THE DESIGN OF AN OIL-BURNING SUPERHEATER

BY

WILLIAM IZAAK DENTON

A Thesis submitted for the degree of Bachelor of Science in Mechanical and Electrical engineering.

Under the direction of Professor W. R. Woolrich.

UNIVERSITY OF TENNESSEE

1925

The Design of an Oil-burning Superheater

Superheated steam is steam at any pressure having a temperature higher than that of its evaporation from water at that pressure. The use of superheated steam is practiced in the largest and most economical plants in the world, showing that its use results in ultimate plant economy. No general rule can be laid down as the extent of saving made because of the great number of variable factors entering into the problem. Each installation must be considered by itself taking into account all of the items which affect the economy of the installation under consideration.

In connection with power plant work, the salient advantages of superheated steam are:

(1) At high temperatures it behaves like a gas and is in a more stable condition than when in the saturated form. Heat may be extracted without producing liquefaction, whereas, if heat is drawn from saturated steam condensation results. The most cases superheat is only carried so far as to reduce initial condensation, although it may be carried high enough to give dry steam at exhaust. This is the condition for maximum efficiency .

(2) A moderate amount of superheat produces a large increase in volume, the pressure remaining constant. This diminishes the weight of steam per stroke for a given amount of work.

(3) Superheated steam has a much lower thermal conductiv-

ity than saturated steam, and therefore less heat is absorbed per unit of time by the cylinder walls. The water rate of a turbine or engine is decreased by superheating the steam. In practice the gain in heat economy due to superheat is more pronounced in the piston engine than in the steam turbine. The principal advantage to the use of superheat in turbine operation is that it reduces erosion of the blades by lowering skin friction and windage.

The first experiments with superheated steam were made during the first part of the Nineteenth Century. The first patents for superheating apparatus were those of Becker in 1827. The real introduction of superheated steam was brought about by Hern in 1855.

The present type of superheater is built of cold-drawn seamless steel tubes bent in a V-shape and expanded into two wrought steel manifolds. The life of such a superheater is only two to three years.

Superheaters fall into two general classes, (1) those independently fired and (2) those placed in the boilersetting. The independently fired superheater has almost disappeared due to its many disadvantages and the extra fuel necessary to operate it.

The requirements of a successful superheater are:

(1) Security of operation or minimum danger of overheating.

(2) Economical use of heat applied.

(3) Provision for free expansion.

(4) So arranged that it can be cut out without interfering with the operation of the plant.

The object of this experiment is two-fold:

(1) To devise a means of burning oil in direct contact with steam under pressure, thus utilizing all of the heat.

(2) To prove that a superheater of this type can be made a

commercial success for use in house-heating and superheating exhaust steam for use in laundries.

The apparatus necessary for the conduct of this experiment includes a drum or container through which the steam to be superheated is passed from the steam main to the point where it is to be utilized. The problem is to inject a combustible mixture of air and finely divided oil under a pressure somewhat greater than that of the steam, and burn this mixture, the products of combustion mixing with the steam and going through the engine. The entire amount of the heat generated goes to evaporating the moisture in the steam and to heating the steam above saturation temperature at the pressure in the drum. It is necessary that the fuel and air be correctly proportioned and thoroughly mixed in order to insure economy of fuel and to prevent unburned gas going out at the exhaust. The mixture must be supplied uniformly and continuously and when so supplied should burn continuously and without further ignition after being once lighted by means of a spark plug.

In previous experiments dealing with this problem** the principal difficulty seems to have been the extinguishing of the flame, by steam coming in contact with it and the tendency for the steam to draw the flame out and thus to extinguish it. The second difficulty was obviously caused by faults of construction and could be eliminated by suiting the sizes and shapes of the various parts to the capacity desired, If the burned gasses themselves have a velocity greater than that of the steam through the drum then there can be no tendency for the steam to draw the flame out. The first

** See Thesis by A. O. Kraehenbuehl, 1921 and H. E. Ayres, 1920.

objection can be obviated by burning the mixture in a separate combustion chamber from which the steam is completely secluded. The mixture enters this combustion chamber from the mixing device where it ignites and increases in volume at the same time giving up heat. If the combustion chamber is so constructed as to be surrounded by the steam to be superheated, none of the heat will be lost. The burned gases carry the heat through an opening into the steam drum at a velocity depending (1) on the size of the opening and (2) on the amount of mixture entering the chamber, In the steam drum the hot gases mix with the steam and superheat it. The amount of superheat is dependent upon the quantity of fuel burned since no heat is lost.

The equipment available for conducting this experiment includes a twenty-five horse-power Corliss engine which can be connected through the superheater to mains supplying steam at a pressure of sixty-five pounds per square inch. An air pump supplies air at a maximum pressure of twenty-five pounds. Since the air pressure must be greater than the steam pressure this limits the pressure in the steam drum to about twelve pounds.

It is necessary that the oil pressure be greater than the air pressure by a constant amount. This condition was secured by placing the oil tank at a considerable elevation above the burner thus giving a static head on the oil. The air line was connected to the top of the oil tank. This gave an oil pressure at the burner equal to the air pressure plus the static head which in this experiment was about thirty feet.

The layout of the apparatus is shown in plate (1). The steam drum consists of a length of five inch pipe being provided at one end with a tee. The side opening of the tee is connected through a valve to the steam main. The combustion chamber and burner are connected to the tee by means of suitable bushings. A length of pipe projects into the drum against which the entering steam strikes. This pipe guides the hot gases and prolongs the time when they will mix with the steam thus insuring complete burning. The combustion chamber itself is a $1\frac{1}{4}$ tee. The side opening is adapted for a spark plug and the end opening is provided with bushings to fit the burner or mixer. The burner itself is designed to mix the gas and air by allowing the air to come into the gas at an angle from all sides causing great turbulence in the $\frac{1}{4}$" passageway. The principal objection found with this burner was the fact that when the misture entered the combustion chamber from the burner at a high velocity a turbulence was set up in the chamber which seemed to extinguish the flame. To overcome this difficulty a diffuser was used. This was a perforated disc of sheet iron which caused the small stream of gases and air to spread out over the entire cross section upon entering the combustion chamber. This had the effect of encouraging stream-line flow and reduced the eddy currents in the chamber.

A continuous spark could be set up at will in the chamber by means of the spark plug and an induction coil, as shown in figure 2.

It was found that in order to secure a proper regulation of the mixture it was necessary to completely vaporize the oil before passing it through the fuel valve. In all of the tests made with this apparatus the mixture was controlled by opening the air valve wide and then adjusting the fuel valve to give the proper mixture as determined by the color of the flame. The fuel was vaporized in a brass pre-heating coil by means of a blow-torch. The color of the flame was observed through a small peep hole drilled near the spark plug. The flame was also observed in the drum itself through a small glass window in the side of the drum. The steam drum was provided with a pressure gage and a thermometer well in which the temperature of the superheated steam was found.

Observations were made under three sets of conditions, (1) Atmospheric pressure in the drum, (2) Pressure in the drum of 12 pounds due to air and products of combustion, no steam being admitted and (3) Pressure in the drum of 12 pounds and steam being supplied to the Corliss engine at this pressure through the superheater.

There was no apparent difference in the results of case (2) and (3), showing that with the form of apparatus used that the flame was independent of the condition of the atmosphere in the superheater. In former experiments the quality of the steam affected the flame, but this did not affect conditions in this case except that the greater the moisture in the steam, the less the superheat obtained due to the absorption of heat when the water was vaporized.

As to the difference in operation between case (1) and (2) or (1) and (3) it can be said that the flame actually seemed to burn better when under pressure. This was true as long as the proper conditions obtained as to difference in air and superheater pressure and proper mixture being delivered to the combustion chamber. But it was found that it was more difficult to control the conditions of pressure and mixture when there was pressure in the superheater. The reason for this was that a change in the pressure in the superheater changed the quantities of air and fuel supplied to the combustion chamber and an adjustment which gave the right mixture at one pressure gave too rich or too lean a misture at another. As long ~~as~~ the proper conditions prevailed the burner gave perfect satisfaction when operating under pressure. The combustion chamber became very hot. In a commercial design the combustion chamber would be surrounded by the incoming steam, also the fuel vaporizing device would secure its heat from the combus-tionchamber, thus eliminating an independent source of heat.

The flame would often go out while burning either under atmospheric or greater pressure. When the spark was kept continuously going this gave little trouble for it would ignite again immediately. There was a certain mixture which gave steady continuous burning. Leaner mixtures while they produced as hot a flame tended to pop off and on to an objectionable degree. A piece of carbon was placed in the combustion chamber, This became red hot and seemed to ignite the flame when it went out even when the spark was not operating.

In preparing to operate the superheater the steam was first turned on and the condensate allowed to drain from the mains. The Corliss was started and run for a few minutes. Then the valve was closed and the condensate was siphoned out of the superheater by means of a rubber tube. The preheating coil was heated up by a blow-torch which was kept operating continuously. When the fuel was vaporized the air and fuel valves were opened and the mixture was ignited through the spark plug opening. It was allowed to burn this way until hot enough to operate satisfactorily. Then the steam valve was opened enough to give sufficient steam to run the Corliss keeping a pressure of about 12 pounds in the drum. The flame could be observed through the glass window or through the 1/16" peephole in the combustion chamber which was stopped up with a wire when not in use. When operating in this way the flame burned satisfactorily.

The temperatures and pressures were taken while operating under the above conditions with the results shown in the following table.

Observation	Quality of entering steam	Pressure in Superheater	Pressure of Air	Temperature in Superheater	Degrees of Superheat.
1	98	12	13	261	20
2	98	12	13	268	21
3	98	12	13	265	20
4	98	12	13	275	31

The conclusions to be drawn from this experiment are that with a certain amount of research work an oil-burning superheater can be designed to work dependably and efficiently. The problems to surmount in developing such a superheater are numerous. Its application for supplying steam to engines will have to be in the non-condensing field, as in the field requiring a low vacuum on account of the combustion products in the steam. There is a possibility that the introduction of these gases would increase the thermal efficiency. Experiments have shown that the introduction of air into steam has this effect. While there are numerous difficulties to surmount in developing this idea, it seems to the writer that the Deisel engine was a much more difficult problem than the one under consideration. In view of the remarkable success of that idea, the oil-burning superheater has the prospect of becoming a standard piece of heating plant apparatus.

Bibliography

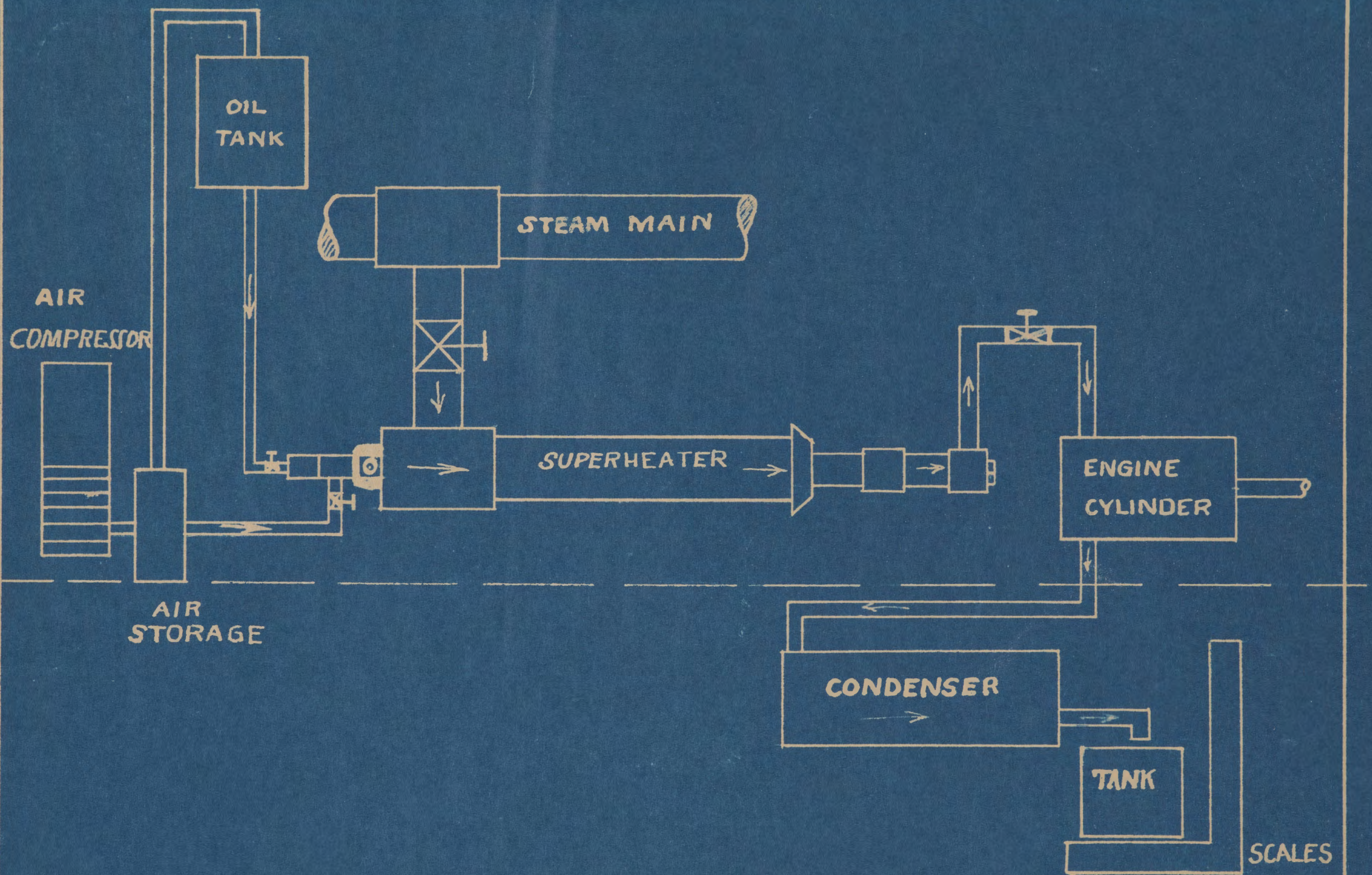
"Power Plant Engineering" - - - - - - - - - Gebhardt
"Steam" - Babcock & Wilcox
Thesis - A. O. Kraehenbuehl
Thesis - H. E. Ayres

APPROVAL.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

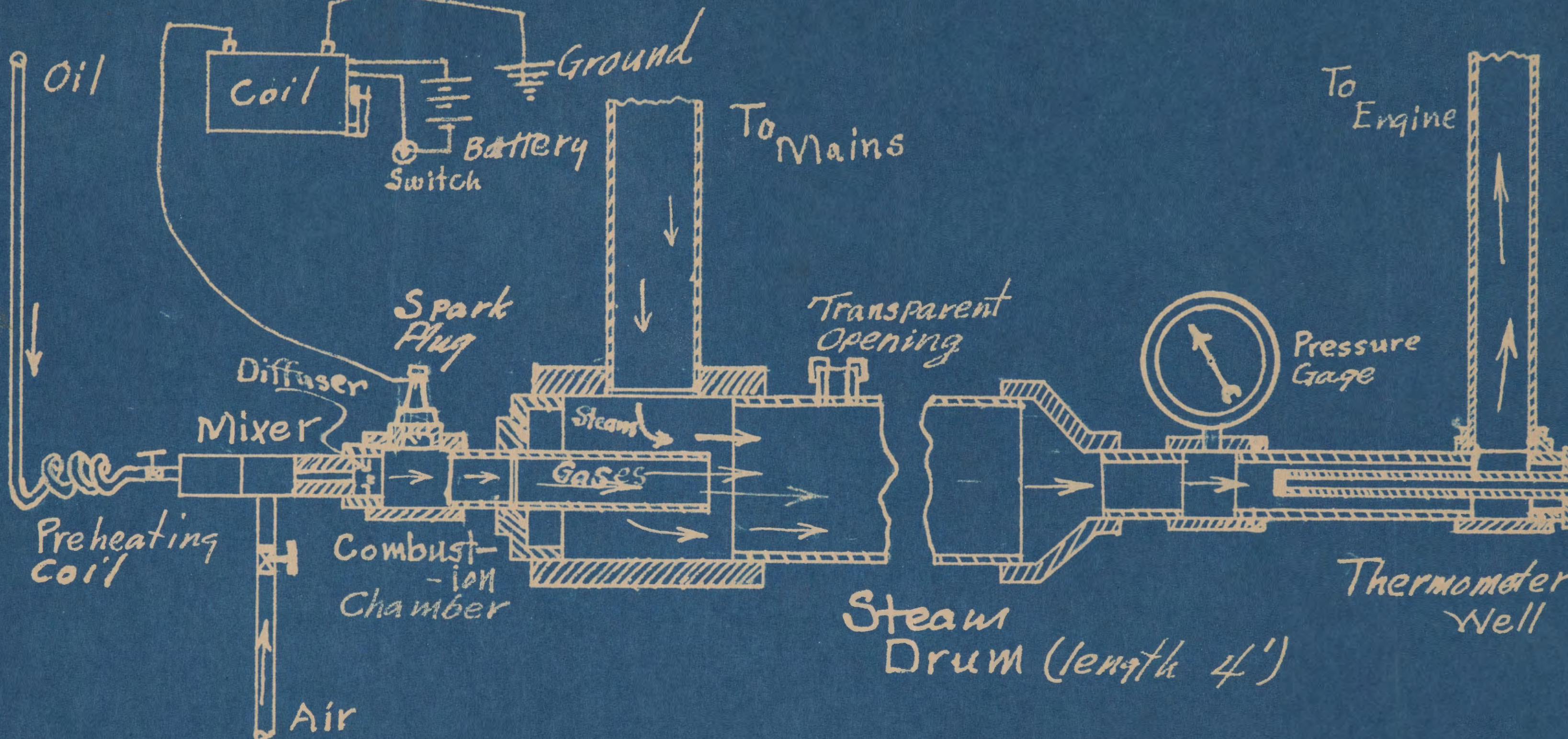
Name W. R. Woolrich

Title Prof. mech. Engineering.



LAYOUT OF APPARATUS

I



DETAILS OF SUPERHEATER

II