

***** THESIS *****

" THE DESIGN OF A GAS SUPERHEATER "

PRESENTED

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THE DESIGN OF A GAS SUPERHEATER.

Superheated steam is a steam of any pressure at a temperature higher than the temperature of its evaporation from water at that pressure. Saturated steam may be superheated by imparting additional heat to it at a constant pressure, during which process its volume increases. By permitting saturated steam at a given pressure to expand without doing work, superheated steam at a lower pressure may be formed. Steam cannot be superheated in the presence of the water from which it was evaporated, owing to the fact that the water takes up the heat and evaporates into further saturated steam. It has been found that as the steam becomes superheated its properties change and approaches a perfect gas. At a very high degree of superheat it is practically a perfect gas.

The principal advantages of superheated steam may be enumerated as follows:

1. At high temperatures it behaves like a gas and is therefore, in a far more stable condition than in the saturated form. Considerable heat may be abstracted without producing liquefaction, whereas the slightest absorption of heat from saturated steam results in condensation.
2. A moderate amount of superheat produces a large increase in volume, the pressure remaining constant, and diminishes the weight of steam for a given amount of work.

3. Superheated steam has a much lower thermal conductivity than saturated steam, and, therefore, less heat is absorbed per unit of time by the cylinder walls of a steam engine.

The economy attending the use of superheated steam in engine cylinders has been shown at least since 1828, when Richard Trevithick reported on the engines at Binner Downs Mines in Cornwall. The engineer of the mines, Capt., Gregor, wishing to rival the record of a neighboring mine, where the cylinders had been cleatted in sawdust, built in his cylinders and steam pipes with brick work, making a fire-grate underneath them, and flues around. The results were unexpected, and the duty of the engine was raised from forty-one to sixty-three million pounds per bushel (eighty-four pounds) of coal. The steam pressure was forty-five pounds per sq. inch and eight strokes per minute. Trevithick followed this up in 1832 by inventing a tubular boiler, combined with a superheater between the boiler and the engine cylinder.

The earliest patents were those of Becker, November 20, 1827, proposing a maximum temperature of 210° C., using a tubular superheater, into which water was injected in minute quantities as required to produce superheated steam of the desired quality. Quillac, July 3, 1849, patented devices for producing the familiar method of superheating, claiming that every form of engine would gain by its use. Hirm patented,

November 12, 1855, his "hyper thermo-generator," which was a simple cast iron superheating apparatus, consisting of an assemblage of tubes placed in the flue, with an arrangement by means of which more or less of the current of flue gases could be taken through it to adjust the degree of superheating to the demands of the engine. By this date, superheating was recognized in all the countries as a legitimate and promising method of securing economical use of steam in the steam engine, and inventors in all civilized lands were seeking to find practical ways of availing themselves of its advantages without submitting to the disadvantages which common experience soon revealed as apparently universally arising.

By the middle of the nineteenth century, Hirn and his followers were making a moderate success of it, due to the advances in mechanical construction, which by this had reached such a point as permitted them to make use of joints which were fitted perfectly and remained tight, the abutting surfaces being held firmly into metallic contact by a system of heavy bolts. French writers ascribe to Becker (1827) the invention, and to Hirn (1855) the real introduction of this system of economical use of steam in the steam engine.

M. A. Mallet, the distinguished French authority, attributes the origin of this improvement and attempts at its application at the earliest dates, to the inventors preceeding 1830. The real beginning of this subject is unknown; but the early inventors of the steam carriage,

included provisions for superheating and often of directly producing superheated steam by injecting water upon hot plates or into highly heated tubes, stroke by stroke as required by the engine, and some date earlier than 1830. John Bourne, in his "Recent Improvements in the Steam Engine" published in 1869, attributes the practical success of the superheating system to an American inventor, Wethered, 1853-54.

Bourne's superheaters were substantially like those of later practice, and were either made of fagots of tubes placed in the uptake or were similar to the "steam chimney" of American river-boats boilers of the time of the Stevenses and the beam-engine (1825-60). Annular chambers surrounded the chimney flue from the point of issue from the boiler to that of union with the smoke-stack.

These different types of superheaters became very common practice for a time, because of their efficiency in the saving of fuel, but after a short period, were abandoned. The reasons were the trouble experienced at the valve faces and in the cylinders from the decomposition and destruction, at the high temperatures of superheated steam, of the tallow and low-class lubricants then in vogue. This trouble was twofold: the cutting and excessive wearing in the absence of lubrication; and the pitting caused by the fatty acids in the lubricant. On this score however no trouble need be anticipated,

at any degree of superheat likely to be used, where good hydro-carbon oils are used. Gas engines running regular work with a cylinder temperature in the neighborhood of 2000° F., lubricated with good oil; and with ordinary care and attention instance of cutting are not frequent. The common use of metallic packing for glands, and the piston valves in place of flat valves, has removed another serious obstacle. Much of the trouble which was attributed to the superheated steam, perhaps might have been credited to the alternate passing of superheated steam and water through the engine due to not having proper control of the superheater. The faults of this failure cannot be laid to the engine alone as the superheaters had their failures. Some of the superheaters were equipped so as to by-pass the steam, but not the gases, the boilers were worked with the steam shut off from the superheater; and as a result the latter deteriorated rapidly.

Concurrently with the increased efficiencies gained in both boiler and engine, competition has also increased; and with it has arisen the continual cry for cheaper power, cheaper transportation, cheaper means of production. The result was that the engineer could not afford to dismiss without careful examination the claims of any plan, the adaption of which might diminish the fuel consumption. It was this fact that brought the superheater to the front (about 1890). From this

study and experiments came the present design of superheaters.

At the present time superheaters are manufactured by practically all boiler builders, the characteristics of the boiler being embodied to a large extent in the design of the superheater. The superheaters are divided into two classes, (a) those independently fired, (b) those placed in the boiler setting. In the latter arrangement the superheater may be placed in the furnace, at the end of the heating surface, or at some intermediate point. The independently fired superheater is disappearing due to its many disadvantages and the extra fuel necessary to operate it. Since the absorption of heat depends chiefly upon the average temperature difference between the gases and the steam and the extent of heating surface in the furnace, a large amount in the rear of the heating surface or a proportional amount in intermediate locations.

The requirements of a successful superheater are:

1. Security of operation, or minimum danger of overheating.
2. Economical use of the heat applied.
3. Provisions for free expansion..
4. Disposition so that it may be cut out without interfering with the operation of the plant.
5. Provisions for keeping tubes free from soot and scale.

As ordinarily installed the indirectly fired

superheater is subjected to the fluctuating temperature of the furnace so that forcing the boiler has a similar effect on the superheater. In some cases the superheater adjusts itself automatically to the load requirements maintaining a constant degree of superheat at all loads, but in most cases the degree of superheat increases with the load.

The present type of superheater is built of cold drawn seamless steel tubes bent in a U-shape and expanded into two wrought steel manifolds. The tubes are inclosed in heavy cast-iron rings shrunk onto them. The heater must be equipped with a **safety** valve and a means of flooding when the boilers are being brought into operation. All these characteristics make this type of superheater costly to build, while the life of one is only eighteen to thirty months. The cast-iron rings make the apparatus extremely hard to keep clean and the coefficient of heat transfer through such a thickness of iron and steel is very small thus reducing the efficiency.

The object of this experiment is two-fold:

1. To devise a method of burning gas or oil directly in contact with steam thus securing one hundred percent efficiency in heating,
2. To prove that a superheater of this type is more economical than the one described above.

The equipment available for conducting this experiment is a bank of boilers supplying steam at approximately ninety pounds per square inch gauge pressure.

A twenty horsepower return tubular boiler to be used as a storage tank for gas.

A twenty-five horsepower Corliss engine connected to a surface condenser, such condenser only used to condense the steam at atmospheric pressure.

Compressor used to compress the gas and air necessary for combustion.

Plate No. 1. shows the superheater in section. It consists of an outer casing made offive inch steam pipe onto one end of which is screwwd a five inch cast-iron "T", to the other end a coupling and reducing bushing. Into the upper end of the "T" is screwed a reducing bushing connected directly to the steam line. In the head of the "T" is a series of bushings, the first from five to two inches supports a section of two inch pipe in the inside of the superheater about twenty-four inches long which prevents the moist steam entering the superheater coming in direct contact with the burning gas and tending to put it out. Into the outer end of this bushing is screwed another bushing and into this the burner, the tip of which extends about twelve inches into the inner pipe in order that the flame will be located where it will be surrounded with live steam. A steam trap is connected in the lower part of the "T" to keep the superheater as dry as possible and to prevent

it from ever flooding. A spark plug is screwed into the outer pipe and extends down into the inner pipe to the center of the flow of gases from the burner as shown for the ignition of the fuel. To the other end of the heater is connected the engine, which is connected at right angles to the "T" at the end of the steam from the superheater as shown. In one end of the "T" before entering the engine is a glass sight hole, placed so that the action taking place in the superheater may be observed. A thermometer well is placed in the steam line as shown so that the degree of superheat may be determined.

Plate No. 2. is a layout of the equipment as installed. Steam is applied to the superheater from the boiler and passes from this directly to the engine. The engine is equipped with a prony brake for varying the load and consequently the amount of steam consumed. The condenser is arranged with two pairs of scales and two tanks for measuring continuously the amount of steam condensed. A throttling calorimeter is inserted in the steam main as it enters the heater for the purpose of determining the quality of the steam as it enters the superheater, and a thermometer is inserted in the outlet for determining the temperature of the superheated steam leaving the superheater. As only one compressor is available it is necessary to use this for both the compression of the gas and air, this is accomplished as follows; the twenty horsepower boiler is used as a storage tank for the gas, having a capacity of approximately fifty-six cubic feet. this boiler is filled

with water so as to exclude all the air and connected to the high pressure end of the compressor. The valves to the air storage tank and air inlet on the low pressure side are closed, the valve to the gas main is opened. The drain to the boiler is then opened and the compressor started. When the water has all been drained out of the boiler the drain valve is closed and the compressor operated until the boiler is filled with at the desired pressure which is about one hundred pounds per square inch gauge. The valve between the compressor and boiler is then closed and the gas from the main shut off. The air inlet and the valve to the air storage tank are opened and the pump used to compress air. The gas is forced from the boiler as needed by means of city water pressure. The amount stored is sufficient for a short test. The compressor is operated throughout the tests to supply the necessary air as the storage is very small. A water seal is placed between the boiler and the burner so that under no condition will it be possible for the flame to back fire into the gas storage tank.

The design of the burner and its construction are given in detail in the Thesis by Mr. H. E. Ayres, University of Tennessee in 1920.

DATA AND RESULTS.

The apparatus was assembled as shown in figure 2 with the exception that the spark plug was set in a tee in the two inch pipe flush with the outer casing. The

sight hole was not installed at this time and the operation of the burner was checked by a thermometer. After several days of experiment without success the design was changed to that shown in figure 2.

After reassembly, the superheater operated very successfully with a superheat of 125° F., continuously for about three hours. Instruments were not at hand to secure much data as to its effect on the operation of the Corliss driven by the superheated steam, but several indicator cards were taken at no load and about 10 horsepower. The water rate of the engine was not determined under the above conditions.

This experiment was followed up by a long series of attempts to operate the superheater and to obtain the water rates of the Corliss, when using superheat and varying the load. Here we encountered difficulty, as the flame would begin to burn at times but after a very short operation would go out without any apparent cause. A study of the conditions of the steam as to pressure and quality at the time of lighting and going out was made and the following data was obtained;

Operated for three days at a constant quality of 96 % and steam pressure of 89 pounds gauge and it was impossible to get the burner to operate under these conditions. If the steam to the superheater was turned off and the drain valve opened, thus opening the heater

to atmospheric pressure the burner would light. In this way the pipe was heated very hot and with the burner operating the steam was turned on. In this manner it was possible to get it to operate the Corliss for about fifteen minutes at no load. The flame then went out and could not get it to burn again. Began operation with steam pressure varying from 85 to 87 pounds gauge and quality of 97 %. The burner operated with ease under these conditions and operated engine at no load for about twenty minutes, the load was increased to ten horsepower and operated about fifteen minutes and then went out.

	Steam Pressure,	Steam Quality.	Operation Going On.
Observations made in series of tests extending over several weeks.	84	97.8	Began to burn.
	85	97.4	Went out.
	85	97.6	Began to burn.
	81	97.0	Went out.
	90	97.3	Flashing.
	88	95.5	Flashing stopped.
	81	98.0	Began to burn.
	83	96.8	Went out.
	86	97.9	Began to burn.
	83	96.8	Flashing.
	80	96.6	Flashing stopped.
	75	97.8	Began to burn.
	55	97.2	Went out.
	82	97.7	Began to burn.
	86	97.3	Went out.

The following results were obtained as a comparison of the water rate of the engine operating with saturated and with superheated steam.

Length of engine's stroke 1.5 feet.

Diameter of cylinder 8 inches.

Diameter of piston rod 1.882 inches.

Length of brake arm 4 feet.

Tare on brake 18 pounds.

Area of cylinder, crank end of engine 47.47 sq. in.

Area of cylinder, head end of engine 50.25 sq. in.

NO LOAD TEST SATURATED STEAM.

Duration of test 1.5 hours.

Quality 96.6 %. Steam pressure 85.2 #

Water consumed 567#. Speed of engine 161 R.P.M.

Mean Eff. Pres. Crank end 7.5# Head end 3.6#.

I.H.P. Head end 1.32 H.P. Crank end 2.61 H.P.

Total I.H.P. 3.93 H.P.

Water rate 378 # per hour.

Water rate per I.H.P. 96.2 # per hour.

NO LOAD TEST SUPERHEATED STEAM.

Duration of test 43 minutes.

Quality 96.8 Steam pressure 63 #

Gas pressure 93 #. Air pressure 98 #

Water consumed 117 #. Speed of engine 161 R.P.M.

Temperature of steam 627°F. Degree of superheat 317°

Mean Eff. Pres. Crank end 9 #. Head end 5.6#.

I.H.P. Crank end 3.13 H.P. Head end 2.06 H.P.

Total I.H.P. 5.19 H. P.

Water Rate 163 # per hour.

Water rate per I.H.P. 31.4 pounds per hour.

LOAD TEST SATURATED STEAM.

Duration of test 1 hour.

Quality 96.7 %. Steam pressure 77.7 #.

Water consumed 596 #. Brake load 82 #.

Engine speed 154 R.P.M. B.H.P. 9.63 H.P.

Mean Eff. Pres. Crank end 20.4#. Head end 16.9 #

I.H.P. Crank end 6.79 H.P. Head end 5.94 H.P.

Total I.H.P. 12.73 H.P.

Water rate per hour 596 #.

Water rate per I.H.P. 46.8 # per hour.

Water rate per B.H.P. 61.9 # per hour.

LOAD TEST SUPERHEATED STEAM.

Duration of test 10 minutes.

Quality 97.4 %. Steam pressure 83.5 #.

Water consumed 78 #. Brake load 82#.

Engine speed 154 R.P.M. B.H.P. 9.63 H.P.

Air pressure 104 #. Gas pressure 97 #.

Temperature of steam 510 ° F.

Degree of superheat 184°.

Mean Eff. Pres. Crank end 20.4 #. Head end 17.5 #

I.H.P. Crank end 6.82 H.P. Head end 6.15 H.P.

Total I.H.P. 12.97 H.P.

Water rate 468 # per hour.

Water rate per I.H.P. 36.1 # per hour.

Water rate per B.H.P. 48.6 # per hour.

Plate No. 3 shows indicator cards taken from the engine at no load and at about 10 horsepower with both saturated and superheated steam.

Plate No. 4 shows Theta Phi Diagram, showing the relation between saturated superheated steam at no load. Saturated steam dotted lines, superheated steam solid lines.

CONCLUSION.

This experiment has shown that under proper conditions gas may be burnt in direct contact with steam, superheating the steam and the products of combustion combining with the steam which passes out through the engine cylinder. The conditions under which the superheater will operate are hard to determine, the quality of the steam entering the superheater seems to have a very marked effect for as the quality decreases the increased moisture in the steam seems to quench the flame in the pipe. The superheater seems to operate better when the pressure of the steam is low and thus the pressure difference between the steam and the gaseous mixture to be burnt is greater. The great velocity in the superheater when the engine is operating especially under load has a tendency to draw the flame out. The steam mixes with the gases they have had time to ignite. This type of superheater may be

developed into a commerical success, but not till a great amount of research work has been carried on, so that the conditions of operation can be controlled and their relation to operation understood.

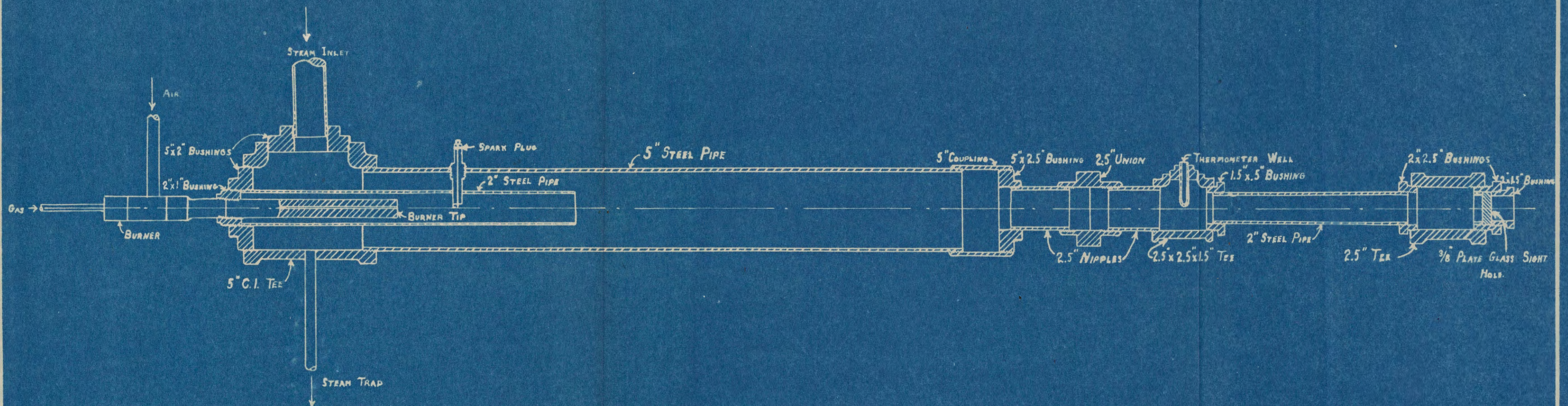
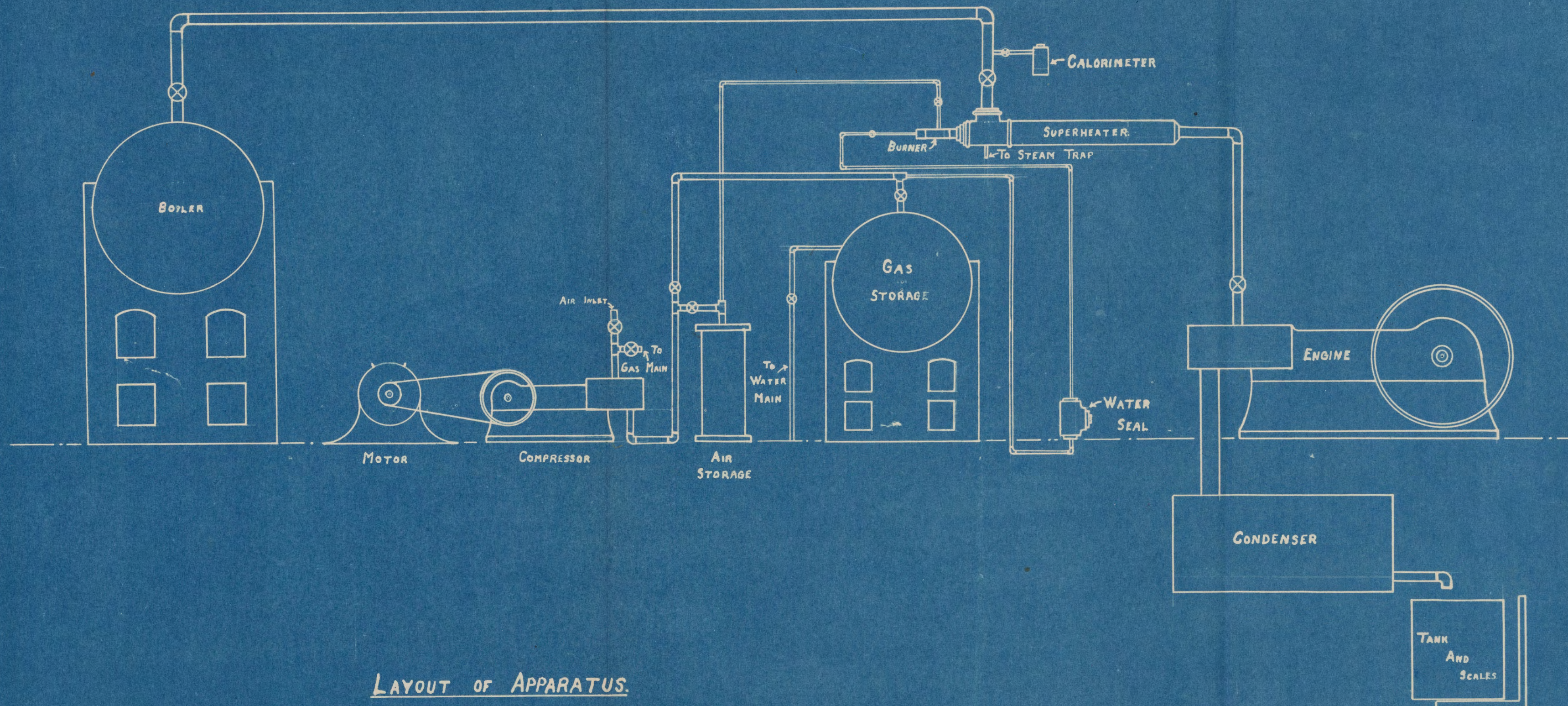


DIAGRAM
OF
SUPERHEATER

SCALE 1"=6"

PLATE No. 1





NO LOAD SATURATED.



NO LOAD SUPERHEATED



LOADED SATURATED



LOADED SUPERHEATED

