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ScienceDirect

Procedia Engineering 152 (2016) 169 – 172

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Oil and Gas Engineering, OGE 2016

Turbo-refrigerators using for cooling the cryotherapeutic units

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Abstract

The Paper is devoted to rationale for using refrigerators, working on air refrigeration machine cycle, for cryostating low-temperature space of cryotherapeutic complexes. The low energy efficiency of cryotherapeutic complexes restricts its extensive practical application. The reason for this energy efficiency is that liquid nitrogen with boiling point 78 K is used for exhausting heat at the level 120 – 140 K. The replacement of nitrogen cooling system by the turbo-refrigerator with operating temperature 140 K reduces the energy consumption to the one procedural cycle from 23 to 5.85 mJ.

Peer-review under responsibility of the Omsk State Technical University

Keywords: turbo-refrigerator; cryotherapy; heat load; cryostating; fluid; cryogen.

1. Introduction

Devices for general cryotherapeutic influence (cryotherapeutic complexes) are used for prevention and treatment of severe diseases. Procedures in cryotherapeutic complexes (for general cryotherapy) provide stimulating effect on human's cold receptors of skin. The maximum intensity of receptors signals are provided when a thin layer of the skin where there are receptors supercooled to a temperature of 2^0C. Heat elimination by cryogenic gas provides such an overcooling the entire surface of the skin for 150-180^{0}C At the same time the supercooling zone of skin does not have time to penetrate into the deeper layers of the body. Therefore, the procedure is absolutely safe for patients. Modeling process of supercooling a body by cryogenic gas has shown that heat elimination from the entire surface is not more than 600 kj. However because of the short duration of the procedure, the average thermal load is 4 kW. Evaluation of true thermal emissions from a surface of the body was made much later than start of cryotherapeutic complexes production. Therefore the majority of cryotherapeutic devices are calculated based on normal heat release of human body 150 W. Deficit of power cryostatting system cannot maintain the gas temperature in cryo-cabins at a constant level. Modeling process of cryotherapeutic influence at different cooling-gas temperature has shown that the greatest therapeutic effect is achieved at a temperature of 140 K. Cryotherapeutic complex should provide with elimination of heat flow with an average intensity of 4 kW per patient at the temperature level not above than 140 K. Considering that, the quantity of irrational heat inleak in most cryotherapeutic complexes is not less than 50%. To implement effective cryotherapeutic influence, the cryostatting system must have an ability to take 140 K not less than 8 kW of heat per patient. Taking into account that the part of cryotherapeutic devices was designed for the procedures for groups of 5-8

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Peer-review under responsibility of the Omsk State Technical University
doi:10.1016/j.proeng.2016.07.686

patients, the calculated refrigerating capacity of cryostatting complexes systems on temperature level is not above 140 K and should be 40-65 kW. For a specified temperature level to elimination of this heat load a refrigeration unit is required with a drive power of 160-250 kW. A strict requirement for power availability of cooling system of cryotherapeutic complex was the reason for the replacement compressor refrigerators nitric quasicycles.

2. **Study subject**

To implement medical technology general cryotherapeutic effects two types of cryotherapeutic complexes are used: multi-seat (5-8 patients) and single units. Design and energetic characteristics of different types of cryotherapeutic devices make its matching difficult. All multi-placed systems have a similar design and consist of the insulated room in which the procedure of general cryotherapeutic influence is conducted. Patients enter cabins via the lock-chamber in which temperature 210 K is maintained. The lock protects the main cabin from intake of warm atmospheric air. Till 1995 all multi-placed complexes used nitric cooling for cryostatting of a cabin. Liquid nitrogen moved in the recuperative heat exchangers placed on walls of low-temperature cabins. Later there were cryotherapeutic complexes with system of cryostatting the cascade refrigerator based on use or a throttle cycle on the mixed working body. These refrigerators have the limited range of cryostatting so temperature in the complex main cabin has increased with 140 to 160K. Such temperature increase in a cabin of a cryotherapeutic complex has reduced efficiency of cryotherapeutic procedures by 10 times therefore many-placed complexes with the compression cooling system are unreasonably ranked as cryotherapeutic devices [1]. Specifications of multi-placed cryotherapeutic complexes are presented in Table 1.

Table 1. Specifications of multi-placed cryotherapeutic complexes.

Specifications	«KR-2005N»	«Zimmer»	«Cryospacecabin»
Fabricator	«CREATOR», Poland	«ZimmerMedizinSysteme», Germany	«LindeGroup», Germany
Cabin capacity, people	6	5	5
Gas temperature in the cabin, K	140	160	160
Gas temperature in the lock, K	210	210	210
Procedure duration, min	3	3	3
The number of procedural cycles, $hour^{-1}$	15	4	4
The drive power of the refrigerator, kW	7	18	20
Nitrogen flow rate, kg/h	100	-	-
the measurements of the main cabin, m	2.5x2.5x2.5	2.0x2,0x2.0	2.0x2.0x2.0

The data of table 1 allow us to leave idea of power availability of multiple cryotherapeutic complexes. Units with compression refrigerators, "Zimmer" and "Cryospacecabin", have obvious power deficiency as work with big breaks between procedures and for an hour provide only 4 sessions of cryotherapy. The Polish "KR-2005N"complex uses for cryostatting not only nitric system with a flow of cryogent 100 kg/h, but also refrigerator unit with the drive power 7 kW that allows to hold cryotherapy sessions without breaks. However the nitrogen flow rate stated by fabricators allows us to take away at the temperature level 140 K. And for the cryotherapeutic influence on a group of 6 people we need to take the heat flux with power not less than 48 kW.

Single cryotherapeutic complexes are different from multi-placed ones in a design and the principle of action. These devices were designed after 1995 considering the identified deficiencies of multiple units. The second advantage of the single systems is that they are designed to comply with the requirements of efficacy and safety of cryotherapy, which were formulated only at the end of the twentieth century. The single cabin space is 0.5 – 1.2 m^3. Quantity of available surface in the single cabin is from 85%, while in multiple complexes the amount of available surface is up to 97%. Due to the high compactness of billeting in a single procedural cabin the percent of heat load associated with the implementation of cryotherapeutic influencet on the patient's body is up to 75 %. In multiple cryotherapeutic units, the percent of useful thermal load on the cryostatting system is not more than 49 % [1]. The second advantage of the single cryotherapeutic systems is the use of nitrogen cooling. Over-heated nitrogen vapor is invading to the cabin. These vapors are formed in the refrigerating system due to contact for supplying heat to the liquid nitrogen. For cryostatting of a cabin it is necessary to provide a consumption of nitrogen vapor not lower than 0.25 kg/s. Specifications of single cryotherapeutic complexes are presented in table 2