Fermilab

TM-1409
(SSC-N-200)
0102.000

SUB-COOLED LIQUID HELIUM FLOW SUPPLY FOR DESIGN D MAGNET COOLING AT MDTF

T. Ohmori

July 1986

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Abstract:

The parameters of the subcooled 4ATM helium flow from MTDF refrigerator and helium subcooler proposed to cool the SSC Design 'D' magnet is discussed. The system operating parameters are pressure = 4ATM and temperature = 4.35K. The higher than normal operating pressure is obtained by shutting down the cold turbine (T2) of MTDF refrigerator, and then not J-T the high pressure dense helium gas until after the magnet and liquid return line. The resultant helium temperature at the refrigerator outlet is described and the heat transfer tube length of the subcooler required to cool the flow to the ultimate desired temperature is evaluated.

Introduction:

Preliminary string tests of the six SSC Design 'D' magnets will be started May, 1986 at the Tevatron "ER" section. These magnets will be pre-tested and their magnetic performance evaluated at Magnet Development and Test Facility prior to installation.

Design 'D' magnets require high pressure subcooled single phase helium coolant which will be provided by MDTF's CTI-Sulzer 1500W helium refrigerator. Because 4ATM pressure is abnormally high, the maximum helium flow rate obtainable must be evaluated. Two relevant problems are investigated in this report.

1. Evaluation of the temperature at the outlet of the cold box with a helium output pressure of 4ATM or 5ATM.
2. Determination of the temperature profile of the helium stream in the subcooler and it's suitability to cool the "SSC" long magnets. The subcooler is located in the MDTF distribution box.

High Pressure Helium Gas Stream in the Cold Box:

It is possible to obtain the high pressure (p = 4 or 5ATM) cold helium gas with the cold turbine (T 2) of refrigerator shut down and isolated by valves or on. The reason for this turbine off running scenario is to protect the turbine from back pressure waves through the helium transfer tubes caused by a magnet quench.

The helium gas, after the heat exchanger #4 (Hx4), is expanded by the J-T process to 4ATM and cooled by the heat exchanger #5 to 7.08K. In this report, it is assumed that the heat exchanger #5 has the same cooling capacity of 772W as it does in the regular operation. The helium gas cooldown process, after heat exchanger #4, is shown in Figure 1 for various possible operation scenarios,, including normal liquification mode used in 'Tevatron' testing operation.

1. Operation of cooling the SSC magnet: (turbine off:)

   A → E: J-T expansion by the PCV-56 Valve

   E → F: heat exchanger No. #5

   P_f = 4ATM; T_f = 7.08K

2. Regular Operation:

   A → B → C → D

   He liquification: 11.7g/s at 4.42

   Cold turbine; working

Mass flow of helium gas is m = 65.5g/sec in each operation.

It is shown that the helium outlet temperature from the cold box is 7.08K or 7.41K and is indicated by the point "F" for a pressure of 4 or 5ATM respectively. Suppose the required inlet helium temperature of design 'D' magnet is 4.35K; point "G", helium gas must be cooled in the subcooler from point F to G.

Heat Transfer in Helium Subcooler

Subcooler has three helically wound, 240 inch long, finned heat-transfer tubes. High pressure helium flows parallel in these tubes and is cooled by the liquid helium located outside shell. In order to cool the tube side stream to

4.35K, the shell side temperature must be lower than 4.35K. It is difficult to maintain the shell side temperature lower than 4.35K because of the pressure drop of the helium return to the cold box.

In this report, the bath or shell side temperature is 4.42K and 4.224K when the shell side pressure is 1.19ATM and 1.0ATM respectively. The heat transfer, dQ, between the (inside) tube side stream and (outside) shell side helium, is described for a length "dx" along the axis of the tube as follows:

For tube side flow:

$$dQ = \pi D\, q_t\, dx$$

$$q_t = h(T_g - T_w)$$

Where T_g is the bulk temperature of helium; T_w is the wall temperature; and "h" is the heat transfer coefficient between helium gas flow and finned tube. The value of "h" is obtained from the equation of supercritical helium heat transfer shown in Fig. 2.

$$Nu = 0.024\, Re^{0.8}\, P_r^{0.4}$$

For shell side heat transfer:

$$dQ = \phi\, A_r\, q_s\, dx$$

"q_s" is obtained from Kutateradze correlation co-efficients for boiling heat transfer of liquid helium. Note that "q_s" is a funtion of the temperature difference, $\Delta T = T_w - T_L$. T_w is the bottom temperature of fins, and "a_r" is the outside surface area of the finned tube per unit length. "ϕ" is the fin co-efficient. Eq. (1) and eg. (4) combined yield the following expression:

$$q_t = [Qa_r/\pi D] q_s$$

The wall temperature of the finned tube, "T_w" (i.e. which is the bottom fin temperature as well) and the heat transfer dQ/dx are obtained from eq. (5) for the different T_g. (Figures 4 and 5)

Entalpy decrease di of the tube side helium flow is related to the heat transfer dQ/dx and total mass flow "m" in the following relationship:

$$m/n \; di/dx = dQ/dx$$

Where "n" is the number of finned tubes (n=3). The finned tube length "dx" to cool the helium flow by "di" is obtained from eq. (6).

Figures 6 and 7 show the cooldown of the helium in the subcooler for pressures P_t = 4ATM and 5ATM respectively. The 4ATM helium flow is cooled to 4.62K at the subcooler outlet when the (bath) shell side temperature is 4.42K. If 4.35K is required for the inlet temperature of the design "D" magnet, then another subcooler, contained in the feed can, will be necessary. This subcooler is now under construction and has 6 finned tubes of the same size as that of the MTF subcooler. Figure 8 shows the temperature reduction of the helium stream in the second feedcan subcooler. If the inlet temperature is 4.62K, helium flow can be cooled to 4.35K in 71 inches along the heat transfer tube at shell side (bath) temperature of 4.22K.

An alternate way to obtain a helium temperature of 4.35K is to employ a cold pump for the compression of the return flow from the subcooler shell side to the refrigerator cold box. In this case, the pressure of the subcooler shell side will be subatmospheric.

If the pressure of the helium flow for magnet cooling is raised to 5ATM, it's outlet temperature at the cold box increases to 7.41K. But, this flow can be cooled to 4.41K or 4.58K by a shell side bath subcooler 4.224K or 4.42K temperature respectively. This is because the specific heat C_p of helium is much lower around the transposed critical region, 5ATM, than at 4ATM. The total mass flow rate is assumed to be the same value 65.5g/sec in each case.

Conclusion:

The helium operating the SSC design "D" magnet can be cooled to 4.62K or 4.58K by MTF subcooler when the pressure of the flow is 4ATM or 5ATM respectively and the subcooler shell side temperature is 4.42K. The maximum total mass flow rate and still to operate with these parameters is 65.5g/sec that can be supplied by the MTF refrigerator. Apparently, one more subcooler will be necessary if the design "D" magnet is to be cooled to 4.35K or below.

The feedcan subcooler now under construction, which has 6 heat transfer tubes each of the same size as that of the MTF subcooler finned tubes which is certainly adequate. The helium flow after the MTDF subcooler can be cooled to 4.35K in just 71 inches of heat transfer tube length which is only 30% of the length available.

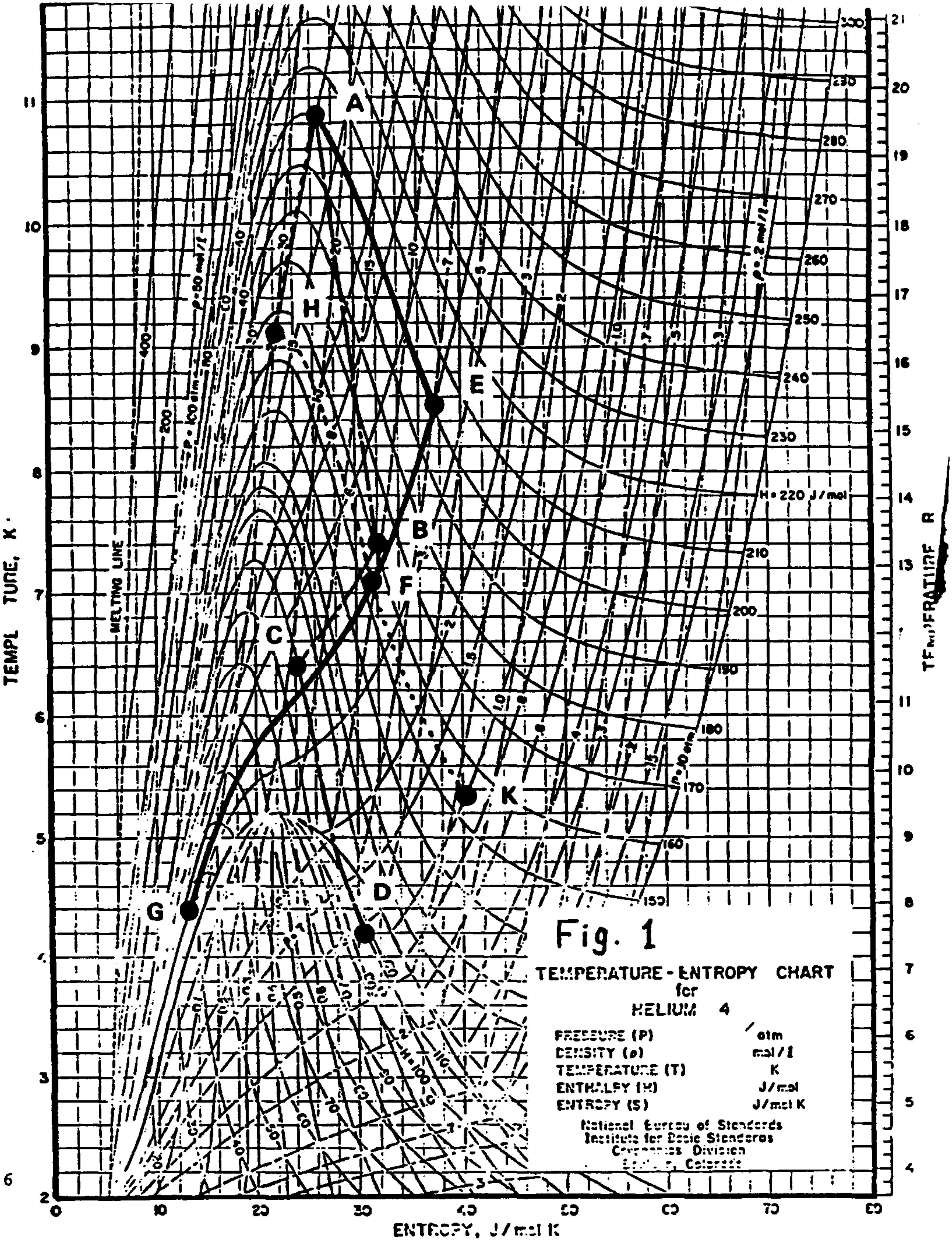


Fig. 1
TEMPERATURE - ENTROPY CHART for HELIUM 4

PRESSURE (P) atm
DENSITY (ρ) mol / l
TEMPERATURE (T) K
ENTHALPY (H) J/mol
ENTROPY (S) J/mol K

National Bureau of Standards
Institute for Basic Standards
Cryogenics Division
Boulder, Colorado

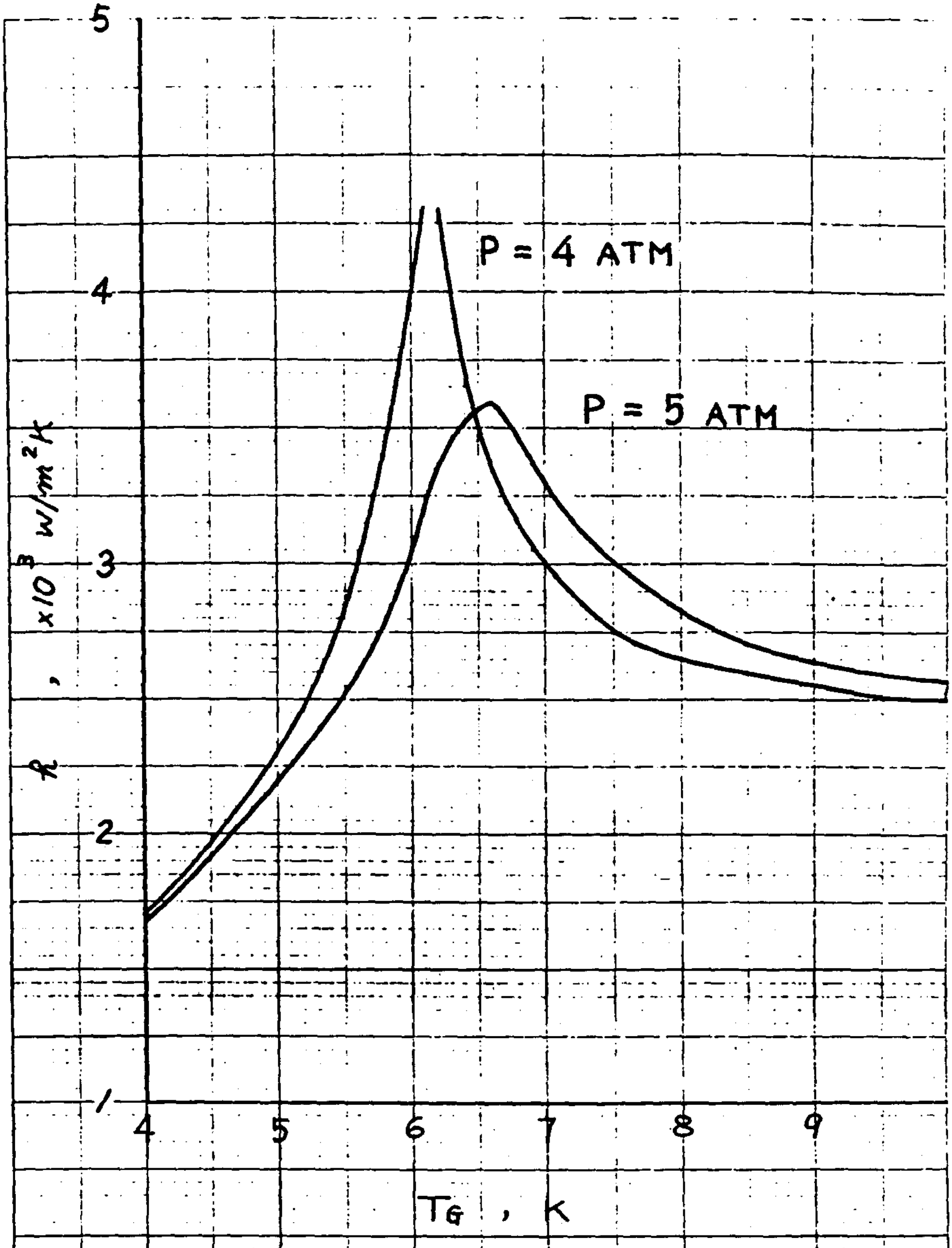
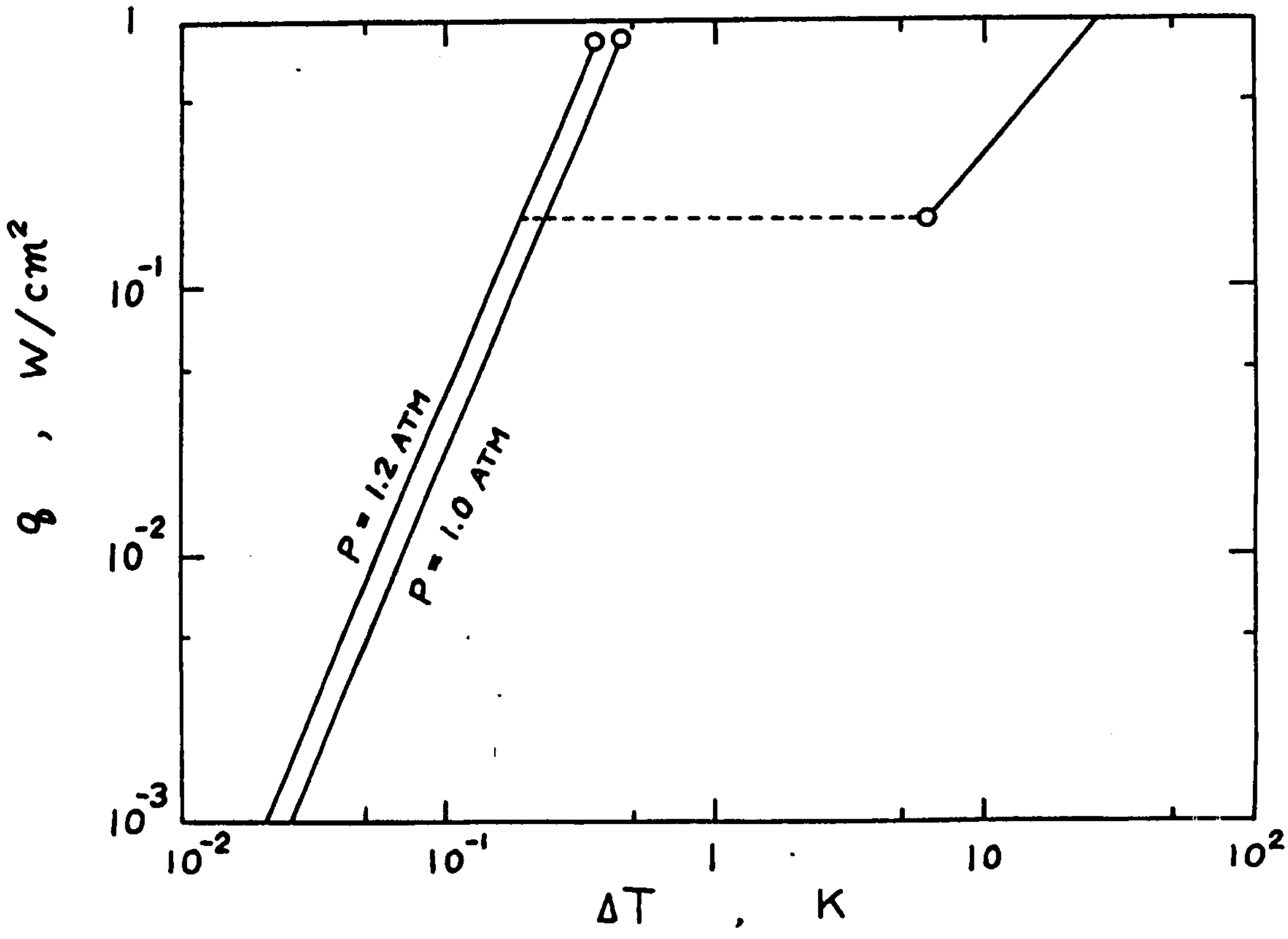


Fig 2 HEAT TRANSFER COEFFICIENT OF HELIUM FLOW IN SUBCOOLER ($\dot{m}$ = 65.5 g/s , n = 3)



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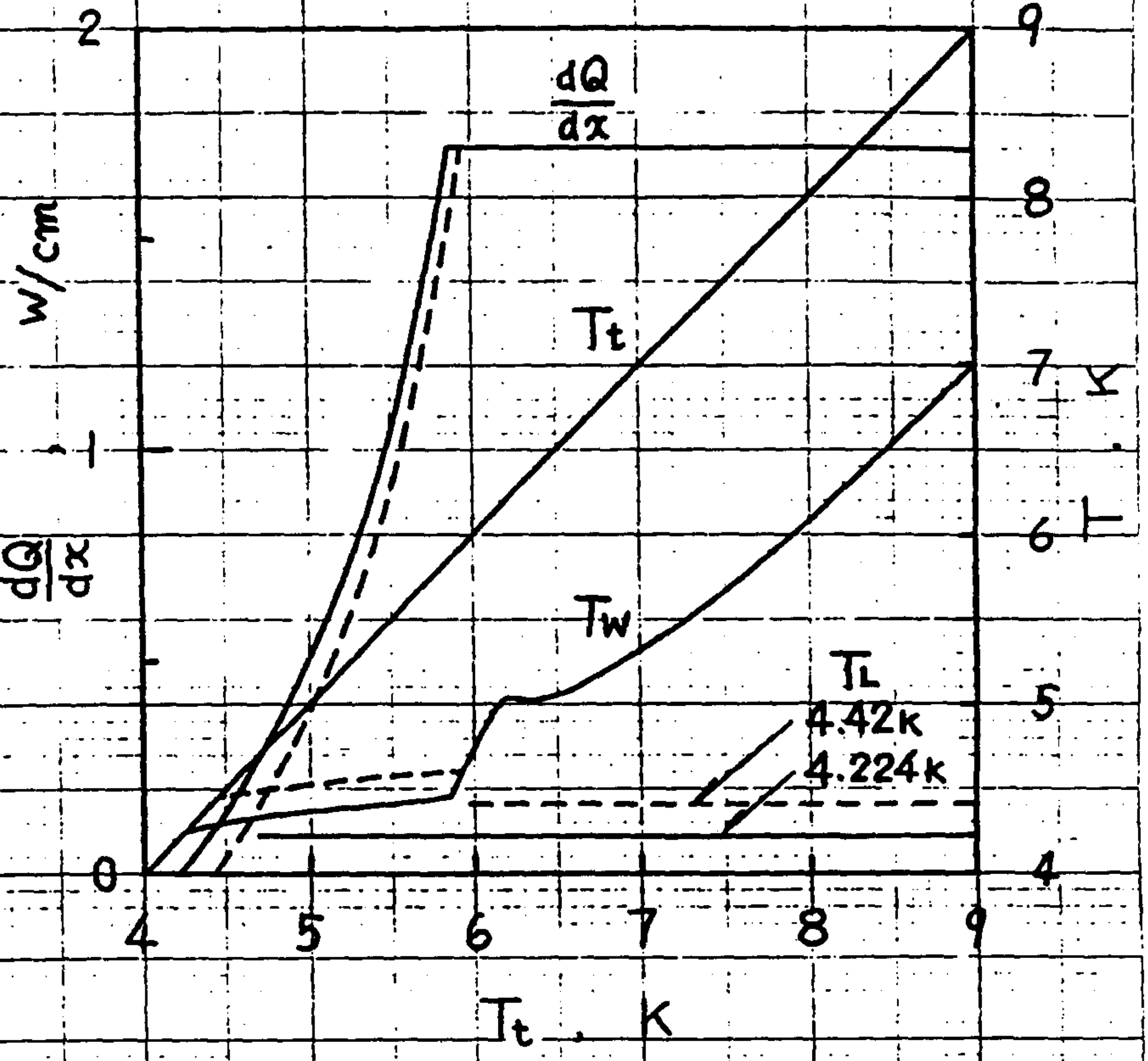

Fig.4 Tube-side Temperature T_t v.s. Heat Transfer $\frac{dQ}{dx}$ and Wall Temperature T_w in MTDF Subcooler

(shell-side temp.; —— 4.224K, - - - - 4.42K, tube-side press.; 4ATM)

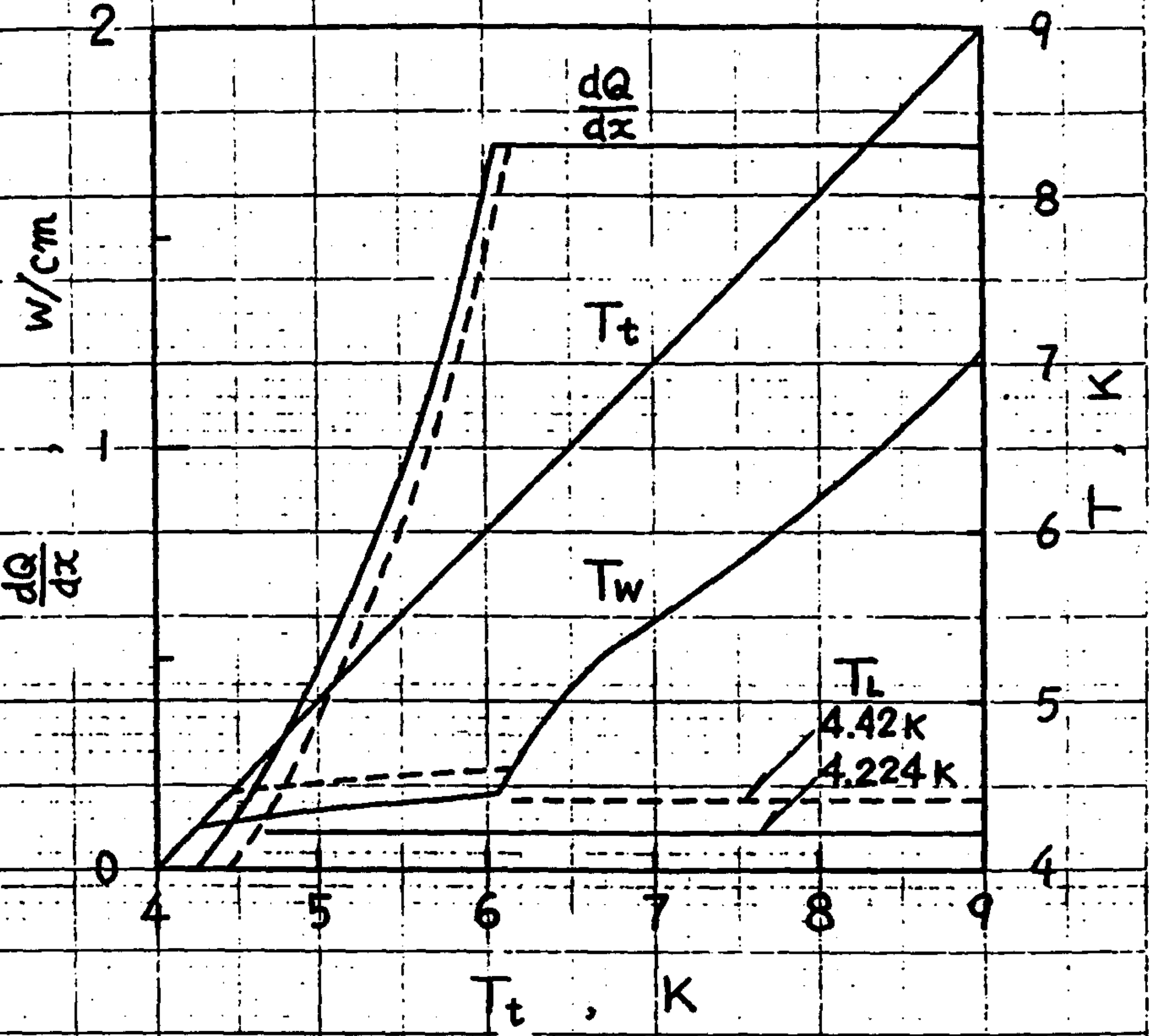

Fig. 5 Tube-side Temperature T_t v.s. Heat Transfer $\frac{dQ}{dx}$ and Wall Temperature T_W in MTDF Subcooler

(shell-side temp.; —— 4.224K, ---- 4.42K, tube-side press.; 5ATM)

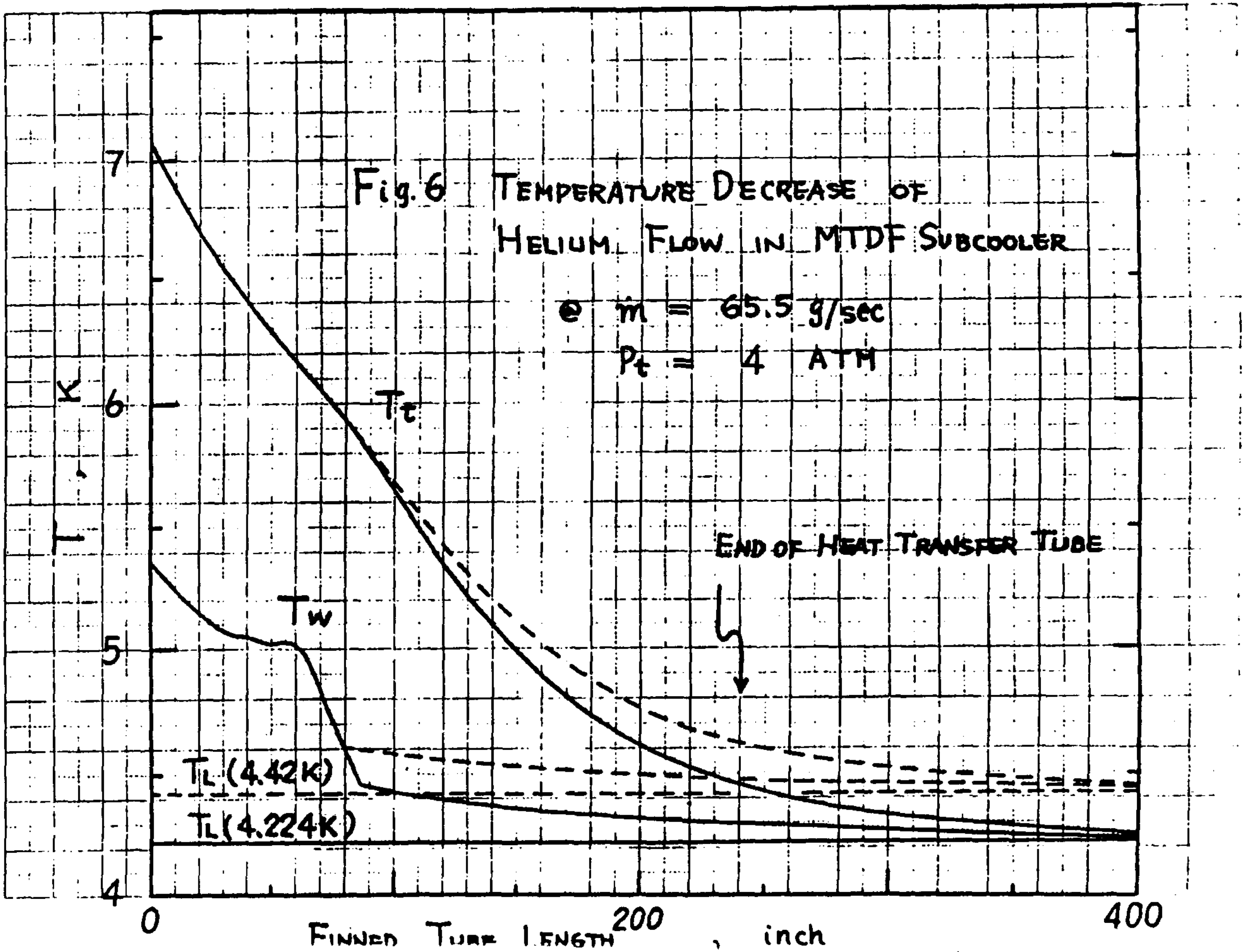
Fig. 6 TEMPERATURE DECREASE OF HELIUM FLOW IN MTDF SUBCOOLER
@ ṁ = 65.5 g/sec
Pt = 4 ATM
Tt
Tw
END OF HEAT TRANSFER TUBE
TL (4.42K)
TL (4.224K)
T , K
7
6
5
4
0
200
400
FINNED TUBE LENGTH , inch

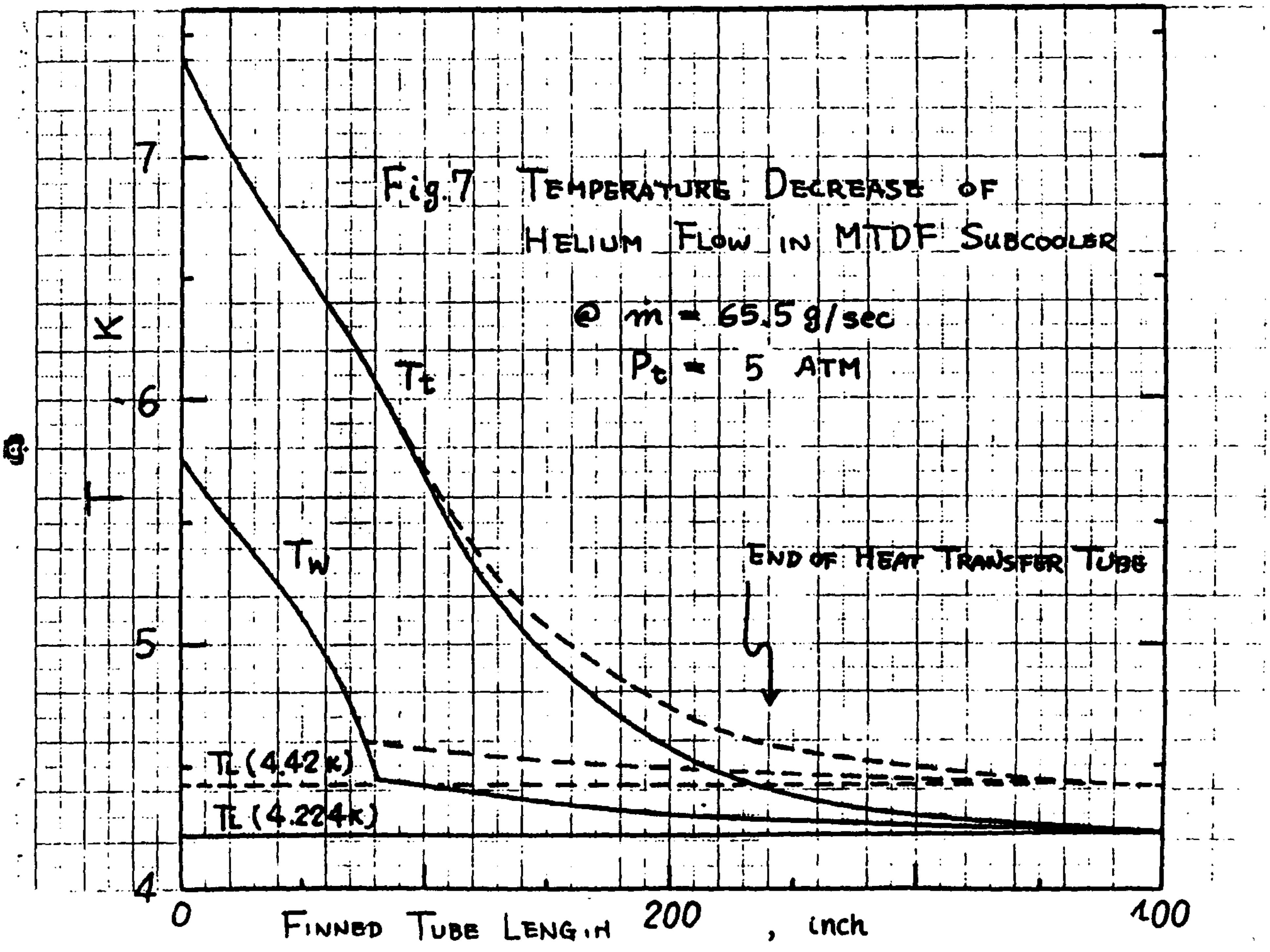

Fig.7 Temperature Decrease of Helium Flow in MTDF Subcooler
@ ṁ = 65.5 g/sec
Pt = 5 ATM
Tt
Tw
End of Heat Transfer Tube
TL (4.42 K)
TL (4.224 K)
T K
7
6
5
4
0
200
400
Finned Tube Length, inch

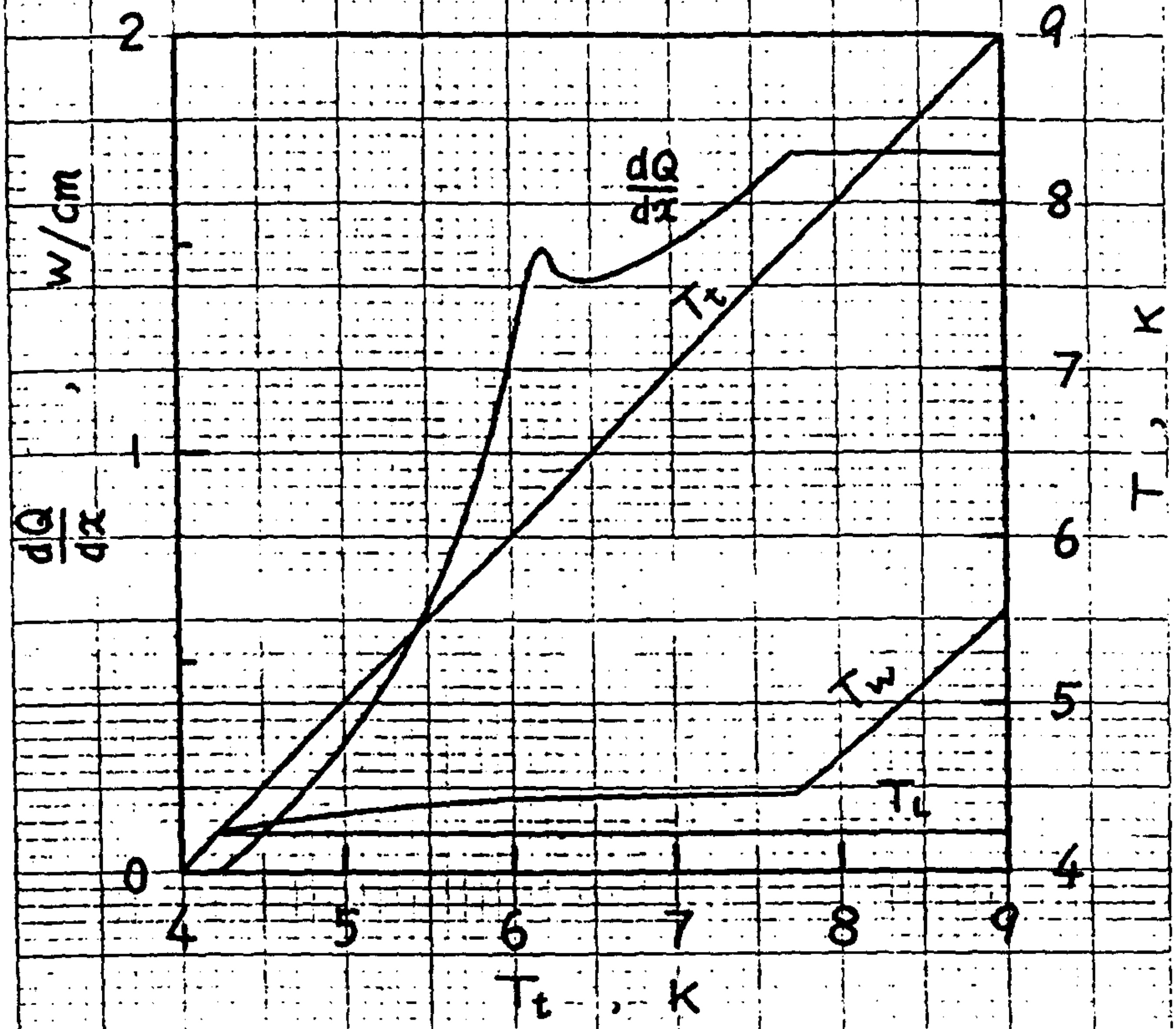

Fig. 8 Tube-side Temperature T_t v.s. Heat Transfer $\frac{dQ}{dx}$ and Wall Temperature T_w in Feed Can Subcooler (shell-side temp. $T_L = 4.224$K, Tube-side press. $P_t = 4$ ATM)

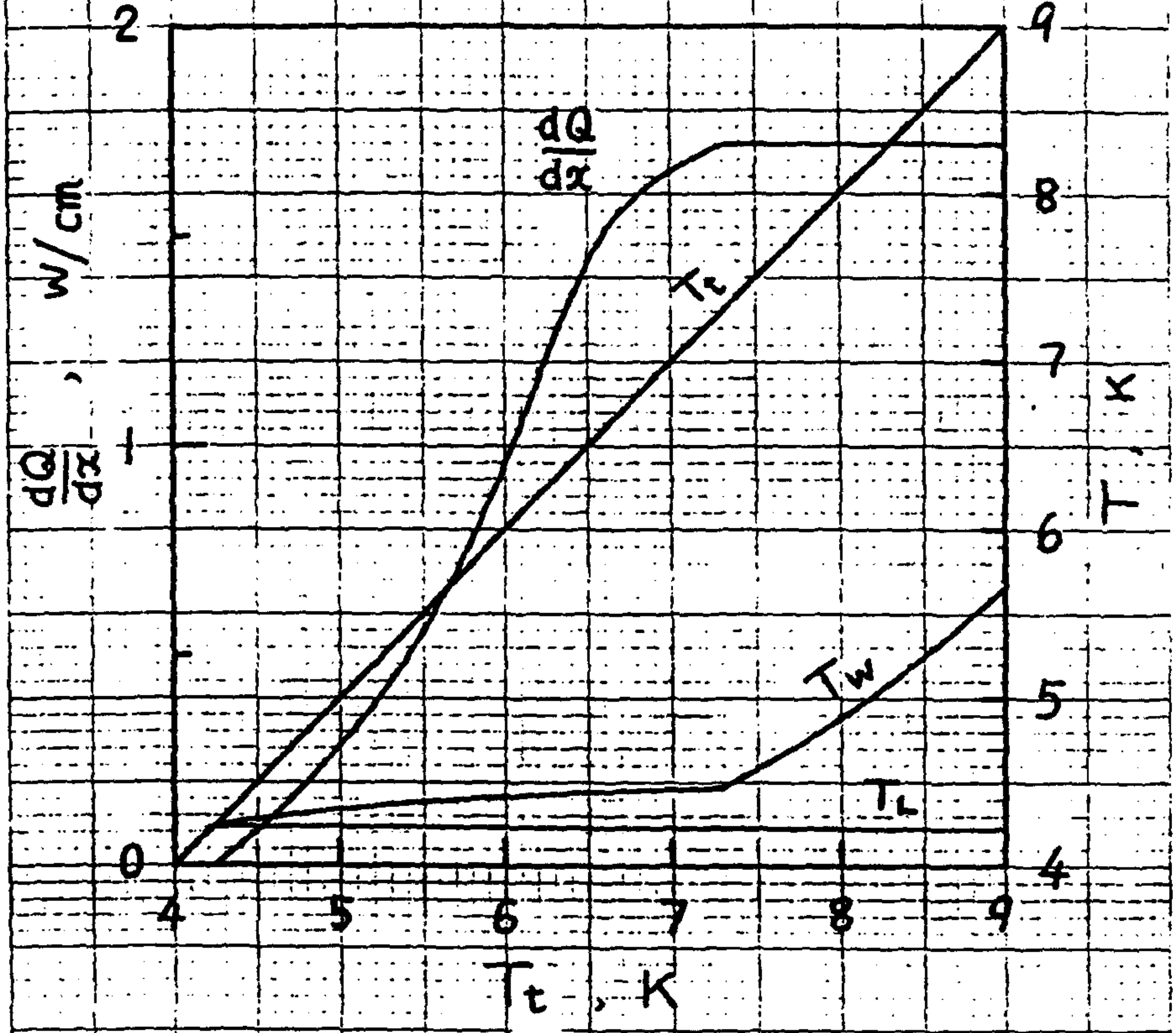

Fig. 9 Tube-side Temperature T_t v.s. Heat Transfer $\frac{dQ}{dx}$ and Wall Temperature T_w in Feed Can Subcooler (shell-side temp. $T_L = 4.224K$, tube-side press. $P_t = 5 ATM$)

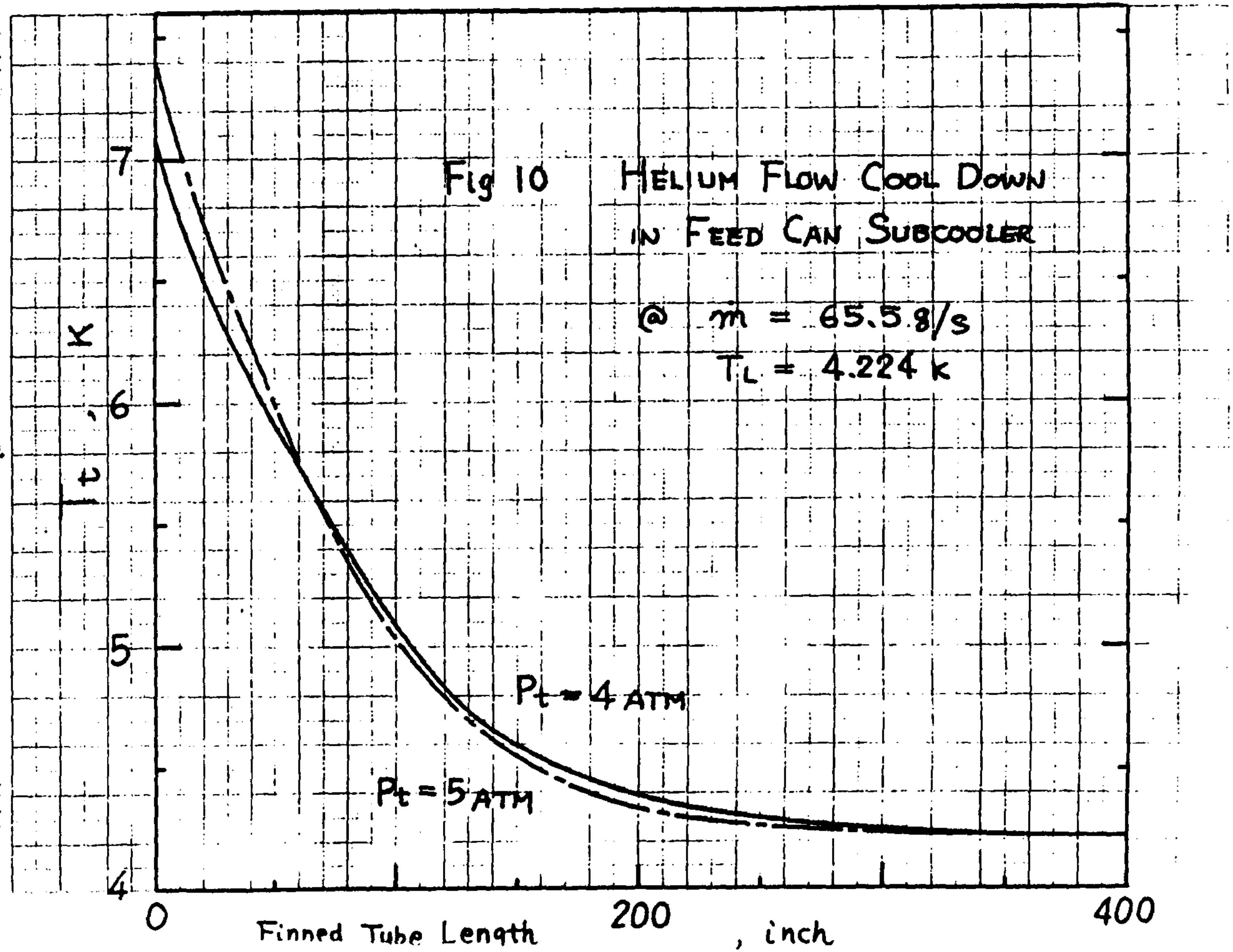
Fig 10 Helium Flow Cool Down in Feed Can Subcooler
@ ṁ = 65.5 g/s
T_L = 4.224 K
P_t = 4 ATM
P_t = 5 ATM
T, K
7
6
5
4
0
200
400
Finned Tube Length, inch