SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 2698.)

“Experiments on the Condensation of Steam in Cylinders
of Iron and other Metals.”

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THE Author has considered that some further experimental investigations¹ on the important subject of the condensation of steam were desirable; especially to ascertain, if possible, how far the temperature of the surfaces touched by the steam affect the results. He has also wished to make a comparison between the steam-temperature ranges and the amounts of steam condensed. In an engine, before the piston moves, the steam has to fill the passage and clearance spaces, and this it does at constant volume in a certain time. During this time, no doubt, the greatest amount of condensation takes place, and it is probably almost instantaneous, as the steam is at its maximum, the walls are at their minimum temperature, and the conditions are favourable for rapid exchanges of heat.

In the experiments described in this Paper, indicator diagrams were taken, and the number of lbs. of water condensed per hour per square foot of internal surface was calculated. The cylinders used were of cast-iron, phosphor-bronze and glass. The temperatures of the metal cylinder-walls were taken, also the range of temperature of the steam, and the quantities of steam used were weighed. The ratio of the cylinder-volumes to the internal surface touched by the steam was varied, and also the number of fillings per minute. Experiments were made, working both condensing and non-condensing. No piston was used, as it was desired to obtain the effects of condensation apart from power. With this exception, all the other conditions were similar to those of slow-running steam-engines. Generally the cylinders were filled 35 times per minute, and steam of 50 lbs. pressure per square inch used; the cut-off occurring at about $\frac{1}{5}$ th to $\frac{1}{4}$ th of the time of the steam-stroke. By this arrangement there was no expansion of the steam. The weight of water produced from condensation

¹ Minutes of Proceedings Inst. C.E., vols. xeviii. p. 250; c. p. 347; cvi. p. 264.

under the different surface-conditions was determined, and also the weight of steam shown by the diagrams. After the cut-off, the percentages of the water and of the steam in the mixture, could be determined. Thus the effect of time alone, in diminishing the pressures of the steam by condensation, for a given set of surface-conditions, could be ascertained. The indicator diagrams resembled in shape those taken with a moving piston, where the vertical lines are proportional to the pressures in lbs. per square inch, and the horizontal lines to the feet per minute passed through by the piston. Working without a piston, the verticals give pressures as before; but the horizontal lines represent time only, in parts of a second, when the diagrams are developed for equal times. These areas may, therefore, be called "second-lbs." in contradistinction to the usual "foot-lbs." in power diagrams. The drum of the indicator was driven in the ordinary way from a radius-rod. The tests being made with small cylinders, the results will not bear comparison with those of ordinary steam-engines, but they are comparable with each other. When the surface-temperatures are mentioned, the internal surface touched by the steam is referred to.

It may be well to consider the full meaning of the condensation of steam of 50 lbs. pressure per square inch, corresponding with a temperature of 297° F. in an ordinary engine, and the importance of keeping every part of the metal touched by it, at this or a higher temperature. Apart from the question of power, condensation is produced by contact of the steam during a certain time with surfaces at a lower temperature than itself. It should be the object of the engineer to reduce this condensation to a minimum, or to obtain from a given weight of steam the maximum area of diagram. The less the area of surface exposed for a given volume of steam, and the less the time of exposure, the less the condensation. Besides the area exposed, there is another important factor, viz., the heat penetration into the depth or thickness of the metallic boundary walls, at each filling of steam. In other words, and in most engines, a certain weight of metal, after being previously exposed and cooled to nearly the condenser temperature, is again heated to about that of the steam, at the expense of the heat of the latter. This depth of heat-penetration is found to be much smaller with the hotter than with the colder walls, and with the hotter cylinders there is much less steam condensed. The heat-penetration per revolution is not always understood. Taking the case of a small vertical non-jacketed engine making 50 revolutions per minute, experiments have shown that, at a depth of about 7 millimetres from the inner surface, the

temperature is constant; but at a depth of $1\frac{1}{2}$ and 3 millimetres from the same surface, the mercurial column of the thermometer rises and falls regularly at each revolution—rising with the hot steam, and falling with the cooler exhaust stroke. The heat-range of the metal at $1\frac{1}{2}$ millimetres from the internal surface is much greater than that at 3 millimetres. The greater the depth in the metal, the less this range of heat. The internal surface when dry and clean probably assumes the whole range of temperature, say 100° F. Taking a vertical section of the cylinder 1 millimetre thick, there will be a wedged-shaped part of the thermal gradient of this thickness, varying in temperature per revolution, from about 100° F. at the inner surface to nothing at a depth of 7 millimetres. Similar heat curves, or thermal gradients are shown in Plate 8. By taking the average depth, and the average temperature range of the metal, the weight of metal heated and cooled so many degrees per stroke can be calculated. This should give the number of thermal units lost by the steam, representing so much water per stroke of the piston.

The number of square feet of internal surface, and the weight of steam condensed per hour in the cylinder being known, the number of lbs. of steam per hour per square foot can be calculated for a certain steam-range and metal-temperature. Any device that reduces heat-penetration will certainly tend to increase economy. Increasing the speed has the same effect, by reducing the time of exposure to the cooling influences. In the experiments, it may be seen how much the initial pressures and the areas of the diagrams vary with the different cylinder-temperatures, the hotter walls giving much larger diagrams. The quantity of water produced by the condensation of the steam varies from 1 lb. to 43 lbs. per hour per square foot of internal surface, according to the quality of the steam and temperature of the surfaces. With the Parsons rotary steam-engine there is no such alternate heating and cooling of the metal.

When engineers desire to condense steam, they arrange to keep all the condensing-surfaces much cooler than the steam. In many engine-cylinders this is unconsciously done, in a less degree; much water being produced, because the boundary walls are colder than the steam that touches them. The results of heating the surfaces are shown in these experiments. Superheated steam is used with the same object, as it must become saturated before any condensation takes place. Neither the heated metal wall nor the superheated steam, however, seem to stop condensation entirely, as appears from the diagrams. The presence of water in various

forms in the cylinder, as fog, mist, drops, &c., has probably some effect upon the steam.¹

It is now generally recognized by steam-engine authorities, that for the maximum economy in any engine, the exhaust should be steam only, and not a mixture of steam and water; on the other hand, it should not be allowed to escape super-heated, or again there will be loss. If there is water present at exhaust, its evaporation from the walls carries much heat to waste into the condenser or into the air. If there is no water present in the mixture, the walls are practically dry, and no heat is lost from the walls to the condenser. Professor Dwelshauvers Dery has lately carefully pointed this out,² and quotes some of the Author's experiments on this point.

The use of a bad heat-conductor does not, unfortunately, prevent condensation, as will be seen in the experiments with glass walls. Covering the metallic surfaces with varnish has a considerable effect in diminishing condensation, and some experiments on this point are added. The tests show that the temperature of the metallic surfaces has the greatest influence on condensation, the hotter walls reducing it considerably, and at the same time increasing the steam temperature range, so that there is less condensation with the greater ranges.

The Author's experiments had special reference to the following:

1. Variations of the size of the cylinders, and in this way changing the ratio of the volume, to the surface touched by the steam. In two sets of experiments non-heated surfaces were added, until very little steam was left to form a diagram.
2. Varying the range of temperature of the steam in the cylinders by working condensing or non-condensing; the difference between the steam temperature by gauge, immediately before admission, and that at the end of the exhaust stroke, is called the steam temperature range. These temperatures are taken from the corresponding pressures.
3. Working with ordinary or slightly super-heated steam.
4. Varying the material of the cylinders;—cast-iron, phosphor-bronze, or glass.
5. Varying the temperature of the cylinder-walls in the different experiments, so that their internal surfaces were either hotter or colder than the temperature of the steam first touching them, all other conditions being the same.
6. Variations

¹ As early as 1859, John Penn, then President of the Institution of Mechanical Engineers, very clearly and exactly defined the action of steam in a steam-engine. *Proc. Inst. Mech. Engs.*, 1859.

² *Étude Calorimétrique de la Machine à Vapeur*, Paris, 1892.

of time, and its effect on the pressure of the steam touching the surfaces, as shown by the indicator diagrams. This was done by varying the number of fillings per minute. Steam in contact with hot or cold walls produces marked differences in the condensation during extremely short periods of time. 7. Changing the working pressure of the steam in lbs. per square inch within certain limits, to alter the steam temperature range. 8. Varying the depth of heat-penetration into the metal walls at each steam filling by altering the surface-temperatures.

9. Variations in the temperatures of the cylinders throughout their thickness. 10. The area of the indicator diagrams taken in the usual way under the different conditions, and their shape, after steam was cut off. 11. The "dryness fraction" of the steam both at cut-off and release, giving the amount of steam and water present in the mixture in the different experiments. 12. The weight of water condensed per square foot (of internal surface touched by the steam) per hour with different cylinder temperatures, and different steam temperature ranges. Comparison of the amounts of condensation with the steam temperature ranges. 13. The weight of steam used for the different working conditions. 14. Varnishing the surfaces exposed to the steam.

EXPERIMENTAL APPARATUS.

Fig. 1 shows a general drawing of the apparatus used, as fixed in the engine-house at Bermondsey, where steam, water, and gas power were available for the purposes of the experiments.

Steam was conveyed from the main steam-pipe by the small well-covered pipe, shown at the top of the drawing, to the cylinder or revealer under test. This pipe was provided with a trap to keep back any water. The steam-gauge was duly tested. The two piston-valves, one at the top for the steam, and another at the bottom for the exhaust, were worked by four cams. These cams and the indicator were driven by a reciprocating lever from the parallel-motion of the steam-engine. The two upper cams actuated the steam-valve, one letting the steam into the cylinder and the other cutting it off at the required moment. The two lower cams moved the exhaust-valve, one opening it at about 95 per cent. of the stroke, and the other shutting it a short time before steam was admitted. The surface-condenser consisted of two thin small brass pipes, one inside the other. The steam thus condensed passed through the small vertical air-pump into a glass receiver, where it was afterwards weighed. The circulating-water taken

Fig. 1.

GENERAL ARRANGEMENT OF THE EXPERIMENTAL APPARATUS.

Index to Parts.

SP	represents Steam-pipes.	T	represents Thermometer.
DP	" Drain-pipe.	TH	" Temperature holes.
PG	" Pressure-gauge.	CI	" Crosby indicator.
SV	" Steam- (piston) valve.	EP	" Exhaust-pipe.
C	" Cylinder or reveler.	SC	" Surface Condenser.
CA	" Cam apparatus.	CI	" Circulating (water) in-
AC	" Admission cam.	let.	
CO	" Cut-off cam.	CWO	" Circulating(water)out-
EV	" Exhaust- (piston) valve.	let.	
RC	" Release cam.	AP	" Air-pump.
CC	" Compression cam.	AD	" Air-pump discharge.
GP	" Gas-pipe.	VG	" Vacuum-gauge.
GJ	" Gas-jets.	NC	" Non-condensing cock.

The cam apparatus (CA) is pulled up and down vertically by a lever from an adjacent steam-engine.

from an adjoining water-pipe, after passing through the surface-condenser, was led into a small tank on a weighing-machine. A Crosby indicator was fixed horizontally, having a short and direct connection with the cylinder. Vertical temperature-holes were drilled in the cylinder walls. These were filled with mercury, and into the mercury small 3-millimetre glass mercurial thermometers were inserted. Thin steel temperature-cups were fixed inside the cylinders, as shown in the drawing, exposed all round to the steam. In some of the experiments, the bulb of a thermometer was also placed inside the cylinder. When it was desired to raise the temperature of the cylinder walls, a row of small gas-jets acted on the outside of the cylinder, and another row acted upon the bottom cover. The first set of jets heated the top cover as well as the external walls. The temperature of the cylinders could thus be very readily raised or lowered a few degrees, or kept at a constant temperature.

The surface-condenser was used for the non-condensing as well as for the condensing tests, but in the former a small cock was opened to the atmosphere. In this way the exhaust was at atmospheric pressure—the apparatus working as if non-condensing, the vacuum-gauge was at zero, and all the steam used was condensed and weighed as in the condensing experiments.

Each experiment lasted 40 minutes, and was divided into two distinct tests of 20 minutes each. If the two did not agree closely, they were condemned and repeated. Experiments of much longer duration were also made, but they always gave practically the same results as the shorter ones. Before a test was commenced, the apparatus was worked for about half an hour under the required conditions, so that all temperatures became normal. Indicator diagrams were obtained every 10 minutes, and an average of the four was taken. Those given in Plate 7 are the nearest to the mean. Equal parts along the base lines of the diagrams do not therefore represent equal times. One diagram (Fig. 2, Plate 7) is added representing pressures for equal times. The external portions of the cylinders and ends were left uncovered. The temperatures of the cylinder-walls were noted every 10 minutes, the pressure of steam and the vacuum every 5 minutes. The temperature of the hot circulating-water was recorded every minute, and that of the cold water every 2 minutes. This water was run into a small tank and weighed. The air-pump discharge, giving the quantity of steam used, was weighed, and its temperature taken. A counter gave the number of fillings per minute. The steam- and exhaust-valves and the

surface-condenser were frequently tested and found tight. To determine the exact volume of the different cylinders and pipes, &c., two methods were adopted: they were filled with water and the latter weighed; the volumes were also calculated, and these gave the same results. The exact volumes were necessary in order to obtain the "dryness fraction" at cut-off and at release, &c. A heat-balance was calculated in nearly all the experiments. The number of pounds of steam used multiplied by its total heat gave the number of thermal units per stroke received by the apparatus. The total heat rejected in thermal units per stroke was,—(1) the air-pump discharge in pounds per stroke multiplied by its temperature; (2) the pounds of circulating water per stroke multiplied by its rise in temperature; (3) the radiation in thermal units; and (4) the thermal units per stroke unaccounted for.

The following is a list of the various cylinders experimented on. Three of these are shown in Figs. 3, 4 and 5, Plate 7, and three in *Figs. 3a, 4a, and 5a*, pp. 288, 289.

No. 1. Glass Cylinder and Cast-Iron Covers.—2 inches internal diameter, 3 inches long. Volume 0.00838 cubic foot; surface of glass (vertical walls) 0.13 square foot and 0.39 square foot of metal, a ratio of 1 cubic foot of volume to 62 square feet of surface. Glass walls $\frac{1}{8}$ -inch thick, wrought-iron cylinder outside, and cement between. No temperature-holes in the wall. Two experiments, Nos. 13 and 14, condensing and non-condensing, with cold walls only, and saturated steam.

No. 2. Glass Cylinder Air-Jacketed and Cast-Iron Covers.—2.7 inches in internal diameter, 3 inches long. Volume 0.0135 cubic foot; surface 0.177 square foot of glass and 0.42 square foot of metal—a ratio of 1 cubic foot of volume to 44 square feet of total surface. Two glass cylinders were used, one within the other, with annular air-jacket between. Inner cylinder, 2.70 inches in internal diameter; outer cylinder, 3.76 inches in internal diameter; both 3 inches long. Thickness of wall of inner glass cylinder 0.145 inch. No temperature-holes. One experiment, No. 23, with cold walls, condensing, saturated steam. These glasses stand the steam-pressure well, if care be taken to heat them very gradually with hot water (*Fig. 3a*, p. 288).

No. 3. Glass Steam-Jacketed Cylinder and Cast-Iron Covers.—Two vertical glass cylinders, as before, with annular space and steam between forming a steam jacket. Inner cylinder 2.7 inches in internal diameter, 3 inches long. Volume 0.01378 cubic foot; surface 0.179 square foot of glass, and 0.422 square foot of metal—a ratio of 1 cubic foot of volume 43 $\frac{1}{2}$ square feet of surface.

Inner glass 0.145 inch thick. One experiment, No. 33, with hot glass walls, saturated steam, condensing (*Fig. 3a*, p. 288).

No. 4. Phosphor-Bronze Cylinder and Cast-Iron Covers (*Fig. 5, Plate 7*).— $5\frac{1}{2}$ inches in internal diameter, 3 inches long. Volume 0.04612 cubic foot; surface 0.366 square foot of phosphor-bronze, and 0.612 square foot of iron—a ratio of 1 cubic foot of volume to 21 square feet of surface. Walls of cylinder $\frac{1}{2}$ inch thick, with four holes for taking temperatures. Walls heated externally by gas. Tests with hot and cold walls, saturated and super-heated steam. Six experiments, Nos. 27 to 32, condensing and non-condensing.

No. 5. Cast-Iron Cylinder and Covers (*Fig. 3, Plate 7*).—2 inches in diameter, 3 inches long. Volume 0.009219 cubic foot; surface, 0.62 square foot—a ratio of 1 cubic foot of volume to 67 square feet of surface. Wall 1 inch thick. This thickness was adopted as that generally used in steam-cylinders, but thinner walls were also experimented upon. Eight temperature-holes through the thickness of wall. Tests with hot walls heated by gas-jets, and with cold walls. Experiments made at full and half speeds, and with two different ranges of steam-temperature. Saturated steam. Eight experiments, Nos. 2 to 12, condensing and non-condensing.

No. 6. Cast-Iron Cylinder and Covers (*Fig. 4, Plate 7*).— $5\frac{1}{2}$ inches in diameter, 3 inches long. Volume 0.04411 cubic foot; surface 1.28 square foot—a ratio of 1 cubic foot of volume to 29 square feet of surface. Walls $\frac{5}{8}$ inch thick, with five temperature-holes. Here the internal surface was much less compared with the volume than in the preceding experiments. Both saturated and super-heated steam used. Eight experiments, Nos. 15 to 22. Cold walls and also cylinder heated by gas. Condensing and non-condensing.

No. 7. Cast-Iron Cylinder and Covers Varnished.— $5\frac{1}{2}$ inches in diameter, 3 inches long. Dimensions the same as those of *No. 6*, but with the vertical walls and top and bottom covers varnished inside. Three coats of varnish were applied, giving smooth glazed surfaces. The varnish stood the temperature well. Total surface varnished 0.84 square foot. Unvarnished and small pipes 0.49 square foot—a ratio of 1 cubic foot of volume to 30 square feet total surface. One experiment, No. 34. Condensing, cold walls with saturated steam (*Fig. 4, Plate 7*).

No. 8. Cast-Iron Cylinder and Covers.—Dimensions of cylinder, the same as in *No. 6*, but with 24 and also with 12 wrought-iron plates, 0.094 inch thick, placed radially inside the revealer, to increase the surface. Total internal surface, with 24 plates inside, 3.42 square feet, taking both sides of the plates. Total volume

0.03548 cubic foot—a ratio of 1 cubic foot to 96 square feet (the maximum ratio used). With only 12 plates inside the revealer, the volume was 0.03933 cubic foot, and the surface was 2.37 square feet—a ratio of 60 to 1 (*Fig. 4a*, p. 289).

Three experiments, Nos. 35, 36 and 37, were made, condensing, with cold walls and saturated steam, with the principal internal surfaces varnished and unvarnished, so as to determine the effect of varnishing.

No. 9. Cast-Iron Cylinder and Covers.—Dimensions—as in No. 6, with one or two rings of cast-iron $\frac{5}{8}$ inch thick placed inside. With the small inner ring, $2\frac{1}{4}$ inches in internal diameter by $2\frac{3}{4}$ inches long, surface 1.50 square foot. Volume 0.03577 cubic foot. Ratio 42 to 1. With large inner ring, $3\frac{3}{4}$ inches in internal diameter by $2\frac{3}{4}$ inches long, surface 1.77 square foot. Volume 0.03157 cubic foot. Ratio 56 to 1. With both rings together, surface 2.16 square feet. Volume 0.02281 cubic foot. Ratio 95 to 1. (*Fig. 5a*, p. 289.)

Three experiments were made, Nos. 38, 39 and 40, condensing, cold walls, and with saturated steam. No surfaces varnished.

ON THE FORMS ASSUMED BY WATER CONDENSED FROM SATURATED STEAM. PRESSURE ABOUT 30 LBS. PER SQUARE INCH. FILLINGS, 34 TO 35 PER MINUTE.

In endeavouring to describe what was seen inside a double-glass air-jacketed revealer, the remarks are divided into two portions, the steam-stroke and the exhaust-stroke, the phenomena being different during these two periods. The walls were not heated in any way, but their temperature would be much less than that of the steam.

Steam-Stroke, Vertical Glass Walls.—On the admission of steam, the walls were immediately covered with the finest white mist, as well as all sizes of circular drops, from $\frac{1}{2}$ millimetre to 3 millimetres in diameter. The smaller drops were very near together, and the larger ones further apart. The general aspect (full size) was that shown in *Fig. 7*. During the admission of the steam, and before it was cut off, the drops were in rapid motion on all the boundary walls, urged along by the velocity of the entering steam. The 3-millimetre drops ran down the vertical wet surfaces. They never seemed to exceed about $3\frac{1}{2}$ to 4 millimetres in diameter.

Exhaust-Stroke, Vertical Walls.—The instant the exhaust-valve opened, due to the fall of the pressure, drops of all sizes were in violent ebullition. There was instantaneous disappearance of all

fine mist, the glass surfaces becoming quite clear. All the drops broke up and lost their circular shape. At the end of this stroke, however, many of the larger drops (2 to 3 millimetres in diameter) remained, leaving the walls between quite dry.

Horizontal Cast-Iron Bottom Cover.—All over this bottom cover there was about 1 millimetre to $1\frac{1}{2}$ millimetre of moving water during the steam-stroke. Immediately the exhaust-valve opened, strong ebullition took place during the whole exhaust-stroke. This surface, however, never became quite dry.

Horizontal Cast-Iron Top Cover.—On this internal surface there were also drops and mist, much as on the vertical walls, which during the admission of steam were also in rapid motion. The drops often fell vertically. During exhaust, the same quick boiling was observed. Working either condensing or non-condensing, the same general phenomena took place, with rather more violent and quicker evaporation during exhaust in the former case.

Fig. 6.

Fig. 7.

FORMS OF WATER ON ENGINE CYLINDERS.

HOT JACKET WALLS.

COLD NON-JACKETED WALLS.

Other Experiments with Glass and Cast-Iron Walls.—In some other experiments with saturated steam at a pressure of 50 lbs. per square inch, all the phenomena were practically the same, with the addition of a little more moisture, and sometimes films of water on the cold walls. All these forms of moisture were forced by the in-coming steam to move rapidly over the surfaces, splashing in all directions. Sometimes there were no films, but only drops of various sizes. When the glass cylinder was jacketed with steam and its surface was considerably raised in temperature, the wet condition of the glass was very much changed, showing less water present in the mixture, viz., few drops and principally the finest white mist (*Fig. 6*). The above description approximates to a small slow-running single-cylinder engine, and therefore rather more water would be present than in most unjacketed engines.

Double-Glass Revealers fixed on to Steam-Engines.—The Author
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has had the opportunity of placing this instrument with an air-jacketed cylinder on various engines, and adds a few notes of the observations made on two of them. The first was fixed on to the low-pressure cylinder of a jacketed compound vertical condensing-engine, indicating some 200 HP., and working at about 60 revolutions per minute. In this cylinder the pressures were under that of the atmosphere. By previous calculations and tests, the steam was known to be practically dry at release, and the revealer confirmed this fact. After the apparatus had been on the cylinder some little time, and the internal parts had assumed their normal temperature, only the finest white mist was seen inside the glass cylinder during the steam-stroke similar to that presented in *Fig. 6*, and disappeared instantaneously at exhaust. There were no large drops like *Fig. 7* and no water films, the internal walls becoming dry before the end of the exhaust. As the revealer was only air-jacketed, the mist or moisture would probably be still less on the actual cylinder walls. With the second engine, and the same air-jacketed revealer, fixed on to the low-pressure cylinder of a compound jacketed condensing-engine, indicating about 50 HP., and running at about 35 revolutions per minute. Here it was also known by experiments that the steam was dry at release. As in the last case, only the finest mist was seen, the particles being perhaps a little larger than before, with rapid disappearance at exhaust. The initial steam-pressure in this cylinder was a little higher than that of the atmosphere.

What has been observed with steam-engines, as to the various shapes the condensed steam assumes on the surfaces during the steam stroke, may be summarized thus: These shapes depend upon the temperature of the internal surfaces, whether they are hotter or colder than the entering steam. In the case of non-jacketed engines, with cylinders much colder than the steam, the drops vary from $\frac{1}{10}$ millimetre to $3\frac{1}{2}$ millimetres in diameter, with the addition of some moving films of water (*Fig. 7*). With efficiently jacketed cylinders, the drops are much smaller in diameter, and probably never exceed $\frac{1}{2}$ millimetre, and there are no films of water (*Fig. 6*). In all cases, there is rapid motion of the various kinds of moisture on all the surfaces and quick evaporation at exhaust. This is with moderate steam-pressures and speeds and fairly dry saturated steam.

From the Author's observations, he considers that the drops and water-films are never at rest in engine-cylinders, either on the vertical or the horizontal surfaces. It is difficult for the eye to follow the storm of mist, fog, drops, films, &c., dashing against the walls in all directions and then evaporating more or less

rapidly at exhaust. With these violent movements inside the cylinders, especially on all the surfaces and passages, during the whole period of the steam-stroke, with the action of the piston wiping off and removing at each stroke all the moisture from the cylindrical portions, it seems natural to conclude that the innermost metallic surfaces should almost immediately assume the varying temperatures of the rapidly-moving steam. The condensed water in all its various wet forms, has probably also an uneconomic effect on the in-coming steam. The action, therefore, not only of the iron, but also of the water, has to be considered. It may be not so much a question of iron *versus* water, but of iron as well as water, that diminishes so considerably economy in steam-engines. With internal-combustion or gas-engines, where the surfaces are very dry, the case is very different. In both, however, there is a certain amount of lubricant which has some effect on all the surfaces upon which condensation can take place. In steam-engines, there is—firstly, a solid and good conductor of heat—cast iron; secondly, a liquid and often bad conductor—water, fog, mist, &c.; and thirdly, a gas—steam, which, if not super-heated, generally contains a small percentage of water.

LIMITS OF EXPERIMENTAL ERRORS.

As the indicator-springs were checked, the diagrams are as correct as usual, say, within two per cent. As to the weights of feed-water and circulating water, the weighing-machines being verified, the results are doubtless within the same limit of accuracy. The thermometers were also checked, and were found to be practically correct. In taking the various temperatures of the cylinders at different depths, the small vertical temperature-holes were filled with mercury, into which small glass thermometers were placed. Glass being a bad conductor of heat, there is little doubt that in the holes situated nearest to the steam-surfaces, the temperatures of the metal given is less than it would be in reality. The nearer the temperature-holes are to the surface, the greater the temperature range. Fig. 21, Plate 8, shows not only the actual thermal gradient in this manner, but also in dotted lines what the thermal gradient probably would have been, had a perfect thermometer been used. The mean temperatures are no doubt nearly right, as it is only the extent of the ranges that would be influenced. In the non-fluctuating part of the metal of the cylinder, the question is very different, as here the temperatures are constant; they are therefore practically correct.

At some future time, the Author hopes to use either a metallic bulb thermometer or some type of metallic electrical thermometer or thermopile. The readings of the counter giving the number of fillings per minute are correct. The pressures of steam have often been transposed in these experiments to their corresponding temperatures. This has been done from Professor Dwelshauvers Dery's steam-tables. In order to check the thermometers in position with different pressures of steam, the apparatus was stopped, and steam was allowed to remain for some time inside one of the cylinders. The readings of the glass thermometers were found to correspond with those given by the steam-tables. The steam- and the vacuum-gauges were also often checked and found correct.

REMARKS ON AND COMPARISONS OF SOME OF THE EXPERIMENTS.

General.—Table I, Appendix, gives the results of the experiments, and the headings of columns 14 and 16 only need explanation. If no steam were condensed, the cylinder would only be required to be filled once; but this is seldom the case. The number of times it was necessary to fill them (up to release) is given in Table I, and varies from 50 to 1. These figures mean, therefore, the number of times it was found necessary to fill each cylinder under test, to make up for the condensation of steam under the different conditions of each experiment. The total volume of steam calculated from the feed-water used, divided by the total volume of the cylinder gives this number. For example, if there was 50 per cent. condensation the cylinder would have to be filled twice. These results can be compared together in so many different ways, that the Author will only make a few comparisons.

Comparing generally the condensing with the non-condensing experiments (having the same temperature of walls) the latter give less condensation of steam per square foot of surface than the former, and the "dryness fraction" is usually higher. The same result takes place when comparing experiments with hot and with cold walls, saturated or super-heated steam. The steam temperature range is less working non-condensing than condensing, and this is probably one reason for the reduced condensation. If, however, the experiments with cold walls, condensing, be compared with hot walls, non-condensing, the steam range is often less, and the condensation less. When heated walls are compared with those not heated, the rates of condensation per square foot of surface exposed, seem to have no relation to the range of the steam-temperature.

Temperature of the Cylinder-Walls.—In reference to the temperature of the cylinder-walls, condensation is always less when they are heated than when not heated, and the “dryness fraction” at release is always higher. The temperature of the metal exposed to the steam seems to have a great effect on the condensation results.

Super-heated Steam.—When super-heated steam is used there is always less condensation than with saturated steam. This holds good whether working condensing or non-condensing, or with heated or un-heated cylinders. It is found also to raise the temperature of the metallic walls.

Different Cylinders.—With regard to the sizes of the cylinders used, the $5\frac{1}{2}$ -inch diameter iron cylinder gives much less condensation per square foot of exposed surface, than the smaller 2-inch diameter iron cylinder with the same temperature of walls. With the larger cylinder, the area touched by the steam is much reduced in proportion to the volume.

Heat-Penetration per Stroke.—It will be seen by the drawings of the various thermal gradients on Plate 8, that the heat penetrates into the metal walls at very different depths, not only inversely as their temperatures, but (by working the apparatus faster or slower) in proportion to the time allowed for such penetration. For the same number of fillings, this depth is much greater with cold than with heated walls. For the same temperature of wall, by halving the number of fillings per minute, or in other words doubling the time for the heat to take effect, the depth is considerably increased. *Fig. 8* gives a graphic representation of this heat-penetration per stroke on a temperature base deduced not only from these experiments, with No. 6 cylinder, *Fig. 4*, Plate 7, but also from some on an experimental steam-engine. The heat-penetration per stroke with hot walls and saturated steam is $1\frac{3}{4}$ millimetre. The maximum penetration, with a cold wall and at the slowest speed, is 14 millimetres. Less heat-penetration always corresponds with less condensation per square foot. It will be seen that as the walls are raised in temperature so the heat-penetration is reduced.

Plotted Results.—Some of the experiments on Revealer No. 6 have been plotted on a base line of the temperature of the cylinders, as it is this temperature which seems to have the greatest influence in diminishing or increasing condensation. With walls colder than the steam, there is greater condensation per square foot, and with heated walls much less. *Fig. 8* gives:—

First, the weight of water condensed per hour per square foot of internal surface; secondly, the depths of heat-penetration into

the cylinder-walls; thirdly, the ranges of steam temperature; fourthly, the percentage of steam and water present at release.

It will be seen how the curves of condensation, heat-penetration and water present, all gradually diminish with the increasing temperatures of the cylinders. The steam-range curve does not seem to follow any of the others.

Effects of Time on Condensation.—Comparing two sets of experiments (2 and 11 with the 2-inch cast-iron revealer, Table I),

Fig. 8.

GRAPHIC REPRESENTATION OF STEAM-RANGE; STEAM AND WATER PRESENT, AND HEAT-PENETRATION ON A BASE OF TEMPERATURE OF WALLS.

where the number of fillings per minute was varied considerably, the following results were obtained. With about the same steam temperature range and with cold walls, the condensation is about 40 per cent. less per square foot at half speed than at full speed, whether condensing or non-condensing. So that doubling the time of exposure with the same steam-pressure reduces the condensation considerably. This tends to prove that most of the condensation takes place very quickly.

Condensation Results.—In Table II will be found the various experiments arranged in order, on a scale of pounds of steam condensed per square foot-hour; the different results being arranged according to the amount of condensation. At the top are seen the results with the hot cylinders and super-heated steam, then those of the cooler metal with saturated steam, and at the bottom the maximum condensation with the smaller cylinders and the colder walls.

Comparing experiments 28 and 30 with the same steam range and with saturated steam, the condensation per square foot is about three times greater with cold than with hot walls. With experiments 31 and 32, with the same range and with super-heated steam, the condensation is also about three times greater with the cooler walls. This is repeated in experiments 16 and 18.

Glass Cylinders.—The air-jacket round the glass cylinder is found to reduce condensation and to increase the area of the diagram. With steam in the jacket, there is a gain of 17 per cent. in diminished condensation over air in the jacket. Comparing the glass cylinder with and without steam in the jacket, there is 30 per cent. less condensation, and 83 per cent. more steam present with the same steam range. The cylinders, however, were not of the same diameter. Cold vertical glass walls, condensing or non-condensing, give 22 to 28 per cent. less condensation than the cold metal vertical walls. With less steam range there is less condensation. In many of these experiments the steam range is about the same, but the condensation results vary considerably.

Phosphor-Bronze Cylinder (Vertical walls only).—The comparison of experiments 27 and 28 shows a gain in working non-condensing over working condensing, both with cold walls and with saturated steam, of 12 per cent. reduced condensation with 25 per cent. less range and 6 per cent. more steam present at release. The comparison of experiments 27 and 29, working condensing and with saturated steam, shows a gain of the hot over the cold walls of 63 per cent. reduced condensation, 35 per cent. more range, 85 per cent. less penetration, 119 per cent. more area diagram, and 324.7 per cent. more steam present at release. Here there is less condensation with greater range.

The comparison of experiments 27 and 31, working condensing and with cold walls, shows a gain, by super-heated steam, over saturated, of 59 per cent. reduced condensation, 12 per cent. more range, 85 per cent. less penetration, 76 per cent. more diagram area, and 292 per cent. more steam present at release. Experiments 27 and 32 are both condensing; one with cold walls and

saturated steam, and the other with heated walls and super-heated steam. Here the gain is 88 per cent. less condensation, 16 per cent. more steam range, 109 per cent. more area of diagram, and 521 per cent. more steam present at release. The minimum weight of steam condensed per square foot with heated walls and super-heated steam is on this Table.

In experiments 29 and 32, the quality of the steam only was changed to see the advantage of super-heated over saturated steam, working condensing and with heated walls. The gain was:—68 per cent. less condensation, 15 per cent. less range, 4 per cent. less area diagram, and 46 per cent. more steam present at release. Experiments 28 and 30 are both non-condensing with saturated steam, but one with heated, and the other with cold walls. The gain by the heated walls was 66 per cent. less condensation with the same steam range, 69 per cent. more area of diagram, and 289 per cent. more steam present at release. In this Table the rates of condensation are not at all proportional to the steam ranges; and the best results are with super-heated steam and heated walls.

Cast-Iron Small Cylinder.—The first two experiments, both with cold walls, show that there is 23 per cent. less condensation when working non-condensing than working condensing. There is less condensation with less range.

In comparing experiment No. 2 with Nos. 5 and 6 experiments, both condensing, one with hot and the other cold walls, there is more range with much less condensation. With the hotter walls there is 80 per cent. less heat-penetration, 68 per cent. less condensation, 57 per cent. more area diagram, 650 per cent. more steam present.

*With 5½-inch Cast-Iron Cylinder.*¹—In the first pair of experiments (15 and 16), the condensation is 12 per cent. less non-condensing than condensing, with saturated steam and cold walls. In the second pair (15 and 17), only the temperature of the walls was changed; both with saturated steam, condensing. The hotter walls gave 69 per cent. less condensation, 80 per cent. less penetration, and 91 per cent. more area of diagram with 375 per cent. more steam present. Third pair (15 and 19), both condensing, with cold walls. Working with super-heated gave the following advantage over saturated steam: 76 per cent. less condensation, 92 per cent. more area of diagram, 440 per cent. more steam present. Fourth pair (15 and 21), with cold walls and saturated steam against

¹ Compare columns 1, 2, 11, 12, 15, 24, 26 and 30 of Table I for each of the experiments mentioned under this heading.

hot walls and super-heated steam. The advantages in favour of the latter were:—82 per cent. less condensation, 78 per cent. less penetration, 114 per cent. more area, and 500 per cent. more steam present at release. Here the relative amounts of condensation were 16 lbs. and 3 lbs. Cold walls and saturated steam give, therefore, five and a half times more condensation per square foot per hour than with hot walls and super-heated steam. The minimum condensation on this Table is 1·3 lbs. per square foot. The fifth pair of experiments (17 and 21) were with hot walls, condensing. There is a gain of 43 per cent. less condensation, and 27 per cent. more steam present at release with super-heated than with saturated steam. The steam ranges and rates of condensation do not seem to have any relation to each other on this Table.

*Comparison of Iron and Phosphor-Bronze Cylinders of same size.*¹—First pair of experiments (15 and 27) with cold walls, condensing, saturated steam. The disadvantage of phosphor-bronze is 47 per cent. more condensation, and 43 per cent. more heat-penetration. Second pair (17 and 29) with hot walls, condensing, saturated steam. Phosphor-bronze gives 79 per cent. more condensation with about same heat-penetration and the same area of diagram. Third pair (19 and 31) with cold walls, condensing, super-heated steam. Phosphor-bronze gives 160 per cent. more condensation and 70 per cent. less heat-penetration.

Fourth pair (21 and 32) with hot walls, condensing, super-heated steam. In this case only is there a slight gain with the phosphor-bronze super-heated steam and hot walls, viz., about 2 per cent. less condensation. In these tests the various steam ranges were not proportional to the rates of condensation. In some cases there is less condensation with greater range, and in others more condensation with less range. Cast-iron seems to be more suitable than phosphor-bronze for a cylinder metal.

*Effect of Varnishing the Internal Iron Surfaces.*²—The first pair of experiments (15 and 34) is with iron cylinders, the chief surfaces being varnished, cold walls, condensing, saturated steam. There is 19 per cent. less condensation per square foot due to the varnishing. Second pair (36 and 37); same cylinder, with the addition of thin plates, increasing the surface considerably. There is a gain of 6 per cent. less condensation due to the varnishing.

Increased area of the Surfaces exposed to Steam.—Experiments

¹ Compare columns 1, 2, 11, 12, 15, 24, 26, 30 and 31 of Table I for each pair of experiments mentioned.

² Compare columns 1, 2, 11, 12, 15, 24, 26, 30 and 31 of Table I for each of the mentioned pair of experiments.

15 and 36. The result of doubling the area of the cold surface gives 38 per cent. less condensation per square foot exposed, condensing, saturated steam. In next pair of experiments, Nos. 15 and 35, with 160 per cent. more surface, there is 55 per cent. less condensation per square foot. Thus considerable additions of surface reduce the rate of condensation per square foot; the reason probably being that, as the condensation is so instantaneous on the increased surface, there is less steam left to be condensed. The difference of temperature between the steam and the metal is also much reduced. The steam-pipe and valve were perhaps rather small for the increased quantity of steam. In comparing the three pairs of experiments (15 and 39, 15 and 38, 15 and 40) with cold walls, condensing, saturated steam, and with additional exposed surfaces, consisting of cast-iron rings (instead of thin plates as in the former case), the same general result appears, viz., that the condensation per square foot diminishes with the increased surface, and probably for the same reason. The area of indicator diagrams and heat-penetration also decreases with the increased surfaces. This method of increasing the surface exposed to the steam, approximates to increasing clearance surfaces in steam-engines. For practical application, the above experiments point decidedly to the following requirements for the most economical working. To keep all the cylinder-walls and passages at a somewhat higher temperature than that of the steam in contact with them, by efficient steam-jackets or other means. To diminish as far as possible the areas exposed to such steam in the clearance-surfaces and passages, so as to obtain the maximum volume with minimum surface. To work with as dry a steam as practicable, and to use super-heated steam if possible. To reduce radiation to a minimum. To reduce heat-penetration in the metallic walls. To exhaust the steam from the last cylinder practically dry, so as to contain the minimum quantity of water and heat.

There are not many direct tests on this subject. The Author is acquainted with those of Mr. Escher,¹ made in Switzerland in 1881, and with the interesting experiments of Lieut.-Colonel English, R.E., on condensation in cylinders, described before the Institution of Mechanical Engineers in 1889. These experiments were also at constant volume, but the temperature of the cylinder was not taken. Colonel English is of opinion that condensation of steam is practically instantaneous in steam-engines. With cold walls this is no doubt the case. When, however,

¹ Der Civilingenieur, 1881.

they are heated, *e.g.*, with a steam-jacket, there will be less difference between the temperature of the metal and that of the steam; but, although the interchange of heat may be as rapid, the amount of dew, drops and moisture will be smaller. It is interesting to note that many of these experiments confirm the opinions expressed by Professor Cotterill, F.R.S., in his work on the Steam-engine.

Thermal Diagrams.—Since the above was written, the bulb of a specially sensitive mercurial thermometer has been fixed inside one of the cylinders, and exposed to the steam and the exhaust. The mercurial column rises and falls regularly at each stroke.

The maximum and minimum temperatures can easily be read, and these were noted during each stroke, the usual indicator diagram being taken at a speed of about eleven fillings per minute. At this speed, this thermometer had time to take the whole temperature range, viz., 95° F., corresponding with the maximum and minimum pressures of the indicator diagrams. At 35 revolutions, it followed only about two-thirds of the steam temperature range. The Author has already obtained some preliminary thermal photographic diagrams, and hopes shortly to improve the apparatus and to take others. A comparison could then be made between the usual pressure diagrams, and these thermal diagrams, both being taken at the same time.

The photographic paper is driven to and fro like that for an indicator, and the mercurial column rises and falls. A heat-diagram is thus obtained similar in form to an indicator diagram of pressures, the base-line being in proportion to the stroke, and the verticals in proportion to the varying temperatures.

Drops of water can be seen falling off the bulb of the thermometer, and violent motion inside the glass cylinder, but this rapid movement of the particles of water, on the bulb and elsewhere, does not seem to prevent the quick alternate action of each filling by heating and cooling the mercury. The Author is aware that further improvements can be made in the apparatus, but the above experiments and results are given in the hope that others may be undertaken on a more complete scale and at greater speeds and steam-pressures. He is much indebted to the care and attention of Mr. Golding and others who have assisted him in these investigations.

The Paper is accompanied by a large number of diagrams from a selection of which Plates 7 and 8 and the *Figs.* in the text have been prepared.

APPEN

TABLE I.—EXPERIMENTS ON THE CONDENSATION OF STEAM, IN CYLINDERS OF GLASS, WALL-TEMPERATURES, VOLUMES, AND

One valve for inlet and one for outlet of steam. Different temperatures of wall, con-steam-filling. 4-8 indicator diagrams taken in each experiment. The minimum depth of steam, about 50 lbs. Number of fillings and emptyings per minute, about 34-35, sometimes half. Experiments with saturated and super-heated steam. External portion of revealers not covered, 75° and 90° Fahrenheit.

No. of Revaler or Cylinder.	1	2	3	4	5	6
Experi- ment No.	Conditions of Experiment.	No. of Fillings and Emptyings per Minute.	Steam-Pressure in Pipe near Revaler.			
			Lbs. Gauge.	Lbs. Abso- lute.	Corre- sponding Tempera- ture, ° Fahr- enheit.	
<i>Experiments on 2-inch Glass Revaler (with Cement and Wrought-Iron outside Glass). 2-inch inch thick; and Wrought-Iron, 0.203 inch</i>						
1	{13} {14}	Saturated steam, {cold {condensing walls {non-condensing	34.57 34.92	47.2 48.0	62.0 62.8	295 296
<i>Experiment on 2¼-inch Double-Glass Revaler. Inner Glass Cylinder, 2.70 inches internal diameter, 0.26 inch thick, 2.95 inches</i>						
2	23	{Saturated steam, {cold {condensing air jacket . . walls }	34.85	48.5	63.3	296
<i>Experiment on 2¼-inch Double-Glass Revaler with Steam-Jacket. Size of Glasses, about the</i>						
3	33	{Saturated steam,} jacketed . } condensing . . .	34.25	35.0	49.6	280
<i>Experiments on 5½-inch Phosphor-Bronze Revaler. ½-inch Wall, 3 inches long. Top and</i>						
4	{ 27 28 29 30	Saturated steam {cold {condensing walls {non-condensing hot {condensing walls non-condensing	34.65	49.0	63.8	296
			34.32	49.0	63.8	296
			34.50	49.0	63.8	296
			35.20	49.0	63.8	296
	{ 31 32	Steam super- heated about 40° Fahrenheit . . {cold {condensing walls {condensing hot {condensing	34.80	49.0	63.8	296
			33.90	49.0	63.8	296

¹ If no steam is condensed, each cylinder would require filling once. These

[Continued on page 286.]

DIX.

PHOSPHOR-BRONZE, AND CAST-IRON, WITH VARIATIONS IN THE TIME OF FILLING, SURFACES, WITHOUT PISTON, 1892.

densing and non-condensing. Thermal gradients of wall. Cut-off about $\frac{1}{7}$ to $\frac{1}{5}$ in time of heat-penetration per stroke given in millimetres. Total weight of steam used. Pressure of this. Dryness fraction at cut-off and at release. Range of temperature in reveler. except with the glass cylinders. The temperature of the engine-house varied between

7	8	9	10	11	12	13	14	15	16	17
Cut-off taken from Indicator Diagrams Per Cent.	Vacuum in Condenser, Inches Mercury.	Weight of Steam Used.		Wall Action, or depth of Metal at which the Range of Temperature ceases per Stroke in Millimetres.	Indicator Diagram. Mean Pressure, Lbs. per Square Inch.	Steam present in Revealer, as shown by Indicator Diagram in Per Cent. of Total Feed-Water used, or Dryness Fraction of Steam.				
		Lbs. per Hour.	Lbs. per Filling.			At Cut-off.		At Release.		Per cent. Difference between Steam present at Release and at Cut-off.
						Per Cent. Steam.	Fillings of Steam per Stroke. ¹	Per Cent. Steam.	Fillings of Steam per Stroke. ¹	
<i>internal diameter, 3 inches long. Glass Vertical Wall, 0·18 inch thick. Cement, 0·133 thick. Top and Bottom Covers of Brass.</i>										
14·3 14·4	25 ..	18·31 13·21	0·00882 0·00630	not taken	27·61 23·68	10·7 12·1	9·31 8·26	4·2 4·7	23·5 21·2	6·5 7·4
<i>internal diameter, 0·145 inch thick, 3 inches long. Outer Cylinder, 3·76 inches long. Air in Annular Space between Glasses.</i>										
17·4	24	17·46	0·00835	{ not taken }	32·26	17·6	5·69	9·0	11·1	8·6
<i>same as in previous Experiment. 1-inch Felt round Outer Glass and Top and Bottom Covers.</i>										
12·3	24 { including 15·51	jacket-water 0·00755	{ not taken }	23·66	17·4	5·74	8·7	11·5	8·7	
<i>Bottom Covers of Cast-Iron. See Figs. 9, 10, 11, 12, Plate 7, for Mean Indicator Diagrams.</i>										
14·7 15·6 15·9 16·9	19 .. 23 ..	27·00 23·97 18·66 14·34	0·01299 0·01164 0·00877 0·00679	10 10 1½ 1½	20·26 20·41 44·29 34·59	25·1 27·7 65·0 64·4	3·99 3·61 1·54 1·55	12·3 13·0 52·2 50·6	8·16 7·71 1·92 1·98	12·8 14·7 12·8 13·8
15·8	20	17·01	0·00815	1½	36·00	58·6	1·71	48·2	2·07	10·4
17·7	18	12·07	0·00593	1½	42·42	90·8	1·10	76·4	1·31	14·4

columns represent the actual number of fillings required, calculated from feed-water.

[Continued on page 287.]

TABLE I.—

No. of Revealer or Cylinder.	1	2	3	4	5	6			
Experiment No.	Conditions of Experiment.	No. of Fillings and Emptyings per Minute.	Steam-Pressure in Pipe near Revealer.						
			Lbs. Gauge.	Lbs. Absolute.	Corresponding Temperature, ° Fahrenheit.				
Experiments on 2-inch Cast-Iron Revealer, 2 inches internal diameter, 1-inch Wall, 3 inches also Figs. 21, 22, 23, 24, 25,									
5	2 mean of 3 and 4	Saturated steam, full speed, and full range of temperature	cold walls { condensing	34·17	47·1	61·7	294		
	walls { non-condensing		33·63	47·0	61·7	294			
	hot walls { condensing		34·28	49·5	64·4	297			
	walls { non-condensing		34·67	49·3	64·2	297			
	9	Half range of temperature in revealer, saturated steam . . .	cold walls { condensing	34·50	{ low steam } 6·8	21·6	232		
	10		walls { non-condensing	34·17				{ low steam } 17·5	32·3
	11	Half speed, full steam, saturated. . . .	cold walls { condensing	17·45	{ half speed }	48·0	62·9		
	12		walls { non-condensing	16·10				{ half speed }	48·0
Experiments on 5½-inch Cast-Iron Revealer; ⅝-inch Walls, 3 inches long. All Metal also Figs. 29, 30, 31, 32,									
6	15	With ordinary saturated steam	cold walls { condensing	34·70	46·9	61·7	294		
	16		walls { non-condensing	34·70	47·3	62·1	295		
	17		hot walls { condensing	35·37	48·3	63·2	296		
	18		walls { non-condensing	35·30	48·4	63·4	296		
	19	With steam superheated about 40° Fahrenheit	cold walls { condensing	34·25	47·8	62·3 { corr. temp. of saturated steam. } 295	295		
	20		walls { non-condensing	34·50	48·5			63·1	296
	21		hot walls { condensing	34·67	48·1			62·9	296
	22		walls { non-condensing	34·17	49·0			63·8	296
	Experiments on 5½-inch Cast-Iron Revealer as above, with								
	7	34	{ Saturated steam, internal surface varnished . . }	cold walls { condensing	34·85	48·4	63·1	296	

[Continued on page 288.]

continued.

7	8	9	10	11	12	13	14	15	16	17
Cut-off taken from Indicator Diagrams per Cent.	Vacuum in Condenser, Inches Mercury.	Weight of Steam Used.		Wall Action, or depth of Metal at which the Range of Temperature ceases per Stroke in Millimetres.	Indicator Diagram. Mean Pressure, Lbs. per Square Inch.	Steam present in Revealer, as shown by Indicator Diagram in Per Cent. of Total Feed-Water used, or Dryness Fraction of Steam.				
		Lbs. per Hour.	Lbs. per Filling.			At Cut-off.		At Release.		Per cent. Difference between Steam present at Release and at Cut-off.
						Per Cent. Steam.	Fillings of Steam per Stroke.	Per Cent. Steam.	Fillings of Steam per Stroke.	
<i>long. All Metal Walls. See Figs. 13, 14, 15 and 16, Plate 7, for Mean Indicator Diagrams; 26, 27 and 28, Plate 8.</i>										
17.5	25	27.50	0.01341	9	22.40	7.0	14.2	2.2	44.7	4.8
13.7	..	21.18	0.01050	8	17.57	7.7	12.9	1.9	51.5	5.8
15.2	26	10.28	0.00500	1½	42.98	24.7	4.05	16.5	6.06	8.2
15.3	..	11.53	0.00555	1½	26.69	16.9	5.94	6.6	15.4	10.3
5.6	23	9.29	0.00449	9	5.025	5.7	17.4	2.0	49.4	3.7
13.6	..	6.45	0.00315	9	7.575	9.4	10.6	3.8	25.9	5.6
15.5	20	15.98	0.01527	14	27.12	6.8	14.6	2.4	41.8	4.4
15.4	..	12.69	0.01314	14	23.46	6.7	15.0	2.3	43.2	4.4
<i>Walls. See Figs. 17, 18, 19 and 20, Plate 7, for Mean Indicator Diagrams; 33, 34, 35 and 36, Plate 8.</i>										
17.6	22	24.05	0.01155	7	22.44	28.5	3.51	12.1	8.24	16.4
17.4	..	21.87	0.01050	7	23.40	31.6	3.16	14.4	6.92	17.2
17.0	21	15.35	0.00723	1½	42.84	72.2	1.38	57.5	1.74	14.7
15.7	..	12.65	0.00598	1½	33.36	69.9	1.43	49.5	2.02	20.4
assuming weight of super-heated steam same as that of saturated.										
16.9	25	14.23	0.00693	5	43.05	75.4	1.33	65.6	1.52	9.8
17.1	..	15.54	0.00750	5	28.42	48.2	2.07	37.2	2.69	11.0
18.3	23	14.06	0.00676	1½	48.03	84.2	1.19	72.8	1.37	11.4
18.7	..	9.75	0.00475	1½	38.46	94.3	1.06	82.0	1.22	12.3
<i>Inner Wall and Top and Bottom Covers Varnished Inside.</i>										
13.1	24	21.33	0.0102	5	23.25	39.5	2.53	16.9	5.92	22.6

[Continued on page 289.]

TABLE I.—

No. of Revealer on Cylinder.	1	2	3	4	5	6	
Experiment No.	Conditions of Experiment.	No. of Fillings and Emptyings per Minute.	Steam-Pressure in Pipe near Revealer.				
			Lbs. Gauge.	Lbs. Absolute.	Corresponding Temperature, ° Fahrenheit.		
<i>Experiments on same 5½-inch Cast-Iron Revealer, with 24 and 12 Radial Plates, both Varnished and</i>							
8	35	Saturated steam { Experiment with 24 radial plates not varnished Experiment with 12 radial plates not varnished Experiment with 12 radial plates varnished . . }	cold walls { condensing condensing condensing	34·57	48·7	63·4	296
	36			34·40	48·5	63·4	296
	37			34·90	48·9	63·5	296
<i>Experiments on same 5½-inch Cast-Iron Revealer, with 1 or 2 Inner Rings of Internal Surface</i>							
9	38	Saturated steam { With large inner ring . . . With small inner ring . . . With both rings . }	cold walls { condensing condensing condensing	34·87	48·7	63·2	296
	39			34·75	49·1	63·6	296
	40			34·17	49·2	63·8	296

[Continued on page 290.]

Figs. 3a.

REVEALERS NOS. 2 AND 3, GLASS.
Diameters, 2½ inches and 4 inches.

Fig. 4b.

continued.

7	8	9	10	11	12	13	14	15	16	17	
Cut-off taken from Indicator Diagrams Per Cent.	Vacuum in Condenser, Inches Mercury.	Weight of Steam Used.		Wall Action, or depth of Metal at which the Range of Temperature ceases per Stroke in Millimetres.	Indicator Diagram. Mean Pressure, Lbs. per Square Inch.	Steam present in Revealer, as shown by Indicator Diagram in Per Cent. of Total Feed-Water used, or Dryness Fraction of Steam.					
		Lbs. per Hour.	Lbs. per Filling.			At Cut-off.		At Release.		Per cent. Difference between Steam present at Release and at Cut-off.	
						Per Cent. Steam.	Fillings of Steam per Stroke.	Per Cent. Steam.	Fillings of Steam per Stroke.		
<i>$\frac{1}{16}$ inch thick inside Revealer. Internal Surface of Revealer, Covers and Plates not Varnished.</i>											
11.3	23	26.39	0.01272	6	5.76	5.7	17.6	4.1	24.3	1.6	
10.7	22	25.99	0.01259	9	9.24	10.9	9.20	6.5	15.3	4.4	
11.9	23	24.97	0.01192	8	14.91	18.4	5.43	8.9	11.2	9.5	
<i>Cast-Iron $\frac{5}{8}$ inch thick inside Revealer. not Varnished.</i>											
11.8	24	24.89	0.01192	4	11.745	12.2	8.16	6.0	16.5	6.2	
13.5	24	24.42	0.01171	5	13.69	16.8	5.95	6.3	15.8	10.5	
13.0	23	25.80	0.01258	2	8.925	7.0	14.2	2.3	43.5	4.7	

*[Continued on page 291.]**Figs. 4a.*

REVEALER NO. 8, CAST-IRON.

Diameter. 5 $\frac{1}{2}$ inches.

[THE INST. C.E. VOL. CXV.]

Figs. 5a.

REVEALER NO. 9, CAST-IRON.

Diameter, 5 $\frac{1}{2}$ inches.

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TABLE I.—

No. of Reveal or Cylinder.	1	2	18	19	20	21	
	Experi- ment No.	Conditions of Experiments.	Pressures and Corresponding Temperatures as taken from Indicator				
			Initial pressure.		Release Pressure.		
			Lbs. Absolute.	Degrees Fahren- heit.	Lbs. Absolute.	Degrees Fahren- heit.	
<i>Experiments on 2-inch Glass Revealor (with Cement and Wrought-Iron outside Glass. 2-inch inch thick; and Wrought-Iron 0.203 inch</i>							
1	{13} {14}	Saturated steam, {cold }condensing {walls }non-condensing	57.2 57.9	289 290	27.2 33.3	245 256	
<i>Experiment on 2¾-inch Double-Glass Revealor. Inner Glass Cylinder, 2.70 inches internal diameter, 0.26 inch thick, 2.95 inches</i>							
2	23	{Saturated steam, {cold }condensing air jacket . . . {walls }	54.7	286	31.2	253	
<i>Experiment on 2¾-inch Double Glass Revealor with Steam Jacket. Size of glasses about the</i>							
3	33	{Saturated steam, steam }condensing jacketed }	43.7	272	24.2	238	
<i>Experiments of 5½-inch Phosphor-Bronze Revealor. ½-inch Wall, 3 inches long. Top and Diagrams and</i>							
4	27 28 29 30	{ Saturated steam {cold }condensing {walls }non-condensing hot }condensing {walls }non-condensing	41.8 48.2 57.1 56.7	270 279 289 289	26.2 31.9 46.2 47.6	242 254 276 278	
	31		{ Superheated steam {cold }condensing about 40° Fahr- {walls } enheit {hot }condensing	50.2	281	42.1	270
	32			55.6	288	47.3	277

[Continued on page 292.]

continued.

22	23	24	25	26	27	28	29	30	31
in Revealer, Diagrams.		Temperature in Steam Pipe Minus Final Temperature = Range of Temperature in Revealer. ° Fahr.	Actual Temperature (taken by Thermometer).			Total Volume of Steam in Revealer and Total Surface (internal) exposed to same, per Stroke.			Steam Condensed in Revealer up to Release in lbs. per Hour per Square Foot of Internal Surface. Lbs.
Final Pressure at end of Exhaust.			Temperature of Wall in 1½-Millimetre hole.		Average Temperature of whole Wall. ° Fahr.				
Lbs. Absolute.	Degrees Fahrenheit.	Average Temperature. ° Fahr.	Hotter or Colder than Initial temperature. ° Fahr.	Volume in Cubic Feet.		Surface in Square Feet.	Ratio $\frac{\text{Surface}}{\text{Volume}}$.		
<i>internal diameter, 3 inches long. Glass Vertical Wall, 0.18 inch thick. Cement, 0.133 thick. Top and Bottom Covers of Brass.</i>									
4.5 15.0	158 213	136.6 82.3	not not	tak tak	en en	0.008381	$\left\{ \begin{array}{l} 0.13 \text{ glass} \\ 0.39 \text{ iron, \&c.} \\ \hline 0.52 \text{ total} \end{array} \right\}$	sq. ft. cub. ft. 62.0 to 1	$\left\{ \begin{array}{l} 33.7 \\ 24.2 \end{array} \right\}$
<i>internal diameter, 0.145 inch thick, 3 inches long. Outer Cylinder, 3.76 inches long. Air in Annular Space between Glasses.</i>									
4.75	160	135.8	not	tak	en	0.0135	$\left\{ \begin{array}{l} 0.177 \text{ glass} \\ 0.420 \text{ iron, \&c.} \\ \hline 0.597 \text{ total} \end{array} \right\}$	44.2 to 1	26.6
<i>same as in previous Experiment. 1-inch Felt round Outer Glass and Top and Bottom Covers.</i>									
3.9	152	128.4	not	tak	en	0.01378	$\left\{ \begin{array}{l} 0.179 \text{ glass} \\ 0.422 \text{ metal} \\ \hline 0.601 \text{ total} \end{array} \right\}$	43.6 to 1	22.2
<i>Bottom Covers of Cast-Iron. See Figs. 9, 10, 11 and 12, Plate 7, for Mean Indicator Drawing of Revealer.</i>									
8.6 15.4 3.3 15.0	186 214 146 213	110.0 82.2 150.8 83.3	227 238 334 335	69 colder 58 colder 37 hotter 39 hotter	226 238 340 347	0.04612	$\left\{ \begin{array}{l} 0.366 \text{ Ph. B.} \\ 0.612 \text{ iron} \\ \hline 0.978 \text{ total} \end{array} \right\}$	21.2 to 1	24.2 21.3 9.12 7.25
6.5	174	123.0	273	$\left\{ \begin{array}{l} \text{assuming temp. of saturated steam.} \\ 24 \text{ colder} \end{array} \right\}$	273				9.91
5.5	168	128.2	341	44 hotter	343				2.91

[Continued on page 293.]

TABLE I.—

No. of Revaler or Cylinder.	1	2	18	19	20	21			
	Experiment No.	Conditions of Experiments.	Pressures and Corresponding Temperatures as taken from Indicator						
			Initial Pressure.		Release Pressure.				
			Lbs. Absolute.	Degrees Fahrenheit.	Lbs. Absolute.	Degrees Fahrenheit.			
<i>Experiments on 2-inch Cast-Iron Revaler, 2 inches internal diameter, 1 inch Wall, 3 inches Drawing of Revaler. See also Figs. 21, 22, 23, 24,</i>									
5	2	Saturated steam full speed, and full range of temperature .	cold	condensing	50·8	282	20·5	229	
	mean of 3 and 4		walls	non-condensing	54·5	286	25·7	241	
	mean of 5 and 6		hot	condensing	61·4	294	41·6	269	
	mean of 7 and 8		walls	non-condensing	60·4	293	33·0	256	
	9	Half range of temperature in revaler, saturated steam . . .	cold	condensing	17·1	220	9·7	192	
	10		walls	non-condensing	29·5	249	21·4	231	
	11	Half speed, full steam, saturated steam . . .	cold	condensing	58·2	290	25·7	241	
	12		walls	non-condensing	58·3	291	31·0	252	
<i>Experiments on 5½-inch Cast-Iron Revaler; ½-inch Walls, 3 inches long. All Metal Drawing of Revaler. See also Figs. 29, 30, 31, 32, 33,</i>									
6	15	With ordinary saturated steam	cold	condensing	45·6	275	26·9	244	
	16		walls	non-condensing	51·1	282	33·1	256	
	17		hot	condensing	56·7	289	46·1	276	
	18		walls	non-condensing	57·2	289	44·9	274	
	19	With steam superheated by gas about 40° Fahrenheit . . .	cold	condensing	52·1	283	45·3	275	
	20		walls	non-condensing	49·6	280	41·4	269	
	21		hot	condensing	58·3	291	50·6	282	
	22		walls	non-condensing	58·7	291	52·7	284	
<i>Experiments on 5½-inch Cast-Iron Revaler as above, but with Inner Wall and</i>									
7	34	Saturated steam, internal surface varnished . .	cold	condensing	48·5	279	26·0	242	

[Continued on page 294.]

continued.

22	23	24	25	26	27	28	29	30	31
in Revealer, Diagrams.		Temperature in Steam Pipe Minus Final Temperature = Range of Temperature in Revealer. ° Fahr.	Actual Temperature (taken by Thermometer).		Average Temperature of whole Wall. ° Fahr.	Total Volume of Steam in Revealer and Total Surface (Internal) exposed to same, per Stroke.			Steam Condensed in Revealer up to Release in lbs. per Hour per Square Foot of Internal Surface. Lbs.
Final Pressure at end of Exhaust.			Temperature of Wall in 1½-Millimetre hole.						
Lbs. Absolute.	Degrees Fahrenheit.		Average Temperature. ° Fahr.	Hotter or Colder than Initial temperature. ° Fahr.		Volume in Cubic Feet.	Surface in Square Feet.	Ratio: Surface = Volume.	

long. All Metal Walls. See Figs. 13, 14, 15 and 16, Plate 7, for Mean Indicator Diagrams and 25, 26, 27 and 28, Plate 8.

4.6	159	135.8	218	76 colder	217	0.009219	0.62	67.2 to 1	43.3
15.0	213	81.2	238	57 colder	236				33.5
2.2	130	167.1	327	30 hotter	329				13.8
15.0	213	83.8	330	33 hotter	325				17.4
4.9	162	70.3	178	53 colder	176				14.7
15.1	213	41.0	227	27 colder	225				10.0
6.9	176	119.3	233	63 colder	226				25.2
15.3	214	81.6	252	43 colder	245				20.0

Walls. See Figs. 17, 18, 19 and 20, Plate 7, for Mean Indicator Diagrams and 34, 35 and 36, Plate 8.

9.9	193	101.3	230	64 colder	229	0.04411	1.28	29 to 1	16.5
16.0	216	78.5	244	51 colder	242				14.6
5.2	164	132.0	329	32 hotter	327				5.10
15.2	214	82.4	334	38 hotter	316				5.00
2.5	135	160.4	281	assuming temp. of saturated steam 14 colder	278				3.78
14.5	211	84.3	266	30 colder	263				7.54
3.3	146	149.8	354	59 hotter	357				2.96
14.9	213	83.8	345	49 hotter	348				1.36

Top and Bottom Covers Varnished.

8.4	185	110.7	227	52 colder	227	0.04477	$\left\{ \begin{array}{l} \text{varnished } 0.84 \\ \text{unvar. } 0.49 \\ \text{total } 1.33 \end{array} \right\}$	29.7 to 1	13.3
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[Continued on page 295.]

TABLE I.—

No. of Revealer, or Cylinder.	1	2	18	19	20	21	
Experi- ment No.	Conditions of Experiments.	Pressures and Corresponding Temperatures as taken from Indicator					
		Initial pressure.		Release Pressure.			
		Lbs. Absolute.	Degrees Fahren- heit.	Lbs. Absolute.	Degrees Fahren- heit.		
<i>Experiments on same 5½-inch Cast-Iron Revealer, but with 24 and 12 Radial Plates, both Varnished and</i>							
8 {	35	Saturated steam { Experiment with 24 radial plates not varnished Experiment with 12 radial plates not varnished Experiment with 12 radial plates varnished . . }	cold walls { condensing condensing condensing	19·4	226	17·0	219
	36			25·5	241	19·6	227
	37			34·3	258	22·0	233
<i>Experiments on same 5½-inch Cast-Iron Revealer, but with 1 or 2 Inner Rings of</i>							
9 {	38	Saturated steam { With large inner ring With small inner ring With both rings	cold walls { condensing condensing condensing	29·9	250	19·9	227
	39			34·5	258	19·9	227
	40			29·0	248	17·9	222

continued.

22	23	24	25	26	27	28	29	30	31
in Revealer, Diagrams.		Temperature in Steam Pipe Minus Final Temperature = Range of Temperature in Revealer. ° Fahr.	Actual Temperature (taken by Thermometer).			Total Volume of Steam in Revealer and Total Surface (internal) exposed to same per Stroke.			Steam Condensed in Revealer up to Release in lbs. per Hour per Square Foot of Internal Surface.
Final Pressure at end of Exhaust.			Temperature of Wall in 14-Millimetre hole.		Average Temperature of whole Wall. ° Fahr.				
Lbs. Absolute.	Degrees Fahrenheit.		Average Temperature. ° Fahr.	Hotter or Colder than Initial temperature. ° Fahr.		Volume in Cubic Feet.	Surface in Square Feet.	Ratio Surface = Volume.	
$\frac{1}{16}$ inch thick inside Revealer. With Internal Surface of Revealer, Covers and Plates not Varnished.									
9.8	192	103.9	209	87 colder	208	0.03548	taking both sides of radial plates 3.42	96.4 to 1	7.4
9.75	192	104.1	218	78 colder	217	0.03933		2.37	60.2 to 1
8.0	183	113	223	73 colder	222				9.6
Cast-Iron $\frac{5}{8}$ inch thick inside Revealer. Internal Surface not Varnished.									
7.2	178	118	215	81 colder	214	0.03157	1.77	56 to 1	13.2
7.8	182	114.6	217	79 colder	215	0.03577	1.50	42 to 1	15.2
9.7	192	104.7	214	82 colder	214	0.02281	2.16	95 to 1	11.7

TABLE II.—22 EXPERIMENTS ARRANGED ACCORDING TO THE AMOUNT OF CONDENSATION OF STEAM UP TO RELEASE IN LBS. PER HOUR PER SQUARE FOOT OF INTERNAL SURFACE.

Lbs. Water Condensed per Hour per Sq. Ft. of Internal Surface.	Ex-periment No.	Cylinder Walls.	Dia-meter of cylin-der.	Non-Con-densing or Condensing.	Hot or Cold Walls.	Satu-rated or Super-heated steam.	Tem-perature of Wall in $1\frac{1}{2}$ Milli-metre Hole.	Remarks.
lbs.			Ins.			Sup.	°Fah.	
1.36	22	Cast-iron.	$5\frac{1}{2}$	Non-con.	Hot.	Sup.	348	{ Hottest walls. Superheated steam. Largest cylinders.
2.91	32	Ph. Bronze.	$5\frac{1}{2}$	Con.	Hot.	Sup.	341	
2.96	21	Cast-iron.	$5\frac{1}{2}$	Con.	Hot.	Sup.	354	
3.78	19	Cast-iron.	$5\frac{1}{2}$	Con.	Cold	Sup.	281	
5.00	18	Cast-iron.	$5\frac{1}{2}$	Non-con.	Hot.	Sat.	334	
5.10	17	Cast-iron.	$5\frac{1}{2}$	Con.	Hot.	Sat.	329	{ Hotter walls. Saturated steam.
7.25	30	Ph. Bronze.	$5\frac{1}{2}$	Non-con.	Hot.	Sat.	335	
7.54	20	Cast-iron.	$5\frac{1}{2}$	Non-con.	Cold.	Sup.	266	
9.12	29	Ph. Bronze.	$5\frac{1}{2}$	Con.	Hot.	Sat.	334	
9.91	31	Ph. Bronze.	$5\frac{1}{2}$	Con.	Cold.	Sup.	273	
13.8	5 & 6	Cast-iron.	2	Con.	Hot.	Sat.	327	{ Cooler walls. Saturated steam.
14.6	16	Cast-iron.	$5\frac{1}{2}$	Non-con.	Cold.	Sat.	244	
16.5	15	Cast-iron.	$5\frac{1}{2}$	Con.	Cold.	Sat.	230	
17.4	7 & 8	Cast-iron.	2	Non-con.	Hot.	Sat.	330	
21.3	28	Ph. Bronze.	$5\frac{1}{2}$	Non-con.	Cold.	Sat.	238	
22.2	33	{ Double glass, steam-jacketed }	$2\frac{3}{4}$	Con.	Hot.	Sat.	..	{ Coolest walls, and smallest cylinders.
24.2	27	Ph. Bronze.	$5\frac{1}{2}$	Con.	Cold.	Sat.	227	
24.2	14	Single Glass.	2	Non-con.	Cold.	Sat.	..	
26.6	23	{ Double glass, air-jacketed. }	$2\frac{3}{4}$	Con.	Cold.	Sat.	..	
33.5	3 & 4	Cast-iron.	2	Non-con.	Cold.	Sat.	238	
33.7	13	Single Glass.	2	Con.	Cold.	Sat.	..	
43.3	2	Cast-iron.	2	Con.	Cold.	Sat.	218	

THE CONDENSATION OF STEAM.

PLATE 7.

MEAN INDICATOR DIAGRAMS OF EXPERIMENTS.

Scale of Diagrams $\frac{1}{32}$ Inch = 1 lb.

EXPERIMENT N° 2. COLD WALLS CONDENSING.

EXPERIMENTS N° 5 & 6. HOT WALLS CONDENSING.

EXPERIMENT N° 15. COLD WALLS CONDENSING.

EXPERIMENT N° 17. HOT WALLS CONDENSING.

EXPERIMENT N° 19. COLD WALLS CONDENSING.

EXPERIMENT N° 27. COLD WALLS CONDENSING.

EXPERIMENT N° 29. HOT WALLS CONDENSING.

Scale of Steam Pressure P.

Fig. 3.

N° 5 REVEALER, CAST-IRON.

EXPT N° 9. COLD WALLS COND. LOW STEAM PRESS. 6 TO 8 LBS.

Fig. 4.

N° 6 REVEALER, CAST IRON.

DIAGRAM FOR EXPT N° 17 CONDENSING, DEVELOPED FOR EQUAL TIMES OF CRANK PIN. (not actual diagram)

EXPT N° 21. HOT WALLS CONDENSING

EXP. N° 31. COLD WALLS CONDENSING.

EXP. N° 32. HOT WALLS CONDENSING.

Fig. 5.

N° 4 REVEALER, PHOSPH BRONZE.

EXPERIMENTS WITH CYLINDER N° 5. CAST-IRON, 2" DIA. 1" WALLS.
THERMAL ACTION PER STROKE WITH HOT AND COLD WALLS, AT DIFFERENT SPEEDS, AND WITH DIFFERENT RANGES OF STEAM TEMPERATURE.

EXPERIMENTS WITH CYLINDER N° 6. CAST-IRON, 5½" DIA. 5/8" WALLS,
WITH TEMPERATURES AT DIFFERENT DEPTHS & THERMAL GRADIENTS, HEAT PENETRATION PER STROKE.

EXPERIMENTS AT FULL SPEED, 34-35 FILINGS PER MINUTE.

EXPTS. AT HALF SPEED, 16-17 P.M.

EXPERIMENTS WITH FULL STEAM PRESSURE, 48 LBS. GAUGE IN STEAM PIPE.

EXPTS. WITH LOWER STEAM PRESSURE.

EXPTS. WITH FULL STEAM PRESS.

STEAM PRESSURE 47 TO 49 LBS. PER SQ. INCH.

AND FULL SPEED 34 TO 35.5 REVS. PER MINUTE.