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# HIGH PERFORMANCE CRYOSORPTION PUMP CSP-1.5D

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***Abstract:***
*A new bath-type cryosorption pump of lightweight, disassembled design with $LN_2$ as a cooling agent is developed. The cryopump is intended to get and maintain high, carbon-free vacuum in chambers, preliminary pumped to 10 Pa. New technical solutions concerning sorbent heat-protection and easily-condensable vapours cryo-trapping are introduced. To optimise pump design, detailed computational investigation of heat and mass-transfer processes occurring in pump elements has been performed. By use of Monte-Carlo method the simulation of rarefied gas flow in pump channels has been carried out. The compiled program for tracing the trajectory of molecular movement allows to determine transmission, reverse dispersion and trapping factors for pump and its elements.*
***Keywords**: cryopump , Adsorption cell, Cryocondenser*

## INTRODUCTION

In majority of up-to-date technologies and research installations to get and maintain high, free of oil traces, vacuum cryogenic pumps are widely used. In case of gas evacuation using gas-desublimation mechanism cryopumps with operating temperatures of cooled down surfaces 4÷20K are needed. Such cryocondensational pumps are capable to gather very high pumping speed and allow to achieve extremely low pressures [1], however to maintain required temperatures the expensive liquid helium is needed or relevant cryocooler must be used. The latter significantly increases complexity of vacuum system and lowers its reliability. In addition, cryocoolers are the source of vibration, inadmissible in many applications. Vacuum system could be dramatically simplified if the same goals (high, pure vacuum) can be gained on $LN_2$ temperature level. It is known, that air main components pressure in state of adsorptional equilibrium with fine-porous carbon sorbents, cooled down till temperatures 63÷78K, can consist $10^{-5}$ Pa and less. However, not infrequently for industrial patterns of sorption-based cryopumps, real-life vacuum characteristics turn out significantly worse then expected. Analysis, supplemented with various sensitivity tests [2], shows that the main reasons of this are unsatisfactory temperature field in sorbent layer and worsening of sorption capacity due to sorbent contamination with easily-condensable vapours. Introducing new methods for sorbent layers heat-protection and trapping of easily-condensable vapours, detailed computational investigation of heat and mass-transfer processes occurring in main parts of pump elements and development of high-performance cryosorption pump is the focus of given paper.

## 1. CRYOPUMP PRINCIPAL ELEMENTS. DESCRIPTION AND OPERATING CONDITIONS.

The principal functional element of any cryosorption pump is adsorption cell - granular or powder sorbent layer fixed on panel, cooled down till cryogenic temperatures (in bath-type cryopumps the other side of panel serves as boiling surface for $LN_2$). To improve cryosorption pump operating parameters the sorbent heat-protection system and special node for binding easily-condensable vapours are also needed.

ISSN 1512-1461

### 1.1. Adsorption cell with compact heat-protection system

The carbon sorbents due to their fine-porous structure have very low heat-conductivity coefficient, what makes difficult sorbent layer cooling. In result, even insignificant radiant heat fluxes coming from ambient temperature parts of cryopump (frame, inlet pipe) induce in sorbent layer considerable temperature gradients. For example, heat flux about $5 \cdot 10^{-3}$ W/cm$^2$, inclined on 1 cm thickness carbon sorbent layer leads to overheating of layer upper surface approximately on 15K relatively to cryopanel temperature. Even though conventional jalousie-type baffle systems are capable to reduce heat load on sorbent layer, they have unsatisfactory volumetric characteristics and occupy large part of cryopump useful internal volume. In addition, they are ineffective in soft vacuum range.

Compact design of adsorption cell with efficient heat-protection performance may be developed by use of optical opaque porous materials as radiant-heat screening coat for sorbent layer. During carried out experimental testes of various porous structures the best results were obtained on porous plates made by hot pressing of 0,2 mm diameter copper wires. Fabricated samples have high porosity and relatively high heat-conductivity coefficient (not less 90 W/m·K), what can provide efficient heat removal. Under operating conditions of adsorption cell along screen is formed parabolic temperature distribution with maximum in the middle part of screen. In accordance with results of calculations, performed for cylindrical adsorption cells with 400 mm height, even at relatively high heat-loads on screen (soft vacuum), to restrict screen maximum temperature below 79K the screen required thickness is only 1 mm. For vacuum applications **is** also important that due to high porosity, formed by traversing channels, and low thickness of screens penetration of evacuated particles to sorbent surface is not very suppressed (satisfactory molecular conductance).

### 1.2. Temperature field in sorbent layer

As it was emphasized, vacuum characteristics of cryosorption pumps are strongly effected by temperature distribution, set in sorbent layer under operating conditions. The last in complex way depends on gas load, layer thickness, sorbent thermal properties and granularity. To optimise parameters of adsorption cell the model of heat-exchange process occurring in layers of granular sorbent has been developed. Due to full screening of heat leakage from outside, the main factor forming temperature field in sorbent layer becomes adsorption heat-release, accompanying gas evacuation. In the layers of granular sorbent heat-exchange is performed by radiation, contact between granules and molecular conductivity of residual gas. At high vacuum the contribution of last two mechanisms is negligible, so may be assumed that dominant mechanism of heat-transfer is radiation. At such approach, cavity formed by granular sorbent may be considered as multi-layer system with number of heat-exchanging surfaces n=δ/R, where D is adsorption cavity thickness and R - average dimension of granules. In stationary mode from heat balance condition for every heat-exchanging surfaces can be derived system of equations linear with respect to $T_i^4$:

$$\begin{cases} T_{scr}^4 + T_2^4 - 2T_1^4 = -\dfrac{W_1}{\varepsilon\sigma F} \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ T_{i-1}^4 + T_{i+1}^4 - 2T_i^4 = -\dfrac{W_i}{\varepsilon\sigma F} \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ T_{n-1}^4 + T_{N_2}^4 - 2T_n^4 = -\dfrac{W_n}{\varepsilon\sigma F} \end{cases}$$

where temperatures of boundary surfaces (porous screen and cryopanel) $T_{scr}$ and $T_{N2}$ can be assumed as known, and $W_i = Q_i \cdot \Delta H_{ads}$ - is characterizing heat-release intensity in i-th surface ($Q_i$ -

ISSN 1512-1461

By use of given model was performed computational investigation of temperature field in plane adsorption cells with area F=0,4 $m^2$, thickness 0,5, 1,0, 1,5 cm and sorbent granularity from 0,5 mm to 3,5 mm. As a result of calculations was obtained that for total gas load Q=1 $Pa \cdot m^3 \cdot s^{-1}$ maximum temperature in 1,5 cm thickness adsorption cavity doesn't exceed 82K. It must be noted that, considering high degree of isothermity of adsorption cell coat ($T_{scr}$ and $T_{N2}$ differ not more then 0,5K), in case when gas-emission in vacuum system is terminated (corresponds $W_i$=0) the solution of system has a view $T_i$=$T_{N2}$. The last means that adsorptional equilibrium sets at lowest temperature.

**1.3. Cryocondenser**

As it may be seen from adsorption cell description the role of porous screen is twofold. On the one hand, it removes radiant heat and prevents sorbent overheating. On the other hand, porous screen is capable to protect sorbent from contamination by easily-condensable vapours either in molecular or viscous modes of evacuated gas flow. However, prolonged desublimation of vapours in screen pores is not desirable, as it causes reduction of screen molecular conductivity. To avoid pores sealing there has been developed special node – cryocondenser (Fig.1) intended to remove easily-condensable components from evacuated mixture of gases.

Fig.1 Cryocondenser

Constructed vapours cryocondenser consists from coaxial conical plates and is placed directly after pump inlet pipe. To optimise given structure geometry simulation of gas flow by use of Monte-Carlo method was performed. The best results were obtained for cryocondenser with cones apex angle 90$^o$ and ratio of distance between cones to its length being equal to 0,25. In accordance with computation results, for vapours with sticking to cryosurface coefficient 0,9÷1, the trapping factor

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is equal to 0,85÷0,88, taking into account partial dispersion of particles in inlet pipe. Consequently, cryocondenser provides almost maximum possible $H_2O$ and $CO_2$ pumping speed. At the same time cryocondenser has low gas-kinetic resistance for non-sticking gases. Molecular transmissivity of this element together with inlet pipe for air main components appeared to be equal to 0,52. In addition, cryocondenser disperses back into chamber about 30 % of radiant heat flux, coming into cryopump through inlet pipe, thus reducing heat load on low-temperature parts of pump and corresponding $LN_2$ consumption.

## 2. CRYOPUMP DESIGN AND OPERATING CHARACTERISTICS

New technical solutions concerning sorbent heat-protection and easily-condensable vapours binding allow to develop several different designs of cryosorption pump. As an example on Fig.2 is given scheme of cryopump with inlet pipe diameter 160 mm [3-5]. Cryopump has thin-wall, completely disassembled construction. The radiation shield for screening the frame and electro-polished internal surfaces provide reduction of heat-leakage and $LN_2$ consumption.

Fig.2 Cryosorption pump CSP-1.5D

Due to compactness of developed heat-protection means the internal space of pump is maximally used to place additional adsorptional cells, thus increasing cryopump adsorptional capacity. On Fig.3 are given charts of limit pressure dependence on amount of adsorbed gas. In accordance with represented data for 1 $m^3$ chamber evacuated from ambient pressure the vacuum $10^{-4}$ Pa can be achieved (not considering $H_2$, He and Ne contribution). However, much more better results can be obtained in case of chamber preliminary rarefaction till 10 Pa by use of any non selective pump. As far as it is necessary, the achieved vacuum can be improved approximately on two orders by

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pumping vapour from nitrogen vessel till 0,0125 MPa, what leads to appearance of solid phase in $LN_2$ and temperature lowering till 63K.

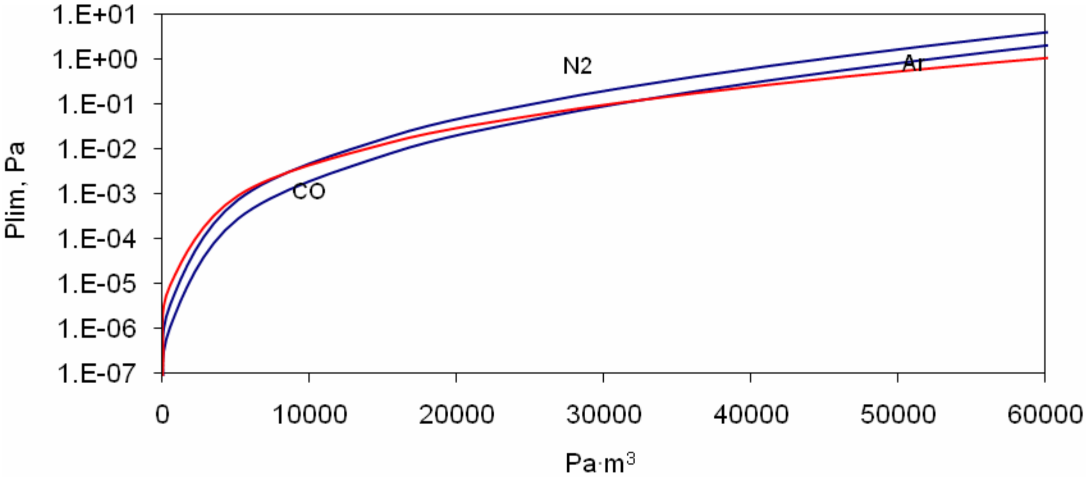


Fig.3. Dependence of limit pressure on amount of adsorbed gas

To investigate cryopump dynamical parameters the program for tracing the trajectory of molecular movement through three-dimensional channels of pump has been compiled. Using computed by Monte-Carlo method cryopump trapping characteristics jointly with adsorptional-diffusion properties of carbon sorbents the charts of pumping speed dependence on pressure in vacuum chamber for various gases and vapours were plotted. The principal operating parameters of cryosorption pump are summarized in table.

| | |
|---|---|
| Inlet Flange, mm | 160 |
| adsorbent mass, kg | 6 |
| Working Pressure Range, Pa | $10 \div 10^{-5}$ |
| Pumping Speed in Working Pressure Range $N_2$ / $CO_2$ / $H_2O$, $m^3/s$ | 1,5 / 2,2 / 4,0 |
| Liquid Nitrogen Consumption | |
| • *on cooling and fill up, L* | *50* |
| • *during operating, L/day* | *10* |
| Regeneration Temperature, K | 293 |

**CONCLUSIONS**

The developed compact sorbent heat-protection system based on application of optically opaque materials and cryocondenser for binding easily-condensable vapours allow:

- maintain lowest disposal average temperature in granular sorbent layer, differing from ɲogens temperature not more then 0,5K;
- to use effectively cryopump internal space for placing of additional adsorptional cells;

ISSN 1512-1461

- to prevent worsening of adsorptional properties caused by sorbent contamination with easily-condensable vapours and to provide maximum possible $H_2O$ and $CO_2$ pumping speed.

On the basis of introduced technical solutions is developed cryosorption pump distinguished by low residual gas pressure, high adsorptional capacity and low $LN_2$ consumption.

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