The size of these boilers is usually determined by the combustion chamber. The combustion chamber is determined by the size and type of fuel. More on this later.

The safest and most efficient type of boiler is the mono-tube boiler. Just as the name implies, it is a continuous coil of tubing with water forced in one end and steam out the other. Typical examples are steam cleaners. Many spas use the same configuration to heat water. So do tankless domestic water heaters.

With no vessel to explode, mono-tubes can only burst at a joint or seam. This is still dangerous, but the damage is limited to the release of heat. I strongly advocate these boilers for beginners. They are inexpensive and, for the homesteader making DC electricity, they suit the purpose ideally.

While it is possible to admit water on one end and get steam out the other, it is customary to have some sort of a chamber at the end to allow the steam and water vapor to separate. This also gives a small amount of residual power to smooth out fluctuations. In general, the more residual you have the less sensitive your control system will have to be.

Boiler Size

How do we determine the size of our boiler? In round numbers, figure about one square foot of grate area per horsepower when burning wood under a light draft. Other fuels may produce more heat. Regardless of the fuel, it takes a certain amount of air to burn efficiently. The more air you add the more fuel you can burn. But as the reaction speeds up the temperatures go up and that may not be all that desirable. Nitrogen will start to oxidize and so will other things. Not only does this create poisonous gases but it is also wasted energy. We want to heat the water, not the air.

A long, gentle, white and orange flame is the most desirable. The flame requires space and time to occur, so give a couple of feet of space between the fuel and the water surfaces. A solid fuel will require more space than a liquid or gas fuel and, with all fuels, combustion space is determined by the amount of fuel and air being joined at a given moment. Better put, forcing more air to the fuel makes a smaller, more intense flame.

A good rule: for every square foot of grate surface add a foot of combustion space. And remember, "Flame shall not touch metal!" It quenches the flame and makes poisonous carbon monoxide.

Another round number to remember is when using wood, figure that 8 to 10 square feet of heating surface produces one horsepower. One boiler horsepower is equated to evaporating 35 to 40 pounds of water into steam in one hour. A hotter fire requires less surface to transfer the heat but we will use wood for our example.

Our engine was fairly efficient for it's size and produced 2 horsepower while consuming 70 pounds of steam (not steam pressure, but the weight of water converted to steam and run through the engine) in one hour. We need to determine the size of the combustion area and the amount of heat transfer area required to evaporate the water.

Build Your Own!

We are going to coil a length of pipe and stuff it inside a casing where the fire will be. 1/2 inch black iron pipe (never use galvanized in a boiler!) has about a 2 inch circumference. So, for every inch of pipe length, we have 2 square inches. There are 144 square inches to the square foot and we need about 16 square feet of surface (2 horsepower). $144 \times 16 = 2204$ square inches. Since every inch of pipe gives us 2 square inches, $2204 / 2 = 1102$ inches or about 92 feet of pipe length. If it is coiled at 12 inches diameter, you would need about 30 turns. That coil would be about 2 1/2 feet long and too long so we would probably need 2 coils; one smaller diameter and fitting inside the larger coil.

Steam Engines

For other than rockets and catapults, steam power is usually converted into a rotary motion. This is broken down into two classifications, turbine and reciprocating.

Turbines

Two types of turbines are in use today, impulse and reaction. There are often combinations of the two types and several variations such as Parsons and Terry for impulse, and dozens of reaction types including centripetal, like turbo-chargers.

An impulse turbine extracts energy by accelerating the steam in a nozzle and aiming it at a curved blade. The steam changes directions passing the kinetic energy to the blade. Theoretically, the blade would move at half the velocity of the steam. Since that is impossible, most turbines have several sets of blades (stages) to allow the steam to change directions each time.

A reaction turbine works by allowing the nozzles ejecting steam to be fixed on the rotating wheel. Generally, this is done in many stages. The blades in these turbines are shaped so the steam enters a small end and exits through a larger end. In doing so, the steam accelerates a little bit each time. These types of turbines are very efficient, but because the steam must keep expanding until its volume is quite large, they are relegated to applications with plenty of area.

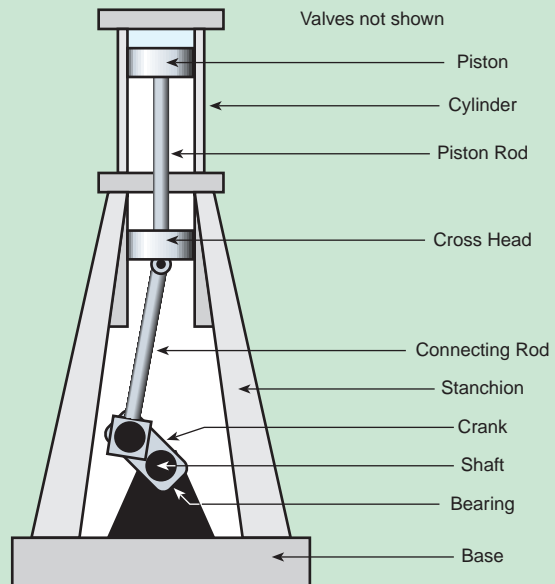
For any turbine to efficiently use steam, it requires that it be a size that allows for the expansion. A pound of steam wants to occupy 27 cubic feet at atmospheric pressure. Most small turbines consume 40 to 80 pounds of steam per horsepower. This inefficiency comes from the lack of physical space to allow all that steam to properly expand, doing its work.

Worth mentioning are rotary vane motors that can run on steam and Tesla designs, which use fluid viscosity and centripetal force. Unfortunately, even though they are practical, the efficiencies of these types of motors are too low to be in common use.

Reciprocating

Reciprocating engines are the method of choice in applications of steam up to 100 horsepower. They take a metered amount of steam and allow it to expand, driving a piston in a cylinder. The piston is connected to a crank which turns a shaft. At common pressures enormous torque can be

Vertical or "Marine" Configuration



Vertical configuration is used where horizontal space is limited, e.g. boats and cars. Side thrust created by angular moment between the crank and piston is taken up by the crosshead. This configuration, almost exclusive to steam engines, allows the piston to be thin, light, and to not touch the cylinder walls. This design is key to steam engine longevity. Flywheels (not shown) on vertical steam engines are usually small due to space restrictions.

achieved delivering a lot of power from a small, practical engine.

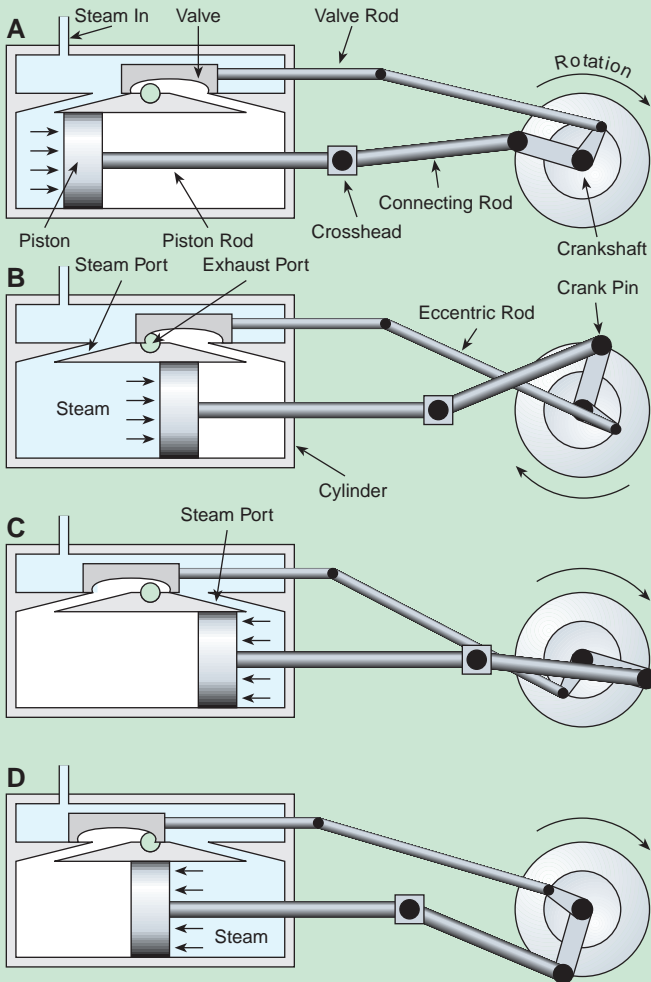
The Mike Brown engine is of this type. A lot of torque means a slow, silent, and even a direct connection to the task. There is no need for high rpm, multiple gears, and their resulting noise.

Reciprocating, or piston, engines are easy to build. Their slow speed and simple design increases longevity. Tour an old refinery or even a food processing plant and you may find piston engines still in operation after 50 years of use!

There are at least two major manufacturers of steam engines in the U.S. Unfortunately, steam engines are expensive due to a limited market. Until recently, small engines could be afforded only on a hobby or research basis. That has changed with the production manufacturing of the Mike Brown engine. Reliable power, parts, and support are now available at a practical price.

In a reciprocating engine, the front port is exposed to steam chest pressure allowing the steam to enter the cylinder and start to drive the piston. The valve then starts to travel forward and will soon cut off the steam admission from the front port and expose the rear port. The piston will continue on to the end of its

Motion & Timing of a Double Acting Steam Engine



Valve action in relation to piston action is shown. Steam chest is filled with high pressure steam at all times. A valve admits the steam into the cylinder through ports in the cylinder wall. The same valve allows steam to escape through a center exhaust port. Since steam force is used on both sides of the piston the engine is called "Double Action." This design allows very low rpms and high torque. Action is as follows:

- The left port is open allowing steam chest pressure into the left side of the cylinder which pushes the piston towards the right.
- The valve is starting to travel left and will soon cut off steam through the left port. The piston will continue to the end of its stroke due to flywheel momentum.
- The valve has traveled fully left exposing the right port to pressurized steam. The piston will be driven towards the left. The left side of the cylinder is now exposed to the exhaust port allowing old steam to vent.
- As the piston continues its stroke the valve again begins moving towards the right. It will soon close the right port and open the left port driving the system towards the condition in diagram A.

stroke at the rear of the cylinder. The valve traveled forward, exposing the rear port to the pressurized steam and allowed steam to enter the backside of the piston which will drive it back again. The valve then moves back in the original direction as the

piston continues forward. The valve will soon cover the rear port and expose the front port to begin the process all over again.

It is important to study the timing of the eccentric, which drives the valve back and forth, and its relation to the crank journal which is connected to the piston rod via the crosshead.

"Single acting" engines operate by admitting steam to only one side of a piston. The other side of the piston is exposed to a much lower atmospheric pressure. They produce power for only 50% of the revolution. This is desirable if construction needs to be inexpensive or a light valve train is needed for higher speed engines.

When maximum power is required in as small a power plant as possible, an engine may be designed to receive steam on both sides of the piston. This is known as "double acting." Both sides of the cylinder are sealed from the atmosphere and a valve system is used to admit and exhaust steam during alternate periods of the stroke. This is the type of engine seen in the drawing and that of the Mike Brown engine. They provide low rpm with high torque. Locomotives, autos, and marine engines use this and, if they have another eccentric that is 180° opposite, they can reverse crankshaft direction simply by switching one eccentric to the other.

The engine alternately admits and exhausts steam through a pair of ports cast into the cylinder. The ports are opened and closed by a valve that slides back and forth over them.

There are many shapes of valves but the one seen in the drawing is known as a D valve. The valve has the high pressure steam on the outside of it and exhausts the steam through the center which is constantly exposed to a port leading to the outside of the cylinder. Note how the outside and inside edges of the valve work back and forth across the cylinder ports.

Due to the thermal reduction of steam as it expands, it is not feasible to expand it by more than four or five times in one cylinder. In order to get more work from a given amount of steam, it is a common practice to exhaust the steam from one cylinder into another larger cylinder. This process is called compounding. Even though the steam is at a lower than initial pressure as it enters the second cylinder, the area of the piston is much larger than the initial cylinder and can provide the same amount of power. Sometimes this is done in 3, 4, or even 5 stages.

Since 2 horsepower will require 2 square feet of grate surface, we can use a round grate of about 19 inches diameter. Just to be safe we'll place our pipe coils 3 feet above the grate. We need to put all this in a casing and it just so happens that a 40 gallon water heater tank fits these dimensions roughly. We cut the tank in half, make holes for a door, air, and exhaust and we're in business.

Other Details

Now we add feed pumps and connect everything together with copper tubing using flare fittings only. But, we're not quite done. There are some important details you need to know. All fittings have to be steam rated, meaning no rubber seats in the valves, etc. Most importantly: add a safety valve! Steam safety valves are expensive and simply a fact of life. Sooner or later, you will have more steam than can be contained and it needs an uninterrupted passage to the atmosphere. A safety valve will release steam at a pre-set pressure and seal again automatically when the pressure drops to a safe level. If you think you can get by without one, forget this article and go buy a diesel generator.

Another thing that you can't overlook is the amount of heat needed to come up to operating speed and what is lost in the cool-down period. Earlier we determined that we needed 5.68 pounds of good dry wood per hour to make 1000 watts. First we'll need to bring about 10 pounds of water and about 100 pounds of steel to 350°. That means an additional 12,000 to 15,000 btus or about 3 pounds of wood. Another 2 or 3 pounds of wood energy can be figured as lost for the cool-down. Go out and chop at least 10 pounds of good wood.

Once you have everything mathematically correct, start calculating your losses to determine your overall efficiencies. This segment ties into everything and where one change is made, everything else will be affected. I call this the "headache phase." For example, we might discover storage losses in the batteries or inefficiencies in our generator. Believe me, there is always something so grab a few extra sticks of wood.

You can start to see the relation between each individual element of your design flowchart and where the most practical modifications can be applied. Many a fun night can be spent with the feet near the woodstove and a calculator by the recliner as you dream up your system.

System Cost

Dollar and "sense" wise, a person could assemble a system like this for less than \$2000. That's not cheap, but it puts it within sight of other energy sources.

Don't just go out and start building a system just because you have the facilities to do so. Do everyone within a hundred yards of yourself a big favor and get

yourself educated in steam first! The best and most fun way to get educated about steam is to attend a steam engine show. There are almost 5,000 shows across the nation. Steam has its own fraternity of dedicated individuals. Many like to restore old machines and show them off. The shows are very family oriented with lots of stuff for kids. They can best be described as a blend of Mad Max and Lake Woebegone. You'll see more NRA belt buckles and Grateful Dead t-shirts than anywhere else. Steamers are an eccentric folk.

Chances are you live close to a steam club, you can find one in a show directory, or ask your local tractor dealer or model shop where they are. Also, the Internet is loaded with steam. Type "Live Steam" into your favorite web searcher and see what happens. Just remember that steam is it's own fraternity and anyone with an imagination is welcome!

Access

Author Skip Goebel, Sensible Steam Consultants (specializing in steam as an alternative energy source and providing instructional videos), 152 von Goebels Lane, Branson, MO 65616 • 417-336-2869

Sources

Live Steam Magazine (premier steam hobby magazine), PO Box 629 Traverse City, MI 49685

Steamboating Magazine (mostly small steam launches and engineering), RT 1, Box 262, Middlebourne, WV 26149

Iron Men Album (old steam tractors, etc., large classified section), PO Box 328, Lancaster, PA 17608

Steam & Gas Show Directory (lists all the shows, a "must have"), PO Box 328, Lancaster, PA 17608

Steam Automobile Club Association, 1680 Dartmouth, Deerfield, IL 60015

Tiny Power Steam Engines, PO Box 1605, Branson, MO 65616 • 417-334-2655

Known Values

231 cu. inches in one gallon of water

One gallon of water weighs 8.34 pounds

One pound of water occupies 27.7 cu. inches or 0.016 cu. feet

One cu. ft. holds 7.48 gallons or 62.39 lbs of water

1 btu = 1 lb. water raised 1° Fahrenheit = 778 ft. lbs. (778 lbs. lifted 1 ft.)

42.44 btus a minute = 1 horsepower at 100% efficiency

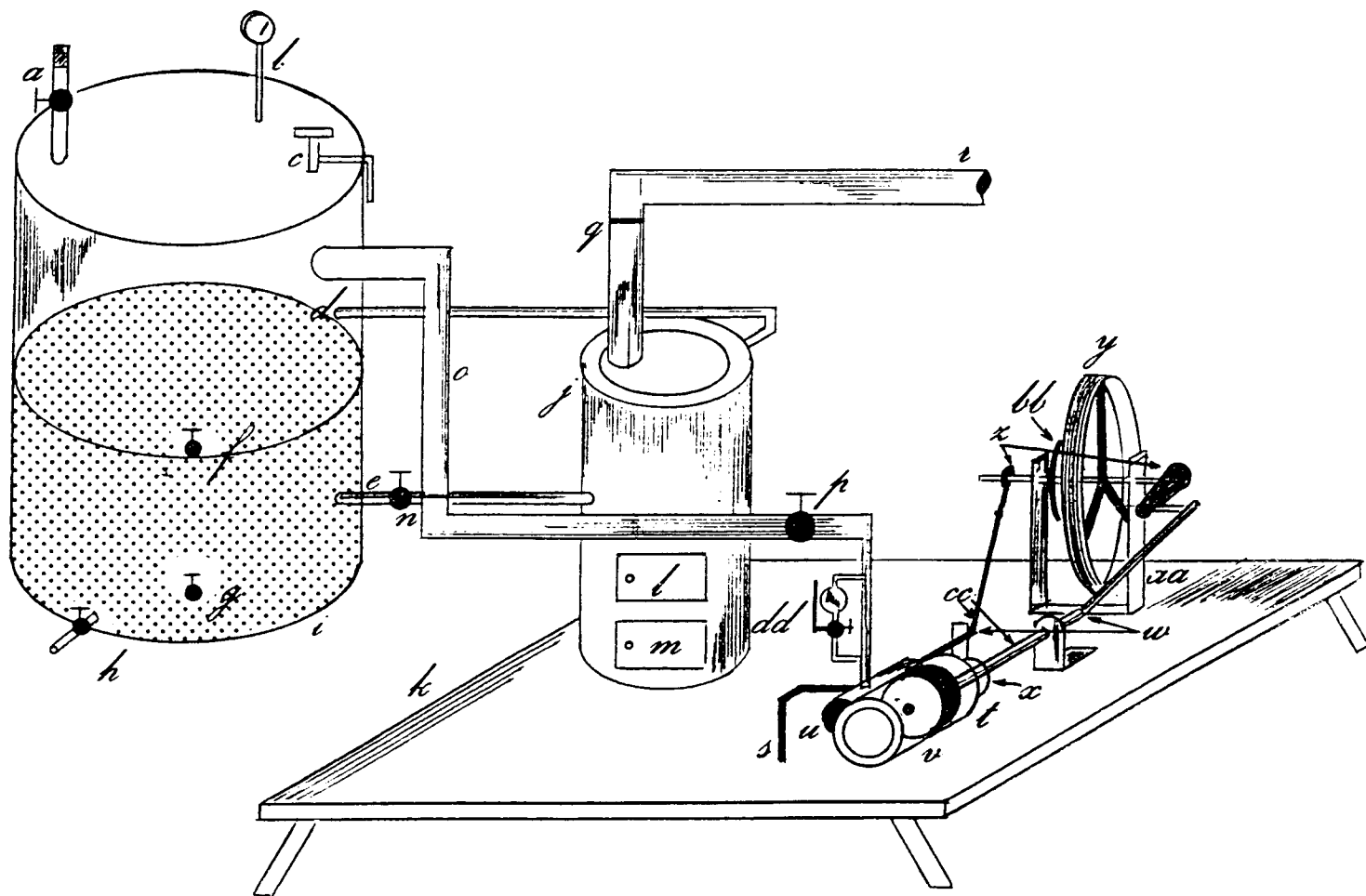
1 horsepower = 33,000 lbs. lifted 1 ft. in one minute = 550 lbs. lifted 1 ft. in one second = 750 watts electrical energy (746 true)

1 kw (1000 watts) = 1.34 hp

Configuration

Below is a diagram of the Reciprocating Steam Engine. This is the most popular design employed in steam dynamics. Although it is not as efficient as the Unaflow Steam Engine, it is simpler to construct.

Figure 1: General Configuration

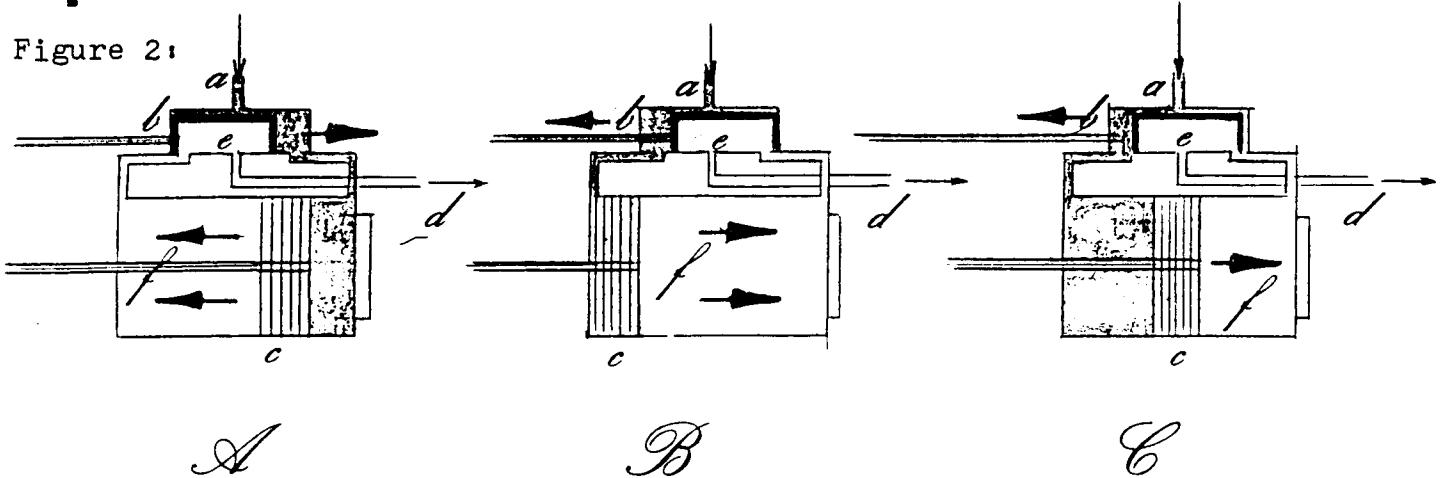


Components

a	Water fill inlet	q	Flue Damper
b	Pressure guage	r	Boiler Flue Exhaust
c	Pressure Safety Cap	s	Engine Exhaust Pipe
d	Boiler return Pipe	t	Cylinder
e	Boiler Intake Pipe	u	Steam Chest with Valve
f	Upper Water Check Valve	v	Piston
g	Lower Water Check Valve	w	Crossheads
h	Holding Tank Drain	x	Steam Seal
i	Holding Tank	y	Flywheel
j	Boiler	z	Eccentric and crank
k	Work Base	aa	Flywheel Support
l	Upper Service Door	bb	Utility Pulley
m	Lower Service Door	cc	Piston & Valve Rods
n	Boiler Intake Valve	dd	Hydrostatic Lubricator
o	Engine Intake Valve		
p	Pressure Regulation Valve		

Operation

Figure 2:



The steam engine utilizes the energy contained in steam under pressure. As the steam expands, it is converted to rotary motion by way of the piston and flywheel. The reciprocating steam engine uses the unique shape of the "D" valve to exert pressure on BOTH SIDES of the piston, as well as facilitate the exhaustion of used steam. A recent improvement on the design of the reciprocating engine is the UNAFLOW engine. This type offers a higher thermal efficiency than the reciprocating model, but is harder to construct. The Unaflow engine is beyond the scope of a home workshop project.

The components can be identified as follows:

a the steam intake	d the exhaust pipe
b the D valve	e the exhaust port
c the piston	f the exhaust area of the cylinder

In Figure 2, diagram A shows the steam engine, with the piston traveling to the left. Steam is bypassing the D valve and entering the cylinder through the tube located at the top-right corner. At the same time, in the area f, the steam is being exhausted. This is because the piston is pushing the steam out through the upper left hand tube. The position of the D valve allows the steam to escape through the center of it, and out the exhaust pipe.

By the time the piston completes its stroke to the left, the D valve has slid over to the right. This cuts off the steam to the right port, but opens the steam to the left port. At the same time, the valve allows the steam that has been pushed out on the right side of the piston to escape through the center of it.

In figure C, the engine is in the middle of a stroke to the right. Note how the valve is just beginning to close the steam to the left port, and is also beginning to close the right port to the exhaust opening.

As the engine rotates, this procedure will repeat itself in a cyclical manner. The D valve is difficult to make using home tools. However, we can easily make a double-piston slide valve with little difficulty that will perform just as well as the D valve.

The other components of importance include the boiler and the flywheel assembly. The boiler system consists of a holding tank and a flash boiler. These units create pressure to displace the piston and operate the engine. The moving piston is attached to a piston rod, which slides in and out of the cylinder. This rod is attached to a heavy flywheel which evens out irregular impulses of the engine, thus making the motion smooth.

The eccentrics connect the piston and valve rods to the engine as well as the flywheel, and are timed to make the piston and valve slide in the correct sequence. To allow the piston rod to bend as the flywheel rotates, the rods have a pivot point known as a crosshead. Lastly, a pulley is connected to the crankshaft. This can be used to drive an alternator, governor or some other piece of machinery.

Method of Operation:

1. The holding tank gravity primes the flash boiler, Since the water can only go in one direction, the holding tank also retains pressure. The pressure retaining valve (p) regulates the steam volume and consequently the speed of the engine.
2. The flash boiler rapidly heats up the water travelling through a heating coil that is inserted in the upper section of the flash boiler. The lower section houses the burning wood, or other safe, suitable fuel.
3. Steam travels to the engine due to back pressure along the intake pipe (o) where it expands rapidly and gives off its stored energy, thus exerting a force on the piston.
4. The utility pulley can be used to drive an alternator or other system.
5. The hydrostatic lubricator (dd) injects oil into the steam line and lubricates the internal parts of the engine (to be discussed later).

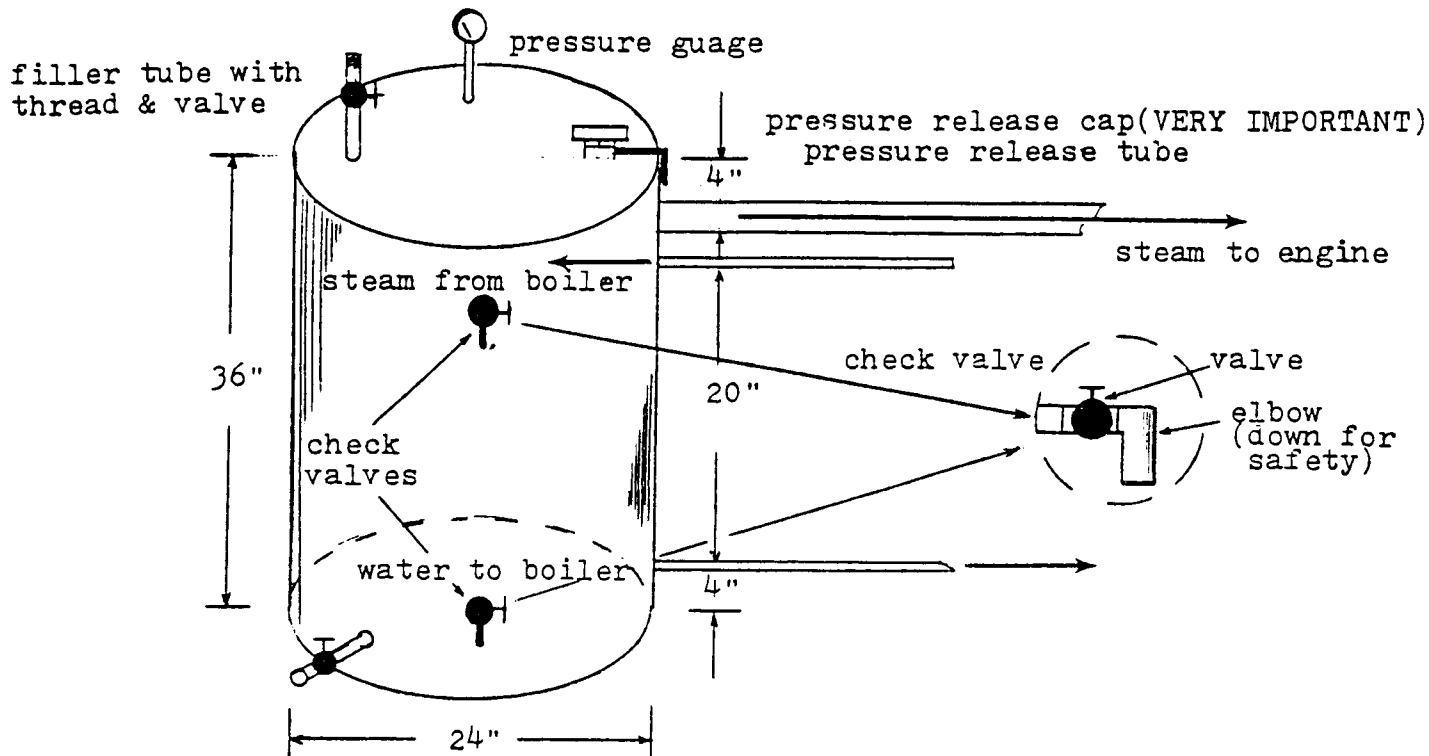
B: BOILER SYSTEM

CONSTRUCTION OF THE HOLDING TANK

The holding tank can be constructed from a standard 55 U.S. gallon oil drum. The oil drum must be relatively new, with absolutely no rust or holes in it. The lower end of the tank must be as high as the coil in the flash boiler, since until pressure is built up, only gravity will prime the coil, once the boiler intake valve(n) is opened. It will be best to place the tank on a 3 foot platform made of concrete blocks. Remember, that water will weigh about 10 pounds per gallon. If the holding tank is about two thirds full, it weighs in excess of 300 pounds. Accordingly, a very secure base of concrete blocks must be built.

Inspect the filling caps. If they are still fitting tightly, leave one closed, and use the other for the water fill inlet pipe(a). Drill a 1" hole into the fill cap and into this install a 1" pipe with a shut off valve as shown in figure 1. A threading at the end of the pipe will facilitate the connection of a hose from your commercial system for filling. The pipe should be brazed to the holding tank, but before doing so, flush out this and any vessels that are to be brazed with plenty of water. Old fumes in the tank may cause the tank to explode if exposed to heat...

To retain a safe but workable pressure, obtain from an automobile shop or scrapyard an old radiator, and cut off the filler tube at its lowest point where it is joined to the radiator top. Cut a snug-fitting hole into the top of the drum and braze this tube into place. Remember to locate it high enough so that the matching radiator cap can be screwed on. Do not use this cap to constantly refill the holding tank, since it will weaken the calibrated spring in the cap. Make occasional inspections for safety, but never remove it during operation. Use a cap rated at about 15 to 17 psi.



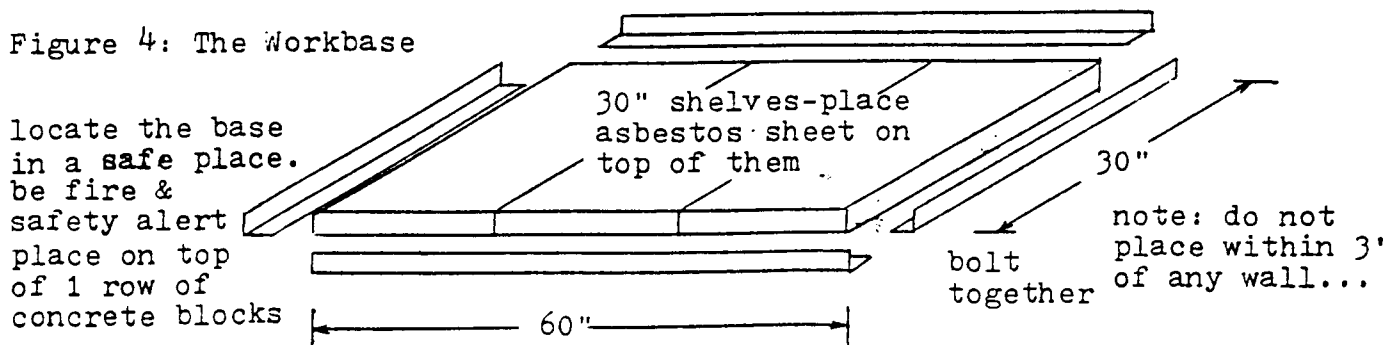
It will be easier to build the larger components separately and then construct the linking pipes and tubes once these components are in their mounted positions. In this manner, the various height and distance differences can be accounted for on your model.

When planning where to place the holding tank, remember that it will be holding pressure at about 15 psi, which can cause serious injury should a rupture or blowout occur. It is therefore strongly advised- Locate the holding tank in an outbuilding, garage etc., so that it is isolated from people. The two check valves f & g should be mounted 6" and 22" from the bottom respectively. They should be brazed to the side of the tank and fitted with elbows pointing downwards for safety. In order to check how much water is left in the tank during operation, open the upper valve SLOWLY to see whether steam or water comes out. If water comes out, you know that water is present up to that valve. As the water level approaches the bottom of the tank, use the lower check valve in the same manner. Use common sense and caution with these check valves. The drain valve should be opened when the system is not in operation and flushed, so that sediment deposits can be removed periodically.

CONSTRUCTION OF THE WORKING BASE

The base should be made out of brackets used to make heavy shelving frames. These can be placed on top of a row of concrete blocks as a support. Running across the frame are metal shelves of a standard length of 30".

Figure 4: The Workbase



locate the base in a safe place. be fire & safety alert place on top of 1 row of concrete blocks

30" shelves-place asbestos sheet on top of them

bolt together

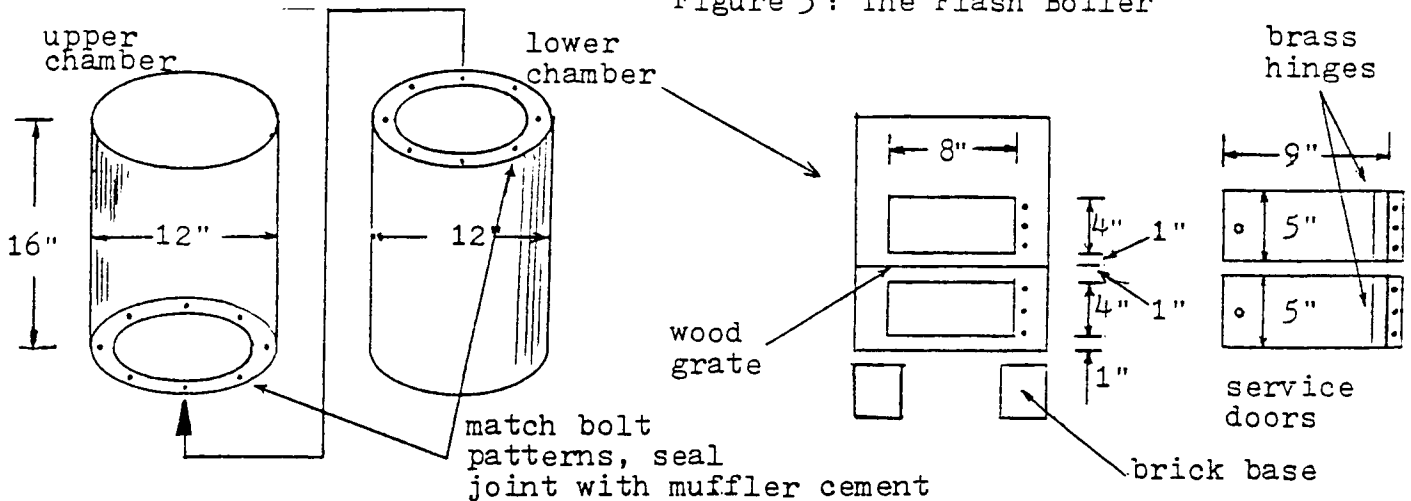
note: do not place within 3' of any wall...

The actual configuration of the flash boiler is a modification of the traditional tube-boiler system. Steeply inclined tubes convey water into the flue gas area of the burner that becomes converted into steam as a result of the exhaust heat. The returning steam builds up pressure in the holding tank which eventually runs the engine. The pressure also maintains sufficient force to continually circulate water through the flash boiler in safe quantities.

The housing can be made from two 5 gallon containers used to hold cleaning fluids, chemicals etc. Whichever containers that you choose to use, size will not be as critical as the wall thickness of the containers. They should be as thick as possible, $3/16$ to $1/4$ " is desirable to prevent warps and cracks later on from the heat. Use flexibility in finding two cylindrical vessels with this requirement in mind. When making the flash boiler, use a light brazing rod at all joints so that they can withstand the temperatures produced in the boiler. The two units will eventually be joined together, one on top of the other. The upper one will house the flue gas area and the heating coil, and the lower one will house the fire and service doors.

Cut off the top of the lower one in a circular fashion, leaving a $1\frac{1}{2}$ " lip all around the perimeter. Do the same with the upper one, but cut out the lower lid in the same manner. These lips will eventually be used to join the vessels together. It will be necessary to use a hacksaw to remove the pieces described.

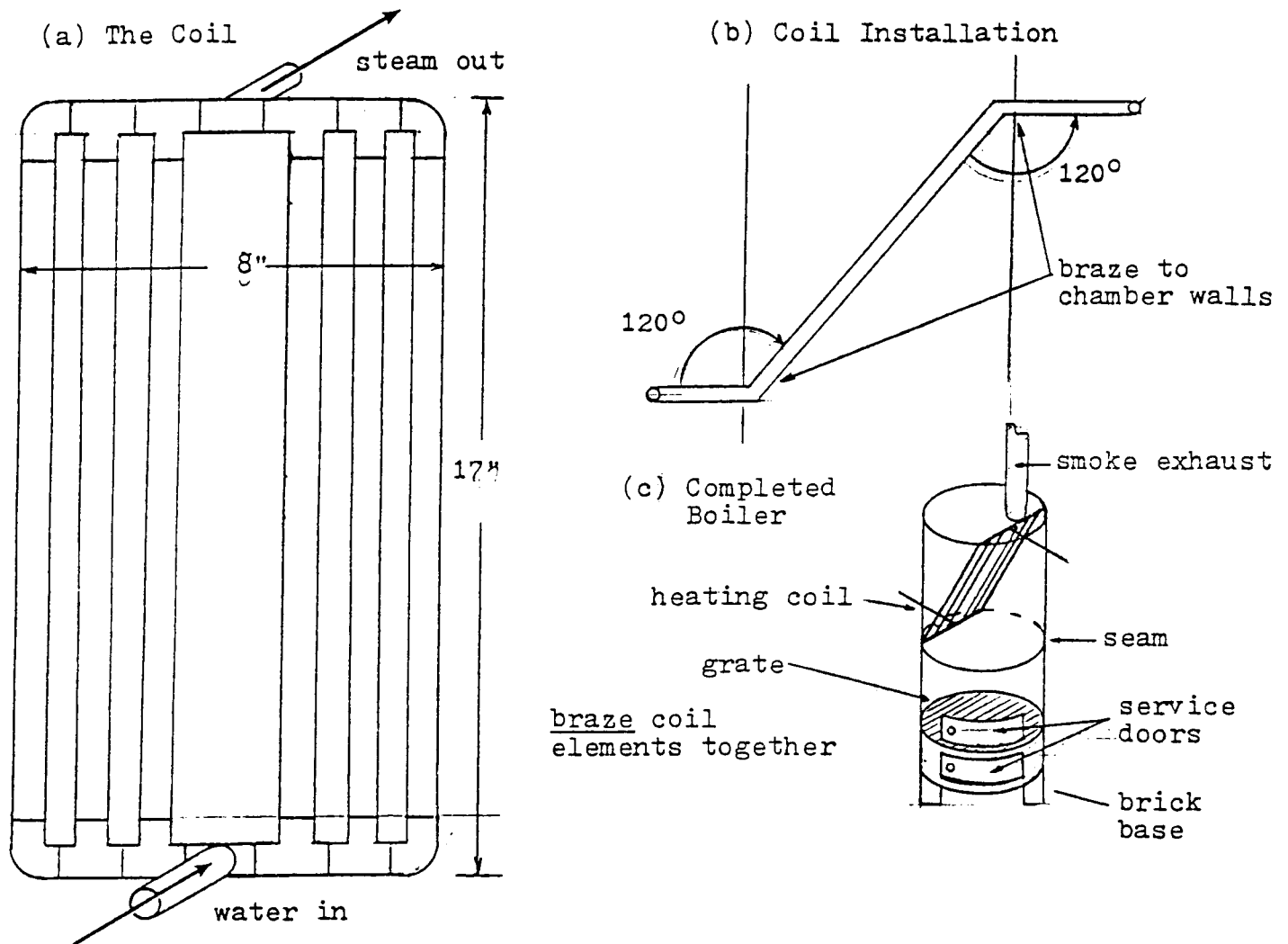
Figure 5: The Flash Boiler



The service doors can be constructed out of galvanized sheet metal, about $3/16$ to $1/4$ " thick. Complicated venting devices can be made if desired, however these are constructed with some difficulty, using limited tools. It will be easiest to simply open the lower door a fraction to regulate the amount of air travelling through the updraft. The lower grate door also facilitates the removal of burnt ash that has fallen down from the grate that the wood rests on. A small latch such as a cupboard latch will keep the grate doors closed when required. The doors should be fastened with heavy metal hinges and shaped to fit the curvature of the vessel, thus making an airtight fit.

The upper chamber will be constructed out of the other vessel, and will house the water heating coil and the smoke exhaust stack. The water heating coil consists of a string of steel pipes ($1/2$ " dia.) that are joined together to form a grid. As the water passes through them it turns into steam due to the hot flue gases surrounding the coil. The exterior dimensions shown are rough guidelines. Make the coil as close to this size as possible.

Figure 6: The Completed Flash Boiler.



The heating coil should be made out of 17" lengths of $\frac{1}{2}$ " steel tubing. To join the individual elements, use standard T joints and 90° elbow joints at the corners. It is best to situate the intake and exhaust tubes in a central position, since this will promote more of an evened-out heat effect. The T joints should be left unbrazed at the point of connection to the intake and exhaust tubes, so that they may be rotated perpendicular to the upper chamber walls, as shown in figure 6(b).

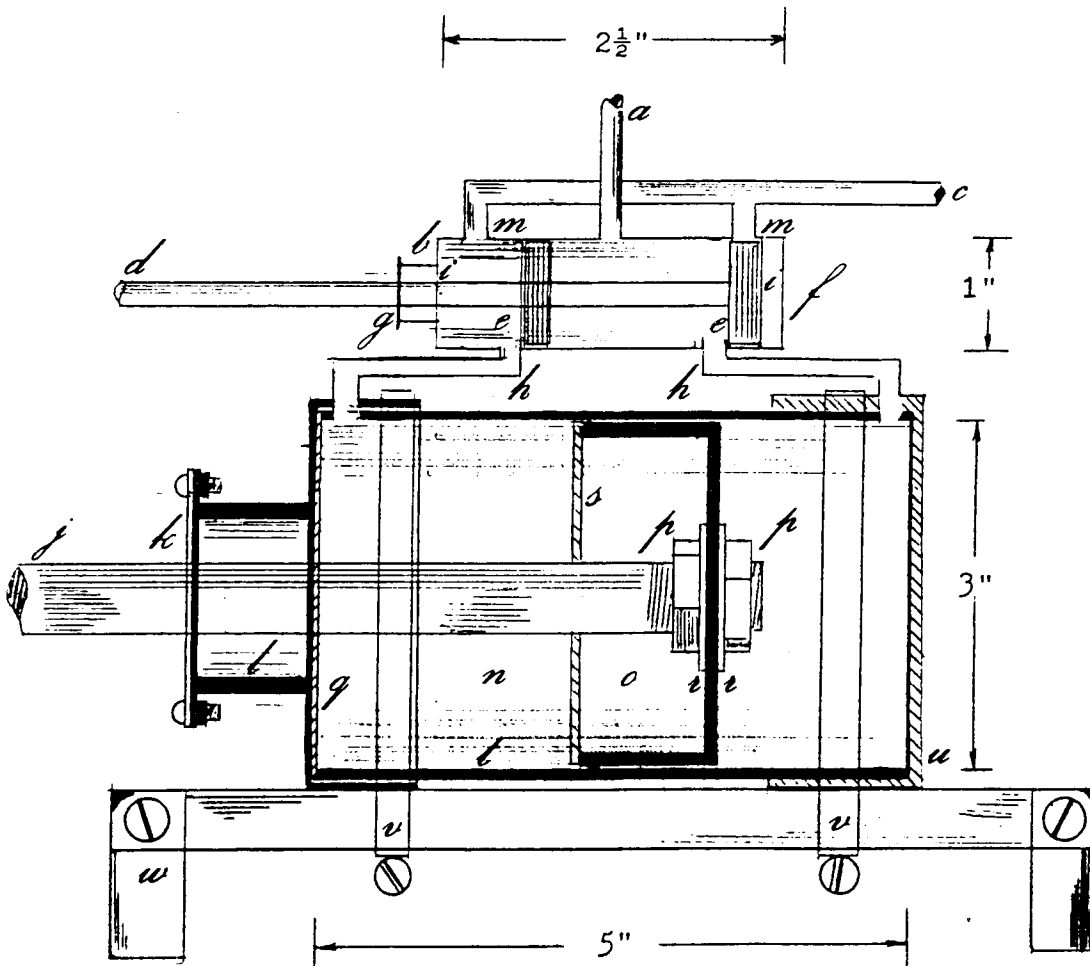
Once the heating coil is in place and all joints are brazed, join the upper and lower chambers as shown in figure 6(c). Use the holes previously drilled and $\frac{3}{16}$ " bolts. It is possible that the vessels you chose have a lip around the circumference of the ends. The lips will therefore not touch each other, and washers as shims should be used to fill the gap. Also, cut a 4" stovepipe hole in the top of the boiler and fit a stovepipe with damper regulator to the unit. Use care and common sense in routing the pipe out of your outbuilding and consult some manuals on wood stove installation if in doubt. Seal the seam with furnace cement.

Place the completed boiler assembly on the workbase, ensuring that there is an asbestos sheet between the metal base and the boiler. Make sure that the brick base under the boiler is at least 5 or 6 inches high to reduce heat transfer to the workbase. If the holding tank is on its base, and in its permanent position, join the pipes between them now, using steel tubing. Remember to install valve (n).

Steam Chest

The block of a commercially produced steam engine is usually made of cast iron. Casting a block is of course impossible for the home builder. Also, the sliding D valve is quite difficult, although not impossible to make. However, a block can still be assembled with little difficulty from a combination of common thick-walled steel piping. When collecting the materials for building the steam chest try to select piping that has thick walls. The thicker the better, since thin walled cylinders will warp and crack under the heat and pressure of the steam. In the diagram below, suggested dimensions are given, and should be followed as close as possible. However, if the availability of parts in your area is somewhat limited, use whatever you can. It is not important whether your cylinder bore is exactly three inches if all you can find in your area is 2 5/8" stock. Unlike an internal combustion engine where the power output is related to the bore and stroke with a fixed compression ratio, the steam engine is more dependent on the steam pressure to determine the power output. In other words, if you decide to build a slightly smaller block, the lower power potential can be compensated for by the delivered steam pressure.

Figure 7 : The Engine Block



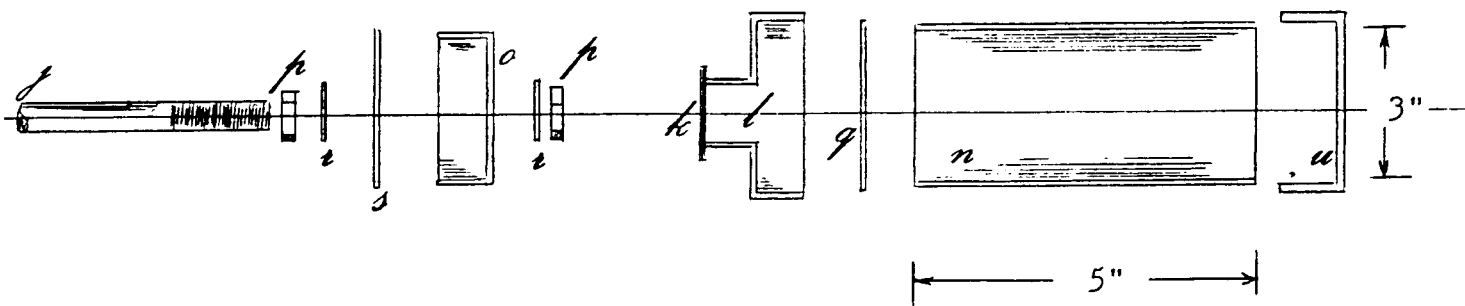
- a steam intake
- b steam seal
- c exhaust
- d valve rod
- e valve piston
- f valve system
- g end cap
- h intake port
- i valve ends
- j piston rod
- k seal plate
- l steam seal
- m exhaust port
- n cylinder
- o piston
- p piston nuts
- q seal plate
- r piston washer
- s back plate
- t sleeve
- u end cap
- v mount strap
- w base

The block can be built up from simple steel piping. For the main cylinder, the sleeve can be made from a length of 3" pipe stock. Try to use the thickest walled possible, since a thin walled sleeve will eventually warp or crack. A wall thickness of about 1/8" to 1/4" is satisfactory. At the rod end of this sleeve should be fitted a steel line adaptor with a bolt-on end cap. These are normally installed in plumbing systems where a reduction in pipe diameter will be required at a later date. Then, the end plate is removed with four or two bolts. This cavity will be used for a steam seal, and will later be stuffed with plumbers wool. Before installing the line adaptor, a circular plate will have to be installed between it and the sleeve. This will have a snug-fitting hole for the piston rod. The purpose of this plate is to enclose the cylinder to reduce steam leakage, and provide a surface to pack the plumbers wool against. Otherwise, it will foul up the piston. On the opposite end of the cylinder assembly, simply install an end cap.

The piston may be built up in several ways. You can go to a machine shop and have them "turn" a piston for you on a lathe. There should be about 1 or 2 thousandths of an inch clearance between the wall of the cylinder and the piston. Then, it can simply attach to the piston rod with two washers and nuts. Another method, as shown in figure 8, is to obtain a steel end cap that closely matches the cylinder diameter. Then, drill a hole into the center of the end cap and run a 3/8" bolt through it. Place the end cap into the drill chuck with the bolt and turn the small difference in diameter with a file. When the end cap fits with a tolerance of about 1-2/1000ths of an inch, enlarge the hole and mount it on the piston rod. The hollow end of the end cap will create a larger volume on one side of the piston. This will cause an imbalance when running. Turn a steel plate and braze it onto the back of the end cap to compensate for this. Or, if the piston rod has enough threading you can simply place 2 end caps back to back. Tighten them together with the piston mount nuts. If using two end caps, you may have to cut them in half laterally, since the piston should not be wider than 1 1/4".

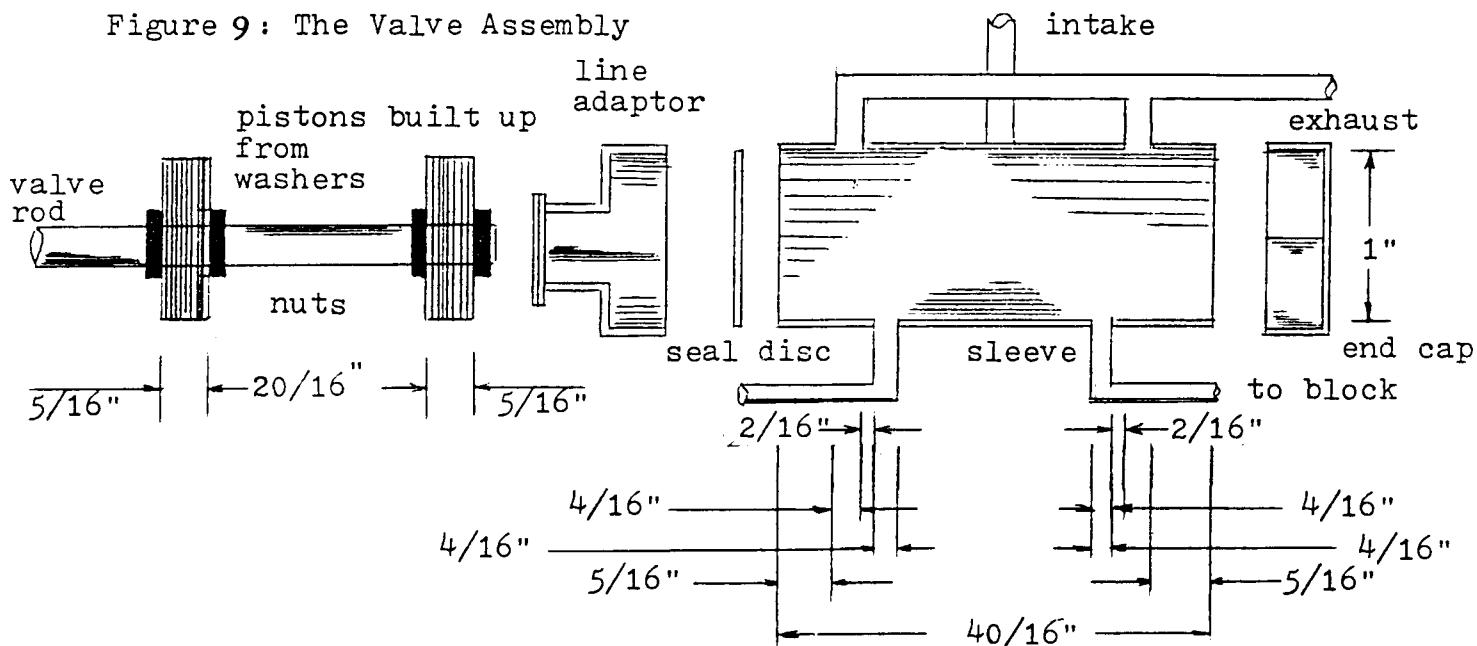
The entire cylinder assembly can then be strapped down with steel tension straps to a small metal frame. This frame can be attached to the working base with bolts. For future dismantling, the piston rod end cap should be removable. This end cap should be either threaded onto the sleeve or bolted on in any suitable manner. One easy way is to braze 4 or 5 angle irons to the sleeve and end cap so that they line up around its perimeter. Then, pass bolts through these angle irons and tighten them up. The other end cap can be permanently welded on.

Figure 8 : The Main Cylinder



The slide valve that can easily be made is a double piston slide valve. This type works just like the D valve, and is even more efficient at higher pressures. The valve assembly can easily be made from 1" pipe stock. An end cap is also necessary with a steam seal. Since the two pistons are smaller, they can actually be built up with washers. These will be turned down in the drill chuck and mounted together on the valve rod. The dimensions of travel to clear the intake and exhaust ports, as well as safely oscillate in the valve sleeve. Remember that a clearance of $5/16$ " should be added to both ends of the sleeve to accommodate the mount nuts on the valve rod. These will hold the washers together and form this pistons. Place a smaller line adaptor on one end as well, with a removable plate, so that the cavity can be stuffed with plumbers wool and form a tight seal. Drill four holes in the appropriate places and braze four tubes, to be used as the intake and exhaust ports. The entire assembly can be brazed onto the engine block, or bolted beside it on the service base. Remember that the slide valve and the engine block will have to be linked to the flwheel, so mount both of them at least 8" off the platform. This will provide clearance for the rods.

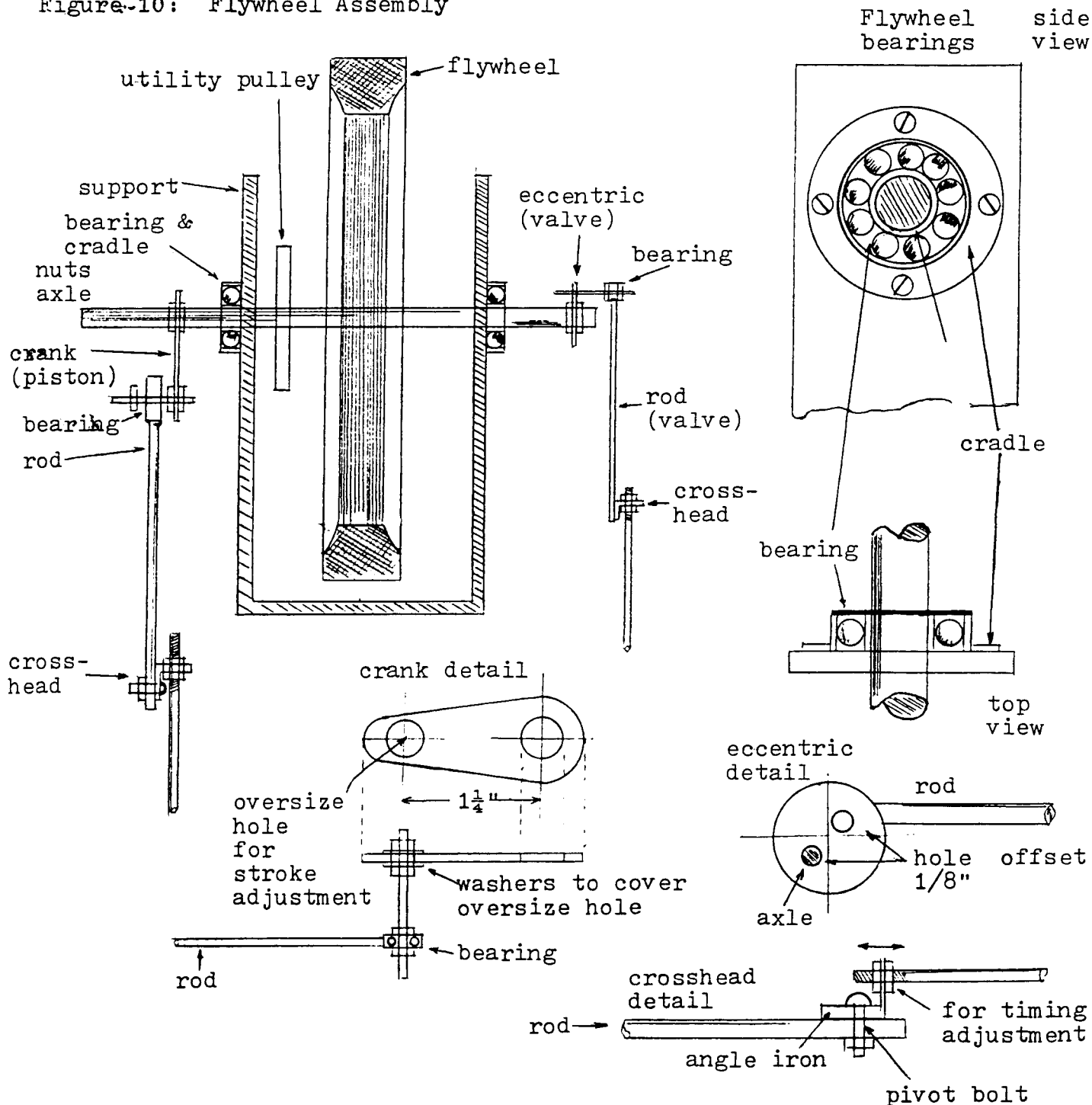
Figure 9: The Valve Assembly



The flywheel assembly is fairly easy to build, however provisions must be made for several adjustments. The first adjustment necessary is the distance of travel of both the piston and the valve. The other adjustment necessary is the actual timing positions of the piston and valve in relation to each other. The approximate travel in the piston is 4 to $4\frac{1}{2}$ inches, depending on the clearances necessary for the anchor nuts (r). The valve should travel $5/16$ ", so that it can shut off the intake and exhaust ports alternately. Onto the flywheel axle will be fitted a crank for the piston and an eccentric for the valve. The flywheel should be as heavy as practically feasible, to even out the impulses of the block. The actual radius of the flywheel is not too important, however the simple U mount must be able to support it. A heavily weighted machine pulley or a small car motor flywheel are the best selections. Again, the configuration of the flywheel is not as important as its actual weight, and its ability to drive the crank and eccentric. It may be necessary to go to a machine shop to obtain a heavy gear or pulley from a machine shop to serve this purpose.

When setting the piston and valves relative to the flywheel, the valve and piston must be completely in reverse phase. In other words, when the piston is travelling to the right, the slide should be travelling to the left. When the piston is at the end of its stroke at say, the right end, the valve must be completing its stroke at the left end. By making the mount holes on the crank and the eccentric oversized, adjustments can be made. The coarse timing can easily be adjusted by mounting the crank and eccentric onto the crankshaft at the correct positions. The rods will be allowed to pivot by way of the crossheads. The crossheads will also allow some minor adjustments of the timing.

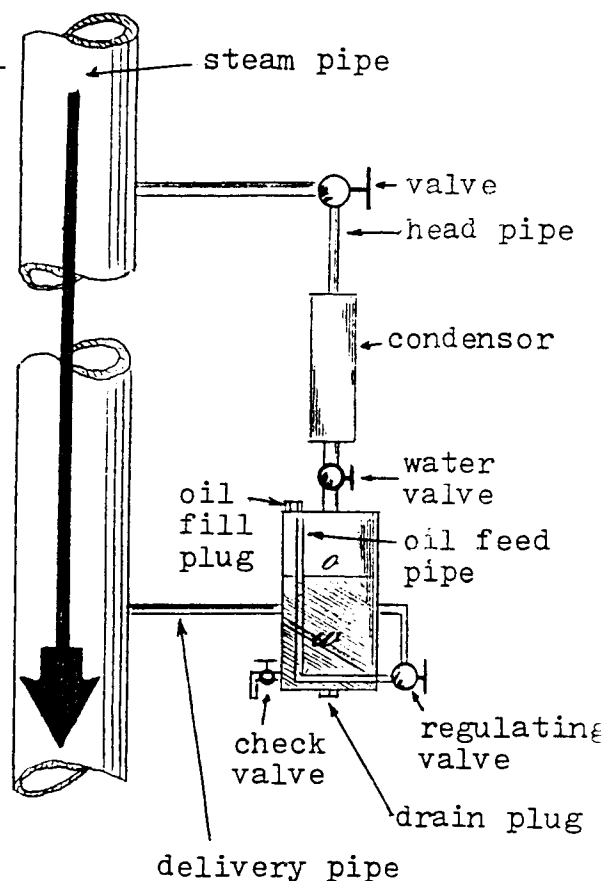
Figure-10: Flywheel Assembly



Lubrication

The external parts of the Steam Engine should be greased periodically. It's particularly important in regards to the flywheel assembly, such as the axle and crank bearings. Also apply grease to the pivot bolt on the crossheads. The internal parts can be lubricated by injecting a small amount of oil into the steam line. The simplest type of lubrication system is a hydrostatic lubricator. This system is mounted at any suitable vertical piece of steam intake pipe. The principle behind the hydrostatic lubricator is that when 2 intake points in the steam line are balanced, the difference in pressure that injects the oil into the steam line is produced by the weight of water below the oil surface, stored in a small vessel.

Figure 11: Hydrostatic Lubrication



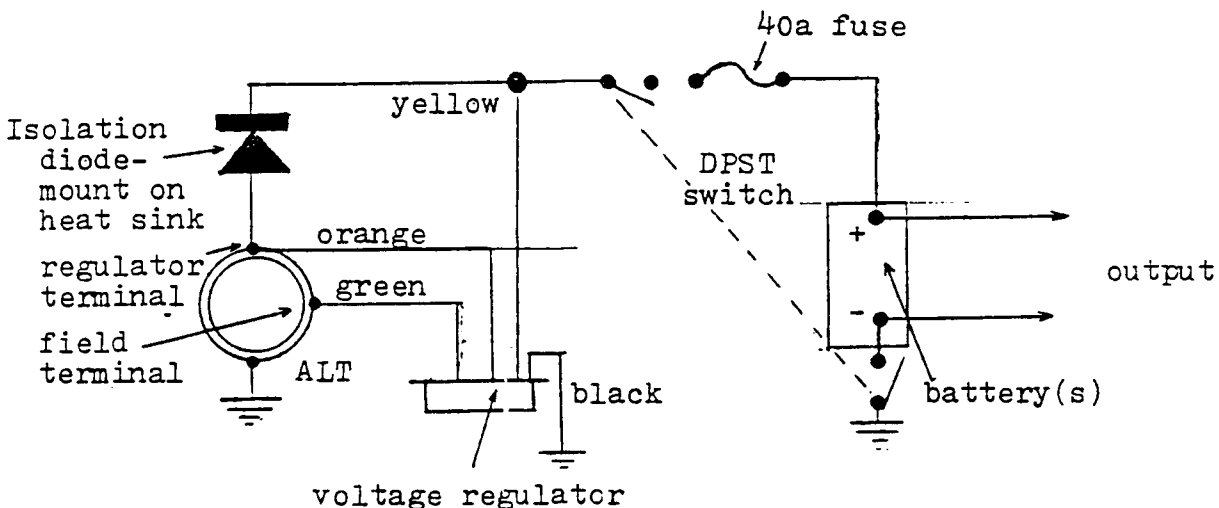
Firstly, steam enters the upper pipe. The increased surface area of the condenser causes the steam to condense into water. The water drips down through the water valve and displaces the oil in the vessel. Since the oil floats on top and does not mix with the water, it displaces out of the oil feed pipe. The regulating valve controls the amount of oil entering the steam line. The small check valve should be opened slowly from time to time to determine if there is still some oil present in the container. After a while, you should be able to determine the average operating period that is possible in your engine's case on one oil filling. The oil can be placed in the container through the oil fill plug, after draining the container through the drain plug and removing the condensed water. This of course should be done before the engine is started. Normally, any 2-cycle gas engine motor oil will work fine.

To produce sufficient pressure to force the oil into the line, the length of the head pipe should be at least 18 inches. This simple hydrostatic lubricator can be easily built from simple copper plumbing with no problems.

Lastly, there are two steam seals at the end of the main cylinder, as well as the sleeve for the valve. Remove the cover plate and pack into the cavity a liberal amount of plumbers wool soaked in motor oil or dabbed with grease. This will prevent steam from leaking out of the cylinder hole, but should not bind the rods involved. This seal will have to be repacked periodically, which should be a simple procedure if access plates were used in the design of these end caps as recommended.

At this point the steam engine is essentially functional and ready to accept an automotive 12 volt alternator. Most alternators built these days offer internal rectification, This means that the A.C. is converted to D.C. so that it may be stored in a bank of batteries. The alternator does not have a permanent field around it like permanent magnet D.C. generators. Therefore there is the need for some field excitation to take place to start the system charging. When the control switch is closed, current leaks back through the alternator by way of the regulator and the field terminal (green). Remember that current will be leaking to the terminal constantly to create the necessary field for charging. If the unit is not in a charge mode, open the switch to conserve your stored electricity. With high variations in the speed of the engine as well, the generated voltage will vary somewhat. The regulator will regulate overcharging by cutting off excess voltages, and the isolation diode will prevent current from leaking back into the alternator and being lost to the ground connection. Since an automotive charge circuit experiences these high variances in rpm and current production as well, a 90 amp alternator with a matched diode and regulator can easily be employed in your engine in the same manner that was used in the automobile. As a trade-off between cost and reliability, purchase the alternator as a reconditioned unit. A 40 ampere fuse is a good safety device. It will protect the battery from burnout and overcharging. The electricity may then be tapped in a parallel manner from the battery or banks of batteries that you have hooked up. One last note on "Runaway Speed": When an alternator is under a heavy load, it is fighting a heavy back electromotive force. If that load is suddenly removed, the alternator and engine will spin at a very high speed and then burn out. So variances in loads are fine, just avoid the sudden removal of a heavy load while the engine is also running. If the engine is shut down, a heavy draw will not affect the alternator. Lastly, on shutting down, leave the pressure retaining valve OPEN and let the steam exhaust out- otherwise the steam inside will condense and cause a vacuum. This will make the boiler collapse...

Figure 16: The Charging Circuit



Note: The steam engine will normally turn at a speed of 300 to 500 rpm. Therefore, the pulley system should gear up the alternator to its selected generating speeds as given by the manufacturer.