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Dropwise vs filmwise condensation of steam on chromium

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Abstract—The question of whether steam condenses in the dropwise form or filmwise on chromium has been uncertain for over 50 years. This study uses steam condensing at atmospheric pressure on a vertical, 25.4 mm diameter disc of chromium electroplate and on 99.9% pure metallic chromium formed by powder metallurgy. Uncontaminated surfaces always result in filmwise condensation. Dropwise condensation lasting over 3000 h takes place on the pure metallic chromium which has been vacuum impregnated with oleic acid promoter.

INTRODUCTION

DROPWISE CONDENSATION has a significantly higher heat transfer coefficient than filmwise condensation. This holds promise for commercial heat exchangers. Nevertheless, dropwise condensation is not used in commercial equipment. The reason is that filmwise condensation seems to be a normal occurrence, whereas dropwise condensation requires a special surface. The special surface can be achieved by the use of organic promoters. But these wash off in a matter of days or even hours. Many such promoters are named in a survey which lists 185 references [1].

Dropwise condensation lasting for months or years has been reported for steam on noble metals with no added promoter. Successful gold surfaces are described in 17 references [2]. Other noble metals used with success include silver [3, 4], rhodium [3], and palladium [3].

Chromium is not a noble metal, but it has excellent durability and resistance to corrosion. It is less expensive than noble metals and is thus of interest as a possible surface for dropwise condensation. The object of this study was to determine under what conditions clean steam would condense in the dropwise manner on chromium electroplated on a base metal as well as on pure solid chromium. The action of a promoter, oleic acid, was examined also.

PRIOR WORK WITH CHROMIUM

The first paper on dropwise condensation, by Schmidt *et al.* [5], was published in 1930. It included some tests with steam on chromium-plated copper. Dropwise condensation occurred, even with no added promoter. The steam supply had been filtered through a bed of gravel and by today's research standards would probably be considered 'dirty' steam. Drew and co-workers [6, 7] reported dropwise condensation on unpromoted chromium-plated brass when they used rubber seals. Later when the rubber was replaced with cotton seals, only filmwise condensation occurred on unpromoted chromium [8]. Other investigators who obtained dropwise condensation on unpromoted chromium include Erb [9], Sundararaman and Venkatram [10–13], and Tanaka and Tsuruta [14, 15]. Investigators who used promoters to achieve dropwise condensation on chromium include Vaaler [16], Watson *et al.* [17], and Tanner *et al.* [18].

The role of chromium surfaces seems unsure because of three deficiencies in some of the prior work. Most, if not all, of these investigators used plated surfaces produced commercially; information as to the actual electroplate composition is lacking. Next, ideas as to what is meant by pure steam have changed greatly over the years. Steam with nano impurities can be achieved today, but not in earlier days. Lastly, the cleanliness of the boiler, flow lines, windows, gaskets, etc. was sometimes achieved in a manner which is considered inadequate by the present authors.

EXPERIMENTAL

Condensation tests were made with steam at atmospheric pressure in contact with a 25.4 mm diameter, circular, vertical condensing surface. Usually the test surface was chromium plated on a piece of pure copper, 6.35 mm thick. A thermocouple in the test piece monitored the temperature at a known position. Before the copper pieces were plated they were polished to a mirror finish using 0.05 μm alumina and then cathodically electropolished in a hot aqueous bath of sodium phosphate and sodium carbonate. Some experiments were made with a test piece of solid pure chromium. This was polished to a fine finish also, but the surface was not shiny, presumably because the solid was formed by powder metallurgy.

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NOMENCLATURE

g	acceleration of gravity
h	steam-side heat transfer coefficient
k	thermal conductivity of liquid
q	heat flux
R	radius of disc
ΔT	steam-to-metal surface temperature difference.

Greek symbols

λ	latent heat of condensation
μ	viscosity of liquid
ρ	density of liquid.

Heat transfer equipment

The condensation tests took place in the condensing cell shown in Fig. 1(a). The design was similar to condensing cells used previously [4, 19, 20]. A window was mounted in the cell so that visual and photographic observations of the condensing surface could be made. A copper–constantan thermocouple was used to monitor the steam temperature.

Cooling water was supplied to the back of the test piece from a constant head tank or from a gear pump. The coolant impinged on the back of the test piece and exited at the top of the coolant chamber. Thermocouples in the cooling water flow measured its temperature in and out. For a test piece of 6.35 mm length, such as depicted in Fig. 1(a), its thermocouple wires fit into a groove cut in the threads of the cooling chamber. A digital voltmeter was used to monitor all the thermocouples.

Steam at atmospheric pressure was generated by two 400 W immersion heaters mounted in a 4 l stainless steel boiler. As shown in Fig. 1(b), the steam flowed through stainless steel tubing entering the left-hand side of the steam chamber and condensed on the test cooling surface. Excess steam was always used, except where noted. The excess exited the right-hand side of the steam chamber and entered a glass auxiliary condenser. Both the main and auxiliary condensates flowed through stainless steel U-tube traps and were metered. During a run the equipment was a once-through steam flow system. During warm-up, the main and auxiliary condensate flows were recycled, by a valve system, back to the boiler.

Through the entire steam system, steam and condensate contacted only stainless steel, glass, Teflon seals, and the condensing surface. To avoid organic contamination, the steam system was cleaned with trichlorethylene, then methanol, then deionized water, a hot alkaline solution, and again deionized water. Then hydrogen peroxide was boiled in the assembled equipment to generate oxygen, which is destructive of organics. The inside of the clean equipment was never touched by human hands, and the condensing cell was never opened unless steam was flowing through it.

To start a heat transfer test, the test piece was rinsed thoroughly and was mounted into the steam chamber while steam was flowing through the system. This procedure minimized contact with air. The cooling water flow was started and was measured with calibrated rotameters. Heat transfer data were taken at timed intervals, thus a history was obtained for each set of test conditions. When needed, boiling make-up water was added to the boiler. The water was from a Barnstead Nanopure purification system which included ion exchange resins and activated carbon. Its resistivity was greater than 12×10^6 Ω cm, and its organic carbon content was below 0.5 mg l^{-1} which is the detection limit of the Illinois State Water Survey.

Heat transfer data included two independent measurements of the heat flux, namely from the condensate rate from the test piece and also from the cooling water heat pickup. These usually agreed to within 5%, inasmuch as the entire equipment was well insulated with glass wool. The condensing surface temperature was calculated from knowledge of the heat flux through the test piece and the temperature at a known position in the test piece. These data allowed calculation of the surface subcooling ΔT and the steam-side heat transfer coefficient h.

Surface examination

Visual observations and photographs of the condensation were made periodically. At the end of most tests, the test piece was removed while steam was still flowing, and it was placed in a covered culture dish. This was taken to the Auger electron spectroscope located in a nearby building. AES analysis is an ultrahigh vacuum technique which uses an electron source to excite the surface atoms. This method allows quantitative analysis of the elements (except hydrogen) on the surface.

Solid chromium test piece

Certain tests were made with a solid test piece of 99.9% chromium obtained from Atomergic Chemetals Corp., Plainview, New York. It has been formed as a hot-pressed cylinder using powder metallurgy techniques. Its measured density was 5767 kg m^{-3} which is lower than the handbook value of 7190 kg m^{-3}. By calculation the volume is therefore 19.8% voids, not an unusual result from powder metallurgy. A test piece of 19.05 mm length was formed on an electrical discharge machine (EDM) as indicated in Fig. 2. Four thermocouple holes, cut by an EDM along radii at 90° intervals around the circumference,

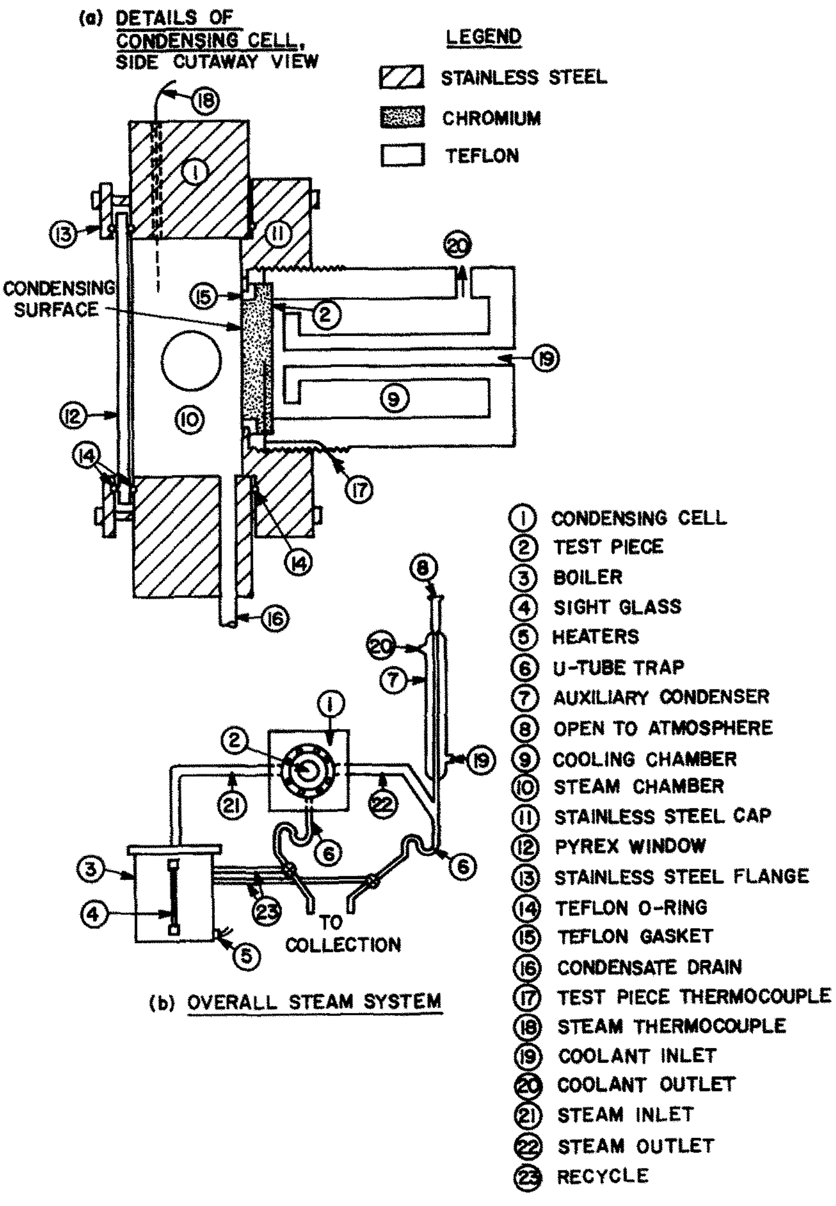

Fig. 1. Sketch of the condensing test equipment.

permitted four thermocouples to be located at known positions along the geometric axis. The test piece was used in the condensing cell, and the temperature gradient was measured for a variety of heat fluxes. This led to a calculation of the conductivity. The measured thermal conductivity was found to be 40.7 J s^{-1} m^{-1} K^{-1} at an average metal temperature of about 60°C. This is 44% of the handbook value for chromium free of voids. Later the chromium test piece was shortened to 6.35 mm, retaining only thermocouple 1 of Fig. 2, so that runs at higher heat fluxes could be made.

Chromium plating

When chromium electroplating is carried out commercially, organic brighteners are sometimes added to the plating solution or to a nickel plating solution sometimes used as an undercoat. For the present study, organic materials were not wanted. Therefore, the electroplating was carried out by one of the authors [21] under known conditions. A standard composition of 124 g CrO_3 and 0.68 ml concentrated H_2SO_4 in a 500 ml aqueous bath was used in a Teflon plating cell with a copper test piece cathode and a 96% lead–4% tin anode. The solution and plating conditions used were as recommended by Fernald [22]. The bath was discarded after one use.

The plating system used a current integrator to count coulombs. Many competing reactions occur when electricity passes through a chromium plating bath, and the plating efficiency for the deposition of

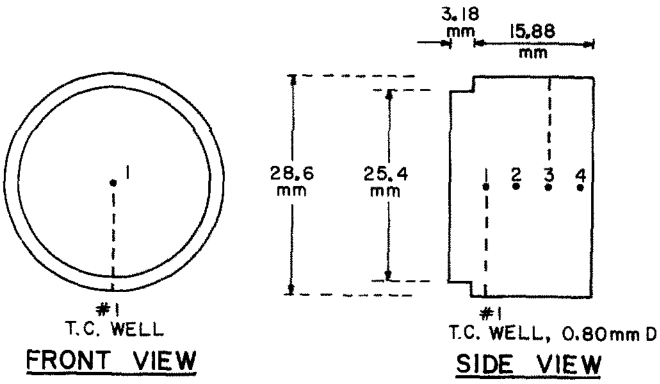

Fig. 2. Sketch of the solid chromium test piece as used for determination of thermal conductivity and for condensing runs at low heat fluxes. The length was reduced to 6.35 mm for runs at high heat fluxes.

chromium is not 100%. A series of calibration tests was carried out to obtain a standard curve for coulombs used vs chromium plate thickness. The procedure involved dissolving the electroplate and doing a quantitative chemical analysis for chromium. The procedure is described elsewhere in detail [21]. The plating efficiency was found to be about 14% for the thinnest coatings and about 20% for the thickest, with a continuous gradation. Literature values for efficiency during chromium plating are usually near 15%, confirming our findings.

RESULTS

Chromium electroplate

Chromium electroplate, on base metal carefully cleaned as described above, yielded only filmwise condensation with steam. Figure 3 shows a graph of Nusselt's equation for filmwise condensation

$$q = 0.83404\,[k^3\rho^2 g\lambda/(\mu R)]^{1/4}\Delta T^{3/4} \qquad (1)$$

modified for a vertical disc [4]. This derivation involves the assumption of laminar flow of the condensate. This equation is a satisfactory description of the data obtained for steam condensing on pure copper, chromium on copper, and chromium on nickel on copper. For these, the condensate flow was definitely laminar, both to the eye and by calculation of the Reynolds number.

Figure 3 shows that, in sharp contrast, dropwise condensation occurred when steam condensed on gold electroplated on copper [19] and silver electroplated on copper [4, 21]. Those prior researchers [4, 19, 21] concluded that gold and silver electroplates are powerful adsorbers of trace organic materials from the surroundings and that these adsorbed organics cause dropwise condensation of steam. The results herein indicate that clean chromium electroplate is a poor adsorber, compared to gold and silver. For example, our chromium-plated test pieces exhibited no development of dropwise condensation for runs up to 500 h. This contrasts with runs by the present

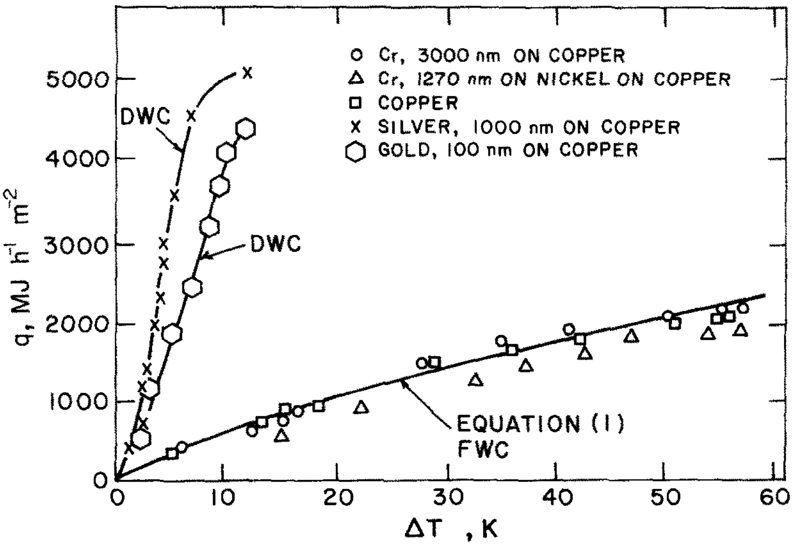

Fig. 3. When no promoter is used, chromium electroplate gives filmwise condensation, but gold and silver electroplate give dropwise condensation.

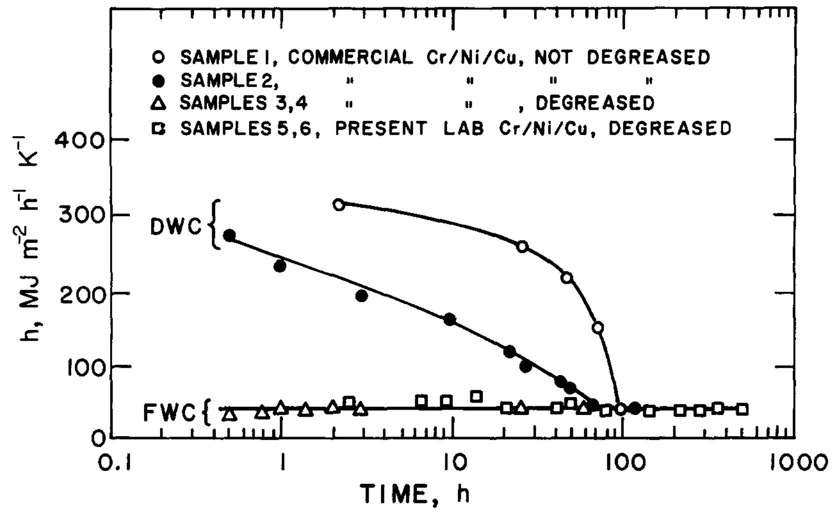

FIG. 4. Commercial chrome electroplate tested as supplied (upper curves) and with degreasing (lower curve). Constant coolant flow rate of 42.6 kg h^{-1}.

authors using a silver-plated piece which showed filmwise condensation at the start, but this changed gradually to dropwise condensation within 6 h. Reference [4] reported similar results with silver.

Prior research concerning steam condensation on electroplated gold [23] and silver [4] found that there was a critical minimum thickness of those noble metals needed to obtain dropwise condensation. Smaller thicknesses resulted in filmwise or mixed condensation. It is of interest to know whether a critical thickness exists for chromium electroplate. Tests were made with chromium thicknesses up to 3000 nm on copper. All resulted in filmwise condensation with data in agreement with the modified Nusselt equation (1). Tests were also made with chromium thicknesses up to 300 nm on nickel on copper. All these produced filmwise condensation. If a critical thickness does exist for chromium, it is greater than 3000 nm. This is much greater than the critical thickness of 200 nm for gold and 100 nm for silver. We conclude that no chromium thickness exists which will produce long-lasting dropwise condensation.

Commercial chromium electroplate

Prior tests by others with steam condensing on chromium used commercial chromium electroplates produced off-site by vendors. Some of these surfaces produced dropwise condensation. As a part of the present investigation, four commercial chromium electroplate deposits were tested. These were 'decorative' chrome plate consisting of 1270 nm of chromium (vendor's statement) on 'bright' nickel on copper. These were produced in Danville, Illinois, by the Newmister Plating Company. The vendor stated that no organic material was put in the chromium plating bath but that an organic brightener was present in the nickel bath.

Figure 4 shows the results. Dropwise condensation was observed initially and the heat transfer coefficient then was as high as 306 MJ m^{-2} h^{-1} K^{-1} for two commercial specimens tested as supplied. But the heat transfer coefficient slowly decreased, and in 75–100 h the condensation was completely filmwise. This is a case of wash-off of an unknown, unintended, promoter. Two other specimens from the commercial plater were degreased in methanol, then trichlorethylene, and then hot alkaline solutions. Figure 4 shows the test results. These gave filmwise condensation continuously, with a coefficient of about 41 MJ m^{-2} h^{-1} K^{-1}. Clearly the unintentional promoter had been removed during degreasing. Also shown in Fig. 4, are the results for two test pieces electroplated in our laboratories with 300 nm chromium on nickel on copper, followed by degreasing. These gave filmwise condensation continuously for 500 h.

Exposure to air

For the usual runs, exposure to air was kept very low. The test piece was kept wet with water, after preparation, and was inserted into the test cell while steam was continuously flowing through. No contact of air on dry chromium occurred. In addition, the steam flow rate to the test piece was in excess of the condensation rate, and the excess steam went to an auxiliary condenser. Thus migration of air from the laboratory into the vent of the auxiliary condenser and thence into the test cell, counter to flowing steam, was minimized.

It was of interest to discover what might happen if air exposure was permitted. Two types of exposure were used. One consisted of letting the test piece remain in room air for 18 h before it was inserted in the test cell. The test piece produced filmwise condensation only. This is in sharp contrast to gold and silver; for those noble metals an air exposure of a few minutes will produce dropwise condensation. Apparently gold and silver are effective in adsorbing organics from air which serve as promoters. Chromium is an ineffective adsorber.

The second type of air exposure was brought about by using deliberately a too-low boilup rate in the boiler such that no excess steam was produced and no steam entered the auxiliary condenser. Air could back up from the vent through the auxiliary condenser and into the test cell. The resulting heat transfer measurements showed that the heat transfer coefficients were smaller than for filmwise condensation of pure steam at the same ΔT. However, the visual appearance was a surprise. To the eye, dropwise condensation was the evident phenomenon. Subsequently when the steam generation rate was increased, the heat transfer coefficient increased, and the appearance of the condensation changed to filmwise. The reversible change from evident dropwise to filmwise was observed repeatedly as the steam flow rate was changed from deficient flow to surplus flow and back again. We must now stress that dropwise condensation must not be judged by sight alone. The heat transfer measurement is of prime importance. By dropwise condensation, most writers correctly mean that drops are seen on the surface, and the heat flux is much greater than predicted by Nusselt's equation for filmwise condensation. We must be aware that an apparent dropwise condensation can exist during which drops are seen but the heat flux is small, in fact sometimes even smaller than predicted for filmwise condensation. This apparent dropwise condensation is caused by the presence of air in the condensing cell. Takeyama and Shimizu [24] also point out that dropwise condensation can occur in the presence of non-condensible gases under the same conditions where filmwise condensation would occur if the noncondensibles were not present. This is the process which occurs when humid air is in contact with a surface which is colder than the dewpoint. Why dew formation should occur as drops rather than a film is not known.

Solid chromium test piece

Condensation tests with the solid chromium test piece gave ordinary filmwise condensation. Results at low heat fluxes, made with the 19 mm thick piece, and at high heat fluxes, made with the 6.35 mm piece gave results in agreement with the modified Nusselt equation for filmwise condensation. The surface cleaning had been by solvent immersion, such as produced dropwise condensation on gold and silver. Chromium in contact with condensing steam does not act like a noble metal.

Promoted surfaces

The deliberate application of a common promoter, oleic acid, was investigated to see whether promoted chromium is in any way superior to other promoted metals. Three modes of promoter application were used.

Monolayer. The test piece was immersed in a solution of 0.5% oleic acid in methanol for 20 min, rinsed in methanol and then in water. This procedure is stated [25] to leave one stable monolayer of promoter on the surface. Figure 5 illustrates the results when steam was condensed on such coated test pieces. Promoted electroplate chromium on copper showed excellent dropwise condensation at first. But the heat transfer coefficient decreased steadily, and filmwise condensation was complete within 24 h. This is a typical case of promoter wash-off. Promoted solid chromium exhibited mixed dropwise and filmwise condensation (50%) at the start. Within 24 h about 90% of the surface exhibited filmwise condensation. Again this is indicative of promoter wash-off. Clearly, a monolayer of oleic acid either on chrome plate or on solid chromium has little value as a promoter.

Promoter in the boiler. Boiler water containing 4 p.p.m. of oleic acid was used for some tests. Figure 5 shows the results for these tests whereby promoter was brought continuously to the surface in the steam. The chromium electroplate showed dropwise condensation continuously for the 820 h run. The heat transfer coefficient was about seven times greater than for filmwise condensation, but not as great as observed with a monolayer of promoter at very short times (before wash-off). After about 100 h, the value of h increased slowly. Tanner *et al.* [26] observed a similar increase of h with time with several promoters. They attributed the rise to desorption of excess disordered promoter.

Vapor-phase promotion of solid chromium produced filmwise condensation throughout the run time of 150 h. The very different behavior of chromium electroplate vs solid chromium may be attributed to their different surface textures. The electroplate was smooth, with a beautiful mirror finish. The solid piece was a poor mirror, presumably because it had 19.8% voids.

Vacuum impregnation of promoter. A 1959 patent by Vaaler [16] states that a metal surface such as chromium may be made porous by etching, and then may be impregnated with a promoter to achieve long-time dropwise condensation. This proposal was examined in our laboratories.

The technique is an art, so various adjustments were made to seek success. The exact procedure stated by Vaaler for chrome electroplate was found to be too severe. This included a 5 min chemical etch in 50% nitric acid. Our tests showed that this removed completely a 20 000 nm layer of chrome plate. A 10% nitric acid solution was better and was used by us.

Consider results with 20 000 nm thick layers of chrome plate formed by gentle plating at 1970 A m^{-2} at 323 K and also by faster plating at 4570 A m^{-2} at 333 K. Each was electrolytically etched to start a porous structure and then chemically etched in 10% nitric acid for 5 min to develop the pores. The specimens were then immersed in oleic acid, and the pressure was reduced to 0.13 atm for 2 h. When these treated surfaces were contacted with steam, the results were as shown in Fig. 6. Mixed condensa-

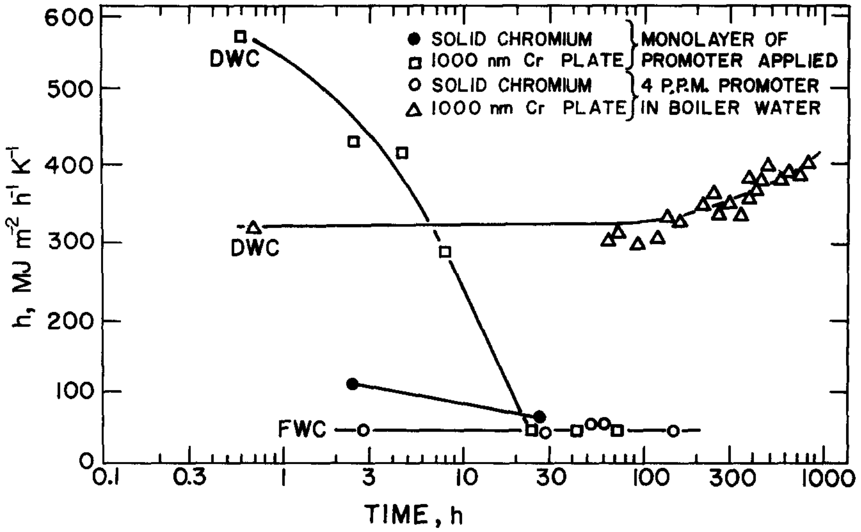

FIG. 5. Solid chromium does not promote well with oleic acid compared to chromium electroplate. Constant ΔT of 15 K for solid chromium and 7.5 K for electroplate.

tion was evident from the start. An excess of promoter appeared soon on the chromium surface as well as on the viewing window. Mixed condensation persisted for the 338 h run with the slowly-formed electroplate. Mixed condensation changed to filmwise condensation when the rapidly-formed electroplate was used. Apparently the promoter was washed off abruptly in the time interval between 116 and 121 h. These long-time runs were made at a constant coolant flow rate.

One test piece with 20 000 nm chrome plating was vacuum impregnated with oleic acid without any intervening electrochemical etching or chemical etching. This produced excellent dropwise condensation which persisted during the 214 h run. Examination in our laboratory of various chrome plates by an optical microscope at 450 × magnification and by a scanning electron microscope at 900 × magnification showed numerous microscopic cracks in the chromium. The literature on chromium plating states that all chromium plating contains microscopic cracks, but that they do not extend continuously down to the base metal. Presumably these cracks store promoter during vacuum impregnation, and no etching is necessary to achieve long lasting promotion.

The solid chromium test piece was also directly vacuum impregnated with oleic acid, with no intervening etching. Considering that the solid was formed by powder metallurgy and contained 19.8% voids, it was expected to retain the promoter. Figure 6 shows that at first mixed condensation occurred on the promoted solid chromium. Excess promoter was evident, but this washed off steadily, and dropwise condensation spread. Within 170 h there was complete dropwise condensation, and this continued for the remainder of the 3072 h run. At the start of the run the heat flux was 440 MJ h^{-1} m^{-2} at a steam-to-surface ΔT of 65 K. At the end the flux

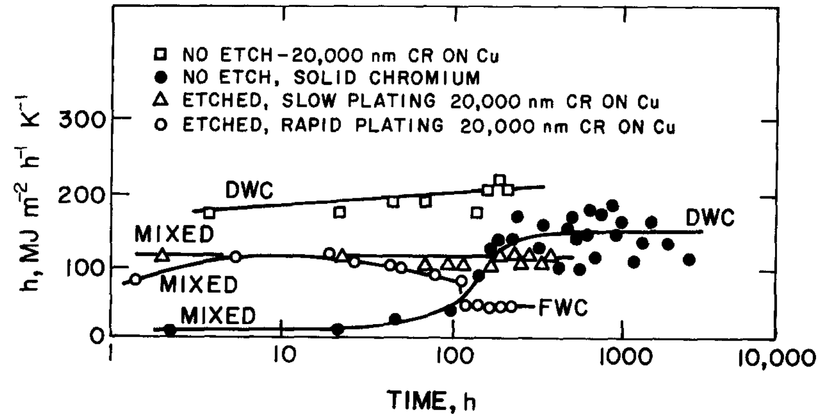

FIG. 6. Steam condensation on specimens impregnated with promoter under vacuum. Pretreatment by electrolytic etch and nitric acid etch was used for two specimens. Constant coolant flow rate of 43.2 kg h^{-1}.

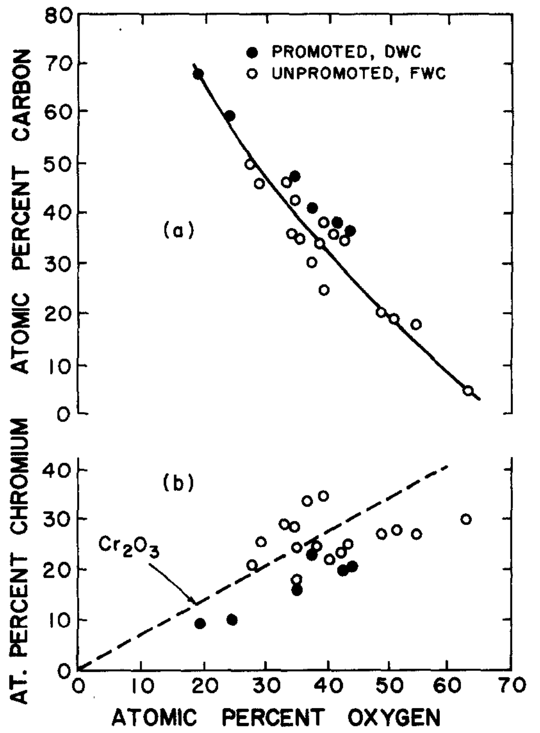

FIG. 7. Surface analysis for electroplated chromium with thicknesses from 150 to 20 000 nm.

was 1253 MJ h^{-1} m^{-2} at a ΔT of 9.1 K. The coolant flow was constant at 43.2 kg h^{-1}. Obviously the use of chromium formed by powder metallurgy and vacuum impregnated with a promoter is very promising for dropwise condensation.

Auger analysis

Some of the condensing surfaces were analyzed by Auger electron spectroscopy. This gives the quantitative composition by atoms, except hydrogen, for the surface to a depth of roughly 5 atoms. Trace amounts of sulfur and chlorine were always present but were assumed to be unimportant. Small amounts of copper were detected for electroplates of chromium on copper. The elements in significant amounts were chromium, oxygen, and carbon.

Figure 7(a) correlates the carbon with the oxygen. Large amounts of carbon are associated with small amounts of oxygen. This is true not only for the surfaces which had been promoted with oleic acid but also for unpromoted 'clean' surfaces. It is significant that dropwise condensation was observed only on surfaces with large carbon contents. The necessary presence of ample carbon for dropwise condensation to occur was observed earlier for steam on silver [4] and on gold [19]. Figure 7(a) indicates that about 40% or more of the surface must be carbon-containing in order to achieve dropwise condensation of steam on chromium. Put more strongly, dropwise condensation never occurred on a chrome plate with less than 35% carbon.

The identity of the carbon-containing species is unknown. The source of the organics probably is air. Air is known to contain over 1600 compounds [27], mostly in amounts of less than 1 p.p.m. An exposure of gold to air for 30 s can result in adsorbed organics sufficient to produce dropwise condensation [20]. The negative slope of the carbon vs oxygen curve in Fig. 7(a) indicates that the adsorbed material is not CO or CO_2.

Figure 7(b) shows a correlation between oxygen and chromium on the surface. The dashed line is the prediction for Cr_2O_3. The literature on chromium states that chromium has a high affinity for oxygen and that the chemical resistance of chrome plate is believed to be due to Cr_2O_3. We agree that much of the surface is Cr_2O_3 and that little of the surface, if any, is uncombined chromium.

CONCLUSIONS

(1) Clean steam on clean chromium condenses in a filmwise manner.

(2) In contrast to gold and silver, chromium cannot be promoted by trace organics normally in air.

(3) Large amount of air in the condenser can produce an apparent dropwise condensation on chromium, with many drops but an abnormally low heat transfer coefficient.

(4) Long-time dropwise condensation on chromium will occur if promoter is present in the boiler.

(5) Pure solid chromium, produced by power metallurgy, can be vacuum impregnated with promoter to achieve a surface giving over 3000 h of dropwise condensation with steam.

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CONDENSATION EN GOUTTES OU EN FILM DE LA VAPEUR D'EAU SUR DU CHROME

Résumé—La question de la condensation de la vapeur d'eau soit en gouttes soit en film sur du chrome est restée posée pendant 50 ans. Cette étude concerne la condensation de vapeur d'eau à la pression atmosphérique sur un disque vertical de 25,4 mm de diamètre de chrome électrodéposé et sur un autre de chrome pur à 99,9%, formé par la métallurgie des poudres. Des surfaces non contaminées conduisent toujours à la condensation en film. La condensation en gouttes qui dure jusqu'à 3000 heures se produit sur le chrome pur qui a été imprégné dans l'ambiance de vide avec l'acide oleique comme promoteur.

VERGLEICH VON TROPFENKONDENSATION UND FILMKONDENSATION AN EINER CHROMOBERFLÄCHE

Zusammenfassung—Die Frage, ob Dampf an Chrom in Form von Tropfen oder als Film kondensiert, ist seit mehr als 50 Jahren ungeklärt. Diese Untersuchung beschäftigt sich mit Dampf, der unter Atmosphärendruck an einer senkrechten, galvanisch verchromten Scheibe mit einem Durchmesser von 25,4 mm und an pulvermetallurgisch hergestelltem, massivem Chrom (Reinheit 99,9%) kondensiert. An sauberen Oberflächen erfolgt immer Filmkondensation. Eine über 3000 Stunden anhaltende Tropfenkondensation tritt an reinem metallischem Chrom auf, das zuvor im Vakuum mit Ölsäure als Promoter imprägniert worden ist.

КАПЕЛЬНАЯ И ПЛЕНОЧНАЯ КОНДЕНСАЦИЯ ПАРА НА ХРОМЕ

Аннотация—Вопрос о том, в капельной или пленочной форме конденсируется на хроме пар, остается неизученным в течение 50 лет. В данной работе исследуется конденсация пара при атмосферном давлении на вертикальном диске с хромированным гальванопокрытием диаметром 25,4 мм и на 99,9%-ном чистом металлическом хроме, полученном методом порошковой металлургии. На незагрязненных поверхностях всегда имеет место пленочная конденсация. Процесс капельной конденсации длительностью более 3000 часов наблюдается на чистометаллическом хроме, обработанном в вакууме олеиновокислым активатором.