

ADHESION OF DEPOSITED FROST

PAVEL CELUNDA, ING.

Division of Compressors, Refrigeration and Hydraulic Machines

Faculty of Mechanical Engineering at CTU in Prague

Technická 4, 166 36 Prague 6

CZECH REPUBLIC

Abstract: - As is known frost will form on a cold surface when the temperature drops below the dew point and will be also less than the freezing point of the condensable component. There are already many of the theories and empirical terms written on the theme of deposition, formation, growth or heat transfer coefficient of the frost, but no one was so far exploring the adhesion of the frost. What are the forces which are the most participating on the so unpleasant adhesion and how different is the adhesion on the different surfaces?! This paper is dealing with this phenomenon of the frost. It's namely describing the experimental stand for measuring the adhesion of the frost issued of the gas compounded of the CO_2 , N_2 and gaseous H_2O on the different samples of materials. This all is done with the feedback to the application for new technology, namely Freezing-out of the Impurities from Gasses with Mechanical removing of deposited frost, which could be used in many environmental applications.

Key-Words: - Frost, adhesion, cryogenics, environmental, biogas, landfill gas.

1. Introduction

Deposition of the frost is the often issue of the present technologies. It has influence in a full range of modern science. Whether you will consider frosted cooling boxes in the supermarkets with putrid yoghurts or car drivers scraping furiously windscreens of their cars every morning or evaporators of the liquid gas covered by the ice balls or freezing-out separation technology or the other, the deposition of the frost is the main issue and the challenge for the designing engineers to improve their technologies as well.

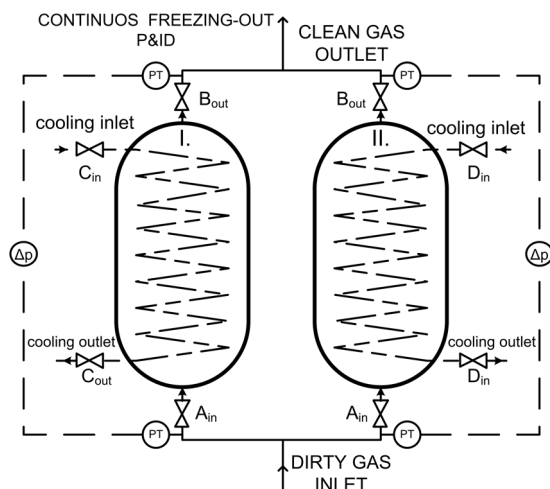
helping us in this industrial era to minimize the effects done to the nature by the strong industry. Nobody can imagine the life without toothpaste, detergents, personal car, fresh fruit or vegetable or other common things for the modern life. This life style can't run without excellent background from chemical industry and using of the energy from the waste industry. One of the matters with high energetic potential is biogas or landfill gas which is produced by decaying of the organic stuff without the air access (anaerobic digestion). This biogas we can get easily from landfills or sewerage plants or other technologies working with the waste [1].

However the biogas is not pure. It's often dirty by other incombustible components which you cannot release to the atmosphere because of many environmental effects what we know they have.

It exist four basic technologies by which we can separate such mixture of gasses, it means to clean the wanted component from the unwanted part.

- Absorption (difficulties with sorbent)
- Adsorption (big fillings)
- Membrane (too much purify)
- Freezing-out (deep temperatures)

How it can be seen from the header of this paper our concern will be in the freezing-out technology, which is in present time very interesting alternate. The liquid gasses, as usual used for cooling, are now very common matter with very interesting economics factors.



base in the environmental idea. All around the world are settled by the technologies which are

In the **fig. 1** is schematically shown the P&ID diagram of the mentioned technology. In this figure it can be seen that the freezing out heat exchanger (scrubber) has to be duplicated. This is common by the 95% of designed technologies from the last page. The reason for this is normally that after some time the heat exchanger, the absorber, the adsorbent or the membrane is being plugged by the separated part and the efficiency decrease a lot. For the need of the continuity of the purification process is necessary to double the working part of the technologies.

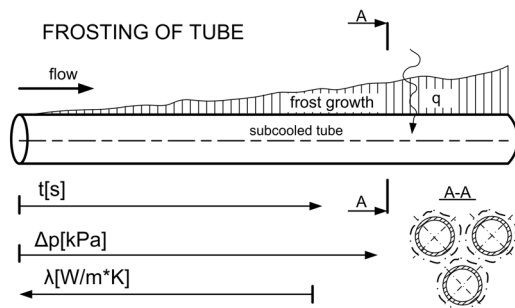


Figure 2

Thereafter in the freezing-out technology if the frozen-out part is deposited on the cold surface in such amount that the area for the clean gas flow is not enough and the heat transfer coefficient decrease because of the heat resistance of the deposited frost (**fig. 2**), than is necessary to clean the heat exchanger. It means to switch to the second one and leave this one to heat up and get melted the frozen staff. Though many of the theories about the growth and deposition of the frost are written, by the industrial technologies couldn't be used [2, 3, 4, 5]. The written theories are not so general to cover all of the cases of heat transfer on the different surface shapes, temperature ranges or types of mediums. Therefore is much easier and more certain to measure the change of the pressure difference on the heat exchanger, how is mentioned in the **fig. 1** and **2** by Δp .

If we would like to evaluate this technology economically, considering acquisition and operating costs as well, than the costs for the regeneration of heat-exchangers make the biggest disadvantage. The costs for the duplication of the heat exchangers are big enough as well, but this is but the issue of the first investment in the technology and usually will quickly return to the client. But the costs for regeneration are the operation cost which will outlast the lifetime of the technology.

2. Frost phenomena

How is mentioned above, the phenomena of the frost has been investigated already from several point of view. It has been found that the frost is initiating on the surface in three consecutive stages, which needs to be known for anybody who wants to understand which problems can the frost bring on, if we are considering the technology discussed above (**fig. 3**) [2, 5, 6, 8].

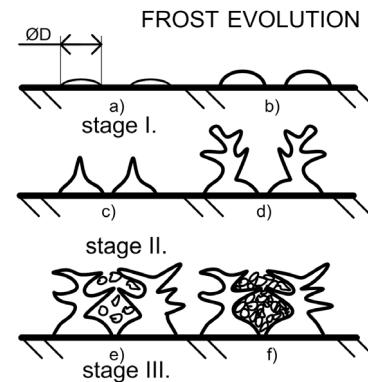


Figure 3

The clear demonstration can be done on the wet air example. Above the cold surface $-20\text{ }^{\circ}\text{C}$ is flowing fully saturated air $+20\text{ }^{\circ}\text{C}$ which is being cooled down up to $-10\text{ }^{\circ}\text{C}$. Than the condensation takes place and the deposition of the frost follow. Than the water molecules are losing the energy (cooling), getting from the gas phase through liquid up to solid phase (phase equilibrium law). The concentration gradient is supplying the surface by the new water molecules. When they decrease their energy (get cooled) enough to condensate, they are drawn to the wall and stopped there mainly because of the different surface energy. Than the heat transfer from these drops increase hundred times and the level of energy for solidification is reached very soon.

2.1. Frost growth

Now is taking place the frost deposition theory [6, 9]. The description can be followed in the **fig. 3**. The frozen drops will be getting larger and the ice crystal shaft will grow up from it. When the ice crystal shaft will have certain height it will become to have branches and the frost become to grow in a pattern similar to a forest of the ice trees. These branches will spread until will touch each other. Until the wet air has the possibility to flow around these ice trees, the branches will grow. In one moment the top of the ice forest will close the surface. In this time the frost layer becomes to be

real insulation layer, where the air gaps hold the heat transfer.

If the process would follow as was described above, than on this closed layer new similar layer would grow and this would repeat on and on and the heat resistance of frost would become larger and larger. But in real it got to be thinking about the diffusion forces which are taking place in this time. The diffusion of the water vapor driven by the concentration forces will thicken lower layers. It can be said that the densification will counterbalance the frost growth and the thermal conductivity won't decrease unlimitedly but on the contrary will get settled on one value ($\lambda_f = 0,1 \div 0,5 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$) [8].

So the grow of the frost can be split into the three basic stages. First is the condensation and sub cooling of the drops, second is crystal growth period. The third will start when the layer on the surface become fully developed frost and the diffusion of the water vapor and densification is started. These three stages are pictured in the **fig. 3**.

2.2. Adhesion forces of frost

In the feedback to the freezing-out technology the adhesion of the frost has been started to investigate. After several studies the picture cleared a bit [11, 12, 13]. It is supposed that the mechanism, by which the frost adheres to all known surfaces, is caused by the forces from these three groups:

- Covalent or chemical bonding mechanism,
- Dispersion of or fluctuation in electromagnetic interaction (van der Waals forces),
- Direct electrostatics interactions.

By this special material as is frost we can reject the first and the last point with the minor interest, the electrostatics forces will dominate [10]. This means among others that the adhesion forces will be strongly dependent on the chemical compound of the deposited material or sub cooled surface layer. From that it can be seen the possibility to influence (minimize or maximize) the adhesion by the right choice of the surface layer for appropriate frozen-out material. To be able to find out which material should be used for which frost, we need to investigate more the early growth period of the deposition to get closer look how the frost adhere to the surface.

3.1.1. Early period of frost growth

By this period condensed high boiling components nucleate on the surface. There it creates drops which will grow in time until the contact with the heat transfer surface will be large enough to hand over the energy for solidification (crystallization). It has been investigated by Tao [9] that the frozen drops will be getting smaller with the lower temperature of the surface. See the **fig. 4**.

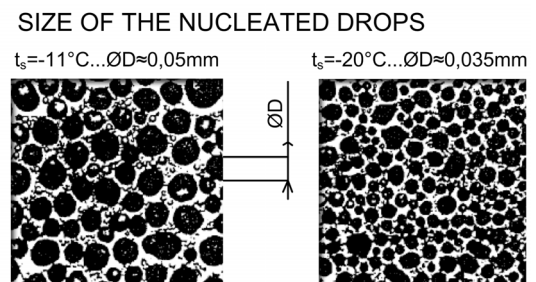


Figure 4

By this we can say that with the smaller temperature difference the adhesion should be bigger because the surface by which the drops are laying on the surface is bigger.

Definitely it will depend on the polarities of both matters. As you can see on the **fig. 5** the drop can be stretched fully on the surface or behave totally oppositely. It means that from the top view in **fig. 4** we could see that the drops are huge but they would have only minimal contact with the surface as is seen in **fig. 5**.

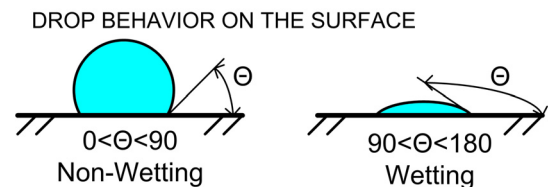


Figure 5

3. The adhesion

Mentioned statements needs to be proofed by the experimental results. The experimental stand has been build to be able to sub cool the sample up to desire temperature and to measure the adhesion of the issued frost on the surface of the sample.

3.1. Measuring of the adhesion

How would you measure the adhesion of such a substandard material, as the frost is? Adhesion of the porous, not homogenous layer which thermo physicals properties are sharply time dependent. Number of methods which could be chosen is huge but with the modest budget which is available has been quickly inclined to one of them. It was decided to measure the resistance of the frost layer

against the mechanical removing (**fig. 6**). It sounds very easily, but when you imagine that the initial period of the frost layer is that sub-cooled drops get frozen and on their peaks crystal trees begin to grow, the imagine gets more difficult. Even when you revealed that one of the biggest drops has its diameter about 0,03mm and height about the same [9]. It is thought to be crucial the adhesion of these drops to the surface because this is the only surface contact layer, though how the time goes this initial layer receives more material by diffusion flow. It is not yet known how the initial layer looks like when frost gets older and rises higher upon the surface. Here we will suppose that the initial layer won't change, especially the contact crystals will remain in the same quantity and contact surface. To measure the resistance of this layer against the scraper, the scraping movement has to be very precise in minimal height above the sample surface.

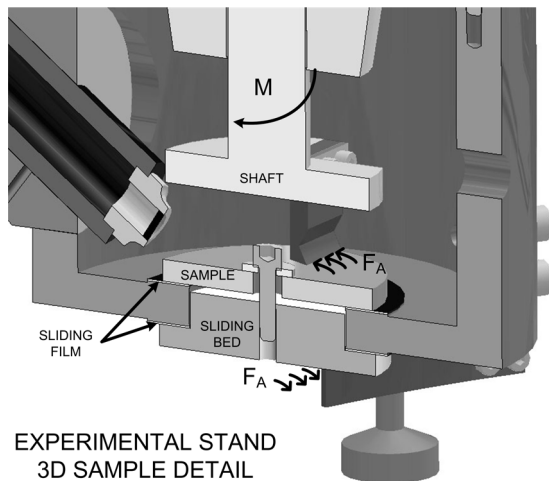


Figure 6

3.2. Experimental stand

To guarantee the repeatability of the experiment a brand new laboratory apparatus has been designed. With the feedback to the previous information this stand is designed according to the **fig. 7**.

Manufactured apparatus was drawn up like a heat exchanger, with the scraper in the cooled chamber. This area will be cooled down by vapors from the liquid nitrogen [LN_2]. The cooling performance is controlled by a powered conductive wire which is supplying the heat to the Dewar-container with LN_2 . The freezing-out medium is the carbon dioxide injected to the chamber from a pressure bottle. The CO_2 is fully saturated with water by the $+30^\circ\text{C}$.

To picture the process of the deposition of the frost and the scraping itself as well as the chamber

will be socketed with a special microscope which has heating of the objective to prevent frosting. By this we would like to investigate the growth process by deep temperatures.

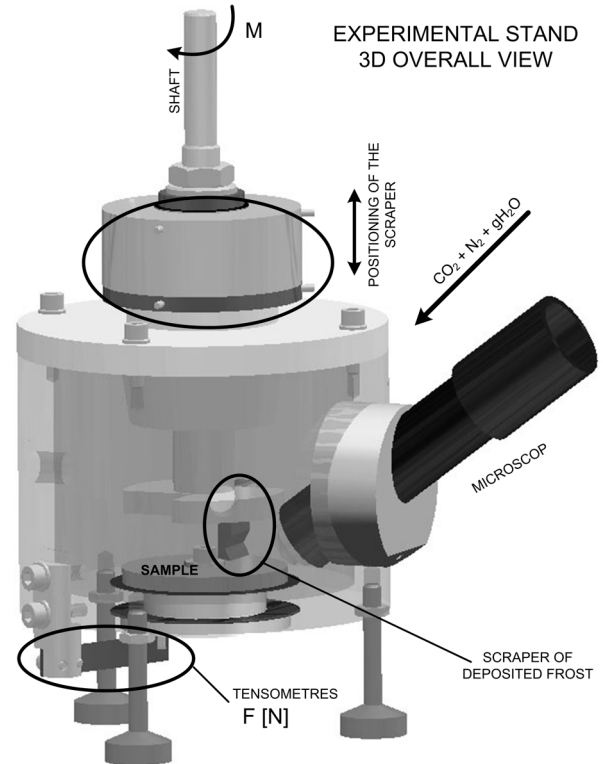


Figure 7

The surfaces which are in connection with the deposited surface and the scraper itself have to be designed and afterwards manufactured with high geometrical precisions. There were prescribed tolerances of about 0,01mm. The sample lies on the sliding bed which is also rotary. At the bottom of

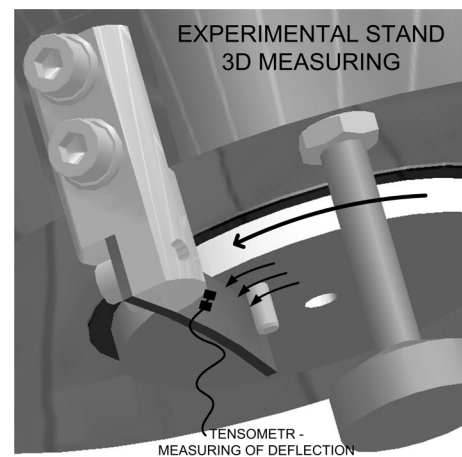


Figure 8

this bed (it means outside the chamber) is placed a metal strip (**fig. 8**). On this strip there are the tensiometer sensors. As the step motor is turning the shaft on which end is the scraper, the sliding bed will spin around. This causes

deflection of the metal strip and the tensiometer is recording the value of the deflection. The desired data are finally to be obtained from this.

The investigated materials have been chosen from the normal construction materials and deposited layers which could be easily used for this purpose. In the first step these surfaces are being tested:

- stainless steel – roughness 0,01mm
- stainless steel – roughness 0,001mm
- stainless steel – polished
- DLC layer
- TiN layer
- CrN layer
- Teflon Rilsan PA11 layer
- commercial PTFE layer
- PTFE layer – non-wetting... $\theta \approx 45^\circ$
- PTFE layer – wetting... $\theta \approx 135^\circ$

After the evaluating the measured data we should be able to progress in the technology mentioned above and in next paragraph and to continue in discovering the frost phenomena as well.

4. Conclusion

The results from this work will help to continue in designing of the new technology. This technology is slightly sketch in **fig. 9**. The cleaned gas can be the landfill gas which is cooled in the first step to

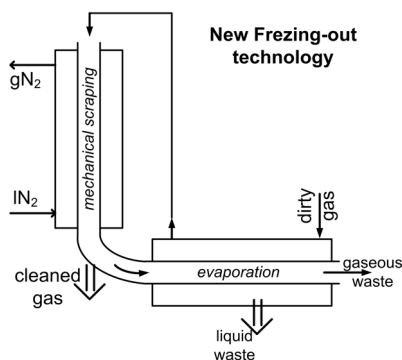


Figure 9

the temperature above the zero to increase the humidity because it's known that the water frost is adhering much more strongly than the CO_2 , which is another big impurity in the biogases. Then the gas goes to the second stage, where is being cooled to get rid of the CO_2 . The issued frost than scraped down and removed from the working area. To enlarge the efficiency the outgoing frost can be used to cool the first stage of the heat-exchanger. This technology can work then like continual purification process.

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