Feb. 7, 1939. S. T. POWELL ET AL 2,146,312

STEAM TESTING METHOD AND APPARATUS

Filed Sept. 25, 1937 2 Sheets-Sheet 1

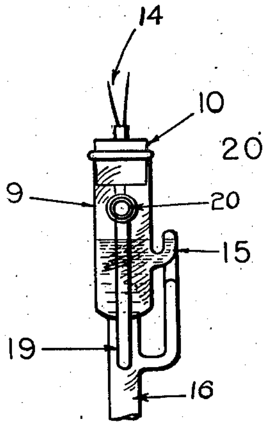

Fig. 2.

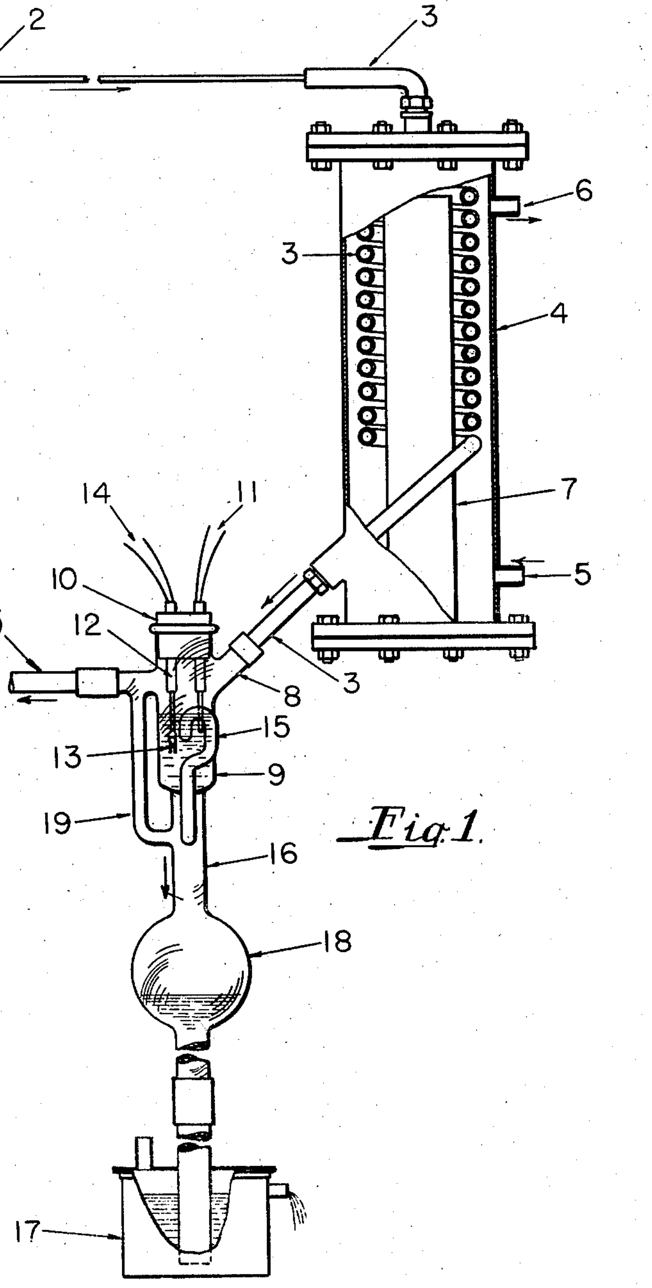

Fig. 1.

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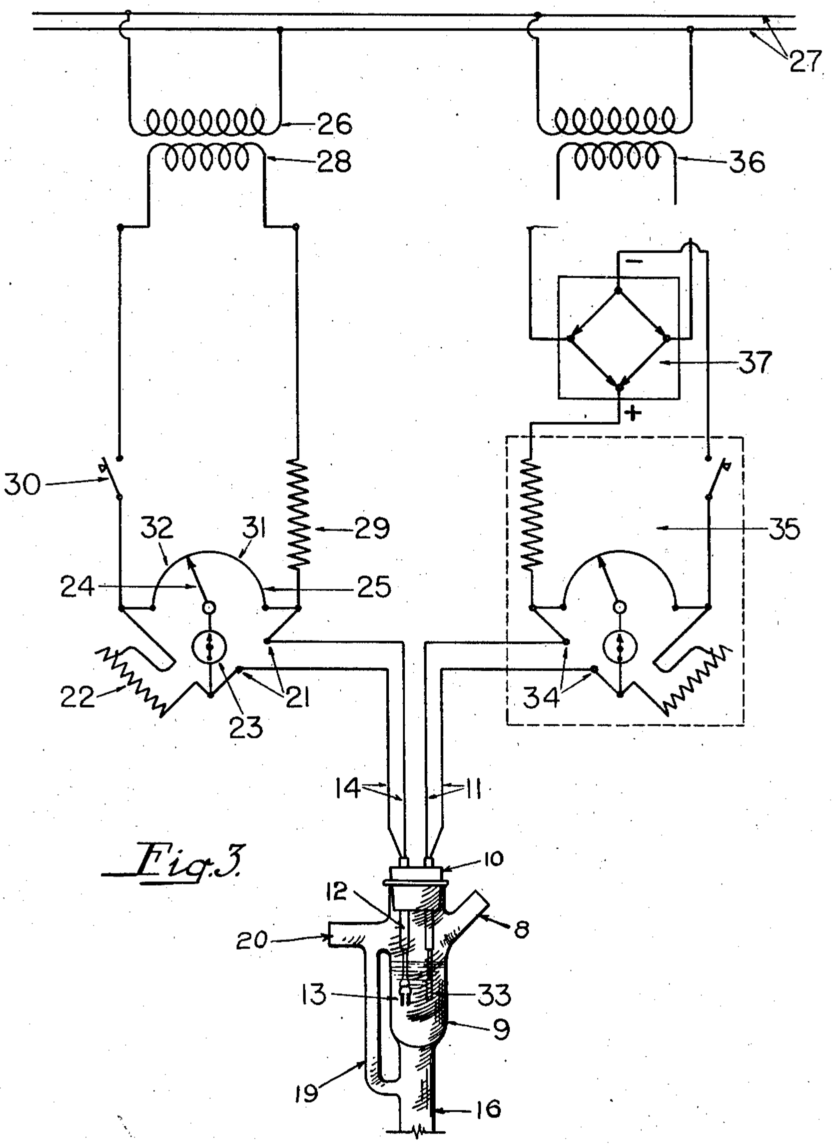

Fig. 3.

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2,146,312

STEAM TESTING METHOD AND APPARATUS

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10 Claims. (Cl. 175—183)

This invention relates to a new method and apparatus for detecting, and measuring the quantity of, impurities in steam, which have been carried over from a steam generating boiler.

During the liberation of steam from the water in a boiler, and its subsequent passage from the boiler, the steam frequently becomes contaminated with droplets of boiler water. The droplets of boiler water thus entrained in the steam contain appreciable quantities of dissolved and suspended materials, mainly inorganic salts such as sodium hydroxide, carbonate, phosphate, chloride and sulphate. These materials are carried through the steam pipes, valves, turbines, processing equipment and other accessories and are deposited at various points within the system. The deposits are abrasive and obstructive to the members of turbines, and reduce the efficiency of such machines. They also obstruct and impair the action of valves, superheater tubes, and other parts of the system. It is therefore necessary to operate boilers in such a manner as to reduce the entrained moisture and solids in steam to the smallest possible concentration.

The quality of steam with respect to entrained impurities is specified by stating the percentage of saturated steam in a mixture of liquid and steam, or by stating the concentration of solid matter in parts per million in a condensed sample of the steam. It is useful and often necessary to determine the quality of steam in order to properly control the operation of the boiler.

The quality of steam in terms of moisture can be measured by the steam calorimeter, in which thermodynamic properties of the steam are measured at the pressure existing in the steam main and again after it has expanded to a lower pressure. The art of steam calorimetry is well known to those familiar with steam generation. However, it is not claimed that such methods are capable of measuring steam quality with an accuracy greater than two tenths of one per cent. This probable error may correspond to one to five or more parts per million of solid matter in the steam, depending on the concentration of the solids in the boiler water. In present steam generating practice it is often desired to reduce the total solids in the steam to less than one part per million, and it is obvious that steam calorimetry is not sufficiently sensitive to test such performance.

It is possible to evaporate to dryness a measured sample of condensed steam and to weigh the solid residue, but such a method requires a great deal of time and elaborate precautions to avoid errors, and does not give a continuous measurement of steam quality.

The quality of steam with respect to entrained solid matter may be measured by drawing a sample of steam through a condenser, collecting the condensate, and measuring the electrical conductivity of the condensed sample. Such a sample may be caused to flow continuously through an appropriate apparatus including a conductivity cell, and its conductivity may be measured whenever desired. The conductivity of such a sample is almost entirely caused by dissolved electrolytes, and these are derived from the boiler water carried over with the steam. Such a method of measurement is not new and has been practiced for some years. However, condensed steam often contains several substances which are gases at ordinary temperatures, and therefore not objectionable in the sense that solids are objectionable. Some of these substances are carbon dioxide, hydrogen sulphide and ammonia. Their aqueous solutions are electrolytes and possess an electrical conductivity just as do aqueous solutions of salts. Hence when these gases are present in solution in a sample of steam condensate whose electrical conductivity is determined, part of the conductivity is due to the relatively harmless gases and part is due to the objectionable solid matter. The estimation of solid matter by electrical conductivity measurements is thereby rendered inaccurate.

To overcome this difficulty it has been proposed to analyze the sample chemically to determine the concentration of electrolytes derived from gases, and to correct the conductivity reading by deducting the known conductivity of such electrolytes. However, the concentration of the substances it is desired to determine may change during the analysis, due to exposure of the sample to the atmosphere, and there are other inaccuracies inherent in the analytical procedures which are, moreover, time-consuming. This method of overcoming the errors due to gaseous electrolytes in determining the quality of steam by measuring its electrical conductivity is therefore unsatisfactory.

J. K. Rummel has invented (U. S. Patent 2,046,583) a method and apparatus in which a flowing stream of steam and water is sprayed into a chamber provided with a vent, the mixture being at such a temperature that dissolved carbon dioxide comes out of solution and escapes through the vent. The condensate is then cooled and flows through a receptacle in which the electrodes of a conductivity cell are mounted. The conductivity of a sample is thus determined after the concentration of electrolytes due to dissolved gases has been considerably reduced; however, the inventor recommends that the residual carbon dioxide be determined by chemical analysis and a corresponding correction be made.

In the operation of this apparatus it is necessary to adjust properly the flow of steam to the apparatus which receives the sample to be measured, as well as the cooling water for the preliminary condenser and the final cooler. There is inevitably a certain amount of loss of steam through the vent, and a resultant concentrating of the sample, and if excessive heat input to the heating coils is permitted this is magnified and causes serious errors. On the other hand, if insufficient heating of the sample is employed, the removal of carbon dioxide is not sufficiently complete. The optimum adjustment of the apparatus to assure accurate results is not only difficult to obtain but this adjustment is difficult to maintain because of the inherent defects in valves for controlling steam at small rates of flow. It will thus be seen that the operation of the Rummel invention is subject to certain serious difficulties.

It is accordingly one of the objects of our present invention to provide a procedure and an apparatus whereby the qualities of steam can be tested in a simple, continuous and direct manner free from appreciable error.

It is another object of our invention to test steam by continuously sampling and condensing it, by passing it to an electrode chamber and there testing it by measuring its electrical conductivity, evacuating gases in the atmosphere in contact with the condensate and then discharging the condensate after the testing operation at atmospheric or barometric pressure.

Other and further objects reside in the various procedural and constructional details hereinafter described and set forth in the appended claims.

We have devised improvements in the art of measuring the quality of steam by determining the electrical conductivity of a condensed sample, and have invented a method and apparatus for carrying out such measurements. Our apparatus is shown in the drawings attached hereto, wherein:

Figure 1 is an elevational view, partly in section, of a preferred embodiment of apparatus according to our invention;

Fig. 2 is a fragmentary elevational view at right angles to Figure 1; and

Fig. 3 is a diagrammatic view illustrating how conductimetric testing is effected.

Similar numerals designate corresponding parts in such drawings.

Referring now to the drawings, 1 is a steam sampling nozzle located in a steam header, superheater header, or any other point within the steam system from which it is desired to draw a sample of steam for testing and which is represented by the pipe indicated at 1a. The design of nozzle 1 is not per se a part of our invention, and those skilled in steam generating practice have agreed on standard designs for such nozzles which will be most likely to draw representative samples. Steam entering the sampling nozzle 1 is conveyed through a length of tube 2, which we prefer to construct of material known commercially as stainless steel, although any material may be used which will withstand the steam pressure and resist corrosion and erosion by the steam. The diameter and length of tube 2 are so related to the absolute steam pressure at the entrance end of the tube that the quantity of steam delivered will be suitable for testing, in accordance with known properties of steam in flowing through tubes of specified diameters. The quantity of steam sampled in our apparatus was thirty pounds per hour, but any convenient quantity may be sampled.

Upon leaving the tube 2 the steam enters the larger tube 3 which forms the coil of the condenser 4. In our apparatus the tube 3 was made of block tin, and was thirty feet long and three-quarter inch in inside diameter. However, the condenser coil may be constructed of any material, such as platinum, which would not be taken into solution by the condensed steam and thus increase or alter its electrical conductivity. The diameter and length of the tube 3 should be such that the internal surface will be large enough to condense all of the steam drawn through tube 2, and cool the condensate to a convenient temperature for measurement of its conductivity.

The outlet end of the tube 3 is connected through the suction pipe 20 to a vacuum pump (not shown). Gases present in the steam are drawn off by this pump, but the steam condenses upon the walls of the tube 3 and the liquid condensate is thus essentially free of dissolved gases. The pressure of gases other than water vapor is very small at the outlet end of tube 3, and for some distance back of the outlet, because of the action of the vacuum pump. Therefore, the concentration of dissolved gases in the liquid condensate is very small, in accordance with Henry's law of the solubility of gases in liquids.

Although it is not essential to the operation of our invention, we prefer to use a sufficiently large surface in tube 3 so that the sample which it discharges will always be at the temperature of the cooling water surrounding the coil. This cooling water flows into condenser 4 through pipe 5 and is discharged through pipe 6. A centrally disposed baffle 7 improves the distribution of the water.

The condensed and cooled sample flows from the tube 3 through tube 8 into the vessel 9, in whose stopper 10 are fixed a thermometer 11 and a glass tube 12 bearing the electrodes 13 of a conductivity cell. The thermometer 11 and the electrodes 13 are submerged in the condensate, and by means of suitable electrical instruments, such as a Wheatstone bridge, a galvanometer, standard electrical resistances and a source of current, all properly connected in a circuit including the electrodes 13 by the wires 14, it is possible to measure the electrical conductivity of the liquid between the electrodes. In practice the temperature of the liquid is read simultaneously. The process of measuring conductivity and the instruments by which it is done are well known and are not per se claimed as part of our invention. Also, thermometer 11, and the electrodes 13 of the conductivity cell, have long been used, and it is to be understood that any suitable form of thermometer and of electrodes may be used in our inventon. However, we prefer to measure the electrical conductivity of the sample by means of a continuously recording conductivity meter, and we prefer to measure the temperature of the sample by means of a resistance thermometer properly connected to a continuously recording resistance bridge. We prefer to make the electrodes 13 of gold, about one centimeter square, plane in surface and fixed approximately one millimeter apart.

The vessel **9** is connected by means of the overflow **15** to a tube **16** which extends to a vessel **17** at a lower elevation. This elevation is such that the column of water between the water level in the tube **16** and in the vessel **17** exerts a hydrostatic pressure at the level in the vessel **17** equal to the barometric pressure at this point. In this manner the tube **16** and the vessel **17** form a barometric seal. The bulb **18** may be provided to prevent surges of water from entering the vessel **9** in the event of a break in the tube **16**.

In the operation of our invention, the condensate flows through tube **8** into vessel **9** and thence through the overflow **15** into the tube **16** and the vessel **17**. Condensate overflowing vessel **17** may be discharged to the sewer or further used as desired. The pressure equalizing tube **19** connects tube **16** with the upper portion of vessel **9** on the suction side thereof so that the pressure above the water in vessel **9** is the same as that above the water in tube **16**. This arrangement permits the condensate to flow continuously through an evacuated apparatus and escape to atmospheric pressure through the barometric seal consisting of tube **16** and vessel **17**.

Any kind of vacuum pump may be connected to the apparatus by means of the suction pipe **20**, providing it is capable of removing the gases from the condenser tube **3**. We have found it best to use, for this purpose, two water jet ejectors connected in series. Any type of condenser may be used in our invention providing it will efficiently condense the steam, will not contaminate the sample, and will permit evacuation without leaking.

In our apparatus we prefer to construct the vessel **9** and its connecting tubes **15**, **16** and **19** of glass, tube **16** however being of glass only for a length of several feet (to permit observation of the water level) and being constructed of copper below this point. We prefer to make stopper **10** of rubber and to seal the joints between vessel **9** and stopper **10**, vessel **9** and the vacuum pump suction pipe **20**, tube **8** and tube **3** and the sections of tube **16**, by means of a wax prepared by melting together four parts of flake shellac with one part of pine tar. However, any materials of construction which will form a tight apparatus and which will not contaminate the condensate in vessel **9** may be used in our invention. Likewise, we prefer to support vessel **9** upon tube **16** and use the disposition of tubes **8**, **15**, **16**, **19** and **20** shown in the drawings. However, in the practice of our invention we have also combined overflow tube **15**, pressure equalizing tube **19** and tube **16** into a single member, and have caused the condensate to enter vessel **9** at the bottom. Our invention is therefore not limited to the arrangement shown in the drawings, but includes any arrangement for condensing a sample of steam in a system subjected to continuous evacuation, permitting the sample to flow through an evacuated vessel containing the electrode of a conductivity cell, and thence to escape at barometric pressure.

Our invention separates from the steam which is to be tested those gases which, were they to remain in solution in the condensed sample, would lead to erroneous test results. The apparatus and process have the advantages over the prior art of bringing this separation about without subjecting the sample to heat. There is a further advantage in the fact that all condensing and cooling of the gases is carried out in one simple condenser, whereas the prior art used a condenser, a degasifier, and a cooler. Our invention is an improvement in that no valves are used in the steam system and the process of sampling and testing can be carried out continuously for long periods without interruptions for adjustment of valves, etc. A further advantage is the testing of the sample in an atmosphere essentially free from those gases which would give erroneous results, whereas in the prior art the sample, after being degasified, was exposed to the air.

As we have above indicated the conductimetric testing is carried out by certain electrical apparatus and circuits and such will now be described in more detail for the purpose of instructing those skilled in this art. Figure 3 is a diagrammatic view of one form of apparatus for measuring electrical conductivity of the sample and one form of apparatus for measuring the temperature of the sample by means of a resistance thermometer. In the measurement of the electrical conductivity of the liquid in the vessel **9**, the electrodes **13** are connected by means of wires **14** to the terminals **21** and this circuit constitutes one arm of a Wheatstone bridge. Variable resistance **22**, which should be of the same order of magnitude as the ohmic resistance across the terminals **21**, constitutes another arm of the Wheatstone bridge. A galvanometer or other instrument suitable for detecting small currents is connected between the two arms of the bridge and the movable contact **24**, which can be adjusted along the slide-wire **25** at any point that may be desired. Slide-wire **25** is of uniform cross-section and resistance throughout. **26** is the primary of a step-down transformer and is connected to a source of alternating current **27**. The secondary **28** of the transformer is connected through the resistance **29** and the key **30** to the ends of the slide-wire **25** and also to the two arms of the Wheatstone bridge consisting of the resistance **22** and the conductivity cell circuit through the terminals **21**. When the key **30** is depressed an alternating current flows through the slide-wire **25**, and also through the two arms of the bridge consisting of the variable resistance **22** and the conductivity cell circuit **21**. The movable contact **24** is adjusted until no current flows through the galvanometer or other current-measuring device **23**. According to Ohm's Law as applied to the Wheatstone bridge, when this adjustment is made, then the resistances of segments **31** and **32** of the slide-wire are related to the variable resistance **22** and the resistance across the terminals **21** by the following equation:

$$\frac{R_{21}}{R_{22}}=\frac{R_{31}}{R_{32}}$$

where R_{21}, R_{22}, R_{31}, and R_{32} designate the resistances of the parts specified by these numbers. Solving this equation for R_{21}, one obtains

$$R_{21}=R_{22}\times\frac{R_{31}}{R_{32}}$$

Or, since the conductance of the liquid between the electrodes **13** is desired, and the conductance is the reciprocal of the resistance,

$$L_{21}=\frac{1}{R_{21}},\ L_{22}=\frac{1}{R_{22}}$$

and

$$L_{21}=L_{22}\times\frac{R_{32}}{R_{31}}$$

Inasmuch as the resistances R_{32} and R_{31} are in direct proportion to the lengths of the segments 32 and 31, the slide-wire 25 may be supplied with a linear scale, and the lengths of the sections into which the wire is divided may be determined by observing the position of the movable contact 24 in relation to the scale, and these lengths of the slide-wire may be substituted for the resistances R_{32} and R_{31}. In practice the scale, not shown, is calibrated to show directly the values of the fraction

$$\frac{R_{32}}{R_{31}}$$

The specific conductance of the liquid between the electrodes 13 is defined as the conductivity of the liquid between parallel electrodes 1 centimeter square and 1 centimeter apart, thus enclosing a 1-centimeter cube of the electrolyte. The specific conductance

$$\bar{L}_{21}$$

is related to the measured conductivity L_{21} of the circuit across the terminals 21 by a constant which depends on the area and separation of the electrodes 13, and it may be determined in known manner by the use of standard solutions of electrolytes. This constant is defined as the cell constant and is equal to the fraction

$$\frac{d}{a}$$

where d is the separation of the parallel electrodes 13 expressed in centimeters, and a is their area expressed in square centimeters. It should be understood that electrodes taking forms other than parallel plates will also have cell constants, which must be determined empirically, as indicated above, by the use of a standard solution. We prefer to so construct electrodes 13 that their cell constant has a value of approximately 0.1 cm.^{-1}.

The specific conductance of the liquid between the electrodes 13 is now calculated as follows:

$$\bar{L}_{21}=L_{21}\times C$$

where C=the cell constant of the electrodes 13.

The temperature of the liquid in the vessel 9 may be measured by an ordinary mercury thermometer, but we prefer to use a resistance thermometer consisting of a coil of wire 33 and enclosed in a suitable cover. This coil is connected through wires 11 to the terminals 34 of the Wheatstone bridge circuit, which may be designated as a whole by the numeral 35. This is similar to the Wheatstone bridge used for measuring the specific conductance of the liquid in the vessel 9 and differs only in the ohmic resistance of the various parts, which should be suitable for measuring the resistance of the coil 33, this resistance being much smaller than the resistance of the liquid between the electrodes 13. The secondary 36 of the transformer in this circuit is connected to a current-rectifying device, indicated diagrammatically by 37, which supplies direct current to the circuit of Wheatstone bridge 35. The slide-wire of Wheatstone bridge 35 is calibrated directly in temperature units, inasmuch as the resistance of coil 33 varies in a known manner with its temperature, which is essentially the temperature of the liquid in the vessel 9. In this manner the temperature of the liquid in the vessel 9 may be measured by the Wheatstone bridge 35.

The specific conductance

$$\bar{L}_{21}$$

of the liquid between the electrodes 13 varies with the temperature of the liquid, and it is necessary to calculate the specific conductance at a fixed standard temperature T_s, which may conveniently be 25° C. (77° F.). Having determined the observed temperature T_o of the liquid in the vessel 9, it is possible to calculate, by known methods, the specific conductance

$$\bar{L}_{21}$$

which the liquid in the vessel 9 would have at the standard temperature T_s. An approximate equation for making this calculation is as follows:

$$\bar{L}_{21}\text{ (at }T_s)=\bar{L}_{21}\text{ (at }T_o)\times\frac{T_s+5}{T_o+5}$$

where T_s and T_o are expressed in Fahrenheit degrees.

The foregoing description is intended as illustrative rather than limitative and, within the terms and scope of the appended claims, we may effect certain modifications, variations, additions and omissions such as will be understood by those versed in this field without departing from the principles herein set forth.

Having thus described our invention, what we claim as new and desire to secure by Letters Patent is:

1. A method of testing the purity of steam which comprises condensing the steam, causing the condensate to flow between electrodes, maintaining the condensate in vacuo and testing the condensate by measuring its electrical conductivity.

2. A method of testing the purity of steam which comprises continuously condensing a predetermined flow of steam, evacuating gases during the condensing operation, discharging the condensate and causing it to pass between testing electrodes, maintaining the condensate free from gases and measuring the electrical conductivity of the condensate between the electrodes.

3. A method of testing the purity of steam which comprises continuously withdrawing steam from a source thereof, passing the same through a tube of predetermined length and diameter to establish a steam flow under known conditions, condensing such steam by means of a cooling medium and reduce the temperature of the condensate until it is substantially equal to the temperature of the medium, discharging the condensate at such temperature into a testing vessel, evacuating gases from said condensate, electrically testing the condensate and discharging it at barometric pressure.

4. A method of testing the purity of steam which comprises drawing a continuous flow of steam from a source thereof, continuously condensing the steam while removing gases therefrom, causing the condensate to flow continuously through an evacuated conductivity cell, continuously measuring the electrical conductivity of the condensate and continuously discharging the tested condensate under atmospheric pressure.

5. In a method of testing the purity of steam, the steps which comprise continuously discharging condensed steam into an evacuated conductivity cell, continuously testing the same therein and continuously discharging the condensate under atmospheric pressure.

6. Apparatus for testing the purity of steam comprising means for continuously sampling a source of steam, means for condensing such steam, means for testing it by measuring its electrical conductivity, means for evacuating

gases in the atmosphere in contact with said condensate and means for discharging the tested condensate at atmospheric pressure.

7. Apparatus for testing the purity of steam comprising means for producing condensed steam free from gases, means for testing the condensate in vacuo by measuring its electrical conductivity and means for discharging the tested condensate at atmospheric pressure.

8. Apparatus for testing the purity of steam comprising a condenser, a conductivity cell in communication with said condenser, means for passing steam from a source thereof through said condenser and, in the form of condensate, into said conductivity cell, means for removing gases in the atmosphere in contact with the condensate, means for electrically testing the condensate in said conductivity cell and means for discharging the tested condensate at atmospheric pressure.

9. Apparatus for testing the purity of steam which comprises a sampling nozzle in contact with a source of steam, a condenser having an outer shell through which a cooling medium is circulated and an inner condenser coil, tubing connecting said sampling nozzle and said condenser coil, a conductivity cell, piping communicating with said condenser coil and said cell, electrical measuring and testing means extending into said conductivity cell, means for evacuating said condenser coil and conductivity cell and means for discharging tested condensate from said cell at atmospheric pressure.

10. In an apparatus for testing the purity of steam, a conductivity cell comprising a vessel, means for discharging condensed steam into said vessel, means for evacuating said vessel, electrical testing means extending into condensate in said vessel and means for discharging tested condensate therefrom at atmospheric pressure.

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