Port Dimensions

This part of the post is largely directed at Bill Hudson and his long stroke stern wheel engine questions, however, I am sure the rest of you PD’s will, hopefully, get something from it, if only a headache…He He.

Bill, you required the formula for calculating the cross section of steam and exhaust ports…, this is: -

Cross sectional area (a) = Av/V

Where A = area of piston.
v = Piston speed in ft/min.*
V = Velocity of steam flow in the pipe/port in ft/min

For steam velocity (V) this is typically 4000 for exhaust and 6000 for inlet.

Where the same port is used for both inlet and exhaust (as in a typical slide valve or piston valve engine) then the port should be designed for exhaust.

Taking your ½” bore x 2 ¼” stroke engine as an example, and assuming a rotational speed of 120 rpm, typical of a stern wheel engine.

Area of piston (A) = 0.19635 sq in.
Velocity of steam (V) = 4000ft/min.
Piston speed * (v) = 45 ft/min.

Port area required = 0.19635 x 45/4000 = 8.83575/4000 = 0.002209 sq in.

For a rotational speed of 150 rpm the piston speed would increase to 56.25 ft/min. And the port area would become 0.00276 sq in.

A port of 1/16”dia would have a cross sectional area of 0.00307 sq in and theoretically should be adequate in both cases, however, for model engines, where other losses, such as frictional and thermal, are much more of an issue, it would be advisable to increase this to 1/8”dia (area = 0.01227 sq in.) or even 5/32”dia (area = 0.01917sq in) and would also cater for somewhat higher rotational speed as well. Naturally, a rectangular port of the same cross sectional area would be equally satisfactory.

The rule governing the clear bore size of the steam feed pipes would also bear this out.
Clear Bore should be roughly equivalent to 1/4 of the piston dia making the minimum pipe size 1/8”, however, for multi cylindered engines this should be increased to 1/3 piston dia = 5/32” Approx.

<u>* PISTON SPEED</u>

In any engine having rotational output derived from a linear reciprocating piston then the piston speed is not constant, but will differ depending upon the position in the stroke the speed is measured.
At the extreme ends of the stroke, the piston speed is actually ZERO, and reaches a maximum at ½ stroke.
If plotted using all the sine's of all the angles of output rotation v piston position in the bore then the result would be a sine wave, identical to that obtained for AC electricity.

For our purpose it is usual to take the peak maximum speed, which occurs at mid stroke.

For a 2 ¼" stroke @ 120 rpm this works out as follows.

At 120 rpm a single rotation takes 60/120 sec. = 0.5sec.
The piston will make 2 full strokes to achieve this; hence one stroke takes 0.25 sec.

So, 21/4" per 0.25sec = 9" (0.75ft) per sec = 45 ft/min.

<u>Boiler Calculations</u>

I don't think you are (theoretically) a million miles of the requirements with your 106.08 sq ins. Heated surface area figure Bill.

I made some quick calculations based upon the engine dimensions and for 150rpm at 65psi and came up with 99.37sq in.

Which leads me on to another subject……Namely 'effective heat transfer'…

The figures worked out for HS assume that all this area is directly available (can be seen by) the heat source. In most boilers, this is just not the case and the transfer of heat can be, and more usually is with model boilers, affected quite severely by a thing called 'boundary layer effect' (skin effect) where the resulting gasses of combustion cling to, and effectively mask (insulate), the surface of the flues and tubes in a boiler. These can have the effect of increasing the resistance to thermal transfer to a point where no heat can get through, and hence the areas of HS affected are of no benefit and may as well not be there.
Several ways of reducing this affect have been proposed, but none succeed in eliminating it completely. The best of these introduce turbulence, by swirling the combustion gasses about, thus reducing the build up in any given area, or by forcing the gasses through small passages, thus increasing their velocity, which has a similar effect, however by far the best way is to have as much of the heated surface as possible in direct view of the heat source, where the direct radiation from the source prevents the build up most effectively.

It has been calculated that the effective transfer of heat via areas directly exposed to the radiant heat of the heat source are 5 times greater than those exposed to combustion gasses only.

The bottom line here is…if you need a high rate of steam production then chose a boiler design with as much of it's heated surface in direct line of sight of the heat source.
IE. A Water tube boiler, such as a Yarrow or Scott, rather than a centre flue or return flue type.

This is not to say that centre flue or return flue boilers are no good, history proves otherwise, however, they do tend to be very much larger, and heavier, for a given rate of steam generation, than do the Water tube types and are much less efficient from a fuel used per lb of steam produced point of view.

<u>Heat loss and condensation</u>

Of all the areas in steam applications this one is the most difficult to grasp and leads to more confusion than pretty well all others.

Fact…a substance cannot be cooled to a temperature lower than that, which directly surrounds it.
Fact…as soon as you try to perform work with steam, it gets wetter.
Fact…wetter steam can be at the same temperature.
Fact…Steam can be both dry and saturated.
Fact…expanding steam can get dryer.

The list goes on…but these will do for now.

Lets take the fist of these, since this has a direct bearing upon the lagging of steam pipes etc, and was of particular concern to you Bill.

If we consider steam passing through a pipe in free atmospheric space then the temperature, which surrounds it, is the temperature of the atmosphere, and for obvious reasons this, naturally, is not a constant.
Therefore heat can easily be lost through the walls of the pipe, how much and how fast is determined by the thermal transfer rate of the pipe material.
Copper has one of the highest thermal transfer rates (only exceeded by silver) with Brass coming a little further down the list (however, there are other considerations when using brass with high temperature/pressure steam. (More later)

However, if the pipe is efficiently lagged, (insulated from the atmospheric temperature) then the temperature surrounding the steam will be very much higher, and can approach that of the steam itself, since any heat passing through the walls of the pipe will be effectively trapped at the surface of the pipe, and will only be effected by the very much lower transfer of heat through the lagging.
So, Heavily lagged pipes, especially over long runs.
In model steam plants this distance can be several ft without major problems, if efficiently lagged.

The same thing applies to steam cylinders and steam chests and if carried out effectively, then the loss of heat through this path can be substantially reduced, even virtually eliminated, but not totally.

The bottom line here is..any heat loss will result in wetter steam (even with superheated steam).

Although extensively used Brass is not really a good material for steam use, even more so when associated with the boiler itself. However, since this effect occurs over quite a long period of exposure, material cost is generally the deciding factor (brass is considerable cheaper than are copper or bronze) in the final choice, especially for fittings and pipe work etc, which can more easily be replaced.
On a boiler, where changing/replacing a component is next to impossible, without recourse to severe surgery, the uses of copper or bronze are the materials of choice.

When brass is in direct contact with high temperature, high pressure, water, as in a boiler, then the zinc content can leach out resulting in a weakening of the material. It’s use for steam pipes (wet steam) also can suffer the same, however, since the direct water contact is lessened, it can be used for this purpose, providing it is checked regularly and replaced if necessary. (It becomes more brittle and in extreme cases can become porous). Copper and Bronze do not suffer from this problem.

The remainder of the above, Fact statements will require me to go more into the generation (enthalpy) of steam and will be the subject of the next instalment.