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# ABOUT MODERN HEAT EXCHANGE SURFACES AND CONDITIONAL CYCLE OF CONDENSATION

*Annotation– The analysis of the features of modern condensation surfaces bearing self-healing coatings is carried out. The possibility of obtaining super hydrophobic, hydrophobic and super hydrophilic heat exchange surfaces along with the existing hydrophilic ones is considered. The coexistence of various types of condensate formations in this case can be characterized by the contact angle and the conditional cycle of the process. The hysteresis of the contact angles (static equilibrium, leakage and ejection) for known types of heat transfer fluids and heat exchange surfaces is leveled when passing to super hydrophobic surfaces. The description of the variety of condensation processes, carried out using the concept of a conditional cycle, receives a number of features for super hydrophobic surfaces.*

*Key words – modern condensation surfaces, contact angle, conditional cycle, heat exchanger, heat exchange.*

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# ПРО СУЧАСНІ ПОВЕРХНІ ТЕПЛООБМІНУ І УМОВНИЙ ЦИКЛ КОНДЕНСАЦІЇ

*Анотація – Проведений аналіз особливостей сучасних поверхонь конденсації, що несуть на собі покриття, які самовідновлюються. Розглянута можливість отримання супер гідрофобних, гідрофобних і супер гідрофільних теплообмінних поверхонь разом з існуючими гідрофільними. Співіснування при цьому різних типів конденсатних утворень може бути охарактеризоване за допомогою крайового кута змочування і умовного циклу процесу. Гістерезис крайових кутів (статичного рівноважного, натікання і відтікання) для відомих типів теплоносіїв і теплообмінних поверхонь нівелюється при переході до супер гідрофобних поверхонь. Опис різноманіття конденсаційних процесів, що проводиться з використанням поняття умовного циклу, отримує ряд особливостей для супер гідрофобних поверхонь.*

*Ключові слова – сучасні поверхні конденсації, контактний кут, умовний цикл, теплообмінник, теплообмін.*

## Introduction

Existing current and future condensation surface coatings must be stable, have a wide range of capabilities and allow process control. The specific combined surface allows complex and effective use of the action of surface tension forces. This is manifested in the conditional condensation cycle [1-2].

The discovery of Wilhelm Bartlott (in 1975) regarding the specific surface of the Lotus leaf in the form of microscopic tubercles, bearing nano-hairs, makes it possible to obtain the effect of a super hydrophobic surface together with the effect of self-cleaning and the possibility of droplets bouncing.

**Analysis of the state of question**

Surfaces with contact angles Θ from 148-150$^0$ to maximum 180$^0$ are considered super hydrophobic. In this case, the hysteresis of the contact angles - static, leakage and swelling - should be low, and in the extreme case, zero. In the case of 180$^0$, there should be no difference between all contact angle options.

Recently, successes have been achieved in obtaining super hydrophobic surface coatings not only for copper, copper-containing alloys, but also for aluminum, aluminum alloys and steel [1-2]. However, the durability of the coating, including when exposed to thermal radiation, can affect the contact angle, significantly varying it during the operation of the surface. This does not exclude the possibility of a transition from super hydrophobic surface properties to simply hydrophobic properties, then hydrophilic, up to super hydrophilic and vice versa. All this affects the mechanism of the condensation process, finding its manifestation in the conditional condensation cycle.

**Aim of work**

One to analyze the features of modern heat-exchange surfaces, regional corners of moistening, conditional cycle of condensation. One consider hydrophobic, super hydrophobic, hydrophilic and super hydrophilic surfaces.

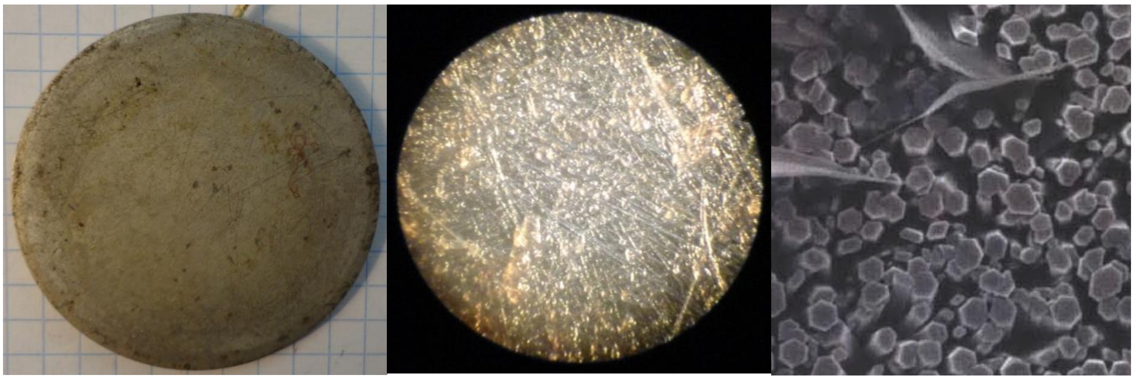
**Results of researches**

Atomic power microscopes, scanning probe microscopes, scanning electron microscopes, and transmission electron microscopes make it possible to trace the features of the resulting modern heat transfer surfaces. The radius of curvature of the tip of the probe in the case of electron microscopy is required on the order of 10-50 nm. However, it is not always possible to monitor the state of the heat exchange surfaces directly during operation when exposed to various types of condensate formations. In this regard, optical microscopes are indispensable.

The production of all modern heat exchange surfaces can be classified in two main directions [1-2]: "top - down" and "bottom - up". The technology of crushing substances (mechanically or chemically) to the nano scale with subsequent application to the surface is called “top-down”. In turn, molecular synthesis from individual atoms and molecules is called "bottom-up" technology. The second direction somewhat prevails over the first.

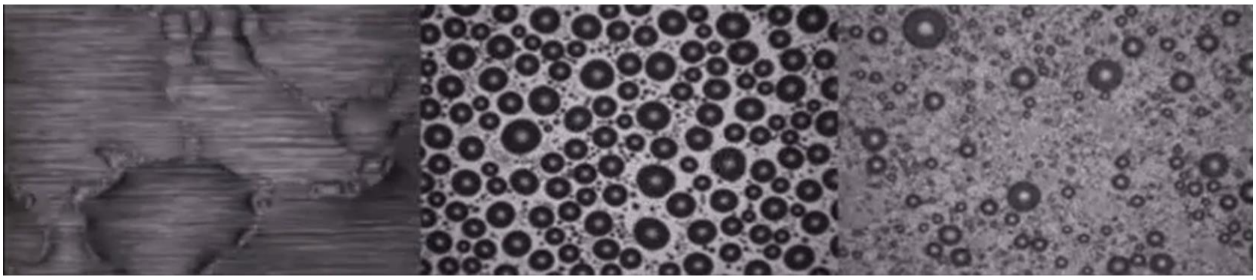
Molecular assembly of coatings can be realized in the form of two- or three-dimensional chains. In this regard, the use of nano tubes is considered promising, such as hexagonal graphite planes rolled into a tube with a hemispherical head - graphenes. Another important element is molecular compounds such as convex polyhedral of an even number of three coordinated carbon atoms - fullerenes. The fullerene coating is based on nano particles with a diameter of 0.7 nm = 7Å. Such coatings are hundreds of times stronger and, at the same time, six times lighter than steel. In addition, aqueous solutions of fullerenes are powerful antioxidants.

Modern multifunctional substances are able to give the effect of an ideal oil film and withstand significant temperatures. They are used in various lubricants. At moderate temperatures, nano particles of such substances are able to adhere to damaged areas of the coating on the heat exchange surface (Fig. 1).



a) b) c)

Figure 1 - Types of condensation surfaces: a) untreated hydrophilic HFL; b) hydrophobic HFB with optical magnification; c) super hydrophobic SHFB with electronic magnification.



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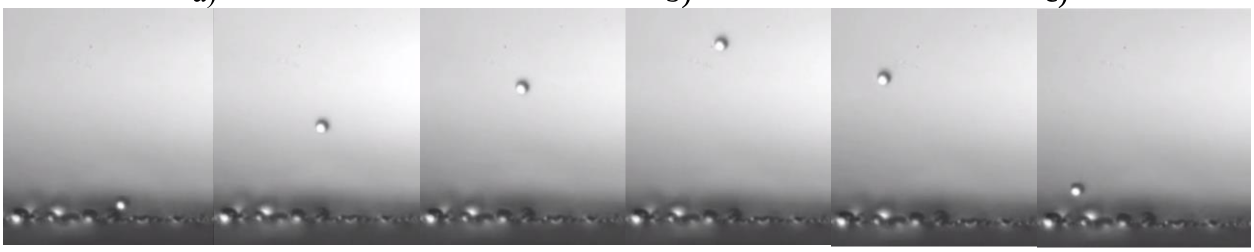


d)

Figure 2 - Visual picture of the condensation process: a) film mode on the hydrophilic surface of the HFL; b) drip mode on the hydrophobic surface of HFB; c) drip mode with droplet rebound (d) on the super hydrophobic surface of the GFB; d) the dynamics of the rebound of drops on a super hydrophobic surface.

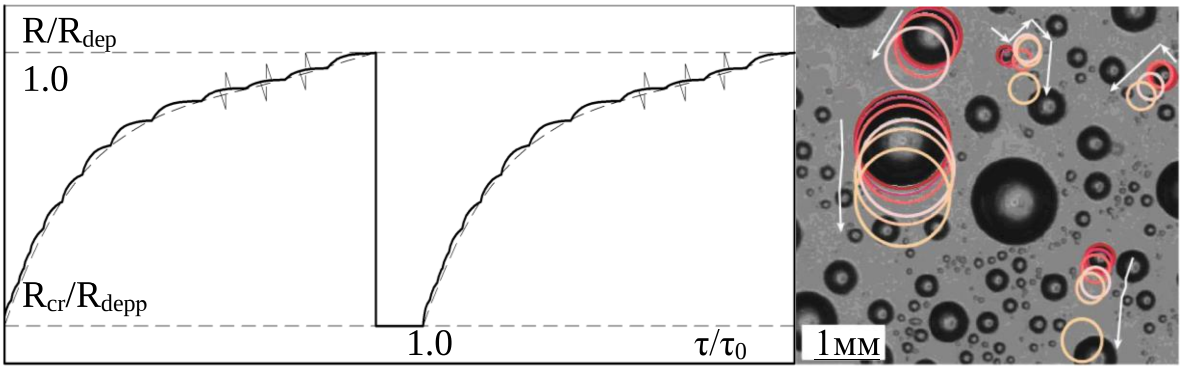
Allotropic forms of carbon (for example, carbine), aero gels - "frozen smoke", and foam made of tubular carbon fibers open up new possibilities.

It cannot be excluded from consideration that self-organized coating mono layers can have structural defects that reduce hydrophobicity (Fig. 1). The correct packing of the monolayer affects the contact angle. Mechanically organized mono layers allow contact angles of the order of $130^0$ to be obtained. The associated surface roughness also affects the inlet and outflow angles. Contact angle hysteresis can reach $85\text{-}100^0$ in the region bordering between hydrophilic and hydrophobic states. At contact angles of the order of $170\text{-}175^0$, the hysteresis is minimized and reaches $1\text{-}2^0$.

A number of modern coatings are characterized by a reversible conformational transition with the formation of elongated and helical chains upon heating and cooling. We are talking [1] about the temperature dependence of the contact angle of wetting. It is possible to achieve a transition from super hydrophobicity to super hydrophilicity with a change in the contact angle hysteresis. In this case, it is also possible to achieve multiple switching of wetting modes without degradation of the coating.

Such a complex and complex situation with heat transfer surfaces, their coatings and contact angles for condensate formations is reflected in the visual picture of the process (Fig. 2). In addition to the possibility of coexistence in the dynamics of drops and local films, the effect of rebound of condensate from super hydrophobic surfaces appears. All this can be described using a conditional condensation cycle, as shown in Fig. 3. The processing of a large number of photo and video material allows us to speak with a certain degree of convention about the average, periodically repeating picture of the process.

The development of condensate formations occurs from the minimum embryonic size to the maximum separation. The division into standard sizes in the cycle can be arbitrary. It is advisable to carry out averaging both within the limits of a separate standard size and the development cycle as a whole. As we approach the super hydrophobic state, the conditioned cycle time will sharply decrease. The rebound property is possessed only by drops of certain standard sizes (Fig. 3b), which allows us to talk about alternative methods of condensate drainage and the need to take this into account when determining the intensity of heat transfer.




a) b)

Figure 3 - Conditional cycle of the condensation process: a) the averaged picture of the process taking into account the effects of the rebound of drops of certain standard sizes (zigzags); b) a diagram of the movement of drops on the heat exchange surface.

The concept of a conditional condensation cycle makes it possible to calculate heat transfer using a dimensionless complex of space-time development of the condensation process *A*. This complex allows one to describe both pronounced $A_{di}$ drops (formula 1) and local films $A_{fj}$ (formula 2). The calculation is carried out for condensate formations of a certain standard size: drops, and local films. It takes into account their spatial development $(S \cdot \Delta N)$. Where *S* is the occupied surface area, $m^2$; and $\Delta N$ is the number of formations in accordance with the size distribution function, $1 / m^2$. The time factor of existence $\Delta\tau$ of each of n classes of drops and m classes of local films refers to the cycle $\tau_0$ (Fig. 3). The division into classes can be arbitrary: $i = 1 \ldots n$ for drops and $j = 1 \ldots m$ for films. The heat transfer intensity factor is determined relative to the Nusselt solution $\alpha_{Nu}$. Moreover, for each standard size of condensate formations, the model of thermal conductivity proposed by Rose in the determination of is considered. The total factor $A_S$ for coexisting droplets and local films is calculated by the formula 3. The calculation of the average heat transfer coefficients $\alpha_{calc}$ is carried out in accordance with the formula 4.

$$A_{di} = \frac{(S \cdot \Delta N)_{di} \cdot \Delta\tau_{di} \cdot \alpha_{di}}{\tau_0 \cdot \alpha_{Nu}} \tag{1}$$

$$A_{fj} = \frac{(S \cdot \Delta N)_{fj} \cdot \Delta\tau_{fj} \cdot \alpha_{fj}}{\tau_0 \cdot \alpha_{Nu}} \tag{2}$$

$$A_S = \sum_{i=1}^{n} A_{di} + \sum_{j=1}^{m} A_{fj} \qquad (3)$$

$$\overline{\alpha}_{calc} = \frac{\sum_{i=1}^{n} \frac{A_{di}}{A_S}\alpha_{di} + \sum_{j=1}^{m} \frac{A_{fj}}{A_S}\alpha_{fj}}{n+m} \qquad (4)$$

The presence of droplets rebound from the condensation surface is taken into account in the calculation as follows. For this, in accordance with the visual picture, it is necessary to take into account that the bounced drop frees the surface for condensate formation of a smaller standard size. And with a possible return of the bounced drop to the surface, a condensate formation of a larger size is formed (See zigzags in Fig. 3b).

Such an approach for determining heat transfer gives convergence with the calculation by balance relations with an error not exceeding the experimental one [4]. It should be noted that this approach has a certain limitation for super hydrophilic surfaces when one continuous condensate film is considered.

## Conclusions

1. The resulting modern nano structured surfaces with enhanced strength characteristics of the coating are effective anticorrosive systems for metal substrates. Predicting the operation time of the encapsulated components is associated with the determination of the geometric dimensions of the coating defects, which must be promptly eliminated. This approach is integral to the study of the lifespan of lyophobic heat transfer surfaces.

2. For self-healing coatings, the possibility of including clusters with functional components is considered in order to restore damaged areas at the macro and micro levels. The functional components must be stable, effective and not manifest earlier than the intended time. Such substances include, for example, pH-sensitive components. In addition, coating modifiers based on nano tubes and nano fibers are considered. A concomitant factor to all of the above features of modern coatings of heat transfer surfaces is the Lotus effect. This effect, in turn, is reflected in the contact angles of wetting, their hysteresis, and, as a consequence, affects the cycle of condensation processes.

3. It is advisable to calculate heat transfer for the coexistence of different standard sizes of condensate formations and the possible rebound of drops using a conditional cycle and a dimensionless complex of space-time development.

## LIST OF DESIGNATIONS

*R* - radius of drops, m;
α - is the heat transfer coefficient, W / (m$^2$ · $^0$C);
Θ - wetting angle, angular degree;
τ - time, s.
Indices:
*cr* - critical embryonic radius;
*dep* – departure tear-off radius;
*d* - related to drops;
*f* - related to local films.

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