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EMISSIVE TESTS OF PAINTS FOR DECREASING OR INCREASING HEAT RADIATION FROM SURFACES

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EMISSIVE TESTS OF PAINTS FOR DECREASING OR INCREASING HEAT RADIATION FROM SURFACES.

By W. W. Coblentz and C. W. Hughes.

ABSTRACT.

The object of this paper is to describe experiments conducted in quest of a means for decreasing or increasing the rate of thermal radiation from heated surfaces.

Data are given on the emissivity of sheet iron, cotton duck, roofing material, artificial leather, etc., covered with white paint, vitreous enamel, aluminum paint, etc. It was found that aluminum paint emits only 30 to 50 per cent as much thermal radiation as the unpainted material and as the white paint, vitreous glass enamel, or other nonmetallic coatings.

The data are useful in giving a means for reducing the heat radiated from the under side of roofs, tents, awnings, automobile tops, etc. A coating of aluminum paint applied to the top of an apaque canopy—for example, automobile top—reduces by 50 per cent the heat radiated from the under side. A coat of aluminum paint applied to the under side of a cotton duck tent cloth shuts out 85 per cent of the heat rays.

The application of these data to house radiators is discussed. It is shown that, owing to the fact that house radiators are essentially convectors of heat, a gain of only 10 to 15 per cent in heat dissipation into the room may be expected by covering the surface of the radiator with a paint which is free from flakes of metals; for example, aluminum or bronze.

CONTENTS.

I. INTRODUCTION.

The assistance of this bureau is sometimes invoked for a means of preventing the interior of observatories, balloon hangars, etc., from becoming heated, by absorption of solar radiation, by applying a suitable paint to the roof of the structure under consideration. Another type of inquiry received concerning the emissive properties of matter pertains to the use of a suitable paint, which, owing to its high emissivity, will assist in preventing machinery (for example, dynamos, motors, etc.) from becoming overheated. A third line of frequent inquiry is for a suitable paint for increasing the heat dissipation of the ordinary steam house radiator.

The object of this communication is to give data which relate primarily to the use of paints for decreasing the intensity of the radiation from flat surfaces—such as, for example, the under side of a roof or a tent, the inside of a metal wall, etc., which is exposed to the sun.[1]

The application of these data for increasing the emissivity of house radiators is also discussed. Since the writers of this paper have made no tests on steam house radiators, for the purpose of comparison, the data on the efficiency of heat dissipation of different kinds of paints on segmented steam radiators, which were originally obtained by Allen [2] and, 10 years later, by Allen and Rowley,[3] are included in the discussion.

The subject matter to be discussed is based on relatively simple principles. The applications depend upon a few experiments in elementary physics, which many beginners in engineering and other professions have forgotten or which they have passed over with the all too frequently expressed view that such experiments will be of no use in their profession.

One of the first demonstrations in heat radiation given in courses of elementary physics is the Melloni cube, which consists of a cubical metal box of hot water, having one face brightly polished and the other faces covered with lacquer, lampblack, or other paints. By means of a thermopile placed at a short distance from this box it is shown that the intensity of the thermal radiation emitted by the bright metal surface is much less than that emanating from the surfaces which are covered with a nonmetallic paint.

The process of heat transfer by conduction through a solid medium—such as, for example, the walls of a steam radiator—is a molecular vibration. At the surface part of this heat is transferred by thermal conduction to the surrounding air, which thus becomes heated and, by convection, is distributed throughout the room.

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[1] The amount of heat carried away by air convection has not been measured. In the case of a steam radiator, which consists of a number of segments, the heating by air convection is more important than the heating by thermal radiation.

[2] Allen, Elect. World, 57, p. 1616; 1911.

[3] Allen and Rowley, Jour. Amer. Soc. Heat and Vent. Eng., 26, p. 103; 1920.

Part of the heat, which is conducted through the metal in the form of a molecular vibration, is transformed into an ethereal vibration at the surface, and is transmitted throughout the room as thermal radiation or, in more popular language, "radiant heat."

The experiments with the Melloni cube show that the bright uncontaminated metal surface offers a much greater resistance to the transformation of the molecular vibration into the ethereal vibration than a nonmetallic coating applied to this same metal surface.

The experiment with the Melloni cube has, therefore, two important applications, depending whether it is desired to (1) *decrease* or (2) *increase* the process of heat radiation; and it may be enunciated, as a general principle, that clean, bright surfaces of all metals or paints of metal flakes decrease the intensity of thermal radiation (are poor radiators; that is, have a low emissivity), while the nonmetals, or paints of nonmetals (oxides, oxidized metal surfaces, etc.) facilitate or increase the rate of heat radiation.

The temperature being low, this heat radiation is of long-wave lengths, invisible to the eye, and hence the color of the paint, whether red, yellow, green, or white, is no indication of its emissive properties. Aluminum oxide, white-lead paint (which is principally a carbonate of lead), and (green) chromium oxide have as high an emissivity as lampblack paint, and they have more pleasant and harmonious decorative properties as applied to steam pipes and radiators.

The brevity of the data presented in this paper is owing to the fact that the emissive, absorptive, and reflective properties of matter are intimately related. Hence, from previous researches on the (diffuse) reflecting power [4] of various substances (for thermal radiation of wave lengths at 4, 9, and 24 μ) much information can be obtained regarding the emissive properties of nonmetals, etc. These data show that the reflecting power of these nonmetals (excepting the silicates and some carbonates) is low. Hence, the emissivity is high for thermal radiation of wave lengths that would be predominately emitted at temperatures of 30 to 100° C. which obtain in roofs, awnings, steam radiators, etc.

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[4] B. S. Bull., 9, p. 283; 1913 (No. 196). This paper describes experiments on white paints for the outside of observatory domes. The present paper shows that a further reduction of heat radiation into the dome will be effected by painting the under side of the roof with aluminum paint. See also publications Nos. 65 and 97, Carnegie Institution of Washington, 1906 and 1908.

Recent data on the emissive power of oxidized surfaces for temperatures ranging from 200 to 600° C. are given in a paper by Randolph and Overholzer.[5]

Data on the energy radiated by various kinds of wire in a vacuum at various temperatures are given in a paper by Suydham.[6]

Experiments on the effect of still and moving air on heat dissipation have been described by Taylor.[7]

II. METHOD OF TESTING THE EMISSIVITY.

The manner of making the test is extremely simple. Duplicate samples of the same material (for example, tent cloth, roofing for balloon hangars, fabrics for automobile tops, or ordinary sheet

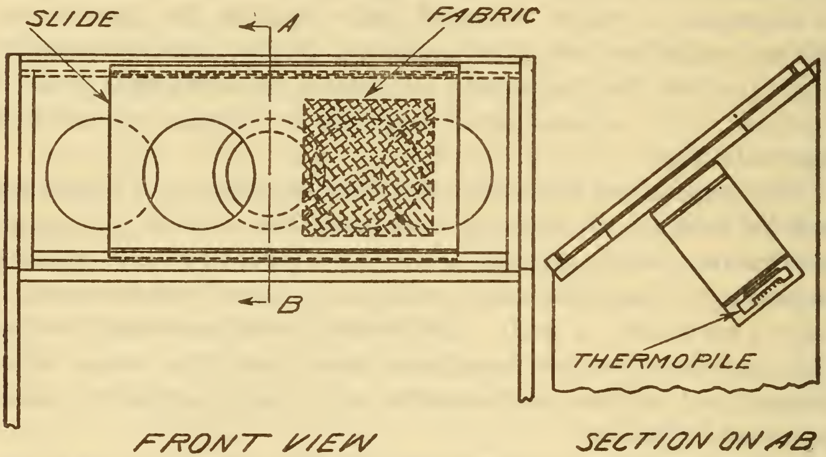

FIG. 1.—*Arrangement of apparatus for comparing the intensity of the heat radiated from painted and unpainted samples of various materials.*

iron) are selected. The under (or upper) side of one sample is coated with aluminum or some other paint. These two samples are then mounted upon a suitable holder, as shown in Figure 1, and exposed to the sun. This holder consisted of a board with two openings 10 cm in diameter, over which were placed the two samples to be tested.

After the two samples have become thoroughly heated by the sun's rays the intensity of the heat radiated from the under side of each one is measured by means of a sensitive thermopile. This was accomplished by sliding the holder, from right to left, by a sufficient amount to bring the sample directly over the thermopile,

[5] Randolph and Overholzer, Phys. Rev. (2), 2, p. 144; 1913.

[6] Suydham, Phys. Rev. (2), 5, p. 497; 1915.

[7] Taylor, Phys. Rev. (2), 15, pp. 218 and 241; 1920; 19, p. 382; 1922.

as shown in Figure 1. In this illustration only one sample is shown in place on the sliding support. The comparison of the radiation intensity of the painted and unpainted samples required only a few minutes, and hence there was no difficulty in obtaining high accuracy.

For measuring the emissivity of paints pieces of sheet iron (150 by 150 by 0.4 to 0.7 mm) were used. The side exposed to the sun was painted with a jet black paint in order to increase the absorption of solar radiation. The under side was covered with two coats of the paint under examination.

The samples of white, vitreous-enameled sheet iron (thickness 1.4 mm) were test pieces obtained from the ceramic division of this bureau. Duplicate samples of preparations marked G_1 and G_3 were examined. In all samples the unenameled surface was painted black and exposed to the sun. The vitreous enameled surface of one sample of G_1 and of G_3 was given two coats of polished aluminum paint.

All tests were made under what may be considered practical working conditions. That is to say, the test sample of white-lead paint (two coats) was put on by a painter using stock material. The aluminum paints (two coats of polished and unpolished) were prepared and applied by E. F. Hickson, of the chemical division, using material which he is investigating in weathering-test panels.

III. PAINTS OF METAL FLAKES FOR DECREASING THERMAL RADIATION FROM THE UNDERSIDE OF CANOPIES.

Prior to making the present tests it was known that paints made of flakes of bronze or aluminum have a much lower emissive power than paints composed of a nonmetal. The object of the present tests was to verify the previous results by a new method of heat application, and thereby determine the emissive power of the metal paints as applied to canopies (for example, tents, awnings, metal roofs, etc.), which are exposed to the sun.

It is, of course, well known that metals have a low emissivity, amounting to only 5 to 10 per cent of that of a perfect radiator, or so-called black body. The present measurements show that aluminum paint has a considerably higher emissivity than a sheet of aluminum. This, no doubt, is owing to the fact that the vehicle (spar varnish) covers the metal flakes and increases their emissivity. These data, however, show that aluminum paint is a ready means for reducing the low-temperature heat radiation from the under side of thin metal roofs, awnings, etc.

In cases where the under side of the metal roof is bright and free from oxide—as, for example, sheet iron covered with zinc or tin—no gain is to be expected in shielding the interior of the structure from heat radiation by applying a coat of aluminum paint to the under side of the roof. In this case the greatest reduction of heating of the interior will be obtained by covering the outside with white paint, "white wash" (in case of small temporary structures), or asbestos.

The observed data are given in Table 1, to which reference may be made for the exact numerical values which form the basis of the practical applications, now to be discussed. In this table the numerical data given in column 3 were obtained by dividing (the galvanometer deflection) the intensity of the radiation emitted from the underside of the sample recorded in column 2 by (the galvanometer deflection) the intensity of the radiation emitted from the under side of the sample recorded in column 1. This ratio is called the "emissivity," although this term should be applied only to comparisons of objects at the same temperature. However, since the numerical value of the emissivity coefficient varies only by about 1 per cent per 10° C. difference in temperature (which is the magnitude of the difference in temperature of the painted and unpainted material) this slight error is negligible in comparison with other factors which enter into the problem.

1. EMISSIVITY OF WHITE LEAD AND LAMPBLACK.

It was found that the intensity of the radiation from the under side of a sheet-iron panel covered with two coats of white-lead paint was the same (to within 4 per cent) as that of a similar panel covered with a dull, black paint, prepared by mixing lampblack with a little shellac in alcohol. The white-lead paint was, therefore, adopted as a standard of comparison (emissivity = 100 per cent) in the measurements on aluminum paint.

TABLE 1.—Emissivity of (Ratio of Intensities of Heat Radiated from) a Painted Flat Surface Compared with a Surface of Similar Unpainted Material Used as a Standard.

Material used as standard.	The same material painted with—	Emissivity of a painted surface compared with the standard.	Remarks.
TENTS, AWNINGS, ETC.			
		Per cent.	
Cotton duck No. 11H, unpainted.	Aluminum on under side	14 to 15	Weight of No. 11H is 13.08 ounces per square yard.
Do	Aluminum on outside	22 to 23	
Cotton duck No. 4H, unpainted.	Aluminum on under side	22 to 25	Weight of No. 4H is 24.54 ounces per square yard.
Cotton duck No. 12H, aluminum on under side.	Cotton duck No. 4H, aluminum on under side.	80 to 81	Weight of No. 12H is 11.45 ounces per square yard.
Cotton duck No. 12H, unpainted.	Cotton duck No. 4H, unpainted	58	Comparison of heavy with light weight material unpainted.
AUTO TOPS.			
Artificial leather, unpainted:	Aluminum on under side:		Weave of cloth backing:
Sample No. 1	Sample No. 1	44	Twilled.
Sample No. 2	Sample No. 2	39	Do.
Sample No. 3	Sample No. 3	47	Do.
	Aluminum on outside:		
Sample No. 1	Sample No. 1	30	Do.
Sample No. 2	Sample No. 2	25	Do.
Sample No. 3	Sample No. 3	27	Do.
BALLOON FABRICS.			
Rubberized cloth; rubber outside.	Aluminum on outside	45	Plain weave, cloth backing.
ROOFING MATERIAL.			
Asbestos	Aluminum on under side	55	Johns-Manville asbestos roofing.
Cypress shingle, unpainted	do	43	Thickness, 1/2 inch; natural color.
PAINTS, ENAMELS.			
Unpolished aluminum	Polished aluminum	100	Sheet iron coated with aluminum paint.
White paint	Lampblack paint	95 to 100	
Do	Aluminum paint	28 to 29	
Vitreous enamel	do	27 to 30	Samples G_3 and G_1, respectively.
White paint	Vitreous enamel	98 to 100	
Lampblack	do	95 to 98	

2. EMISSIVITY OF ALUMINUM PAINT.

The aluminum paints used in these tests were prepared by the chemistry division, as already mentioned. The manner of preparation is based upon the experience of the Navy Department, together with the recommendations of the Aluminum Co. of America in their recent booklet on "Aluminum Paint," page 6.

The paints were prepared by mixing 2 pounds of powder to 1 gallon of varnish, giving a finished paint containing about 21 per cent by weight of aluminum powder and 79 per cent by weight of spar varnish. The two grades of aluminum powder used were "standard polished" and "standard unpolished," both from the Aluminum Co. of America. The liquid used for both aluminum powders was "valspar" spar varnish from Valentine & Co. The unpolished "standard" aluminum powder absorbs more liquid (varnish) than the polished "standard," but both paints were of good brushing consistency. A two-coat job was made in each case.

The backs of these metal panels (to be exposed to the sun) were painted with two coats of ordinary drop black in Japan, thinned to good brushing consistency with turpentine, causing the paint to dry flat, as requested. These panels were prepared in duplicate in order to determine the variation in emissivity of samples of the same material. The results of these tests show that within the errors of observation (which varied by 3 to 5 per cent from day to day, owing to unsteadiness of atmospheric conditions) the duplicate samples had the same emissivity.

By direct comparison of the two samples it was found that (within 2 per cent) there was no difference in the emissivity of the polished and the unpolished samples of aluminum examined. This is probably to be expected in spite of the fact that the unpolished material produced a more granular coat than obtained in the polished sample.

A comparison of the intensity of the radiation emitted from the under side of the above-mentioned panel of sheet iron coated with aluminum paint, with a similar panel of sheet iron coated with white-lead paint, shows that, under these conditions, the aluminum paint emitted only from 28 to 29 per cent as much thermal radiation as the white paint.

3. EMISSIVITY OF ALUMINUM-COATED AWNINGS AND TENTS.

In canopies of white cotton cloth, such as used for tents, awnings, motor boats, etc., there is some sunlight transmitted directly through the fabric in addition to the heat reradiated from the under side as the result of warming of the material by solar radiation.

In these tests hard-texture cotton duck was used. One test consisted in comparing the heat transmitted through and emitted by unpainted samples of light-weight cotton duck (No. 12H, weighing 11.45 ounces per square yard) with heavy-weight cotton duck (No. 4, weighing 24.54 ounces per square yard) exposed to the sun. The results of this test show that the intensity of the thermal radiation emanating from the under side of the heavier sample was only about 58 per cent that of the lighter-weight material, indicating the greater shielding value of the heavier material.

By coating the under side of a light-weight (No. 11) sample of cotton duck with aluminum paint and exposing the clean, unpainted outer surface of the two samples to the sun it was found that the intensity of the heat radiated from the under side of the painted sample was only about 15 per cent that of the unpainted sample.

Painting the outside of the cloth appeared to be slightly less effective, the intensity of the heat radiated from the under side being about 22 per cent that of the unpainted sample.

However, whether the coating is applied on the inside or the outside, there will, no doubt, be many instances where the possibility of shutting out four-fifths of this heat radiation is worthy of consideration.

If the cloth has become soiled, the proper procedure would be to cover the outside with white-lead paint, which is a good reflector of solar radiation, and the inside with aluminum paint, which reduces the intensity of the heat reradiated from the cloth as a result of warming by absorption of solar radiation.

It has been suggested to protect fruit (for example, orange) trees from frost by covering them with paper bags, which are inexpensive and appear to be a feasible means for preventing freezing.

Coverings of paper, cloth, etc., have a high emissivity. From the foregoing data on the reduction in the emissivity of materials covered with a metal paint, it would appear that, by using paper bags covered with aluminum or bronze paint, the rate of cooling would be retarded and the proper temperature within the inclosure would be maintained more easily and at less expense in fuel. This, of course, applies also to tents.

4. EMISSIVITY TESTS OF ALUMINUM-COATED AUTOMOBILE TOPS.

Coverings of conveyances—such as, for example, the tops of automobiles, ice wagons, etc.—consist of cloth, "artificial leather," the black composition of which absorbs, perhaps, 90 per cent of the sun's rays. Practically half of this is reradiated from the under side of the canopy.

In these tests three different types of commercial material (Nos. 1, 2, and 3 in Table 1) were used. Sample No. 1 was a single fabric backing forming the foundation for the outer coating of rubber composition. Sample No. 2 consisted of two fabrics, between which was a thin layer of rubber-friction stock, and the outside of which was covered with a rubber composition. Sample No. 3 was a double-texture fabric frictioned with rubber and coated with a rubber composition.

These samples of "artificial leather," having the outside covered with a coating of aluminum paint, emitted only 25 to 30 per cent as much heat radiation from the under side as the uncoated samples.

When the aluminum paint was applied on the under side, which is rough woven, the heat emitted (from the under side) was 40 to 45 per cent that of the unpainted sample. From this it appears that, by applying the aluminum paint to the smooth outside of this fabric, the heat radiated from the under side will be reduced by 70 to 75 per cent.

The automobile top is mentioned merely as one of numerous applications that can be made of aluminum paint in diminishing heat radiation entering an inclosure which it is desired to keep cool. It is a simple expedient easily applied.

The rubber gas balloon is an excellent example in which it is important to reduce the heating of the inclosure. By painting the outside of the balloon fabric with aluminum paint the radiation into the interior is reduced to 45 per cent of that of the unpainted fabric.

5. EMISSIVITY TESTS OF ALUMINUM-COATED ROOFING MATERIALS.

A cypress shingle one-half inch in thickness, having a coating of aluminum paint on the under side, emitted only 43 per cent as much heat (from the under side) as an uncoated shingle of the same thickness. Similar tests on a 1-inch cypress board showed practically no difference in emissivity. Evidently in thick coverings of wood the question of painting is unimportant. This is owing to the poor heat conductivity of the wood.

Some interesting data were obtained on the emissivity of thin sheet iron covered with asbestos. The particular type of material examined was the three-ply Johns-Manville corrugated asbestos roofing, which consists of a thin sheet of metal covered on both sides with impregnated asbestos felt. Samples of similarly coated material were tested in which the asbestos was covered (on both sides of the sample) with aluminum paint or sprayed zinc.

From consideration of the emissive, absorptive, and reflective properties of these materials it appears that all three of these types of roofing are incorrect in principle when it is desired to decrease the intensity of the reradiation from the under side. This is owing to the fact that aluminum and zinc absorb more (reflect less) solar radiation than asbestos. As a result a roof coated on the outside with these metals becomes much hotter than a similar roof covered with a white reflecting material; for example, white paint or asbestos. (See Table No. 2.) From these considerations it appeared that the most efficient arrangement is to use the roofing material with the outside asbestos coat unpainted, as obtained in commerce, and to reduce the emissivity of the asbestos coat, which is on the under side, by painting it with aluminum. As shown in Table 2, the results obtained confirm our expectations. The sample which had only the under side coated with aluminum transmits only about one-half as much heat to the interior of an inclosure (for example, balloon hangars) as the unpainted material. The sample which was coated with aluminum paint on both sides is not so efficient in mitigating the heat radiation, and, moreover, would probably not stand weathering conditions.

TABLE 2.—Showing the Temperature of a Sample of Roofing Material Above the Shade Temperature (29° C., 84° F.); also its Emissivity when Painted as Compared with a Surface of Similar Unpainted Material Used as a Standard.

Sample.		Temperature of sample.		Emissivity.	Remarks.
Standard outside covered with—	Under side covered with—	°C.	°F.	Per cent.	
Asbestos	Asbestos	44	112	100	
Aluminum	Aluminun	52	126	72	
Asbestos	do	45	113	55	Best arrangement.
Zinc	Zinc	55	131	—	

No emissive tests were made on the sample which had both sides covered with arc-sprayed zinc in view of the high temperature rise of the material exposed to the sun. This showed the impracticability of the use of the zinc coating on the outside. But, as a means of reducing the reradiation from the under side a (sprayed) coating of zinc should be quite as efficient as the aluminum.

No tests were made on the emissivity of a sprayed coat of aluminum as compared with a similar coating of aluminum paint. While there may be a slight difference in the emissive properties of these two types of aluminum coatings, it does not appear to be very important in practical engineering applications.

From the foregoing tests it appears that the best arrangement is therefore a coating of asbestos or white paint on the outside to reflect as much as possible of the incident solar radiation, and a coating of aluminum paint on the under side to reduce the intensity of the low-temperature thermal radiation emitted by the heated metal roof.

As already mentioned, if the under side of the metal roof is bright galvanized iron or tin no marked gain is to be expected in reduction of intensity of the reradiation from the under side by applying a coating of aluminum paint, though some mitigation would result from applying a coating of white paint on the outside.

IV. PAINTS OF NONMETALLIC PARTICLES FOR INCREASING THERMAL RADIATION.

As already stated, the present emissive tests of paints of nonmetals and of vitreous enamels are not extensive. The object in view is mainly to check the results of previous investigations by a novel method which does not involve thermal convection. The application of the data to increasing the heat dissipation of house radiators, which are really convectors of heat, will be discussed, although this is only incidental to the main purpose of the present investigation.

1. EMISSIVITY OF WHITE LEAD AND LAMPBLACK PAINTS.

As already mentioned in the preceding caption, the intensity of the thermal radiation emitted by a rough coating of lampblack paint and a similar coating of white-lead paint was found to be the same within 4 per cent, which is within the errors of observation, including the preparation of the lampblack paint, which was a dull matte surface. From previous researches on the emissive, absorptive, and reflective properties of matter there is reason for believing that there is no marked difference in the low-temperature emissive properties of the nonmetallic materials that are suitable for paints. Hence, these two substances were selected as typical examples.

The emissive properties of paints of bronze, aluminum, iron oxide, zinc oxide, green and white enamel, terra cotta, etc., applied to steam house radiators were previously studied by Allen.[8] He found that the paints and enamels composed of nonmetals had practically (within 5 per cent) the same emissive properties. The paints containing flakes of aluminum or bronze had an appreciably (20 to 25 per cent) lower emissivity, which, as already stated, is to be expected from our knowledge of the low emissive properties of metals. The reason that he did not find a still lower emissivity for the metal paints is to be ascribed to the fact that his tests were made on segmented steam radiators, which are essentially convectors of heat, and, hence, the emissivity of the surface is of secondary importance.

2. EMISSIVITY OF VITREOUS ENAMEL.

No data appeared to be at hand on the emissivity of sheet iron covered with (white) vitreous enamel. The samples examined were test panels (of commercial enamel) prepared by the ceramic division of this bureau in connection with its investigations of vitreous enameling preparations. The intensity of the thermal radiation emitted by the various samples of aluminum-covered enamel was 27 to 30 per cent that of the clean vitreous enameled surface, which is practically the same as was found in the comparison of the emissivity of aluminum with white-lead paint. From this it appears that the emissivity of vitreous enamel is as high as that of white-lead paint. This is in agreement with expectations.

If no other engineering difficulties are encountered—for example, scaling and cracking of the enamel—there will, no doubt, be a use found for vitreous enameled radiators and heating coils.

V. CONCERNING A MEANS FOR INCREASING THE HEAT DISSIPATION OF RADIATORS.

For aesthetic reasons, and also because it seems to be the custom, the radiators used in heating buildings are usually coated with aluminum or bronze paint. From the viewpoint of obtaining the maximum amount of heat from a radiator of a given size aluminum or bronze paints are the most inefficient materials that can be applied.

However, from the results of the foregoing tests, we must not jump to the conclusion, which unfortunately has been given

[8] Allen, Elect. World, 57, p. 1616; 1911.

considerable publicity, that the ordinary steam radiator can be made to emit three times as much heat by applying a coat of nonmetallic paint. As stated in the beginning, the ordinary steam radiator is really a convector of heat. It is so constructed that the room becomes heated principally by thermal conduction and convection of the air which circulates over and between the sections of the radiator.

In this connection it is appropriate to discuss some tests made by Allen [9] on radiators coated with various substances, such as aluminum and copper bronze, terra-cotta enamel, white paint, etc.

Out of about two dozen tests on various paints he found that the aluminum and copper bronze coverings always diminished the heat dissipated by 24 to 28 per cent below that of the nonmetallic paints. In subsequent tests, which will be noticed presently, the values obtained were 17 to 20 per cent below that of the nonmetallic paints. Merely covering the aluminum paint with a coat of terra-cotta enamel increased the heat dissipation by about 28 per cent.

Allen's tests were made on commercial household installations, and, while the experiments are subject to improvement in fine details, the essential parts of his results are of special interest to the engineer.

In the above-cited investigations of Allen, also of Allen and Rowley,[10] an analysis is made of the efficiency of different kinds of paints; also the relative amount of heat dissipated by air convection and by thermal radiation from various types of radiators.

A single pipe, in a horizontal position, loses relatively more heat by radiation than by air convection; but placing the pipe in a vertical position increases the heat lost by convection.

According to the experiments reported by Allen (loc. cit., p. 236) in a wall-coil type (5–A) of radiator, 47 per cent of the heat is given off by convection and 53 per cent by radiation. He calls this a radiator of heat. He found (loc. cit., p. 312) that the coefficient of emissivity of the aluminum coating was about 50 per cent less than that of the other surfaces. From this and from the foregoing tests of the emissivity of aluminum and other paints, it appears that the total heat dissipation from a wall-coil or single-tube radiator can be appreciably increased (perhaps 25 to 35 per cent) by the application of a coat of paint which is free from flakes of pure metal.

[9] Allen, Elect. World, 57, p. 1616; June 22, 1911.

[10] Allen and Rowley, Jour. Amer. Soc. Heat. and Vent. Eng., 26, pp. 103, 305; 1920.

In the more commonly used radiator, consisting of two or more columns and four or more sections, relatively more heat is dissipated by air convection than by thermal radiation. Hence, the kind of paint applied to the surface of a multisection house radiator is of relatively less importance.

In a 2-column radiator of 13 sections Allen found that of the total heat dissipated about 30 per cent was lost by radiation and about 70 per cent by convection. For a 4-column radiator the figures were 27 and 73 per cent, respectively. Allen calls this a convector of heat; but even in this case (loc. cit., p. 317) the aluminum paint dissipated only about 81 per cent (347 Btu per unit surface) as much heat as the nonmetallic surface (428 Btu) or the rusty or black paint surface.

These tests indicate that in a radiator consisting of a number of sections the heat carried away by convection between the sections is a large percentage (Allen's values range from 50 to 73 per cent, depending upon the type of radiator) of the total heat given out, and that the heat lost by radiation from the sides of the radiator is relatively of secondary importance. Hence, the use of a covering which is an inefficient emitter of thermal radiation is not so serious as it would appear from our tests of flat surfaces.

However, a gain of even 10 to 15 per cent in heat dissipation into the room by using a nonmetallic covering is worth considering. By nonmetallic paint is meant any covering which does not have the pure metal flakes, such as bronze or aluminum. The various pigments offer a great variety of tints for decorative purposes with greater efficiency in heat dissipation. It is true that this energy is in the form of radiant heat, which is useful only to the object upon which it impinges and is absorbed. Nevertheless, judging from the radiant heaters (electrically-heated coils with reflectors) there is some advantage in having this extra heat dissipation in the room.

In conclusion it may be added that it is unnecessary to remove the old coat of aluminum paint before applying the coat of nonmetallic paint. This is owing to the fact that the aluminum paint, which has a high thermal conductivity, becomes simply part of the metal wall of the radiator.

VI. CONCLUDING REMARKS AND SUMMARY.

It is beyond the scope of this paper to attempt to mention the numerous applications of data of this type. Suffice it to add one or two instances of saving in fuel by reducing the loss in heat by radiation from the object which is being heated. Take, for example, an ordinary household utensil—an aluminum kettle—which is easily tarnished by contact with a gas flame. Removing the tarnish reduces the radiation from its sides. This is one of the little things, but they all count in the month's gas bill.

Another example worth citing was given by a former colleague interested in the manufacture of Portland cement. By applying a coat of aluminum paint to the outside of the kiln he was astonished to find that the saving of fuel could be measured in tons of coal.

From the foregoing data it seems that owners of small heating installations (whether hot air or steam) could save fuel and money by preventing heat losses from the furnace and rusty, dusty, pipes leading from the furnace to the radiator by covering them with a good coating of aluminum paint. A clean galvanized pipe is probably as effective as the aluminum paint. Then, in the rooms that are to be heated by steam, apply to the pipes and the radiators a coating of nonmetallic paint; for example, white lead, zinc oxide, chromium oxide, enamels, etc. No doubt a covering of heat-insulating material on the furnace and on the concealed pipes leading from the basement to the upstair rooms would be more effective than aluminum paint for retaining the heat within the pipe; but the relative cost of installation and upkeep of heat-insulating coverings as compared with the application of aluminum paint on the bare pipe must also be considered. However, the aluminum and other paints are easily applied without great expense, so that some benefit should be easily obtainable.

In the foregoing pages experiments are described on the emissivity of sheet iron, fabrics, etc., covered with white paint, vitreous enamel, aluminum paint, etc. The results of these tests are of interest in connection with the question of suppressing the heat radiated from the under side of roofing material, tents, awnings, covered conveyances (motor buses), etc., when exposed to the sun. Data are given showing that a coating of aluminum paint emits only 30 to 50 per cent as much as white paint, vitreous glass enamel, or other nonmetallic surfaces.

The application of this information to the painting of radiators for heating houses is obvious; but the gain in heating by covering the surface with a nonmetallic paint is not two to three times that of the aluminum paint, as might be inferred from the abovementioned data. This is owing to the fact that the ordinary steam-heated radiator is in reality a convector of heat, the heat dissipated into the room by radiation from the sides being relatively of secondary importance.

For example, in a 2-column radiator of 13 sections, Allen and Rowley found that of the total heat dissipated about 30 per cent was lost by radiation and 70 per cent by convection. When this radiator was covered with aluminum paint, it dissipated only about 81 per cent as much heat as the nonmetallic covering.

This is in substantial agreement with the tests reported by Allen 10 years earlier, in which the radiators covered with aluminum paint dissipated only 72 to 76 per cent as much as the coverings which did not contain flakes of metal, aluminum, or bronze. From this it appears that we may expect to gain 10 to 15 per cent in heat dissipation into the room by covering the ordinary multisegmented house radiator with a nonmetallic paint. This is worth considering.

By nonmetallic paint is meant a material which does not contain the flakes of pure metal, whether aluminum or bronze. If the radiator happens to be coated with aluminum paint, the nonmetallic coat can be painted over the aluminum paint, which is a good conductor of heat and hence does not impede thermal conduction through the walls of the radiator. This nonmetallic coating need not be black paint. The white lead and zinc oxide paints and enamels, the chrome colored pigments, the greenish colored oxides, such as chromium oxide, etc., offer a variety of tints for decorative purposes, with greater efficiency in heat dissipation.[11]

WASHINGTON, November 20, 1923.

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[11] In connection with the foregoing discussion of the application of paints for decreasing or increasing the emissivity of surfaces, reference may be made to a treatise on "Aluminum Paint," recently issued by the Aluminum Co. of America, Pittsburgh, Pa., and to "Professional bulletin No. 4," issued by the Sherwin-Williams Co., Cleveland, Ohio.