RECOMMENDATIONS REGARDING THE SELECTION OF EQUIPMENT FOR THE CRYOGENIC PHYSIOTHERAPY

The selection of the gas nominal temperature in the procedural cabin is the basic direction of the optimization of technology of cryogenic physical therapy action. The result of studies in connection of the value of the physical therapy result of procedures with the temperature in procedural cabin, became the new classification of low-temperature procedures. It was shown that not all procedures, based on the use of low-temperature gaseous media, can be carried to the cryo-therapy (see Tab.1).

Table 1.

Low-temperature physical therapy procedures.

Designation of procedure	Temperature of gas	Average physical therapy result, uia/m^2
Extreme cryo-therapy	less –160 ˚C	85
Cryo-therapy	from –160 to –130˚C	230
Low-temperature gas hypothermia	more –120˚C	40

It clearly illustrates the reasons for introduction to the classification of the procedures drawing of a change in the parameters of physical therapy effect with the different values of the gas temperature (see Fig.1). Depending on selection of one of three temperature ranges the average therapeutic physical therapy result of procedure changes several times. Qualitatively are distinguished processes in the integumentary tissues of patient. Surface cooling prevails with the extreme cryo-therapy. The processes of cooling surface and supercooling of integumentary cloths are developed synchronously with the cryo-therapy. With low-temperature gas hypothermia the process of the propagation of supercooling anticipates cooling the surface of the skin.

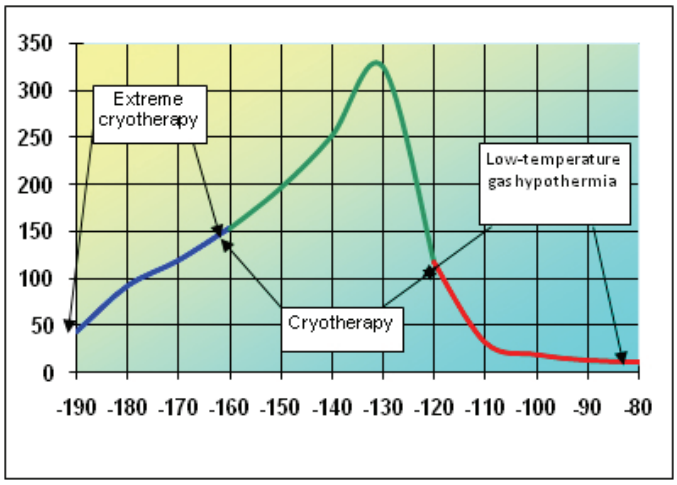

Fig.1 Graph of the dependence of the achievement magnitude of the physical therapy effect per unit of body surface (uia/m^2), with the different of the gas value temperature in the procedural cabin.

On the market for the medical technique of Russia are represented 4 types of the devices, which the salesmen and producers carry to the equipment for conducting the cryo-therapy. Two systems (see Tab.2) are intended for conducting the individual procedures used for the cooling liquid nitrogen, they were developed and are produced in Russia. Alternative direction - apparatuses for the group procedures are represented in Table 3. Group systems are supplied with compression coolers. The installation, supplied by company “Cryotec” (Moscow), cryo-sauna “CRYO- SPACE” is the product of German firm “Medizintechnik Kirscheman + Sweizer”. The cooler of this installation is three-stage refrigerator.

The Ukrainian enterprise of Joint Stock Company “CHOLOD” proposes as its development with the name “CRYO-SAUNA”, the copy the medical installation of German firm “Zimmer”. Cooling the procedural cabin “CRYO-SAUNA” provides choke cooler on the gas mixture.

Table 2.

Technical characteristics of the produced in Russia individual cryo-therapeutic complexes.

CHARACTERISTICS	Unit of meassurement.	Designation	
		«KAEKT-01 KRYON»	«CRYOMED-20/150-01»
Capacity	man	1	1
Volume of procedural cabin	m^3	0,48	1,00
Multiplicity of procedures	1/hour	15	15
Required power	kW	1	1,5
The expenditure of cryoagent, is not more	kg/min	1,5	2
The duration of procedure, is not more	min	3	3
Temperature of cryostating cabin	°C	-140	from 0 to -170

Technical specifications of Table 2 show that according to nominal temperature both individual complexes relate to the cryo-therapeutic equipment. True, some indeterminateness in the temperature level of the complex “CRYOMED-20/150-01” makes it possible to carry it to any of the groups chosen in Tab.1, but in principle this apparatus provides reaching temperatures of cryo-therapeutic range. The cabin of complex “CRYOMED-20/150-01” is two times more by the volume. Taking into account of temperature level and volume of cabin this complex has above expenditure of liquid nitrogen. The insignificant power of electrical equipment of individual cryo-therapeutic complexes, explains by the fact that the basic source of cold in these apparatuses is liquid nitrogen. The use of a liquid cryoagent, makes it possible to remove powerful heat fluxes with the minimum expenditures of energy. For example, the use 1 kg of liquid nitrogen per minute creates at temperature level 140 K refrigerating capacity 4,3 kW.

Table 3.

Technical characteristics of represented on the market of Russia installations for the group low-temperature physiotherapy.

CHARACTERISTICS	Unit of meassurement.	Designation	
		«CRYOSPACE»	«CRYO-SAUNA»
Capacity	man	5	5
Volume of procedural cabin	m^3	8,4	7,1
Multiplicity of procedures	1/hour	4	4
Required power	kW	25	16
The duration of procedure, is not more	min	4	4
Temperature of cryostating cabin	°C	-120	-110

On the declared level of the temperature in the procedural cabin the apparatuses for group action do not provide conditions for the cryogenic physiotherapy. Use in the cooling systems of compression cooling cycles is the basic reason for the overstated temperature level. Because of the low effectiveness of the cooling system in the region of cryogenic temperatures, in the procedural cabin of autonomous cryo-therapeutic complexes is

maintained the temperature not lower than 150 K (~ -120 ˚ C); therefore group systems represented into Tab.3 it follows to the devices for low-temperature gas hypothermia.

Insignificant at first glance differences in the temperature level of cryostating the internal volume of procedural cabin lead to the fact that the self-contained units do not provide the conditions for achievement of essential physical therapy result. Taking into account that the fact that the cost of autonomous apparatuses with the compression cooling systems comprises not less than 100 thousand $, therapeutic establishments must be, caution about their ineffectiveness.

The temperature of gas in the procedural cabin is the determining characteristic of cryo-therapeutic complex, only when cooling system is capable of supporting the assigned temperature level at all stages of the work of complex. To estimate the ability of cooling system to cryostat the zone of cryogenic effect, is possible with the comparison of the heat emissions in the course of procedure and refrigerating capacity of cryostating system.

Cryogenic physical therapy action is ensured due to the intensive cooling of the skin surface down to the temperature from - 2 to +2 ˚C. Hence from the body surface must be led about 600 kJ of heat in 2-3 minutes. On the average from the body surface into the volume of procedural cabin are separated more than 3 kW of heat, for retaining the gas temperature at the assigned level the cooling system with a sufficient heat-transferring ability is necessary. But, because of the low temperature level, at which necessary to remove heat (from - 150 to - 130˚C) the energy effectiveness of the cooling equipment is extremely small. In Fig. 2 is given the graph of the dependence of energetic efficiency for the cooling cycle (ECC) on the gas mixture and the cascade refrigerator [1]. The dependence is there given energetic efficiency for most effective in this temperature range of cooler - cryogenic gas machine. For the cooling cycles the utilized in the group installations efficiency so rapidly is reduced in the temperature range less - 100˚C, that the maintenance of temperature even at the level declared into Tab.3 is represented sufficiently to doubtful.

Assuming that contemporary cooling cycles somewhat more effective than cycles described in [1] should be estimated energy requirements for the cooling system in the case of applying the most effective design concept.

It is evident from the graphs given to Fig. 2 that the cryogenic gas machine can be used as the ideal cooler of cryo-therapeutic complex. In entire recommended for the application in the cryo-therapeutic installations temperature range its energetic efficiency it has satisfactory values and considerably exceeds the parameters of cooling cycles.

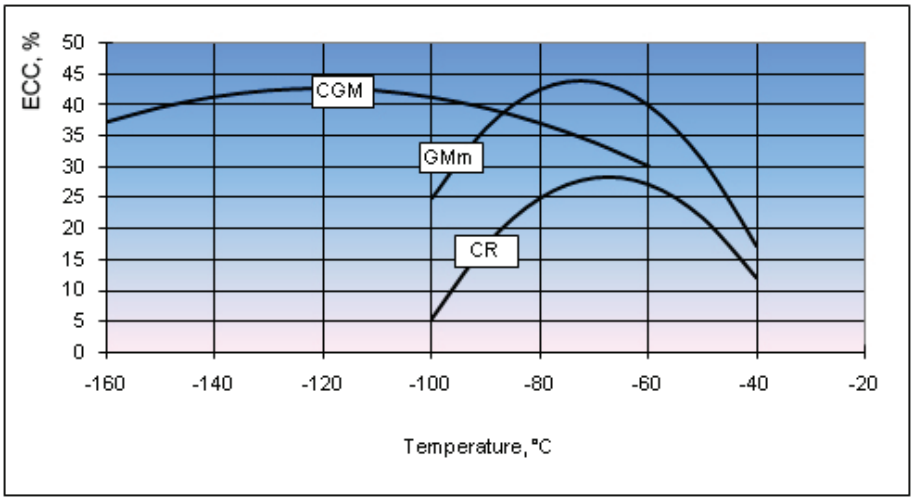

Fig. 2 Change in the energetic efficiency of coolers with a decrease in the level of cryo- stating (CGM cryogenic gas machine, GMm - cooling cycle on the gas mixture, CR - cascade refrigerator).

But, even with the use in the cooling system of cryogenic gas machine specific refrigerating capacity - the ratio of the diverted heat to the expenditures of energy for the work of cooling system temperature range from - 150 to - 130˚C will compose 15- 25% (see Fig. 3).

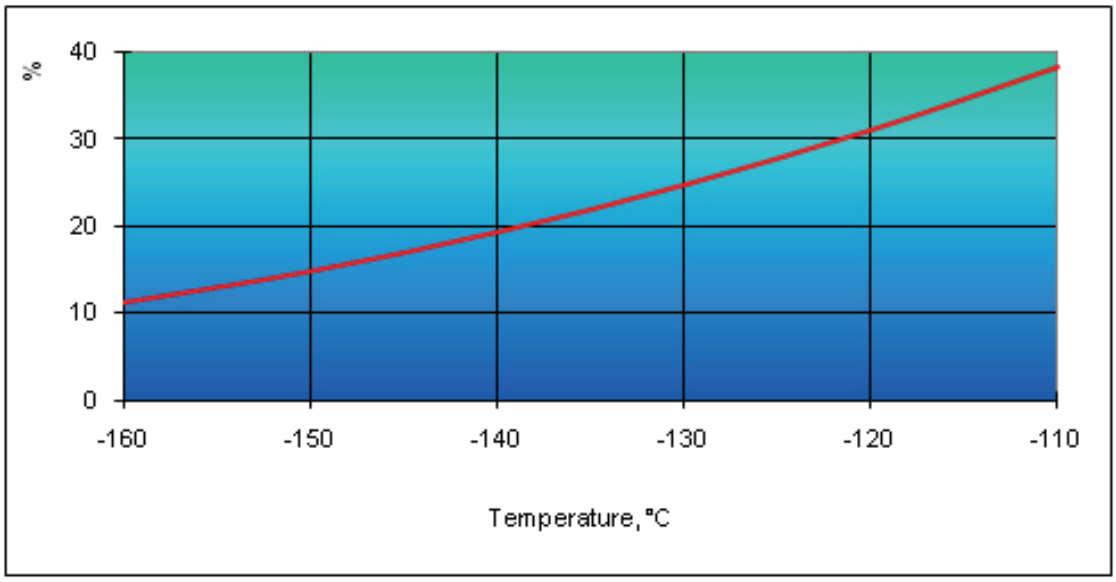

Fig. 3 Specific refrigerating capacity of cryogenic gas machine at low temperatures.

In order to lead from the volume of the procedural cabin 1 kW of heat will be necessary cryogenic gas machine from the required electrical power from 4 to 6 kW. For compensating the liberations of heat from the body surface of one patient (3 kW) average for the procedure the aggregate with an installed electrical capacity not of less than 12 - 18 kW is necessary. In the real cryo-therapeutic devices cannot to use a cryogenic gas machine; therefore the obtained result is suitable only for the designation of the minimum needs for the expenditures of energy.

On the basis of the obtained result, it is possible to estimate the efficiency of a work of those represented cryo-therapeutic complexes on the market for the medical technique of Russia, to illustrate their consumer qualities.

GIVEN ENERGY CHARACTERISTICS OF THE CRYO-THERAPEUTIC COMPLEX

Taking into account essential differences in the operating principle, sizes and the construction of the compared objects, for evaluating their efficiency of a work it is expedient to use the given characteristic - driving power of the referred cooling system to the unit volume procedural cabin. Not only for the objects of those given in Tables 2 and 3, but also for any other apparatuses of analogous designation it is not difficult to determine the power corrected to standard of cooling system. The expenditures of electric power are always given in the advertising materials. For the equipment of that consuming electric power the power corrected to standard will be determined from the relation:

$$N' = \frac{N_{ep}}{V_{cab}}$$

In the cooling systems of those consuming liquid nitrogen, is used the energy spent with the production of cryoagent. The concept of adequate electrical power is possible for the

comparison of apparatuses with the liquid and compression coolers. The power of the electric drive of the ideal cooler, which possesses analogous, with the liquid cooler, refrigerating capacity, is implied by adequate power. At an assigned temperature of cryostating the average expenditure of cryoagent, makes it possible to determine the refrigerating capacity of the liquid cooler:

$$q_5 = \overline{g_a} \cdot [r_a + C_p \cdot (T_1 - T_a'')].$$

It is possible to calculate according to known thermophysical data of liquid nitrogen that the nitrogen cooler at expenditures of nitrogen 1 kg/min and temperature in the cabin - 130˚C ensures the outlet of thermal power flux in 4 kW.

In Fig. 4 are given the graphs of a change in the adequate power of electric drive for the liquid coolers with the flow rate of nitrogen from 1 to 2 kg/min. It is evident from Fig. 4 that the declared expenditure of cryoagent ensures the adequate power, which exceeds the indices of group complexes with the compression coolers to liquid installations. The graph, given in Fig. 4 makes it possible to estimate the available power of liquid cryo-therapeutic complexes and explains the reasons, for which conducting the procedures in the cryo-therapeutic temperature range are not suitable the compression cooling systems.

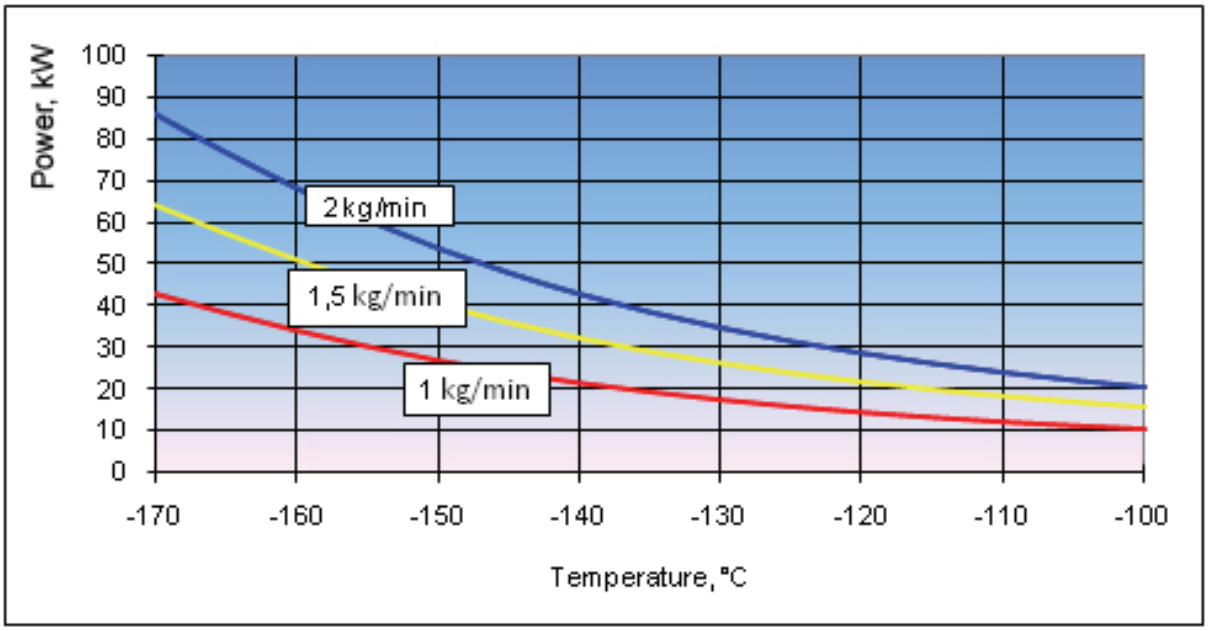

Fig. 4 Adequate power of electric drive for the liquid coolers with the flow rate of nitrogen from 1 to 2 kg/min.

One should consider that the compared groups of apparatuses for the low-temperature physiotherapy with the comparable power-weight ratio considerably are distinguished by the volume of procedural cabin and the number of patients. The power corrected to standard of coolers - ratio of adequate electrical power to the volume of procedural cabin, is represented in Fig. 5.

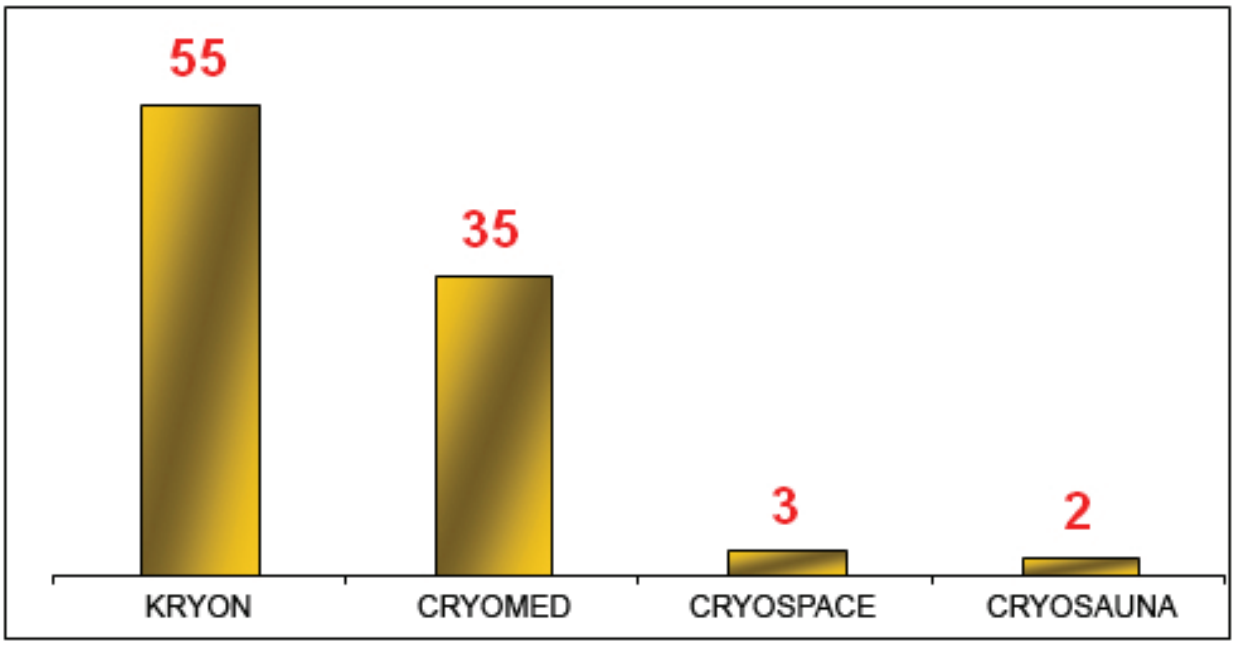

Fig. 5 The power corrected to standard [kW/m^3] of cooling systems for the group and individual cryo-therapeutic systems.

Enormous differences in the compared complexes in the amount of power corrected to standard, make it possible to do the conclusion that the group procedures are not suitable for conducting the cryo-therapeutic ones not only because of the high temperature in the cabin, but also on the power-weight ratio.

On the mathematical model of the cabin of cryo-therapeutic complex [2] was executed numerical experiment on a study of the dependence of the effectiveness of procedures on the power corrected to standard of cooling system.

For increasing the clarity of the analysis results several simplifying assumptions were made. Is assumed that at the beginning procedures the temperature in the cabin composes - 130 ˚ C, patient is the sole source of heat.

With the simulation of the work of cooling system the dependence efficiency on the temperature in the cabin was considered. The results of the simulation of processes in the procedural cabin are represented in Fig. 6.

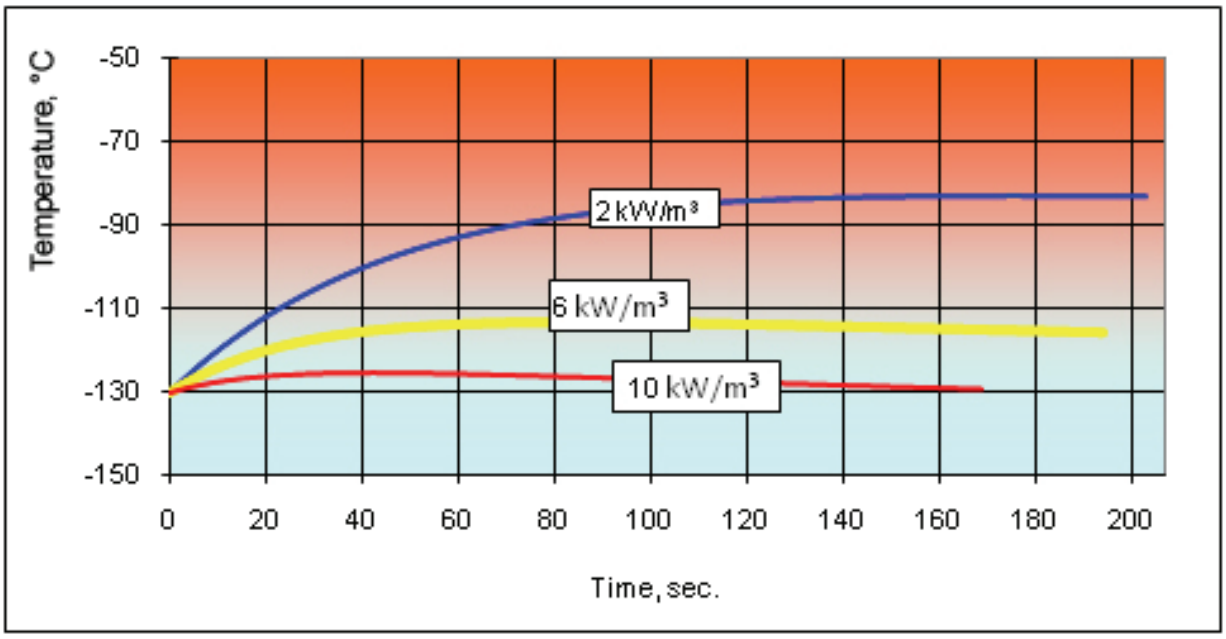

Fig. 6 Change in the temperature of gas in the cabin of complex after the beginning of procedure with the different values of the power corrected to standard of cooling system.

With the low values of that given of the power of cryostating system, immediately after the beginning of procedure the temperature of gas in the cabin rapidly rises. Powerful heat flux from the body surface of patient exceeds the refrigerating capacity of cooling system. The disturbance of heat balance leads to the fact that gas in the procedural cabin is heated with a speed of up to 20 K/s. Temperature rises until the refrigerating capacity of cooling system balances heat emission from the patient. Since with an increase in cryostating temperature the effectiveness of cooler grows, for any value of power corrected to standard there is a temperature of thermal equilibrium. In the version with a power corrected to standard of 2 kW/m^3 this equilibrium is reached only at a temperature - 80 ˚C, i.e., the actual temperature of gas occurs to 50˚C higher than optimum. The power corrected to standard of compression cooling systems (see Fig. 5) has the same order, therefore, the temperature of gas during the procedure it must substantially grow. The scarcity of the power of cooling system is so great that even the declared by producers temperature level of temperatures, cannot be supported in practice. For compensating the small power of cooling system large interruptions between the procedures are used. Thus, is per hour released only 4 procedures on 4 minutes, i.e., the total duration of the procedures only of 16 minutes. Consequently, between the procedures pause is provided by the duration not less than 10 minutes. Only in this time the weak system of cryostating is capable of restoring the temperature in the procedural cabin. So, that the procedure would flow in the calculated temperature conditions, is necessary an increase in the power corrected to standard to 10 kW/m^3.

In practice besides the supply of heat from the body of patient cooling system covers heat emissions from the walls of cabin, compensates heat flow that connected with the losses of cold air through the doors and so forth real thermal load is 1,5 - 2 times more than the values of those used for the analysis; therefore the efficiency of a work of compression coolers is questionable. In any event, neither on the assigned temperature level nor on the power-weight ratio these apparatuses can be examined as equipment for the general cryo-therapy.

For the successful work complex with the compression cooler must be supplied with cooling system several times more powerful. For example, for the camera with a volume of 8 m^3 it is necessary to equip with cooling system with a power not less than 120 kW. But, this increase in the power will lead to repeated increase in the cost of equipment. Furthermore, not in each therapeutic establishment it is possible to connect apparatus with a required power of 100 - 150 kW.

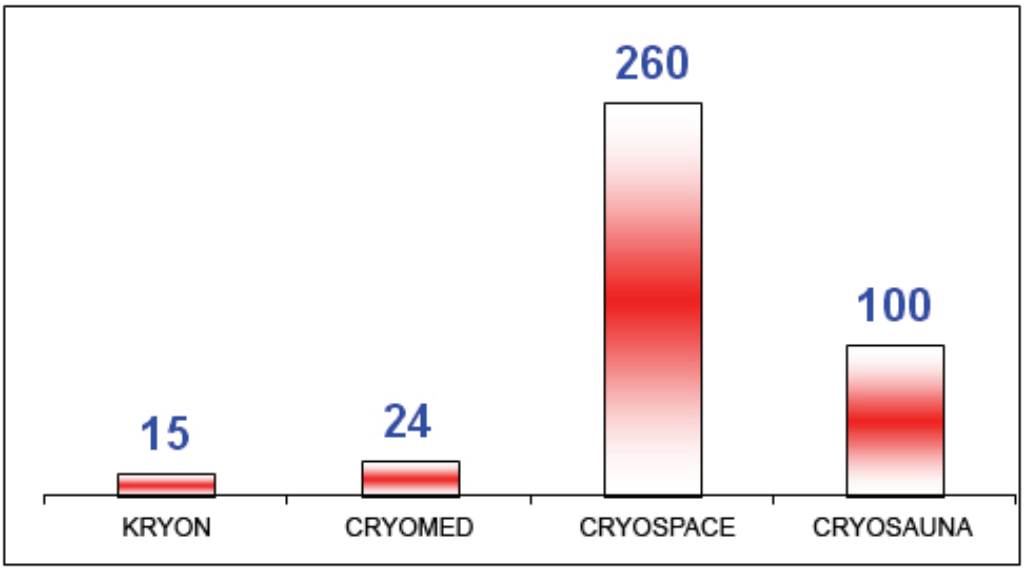

Fig. 7 Cost (in thousand $) of the low-temperature physical therapy complexes.

The expenditure of liquid nitrogen in the complexes with the liquid cooling system repeatedly overlaps the heat emissions of patient, which guarantees effective physical therapy action. The reserve of refrigerating capacity makes it possible to cover the heat fluxes, which were not taken into account in the given above analysis, cooling the walls of cabin, the compensation for the losses of cold gas from the cabin with entrance and output of patient, heat flows from the environment.

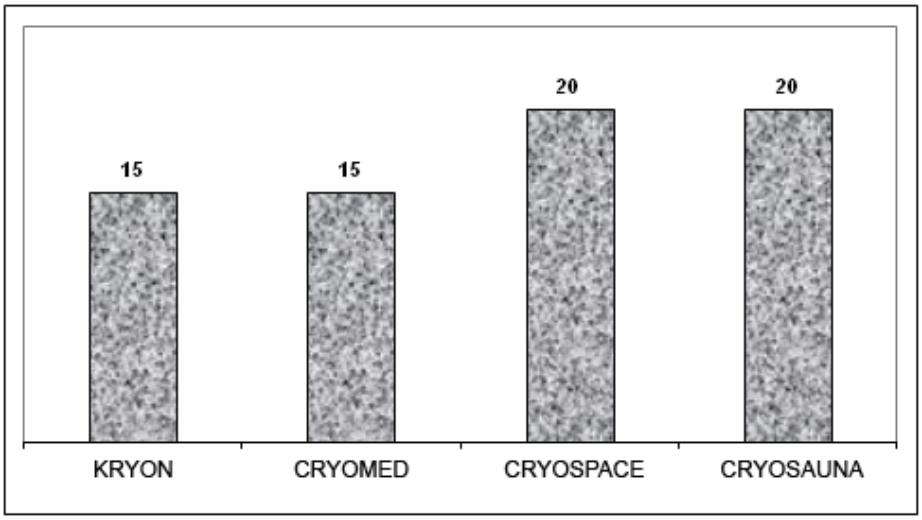

Fig. 8 The capacity (number of patients in 1 hour) of low-temperature physical therapy complexes.

Furthermore, the significant reserve of power of the liquid coolers it ensures the high capacity of cryo-therapeutic complexes (see Table 2). Individual cabins pass not less than 15 patients an hour, but group to 20 people in hour thus, with the gigantic difference in the prime cost (see Fig. 7), the compared apparatuses have the comparable capacity. Paradox consists in the fact that the cheap systems are capable of ensuring effective treatment, but expensive group complexes do not.