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MEDICAL INSTRUMENT BASED ON A HEAT PIPE FOR LOCAL CAVITY HYPOTHERMIA

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The design and results of tests of an instrument based on a heat pipe for local cavity hypothermia are presented. The instrument is a part of a device for noninvasive nonmedical treatment of inflammatory diseases of the organs of the small pelvis, pathologies of alimentary canal, etc.

Methods of medicinal temperature effect on biotissues find wide application in medical practice. The reliability, safety, and efficiency of equipment intended for these purposes can be substantially improved by using heat pipes; in this case new opportunities are opened up for creating fundamentally new apparatuses. In particular, heat pipes allow one to successfully solve the problem of uniform supply and discharge of heat when treating cavity diseases.

The production amalgamation "Monolith" (Khar'kov) together with Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute, Academy of Sciences of Belarus," (Minsk) and Scientific-Engineering Center "TN-VIKT" (Minsk) developed the instrument for local cavity (vaginal and rectal) hypothermia. The instrument is a part of the "Sever-01" apparatus that makes it possible to carry on noninvasive nonmedical treatment of inflammatory diseases of the organs of the small pelvis, pathologies of the alimentary canal, etc.

A medicinal effect is achieved via cooling or realization of a cyclic "cooling-heating" regime (by a special technique) of the mucous membranes that a heat pipe contacts. In this case not only the diseases of the organs in the cooling zone (proctitis, sphincteritis, inflammation of rectum, walls of vagina, etc.) are treated, but also the diseases of those organs that are at a distance from the objects of cooling (e.g., chronic colitis, gastritis, gastroduodenitis, gastric ulcer and duodenal (peptic) ulcer). This is achieved by the effect on the reflex centers of the organism.

The main element of the instrument (Fig. 1) is a heat pipe made of sintered copper powder with a capillary structure and filled-in with a low-boiling heat carrier.

One end of the heat pipe, which is positioned in a hollow shaft 4, contacts thermoelectric microcoolers (TEMC) 2. Heat releasing surfaces of TEMC are cooled by continuous-flow water heat exchangers 3. The other end of the heat pipe (the working section of the instrument) is introduced to either the rectum or vagina of the patient. The surface of this zone of the heat pipe meets the requirements (roughness, quality of coating) associated with the specifics of the device application. As the instrument is switched on, TEMC's cool the heat pipe in the contact zone, heat carrier vapors start to condens inside it, and on the outer surface of the working section evaporation of heat carrier with intense heat removal and cooling of the working section begins due to a pressure drop along the pipe axis. Changing the polarity on electric contacts of TEMC, one can both cool and heat tissues, or alterate these types of temperature effect according to the assigned program.

Each apparatus is provided with three instruments of different types and sizes. In the instrument for treating children the diameter of the working section of the heat pipe is 15 mm, and the length 48 mm. For rectal therapy a pipe with a diameter of 20 mm and a length of the working section of 65 mm is used. In gynecology the instrument with a heat pipe with a diameter of 25 mm and a working section length of 100 mm is employed.

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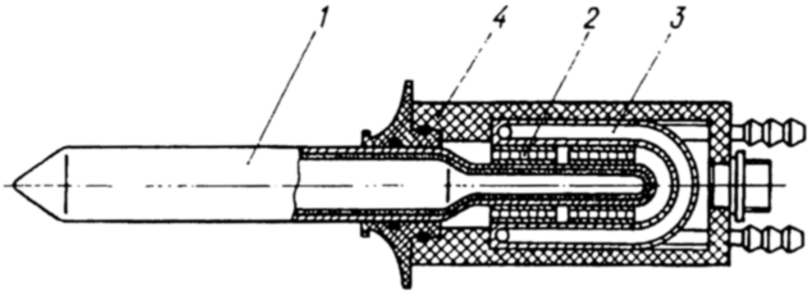

Fig. 1. Medical instrument: 1) heat pipe; 2) thermoelectric microcooler; 3) heat exchanger; 4) shaft.

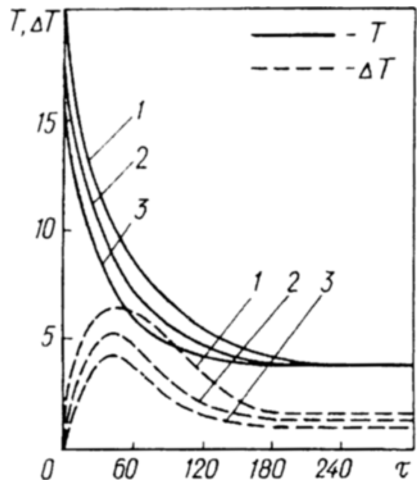

Fig. 2. Dynamics of heat pipe actuation: 1) for gynecological instrument; 2) for rectal hyperthermia; 3) for treating children. τ, sec; T, ΔT, ^{o}C

Characteristics of heat pipes are to a great extent determined by the properties of a capillary structure which serves as a wick for returning condensate of the working fluid to the evaporator and also facilitates heat transfer enhancement in phase transitions. The choice of a metalloceramic porous structure, which is manufactured by the method of powder metallurgy and whose properties were studied experimentally at the Academic Scientific Complex "Institute of Heat and Mass Transfer" [1, 2], is stupulated by the combination of such characteristics as highly effective thermal conductivity at high porosity, reliability, and provision of sufficient capillary pressure for fluid flow through capillaries, thus guaranteeing a reliable operation of the instrument at negative angles of heat pipe slope to the horizontal.

Optimization of a porous coating for the minimum thermal resistance was achieved by the dependence [3]

$$\Delta T = q_{ev}^{2}\, K_{fl}^{-1}\, (l_{ef} l_{ev}/2)\, r_{cap}\, (K\lambda_{ef})^{-1}\,,$$

$$K_{fl} = \sigma \rho r^{*}/\mu\,, \quad l_{ef} = \frac{L - l_{ad}}{2} + l_{ad}\,.$$

In determining the thickness of a sintered porous layer, besides the requirements for minimization of the temperature drop, the need for the determination of the smallest cross-sectional area of a capillary wick at which a working fluid flow from the condenser to the evaporator of the heat pipe is ensured under the conditions of a maximum negative value of the slope angle of the instrument was taken into account [4]:

$$F_{w} = \frac{Q l_{ef}\, \mu}{\left(\dfrac{2\sigma}{r_{cap}} - \rho g D\right) K \rho r^{*}}\,.$$

Thanks to the unique properties of heat pipes the instrument ensures reliable operation of the apparatus within a wide temperature range at a temperature drop along the length of a working section smaller than 2°C, ease of adjustment and tuning, and fast attainment of the regime (not more than 4 min), and has small dimensions and mass. Dynamic characteristics of actuation of heat pipes are presented in Fig. 2.

After insignificant refinement the instrument can be used for treating patients by the method of hyperthermia (in particular, oncological diseases).

The "Sever-01" apparatus was medically tested in a number of hospitals of the Ukraine. The Ministry of Public Health and the Committee for new medical equipment of the Ukraine authorized its clinical application and recommended full-scale production.

NOTATION

D, inner diameter of heat pipe; F_w, cross-section area of wick; g, gravity acceleration; K, coefficient of porous structure permeability; K_{fl}, heat transfer parameter of fluid; L, heat pipe length; l_{ad}, length of adiabatic zone; l_{ev}, length of evaporation zone; l_{ef}, effective length of fluid transport in a capillary structure; Q, heat flux; q, heat flux density; r_{cap}, capillary radius; r^*, latent heat of vapor generation; λ_{ef}, effective thermal conductivity of porous structure; μ, dynamic viscosity; σ, surface tension; τ, time.

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