SOME EXPERIMENTS ON THE CONDENSATION OF STEAM.*

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PART I.

As the result of some experiments by electrical methods on the measurement of the temperature changes of the walls and steam in the cylinder of a working steam-engine, which were made at the McDonald Engineering Building of McGill University in the summer of 1895, the authors arrived at the conclusion that the well-known phenomena of cylinder condensation could be explained, and the amount of condensation in many cases predicted from a knowledge of the indicator card, on the hypothesis that the rate of condensation of steam, though very great, was not infinite but finite and measurable. An account of these experiments was communicated to the Institution of Civil Engineers in September, 1896, and will, it is hoped, be published in the course of the ensuing session. In the meantime, the authors have endeavored to measure the rate of condensation of steam under different conditions by a new and entirely different method, with a view to verify the results of their previous work, and also to estimate the influence, if any, of the film of water adhering to the walls of the cylinder.

In considering the condensation of steam on a metal surface it is usually assumed that the surface exposed to the steam is raised up to the saturation temperature corresponding to the pressure of the steam, and that the amount of condensation is limited by the resistance of the water films to the passage of heat from the steam to the metal and from the metal to the water. If the steam contains air, there may also be a considerable resistance due to the accumulation of a film of air on the surface, but it is comparatively easy to exclude this possibility in experimental work.

In the steam-engine experiments, above referred to, it was practically certain that the water film due to the cyclical condensation never exceeded one-thousandth of an inch in thickness, and that the resistance offered by it was unimportant. At the same time, it appeared clear that the temperature of the surface of the metal at its highest was considerably below the saturation temperature of the steam: a condition which could only be explained by supposing the rate of condensation of steam on a surface to be limited by some physical property of steam itself apart from the resistance of the condensed film of water. Interpreted in this manner, the experiments led at once to the conclusion that the rate of condensation at any moment was simply proportional to the difference of temperature between the saturated steam and the surface on which it was condensing.

The limit thus found was shown to be capable of explaining many of the phenomena of cylinder condensation in a rational manner; but the method by which it was established was of an indirect and somewhat intricate character, and appeared to require some simple and more direct confirmation.

If the rate of condensation of steam were really infinite, it should be possible by a suitable modification of the surface-condenser method (i.e. by getting rid of the water films on the outside of the tubes) to obtain values of the condensation considerably in excess of those given by the formula deduced from the temperature cycle observations.

To accomplish this, it is necessary to eliminate as completely as possible the resistance to the passage of heat through the water films between the steam and the metal, and between the metal and the circulating water, and at the same time to measure as accurately as possible the temperature of the metal.

These considerations led to the form of apparatus which was employed. The resistance to the passage of heat from the metal to the condensing water in this apparatus is practically eliminated by employing a thick cylinder, 5 in. diameter and 2 ft. long, with a screw thread cut on its outer surface. Water from the high-pressure mains is forced to circulate round this surface with a very high velocity in the narrow space between the cylinder and the surrounding tube. In this manner it is possible to obtain a very uniform temperature for the external surface differing but little from that of the circulating water.

If the cylinder is made sufficiently thick, its temperature may be approximately determined at any depth by inserting mercury thermometers. It was intended at first to use thermo-couples for this purpose, but the apparatus in this form would have been unsuitable for students' use in the ordinary course of laboratory work, which was one of the primary objects in view in the construction. It would also have been desirable to make the cylinder of nearly pure copper, which would have reduced the resistance of the metal to the lowest point. The authors were compelled, however, to content themselves for the time with cylinders of cast iron and of mild steel.

The internal surface of the cylinder, upon which the steam was condensed, was a hole one inch in diameter, drilled in the solid metal. In order, as far as possible, to minimize the resistance of the surface film of condensed water, a revolving brush was constructed of very thin strips of steel to wipe the surface five or six times a second. This wiper was found to wear in a very short time to so perfect a fit and the water film must have been so energetically stirred that its resistance to the passage of heat must have been far less than that of the best conducting metal, when there was perhaps some small film present.

Under these conditions, if the rate of condensation of steam were infinite, it should have been possible to obtain a rate of condensation many times greater than the limit deduced from the cylinder-condensation experiments above mentioned.

On making the experiment, however, it was found that the wiper made very little difference to the amount of condensation. With the wiper revolving at the rate of 160 per minute, the condensation was increased by about 5 per cent. on the average of several experiments. It may be concluded from this that the drops of condensed water with which the surface is partially covered are in such rapid motion that they do not appreciably obstruct the passage of heat from the steam to the metal. In fact, Prof. Callendar actually found that the drops increased the condensation. A film of the same average thickness, if it were absolutely quiescent, and if its conductivity, as generally estimated, were only one-hundredth of that of cast-iron, would no doubt prove a serious obstacle; but, as a matter of fact, the viscosity of water at these temperatures is so small, and the motion so rapid, that the drops cannot be treated as a quiescent film.

The temperature at various distances from the inner surface of the cylinder was determined by means of mercury thermometers inserted to a depth of 8 in. or 9 in. in holes drilled parallel to the axis. From the temperatures so observed the conductivity of the metal and the temperatures of its inner and outer surfaces could be approximately inferred. It was found, however, that the presence of the holes interfered materially with the flow of heat through the metal, and that the readings of the thermometer under these conditions were not altogether trustworthy.

From a number of observations on the cast-iron cylinder a conductivity of 5.5 thermal units Fahr. per square ft. per minute per deg. Fahr. per inch was deduced, a result which agrees very closely with the authors' previous determination by a different method. For the steel cylinder a conductivity of 5.8 was similarly deduced. These results apply to a mean temperature of about 140 deg. Fahr., and are much lower than the values generally assumed for iron.

In order to verify the previous results as to the rate of condensation of steam derived from the steam-engine experiments, the temperature of the inner surface of the metal was calculated on the assumption of a rate of condensation equivalent to 0.74 thermal unit Fahr. per second per square foot per deg. Fahr. difference of temperature. The values so found agreed with the observed temperatures within the limits of error of the observations. Owing to the inferior conductivity of the iron the test was not absolutely conclusive, as the difference of temperature between the steam and the surface rarely amounted to as much as 30 deg. With a cylinder of pure copper, and thermo-couples for determining the temperature at a given depth, it should be possible to obtain a more certain confirmation by this method.

In performing the experiments a number of variations in points of detail were introduced from time to time. The flow of the circulating water was varied in velocity, and directed in different ways. In order to secure uniformity in the distribution of temperature measured in different directions from the centre, the spiral circulation was found to be essential. In the second apparatus the screw thread was at first replaced by a baffle-plate, which was intended to direct the water into a spiral course, but the results found were unsatisfactory.

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