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# Development of whole-body cryochambers based on a mixed-gases Joule-Thomson refrigeration cycle

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**Abstract**

Whole-body Cryotherapy (WBC) or cryostimulation stands as a prevalent and extensively employed recovery modality in the realms of sports and exercise medicine, especially post strenuous training and competitions. This practice involves brief exposures, usually lasting between 2 to 4 minutes, to extremely cold air, reaching temperatures of −110 ℃ and below. Individuals undergoing WBC are minimally dressed and positioned within cryogenic chambers. Initially employed within clinical contexts for alleviating symptoms associated with diverse rheumatic diseases, WBC is claimed to diminish pain, edema, and inflammation.

Whole-body cryotherapy equipment gained popularity in the 1970s. Over the past few decades, these devices have been heavily reliant on liquid nitrogen. Cryotherapy at low temperatures inevitably necessitates frequent liquid nitrogen supply, which is challenging to obtain or permit in many urban areas. There are also potential risks associated with oxygen consumption and the need for exhaust system installation. Electrically powered equipment eliminates the need for liquid nitrogen supply, requires less maintenance compared to liquid nitrogen devices, and is considered safer. However, electric cryotherapy chambers face challenges in competing with liquid nitrogen cryochambers concerning temperature control, especially in hot climates, cooling dynamics, and hourly processing capacity. The electric cryotherapy chambers simplify logistics and maintenance, but most commercial electric cryochambers currently use multi-stage cascade refrigeration for cooling, which imposes a limitation on treatment temperatures, typically reaching around -110℃.

The Joule-Thomson refrigeration, based on the real gas Joule-Thomson effect, stands as one of the oldest refrigeration methods, experiencing a resurgence with the utilization of multicomponent mixed gases in recent decades. Various refrigeration cycle configurations have been proposed for diverse applications. Commercialized applications based on mixed-gases Joule-Thomson refrigeration technology include low-temperature cryogenic preservation chambers, cryogenic water traps for high vacuum applications, and natural gas liquefiers. The majority of these applications operate at temperatures around -150℃, signifying the considerable potential for applying Joule-Thomson refrigeration in whole-body cryochambers.

In this paper, both single-person and double-person electric-powered cryochambers were developed utilizing a mixed-gas Joule-Thomson refrigeration system, allowing for treatments at temperatures as low as -140℃. The single-person cryochamber achieves a reduction to -120℃ within 90 minutes, employing a 12 kW compressor unit dedicated to freezing the entire cryochamber. Simultaneously, the double-person cryochamber achieves -120℃ within 50 minutes and can even reach temperatures as low as -140℃ within 90 minutes under significant thermal loads, facilitated by a 28 kW compressor unit. The cooling capacities of the two compressor units in distinct temperature zones were determined, and the mole fraction of the mixed refrigerants was optimized to enhance overall cooling efficiency.

In addition to the refrigeration unit design, concerning the design of cryotherapy cabins, the individual cold therapy cabin has a volume of 1.3 cubic meters, while the double-type cold therapy cabin measures 3.2 cubic meters. The cabins facilitate self-circulation of air, ensuring a high oxygen concentration. Moreover, a glass viewing window is installed on the door, allowing continuous observation of the cabin conditions.

Finally, an economic analysis of the proposed system was conducted, revealing that the electric-powered whole-body cryochamber exhibits superior economic performance when contrasted with devices heavily reliant on liquid nitrogen. The economic advantages become increasingly apparent with each successive use.



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## Submitters Country

China

**Author:** WANG, XIAN (Technical Institute of Physics and Chemistry)

**Co-authors:** Dr WANG, HAOCHENG (Technical Institute of Physics and Chemistry); Mr WANG, YUNXIAO (Technical Institute of Physics and Chemistry); Dr ZHAO, YANXING (Technical Institute of Physics and Chemistry); Prof. GONG, MAOQIONG (Technical Institute of Physics and Chemistry)

**Presenter:** WANG, XIAN (Technical Institute of Physics and Chemistry)

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