A REFRIGERATOR FOR DISSOLVING $^3$He - $^4$He


Refrigerators for dissolving $^3$He [1, 2] are designed for ultralow temperatures (0.2 K and lower). A new, simpler, reliable refrigerator meeting the basic needs of users of ultra-deep refrigeration was designed by "Gelimash" Scientific-Production Association, basing on the experience of construction and use of a refrigerator designed by the Institute of Physical Problems, Academy of Sciences of the USSR [3].

The operation of the refrigerator for dissolving $^3$He- $^4$He is based on the use of the following unique properties of the two helium isotopes: 1) a region of coexistence of two liquid phases of $^3$He- $^4$He solution below $0.87^\circ$K (the lighter upper phase is rich in $^3$He and the lower phase, in $^4$He; 2) finite solubility of $^3$He in $^4$He at zero temperature $\lim_{T \to 0} x_s = 0.064$ (where $x_s$ is the molar concentration of $^3$He); 3) wide difference of saturated-vapor pressures of pure isotopes ($p_3$ and $p_4$) at $T < 1^\circ$K ($p_3/p_4 > 1000$ at $T = 0.6^\circ$K).

The first of the noted properties suggests that a refrigeration of $Q = T(S_d - S_c)$ can be achieved in transition of $^3$He atoms from the concentrated to the dilute phase, for the entropy of $^3$He in the dilute phase $S_d$ is higher than that in the concentrated phase $S_c$. The transition of $^3$He atoms from the upper to the lower phase is analogous to liquid evaporation in vacuum whose role is enacted in the present case by superfluid $^4$He.

The second property allows for sufficient $^3$He flow through the lower phase even at the lowest temperatures.

The third property creates conditions for effective recovery of $^3$He from the dilute solution.

The $^3$He circulation scheme on which industrial refrigerators for $^3$He- $^4$He dissolution are based is shown in Fig. 1. The $^3$He atoms "evaporated" from the upper phase into the dilute (6%) solution with heat absorption pass from the dissolution chamber 1 through the reverse-flow tube of the low-temperature heat exchanger 2 into the evaporation chamber 4. During this, because of thermal osmosis, the equilibrium concentration of $^3$He in the solution falls constantly with temperature rise, reaching ~ 1% in the evaporation chamber. The $^3$He vapors are evacuated from the chamber at 1.33 Pa ($10^{-2}$ torr) pressure with the aid of the steam-jet 9 and pre-evacuation 8 pumps.

The $^3$He atoms compressed by the pump 8 to a pressure of 1.33 Pa pass through the forward-flow tubes of the heat exchangers 7, 6, and 5 where they are cooled successively to 4.2, 1.3, and 0.7 K and are condensed almost fully before reaching the throttle 3.

The liquid $^3$He, cooled in the heat exchanger 2, reenters the dissolution chamber 1. The circulation speed required for the refrigerator operation is maintained by the electric heater 10 placed in the evaporator. During this, because of wide difference in the vapor pressures of $^3$He and $^4$He at the evaporator temperature of 0.7 K, the heavy, less volatile isotope $^4$He practically ceases to circulate and acts as an inert liquid medium where $^3$He transfer occurs. With restricted flow of the superfluid $^4$He film through the evaporator diaphragm, the $^4$He concentration generally does not rise beyond 5%. More detailed information regarding the functioning of the refrigerator is given in [4, 5].

The major components of the $^3$He-$^4$He refrigerator are a cryostat (Fig. 2), a circulation unit, an array of mechanical pumps, and a measuring instrument. The cryostat is functionally the most important and cumbersome device which includes a nitrogen-screened helium Dewar flask and a low-temperature insertion piece.

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Fig. 1. Basic diagram of refrigerator for $^3$He-$^4$He.

Fig. 2. Design of cryostat for $^3$He-$^4$He dissolution: 1) sectional shaft of the cryostat; 2) shaft of the dissolution chamber; 3) low-temperature insertion piece (capsule); 4) Dewar flask; 5) nitrogen screen of the flask; 6) evacuation tube of the insertion piece; 7) tube for filling the cryostat with liquid helium.

Fig. 3. Low-temperature insertion piece (capsule) of $^3$He-$^4$He cryostat: 1) evaporation chamber; 2) dissolution chamber; 3) regenerative heat exchanger; 4) low-temperature heat exchanger; 5) lid of the vacuum jacket.

(Fig. 3) consisting of the evaporation and dissolution chambers 1 and 2, throttling capillary with the impedance $z = 4.8 \times 10^{12} \text{ cm}^{-3}$, the regenerative heat exchanger 3, and the low-temperature tube heat-exchanger 4. Germanium and carbon resistance thermometers and Constantan electric heaters are fitted in the evaporator shells and the tail part of the dissolution chamber. From them are led out, through two hermetic ferrochrome-glass electric leads inserted into the lid 5 of the vacuum jacket of the insertion piece, 14 wires soldered at the hot terminal to the plug connector. The latter is connected with the measuring instrument by an interblock cable.

The tail part of the Dewar flask and the low-temperature insertion piece are sectional. This permits, when a set of replaceable shanks are available, to equip the cryostat for performing variegated investigations. The shanks are sealed by flanges on indium washers. The cryostat provides for placing a superconducting magnet. The valve located on the cryostat roof and the capillary tube are meant for evacuation of the vacuum jacket of the insertion piece and entry of the heat-exchanging gas (hydrogen) during cooling of the inner system of the insertion piece. The tube 6 (Fig. 2) of variable section increasing from the cold to the warm zone is used for evacuating the evaporator. The $^3$He flow is led forward through the capillary tube placed on the surface of the evacuation tube. The helium space in the Dewar flask is evacuated through another evacuation tube. The cryostat is filled with liquid helium through a heat-insulated filling tube.

The circulation block connected with the cryostat contains vacuum accessories and manometers for reversing gas flows and measuring gas pressure, a mercury pump with a liquid-nitrogen trap, a reservoir for the working $^3$He-$^4$He gas mixture, a liquid-nitrogen-cooled absorption column, and a filtering element. In