able amount of heat applied to the interior of a penstock, while the waterwheels were standing still, for the purpose of removing an accumulation of frazil, was probably practicable, but he refused to express any opinion whatever regarding the feasibility of attempting to make an impression upon the contents of a penstock through which the water and ice rushed.

There are probably two excellent reasons why hydraulic engineers have made no serious attempt to cope with the frazil and anchor ice difficulties. The first is their familiarity with the formidable forces of Nature, and the second is their knowledge of the physical properties of water. When a whole river can be blocked by the action of the air in a single night in forming ice, some idea of the extent of the forces of nature which are at work may be imagined, and some figures in connection with the second point, viz., the physical properties of water, may assist in showing why combating frazil seemed so unattractive an undertaking. The output of the Ottawa Electric Company's No. 1 power house is 3,000 horse-power, and it is operated by water under a head of 25 feet. The quantity of water which passes through this plant is, roughly, 100,000 cubic feet per minute. One cubic foot of water weighs 62.4 pounds, therefore, 6,240,000 pounds of water pass through this plant every minute. One B.T.U. is required to raise the temperature of one pound of water one degree Fahrenheit. One horse-power is equivalent to 42.41 B.T.U. Therefore, if it were contemplated to raise the temperature of 6,240,000 pounds of water one degree, it would be necessary to employ 147,000 horse-power. In other words, it would require the total output of 49 stations, each having a capacity of 3,000 horse-power. Startling as this illustration may be, it pales into insignificance when placed beside another which, after all, is the real one to be considered. The latent heat of fusion of water is 142.6 degrees, i.e., it requires the introduction of 142.6 B.T.U. into one pound of ice in order to change it to the liquid state without accomplishing any rise in its temperature. The energy is expended in merely making a change in the molecular arrangement of the water. Bearing the above facts in mind, it may be seen that if the amount of water consumed in the 3,000 horse-power plant had to be converted from the solid to the liquid state, without changing its temperature at all, it would be necessary to employ the output of 7,000 stations, each having a capacity of 3,000 horse-power.

Figures showing the amount of energy necessary to change water from the solid to the liquid state (in the case of the 3,000 horse-power station above referred to, this amount being 21,000,000 horse-power) were used by an eminent engineer at a meeting of a technical society* in order to show the impracticability of a proposed scheme for preventing ice from clinging to the rack of a power plant.

In the fall of 1905 I attempted to put into practical operation my theories in regard to frazil combating. The success of the undertaking was assured from the first experiment. With the aid of an old boiler, which has been operating a couple of steam drills, to which pipes were attached a 3,000 horse-power hydro-electric station which had been tied up every winter from the date of its erection was kept in operation throughout sieges of frazil which shut down or tied up every other waterwheel in the Ottawa district.

The winter of 1905-06, as may be recalled, was a remarkable one on account of there being no long-continued spell of cold weather. As a result the temperature of the water in the Ottawa River on several occasions rose above the freezing point. As each mild spell was succeeded by a moderately cold one, many frazil difficulties were experienced each month. An unusual and excellent opportunity was thus afforded for the thorough testing of this method of frazil combating, and the success of the work may be gauged by the fact that the customers of the Ottawa Electric Company were one and all convinced that no ice troubles had been experienced because, as they said, "the winter had been such a mild one." They spoke from their own knowledge only—their standard of judgment being the excellence of the service that had been maintained. These people overlooked the fact that while the services of the Ottawa Electric Company had not been interrupted, the other hydraulic plants on all sides of them were tied up for several hours on many days during every month of the winter from November until March.

After demonstrating in the above described manner the feasibility of combating frazil in the waterwheels, some experiments were carried out at the racks. With the temperature of the air 15° Fahrenheit—17 degrees below the freezing point—it was only necessary to expend 180 watts, the amount of energy required to light three or four incandescent lamps, upon an iron bar in a rack made up of strips three and one-half inches wide, and one-quarter of an inch thick, in order to detach solid ice which otherwise could only be removed with great difficulty with a chisel or an axe. The section of the rack warmed in this manner was about 5 feet long. This experiment was repeated for the benefit of many skeptics, and in every case it showed that a very small amount of heat energy will detach ice from a surface to which it is frozen, and that a much smaller quantity of heat will prevent ice from attaching itself to any surface. In other words, my method proves the truth of the homely adage that "prevention is better than cure."

In justice to frazil combating methods it should be explained that none of the plants which have their waterwheels equipped with heating outfits have at the present time any means of applying heat to their racks. This explanation is deemed necessary to offset the possibility of an unfavorable report being circulated against the whole scheme owing to a possible interruption of the services by the clogging of the racks which are unprotected.

The protection of the racks, penstocks and draft tubes from the action of the air, and the application of such an amount of energy as will keep the temperatures of the parts of the apparatus through which the water and the frazil flow a thousandth of a degree above the freezing point, will absolutely prevent frazil from interfering in any way with the operation of a hydraulic power plant.

In his book "Ice Formation," Dr. Barnes has generously praised the work that I have done in connection with frazil combating, and says:—"To my knowledge Mr. Murphy is the first to successfully apply such a method, and he deserves all the credit for demonstrating its applicability." At this summer's session of the British Association for the Advancement of Science, held at Leicester, England, Dr. Barnes delivered a lecture on the ice question, and he expressed the opinion that the operator of a hydraulic power plant in northern latitudes need now have no fear of frazil interrupting his services. He made use of some pictures and data supplied by myself, and these are included in the number herewith submitted for your information and consideration.

The following report of Dr. Barnes' lecture has been taken from the British Journal called "Engineering":—

The Ice Problem in Canada.

During the severe Canadian winter there is excellent opportunity for the physicist to study, on a grand scale, the operation of the natural laws governing the formation of ice in many forms with which it is met in large and often turbulent rivers. To the engineer the problem is more serious, for the development of the vast water powers of the country must include means of combating the ice troubles which arise each winter. Rivers are known to have been turned entirely out of their course into new channels during a winter of unusual severity, and in some instances the reversal of a rapid is of yearly occurrence. Nowhere can one witness a more wonderful sight of the delicate poising of the forces of Nature than in one of the Canadian rivers in winter. The steadiness of the temperature of the water throughout the ice season is a matter of great interest. It seldom varies more than a few thousandths of a degree from the freezing point, even in the severest weather. This is true for rivers flowing too swiftly for surface ice to form, as well as for the quieter streams protected by an ice covering. In general, three kinds of ice are distinguished, and present characteristics brought about by their method of production. Surface

*Can. Soc. C.E., Vol. XVIII., 1904, "Some Experiments on Loss of Heat from Iron Pipes, by R. W. Leonard, C.E., and discussion.