THE EFFECT OF A HELIUM CONTAMINATED ATMOSPHERE ON A METROPHYSICS PRESSURE TRANSDUCER

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THE PROBLEM

A Metrophysics pressure transducer (P/N 10311) was flown during the 1968 and 1969 summer flights of the Caltech e^{+-} magnet spectrometer. The instruments were carried aloft from Ft. Churchill by 10.6 million cubic ft. helium filled balloons. Altitudes of about 140,000 ft. were reached which correspond to an atmospheric pressure of about 2 mm Hg. In addition to the Metrophysics unit, a photobaraograph was flown. This instrument consists of a camera which periodically photographs a Wallace and Tiernan absolute pressure gauge. The accuracy of the results from this instrument is believed to be about ±2%; it is certainly good to ±5%. Serious discrepancies between the pressures reported by the Metrophysics unit and by the photobarograph were observed in every flight. The pressures reported by the photobarograph agreed quite well with those which were theoretically expected, while the Metrophysics unit reported pressures which were from 13-52% greater.

THE THEORY

It was suggested that perhaps helium from the balloon was causing the Metrophysics unit to read incorrectly. The device does not measure pressure directly. It actually measures the heat conduction of the gas which is proportional to its pressure. The coefficient of heat conduction for helium is different than that for air so a sizable concentration of helium could conceivably cause the observed error. It was decided to experimentally test the effect of different helium-air mixtures on the response of the Metrophysics transducer.

THE TEST

Our low pressure calibration system was used to make the measurements. Pressures in this system can be read to better than ±.01 mm with an MKS Baratron pressure meter. The transducer was placed in a bell jar into which the desired amounts of helium and air were introduced. Helium concentrations of 0, 10, 25, 50, and 100% were used at pressures of 1.00, 1.50, 3.00, and 6.00 mm.

The procedure in making a run was to pump out the system completely and then to introduce the proper amounts of helium and air to give the desired mixture at 10.00 mm pressure. The system was then pumped back down, stopping at the desired pressures to make the measurements.

The results are shown in Table 1 and are plotted in Figure 1.

Voltage out of Metrophysics as a function of pressure, helium concentration.

Press. \ Media	Air	10% He	25% He	50% He	100% He
1.00 mm	1.17V	1.22V	1.32V	1.42V	1.55V
1.50 mm	1.80V	1.90V	2.05V	2.25V	2.53V
3.00 mm	2.90V	3.10V	3.41V	3.83V	4.51V
6.00 mm	3.83V	4.12V	4.67V	5.43V	6.80V

TABLE I

It is readily obvious that response of the transducer changes significantly with different helium concentrations. Using these results it is possible to compute the approximate helium concentration which would have made the Metrophysics perform as it did during the balloon flights. Fig. 2 is a plot of the photobarograph and Metrophysics data from flight #69C3M (7-6-69). The vertical scale is marked off in gm/cm^2. One mm Hg corresponds to 1.36 grams per square cm. The helium concentrations which would bring the two curves into agreement are indicated for various times during the flight. For example, at 0725 UT if the air around the Metrophysics transducer had been about 20% helium, this would explain the discrepancy. Concentrations ranging from 15-60% are required at various parts of the float.

THE CALCULATION

It was decided to make some simple calculations to see if concentrations of helium of this magnitude could indeed be present under the balloon. The one dimensional diffusion equation is [1]

$$\frac{\partial^2 n(x,t)}{\partial x^2} = \frac{1}{D} \frac{\partial n}{\partial t}$$

where n(x,t) is concentration of helium at the position x at the time t. D is the mutual diffusion coefficient and is given by the formula [2]

$$D = \frac{3}{8} \left(\frac{\pi k T}{2m^*} \right) \frac{1}{n \, \pi \, d_{12}^2}$$

where

$$m^* = \frac{mN_2 \cdot mH_e}{mN_2 + mH_e}$$

$$d_{12} = \frac{(\text{diameter of } N_2) + (\text{diameter of He})}{2}$$

n = absolute density of molecules/cm^3

At a pressure of 2 mm and a temperature of -23^{0}C

D = 775 ft.^{2}/hr.

For the sake of simplicity, the diffusion equation was solved subject to the boundary conditions

$$\begin{aligned} n(x,0) &= 1 \quad \text{for} \quad |x|<|b| \\ n(x,0) &= 0 \quad \text{for} \quad |x|>|b| \\ n(\infty,t) &= 0 \end{aligned}$$

The solution of the equation with these boundary conditions is [3]

$$n(x,t) = \frac{1}{\sqrt{4\pi Dt}} \int_{-b}^{b} e^{\frac{-(x-\xi)^2}{4Dt}} \, d\xi$$

This equation may be reduced to

$$n(x,t) = \frac{1}{2} \operatorname{erf}\left[\frac{b-x}{\sqrt{4Dt}}\right] - \frac{1}{2} \operatorname{erf}\left[\frac{-b-x}{\sqrt{4Dt}}\right]$$

The solutions for various values of b are plotted in Figs. 3-8.

The applicability of these solutions to the problem is hard to judge. One may think of the balloon as being virtually open at the bottom with helium diffusing downward. Thus b would be taken as the height of the balloon (200-300 ft.). This solution would give too high a concentration of helium as the values at the bottom of the balloon are of finite size and the helium would diffuse away in other directions.

Another way to apply these solutions would be to think of the balloon ejecting a large amount of helium at some point, creating a sphere of nearly pure helium. Then b would be taken to be the radius of this sphere. This solution will also give too large a concentration of helium as the helium will really diffuse away in all directions and not just one.

One interesting point to note is that the parameter b makes very little difference to the point $b+x_0$ in the solutions. For bs of 30-300 ft the concentration at the point b+50 ft is about 10% after 1 hr. For bs from 60-300 ft the concentration at b+50 ft only varies from 25-28% for t = 5 hrs. So if we assume that the Metrophysics is sitting 50 ft below the balloon valves with helium diffusing out of the valves it doesn't make much difference what we choose for b.

On the other hand the value of b is very important if we assume a sphere of pure helium is puffed out and the Metrophysics is in the center. If the balloon were to rise and eject 1/8 of its helium in a sphere the sphere would have a radius half that of the balloon or about 60 ft. Fig. 3 says we could have about a 50% helium concentration after several hours.

There is probably a combination of effects of helium slowly diffusing out the bottom of the balloon andhelium being ejected when the balloon rises. About all the calculation is good for is to show that it is quite possible that appreciable quantities of helium (10-50%) could be present around the transducer.

THE CONCLUSION

The test of the Metrophysics pressure transducer shows that it is quite sensitive to helium contamination. Applying these results to the altitude curve for 69C3M we find that concentrations of about 10-50% are necessary to account for the discrepancy. Simple calculations show that concentrations of helium of this magnitude could be expected. Thus one is led to conclude that the Metrophysics transducer is not suitable for use on helium balloon flights.

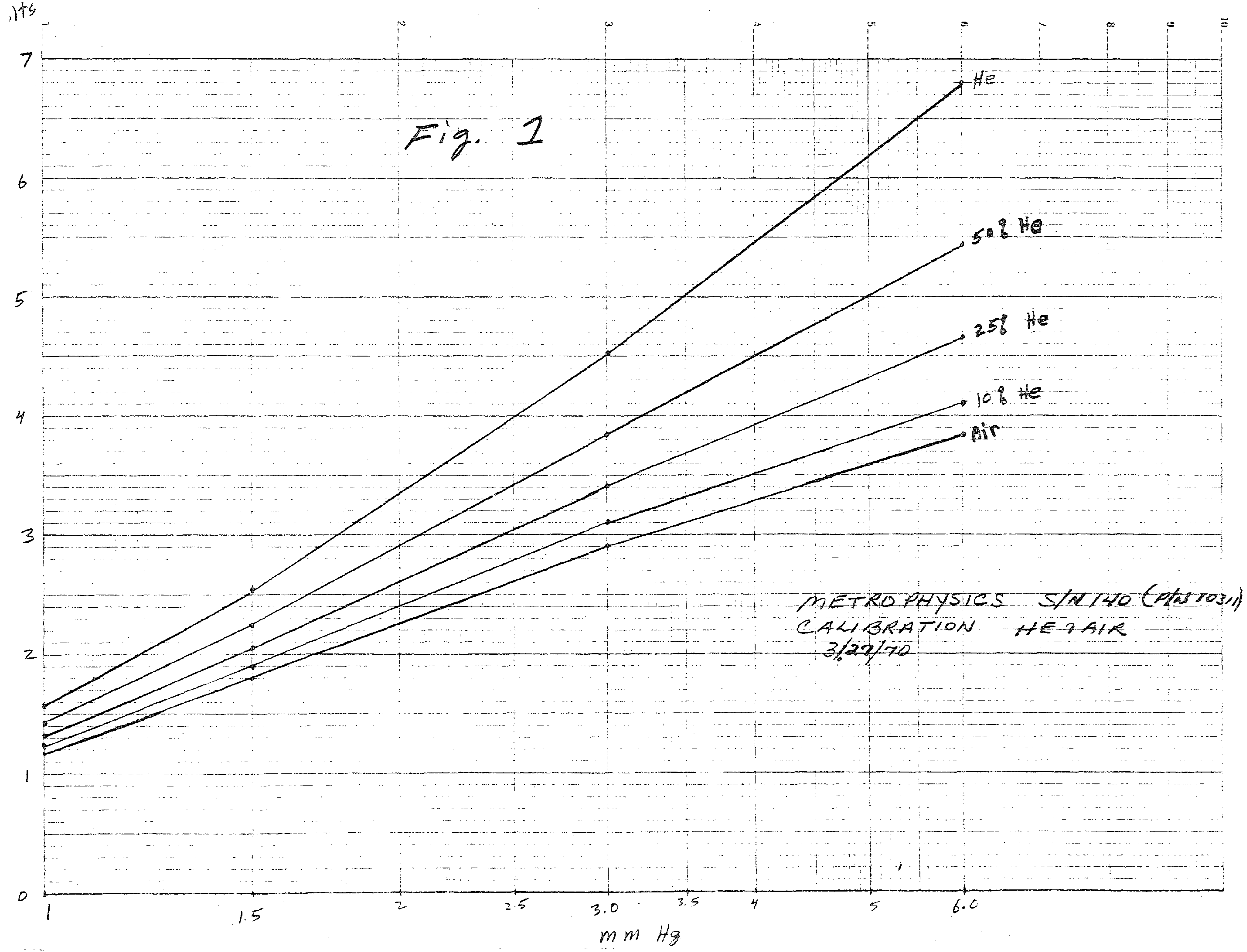
REFERENCES

1. Present, R. D., Kinetic Theory of Gases, McGraw Hill, New York, 1958, p. 65.

2. Ibid, pg. 55.

3. Dettman, John W., Applied Complex Variables, Macmillan Co., New York, 1965, p. 383.

Fig. 1



METROPHYSICS S/N 140 (P/N T0311)
CALIBRATION HE-AIR
3/27/70

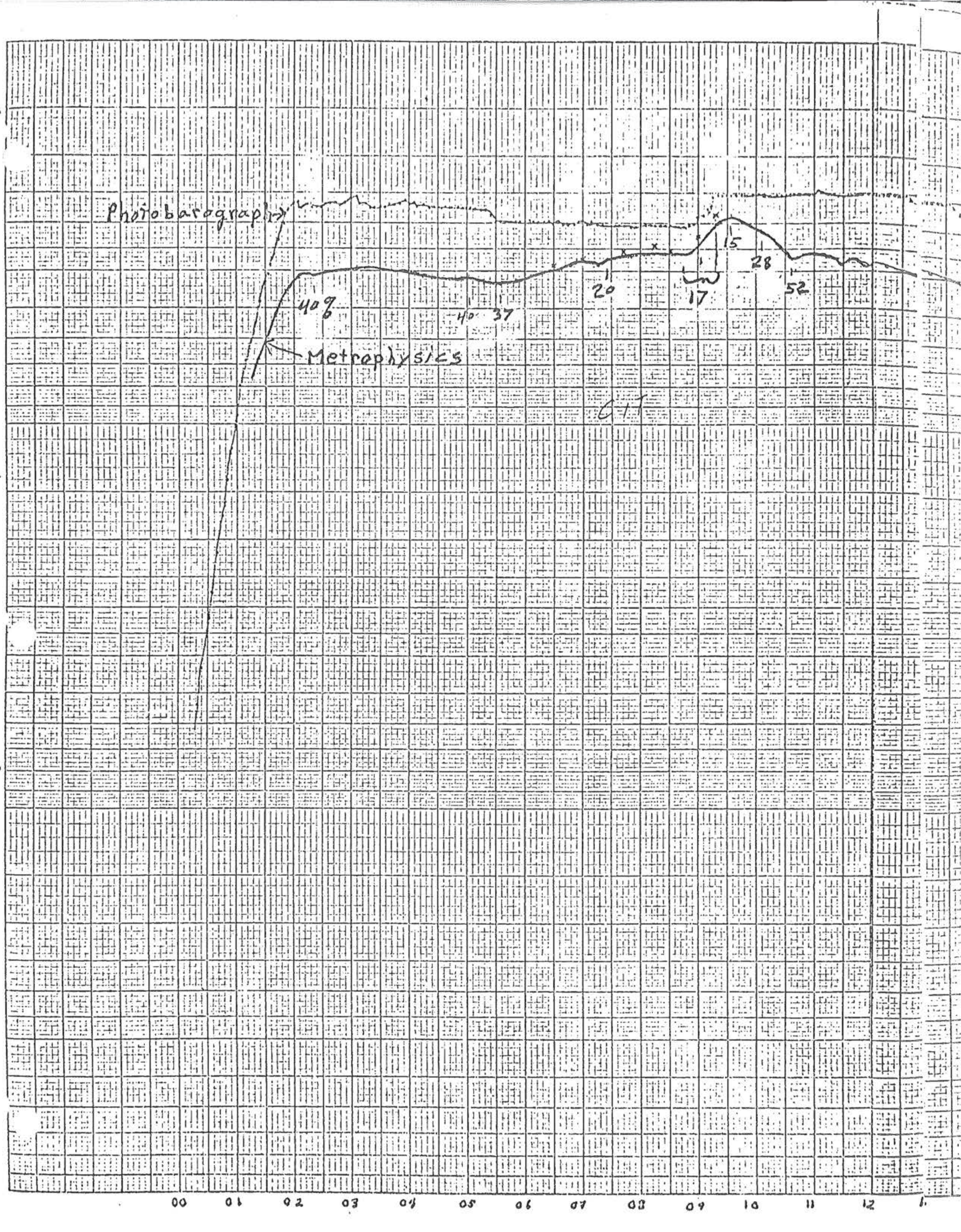

Photobarograph
40%
40
37
Metrophysics
20
17
15
28
52
C-17
00
01
02
03
04
05
06
07
08
09
10
11
12

FIG. 2

69 C3M

10/22/69

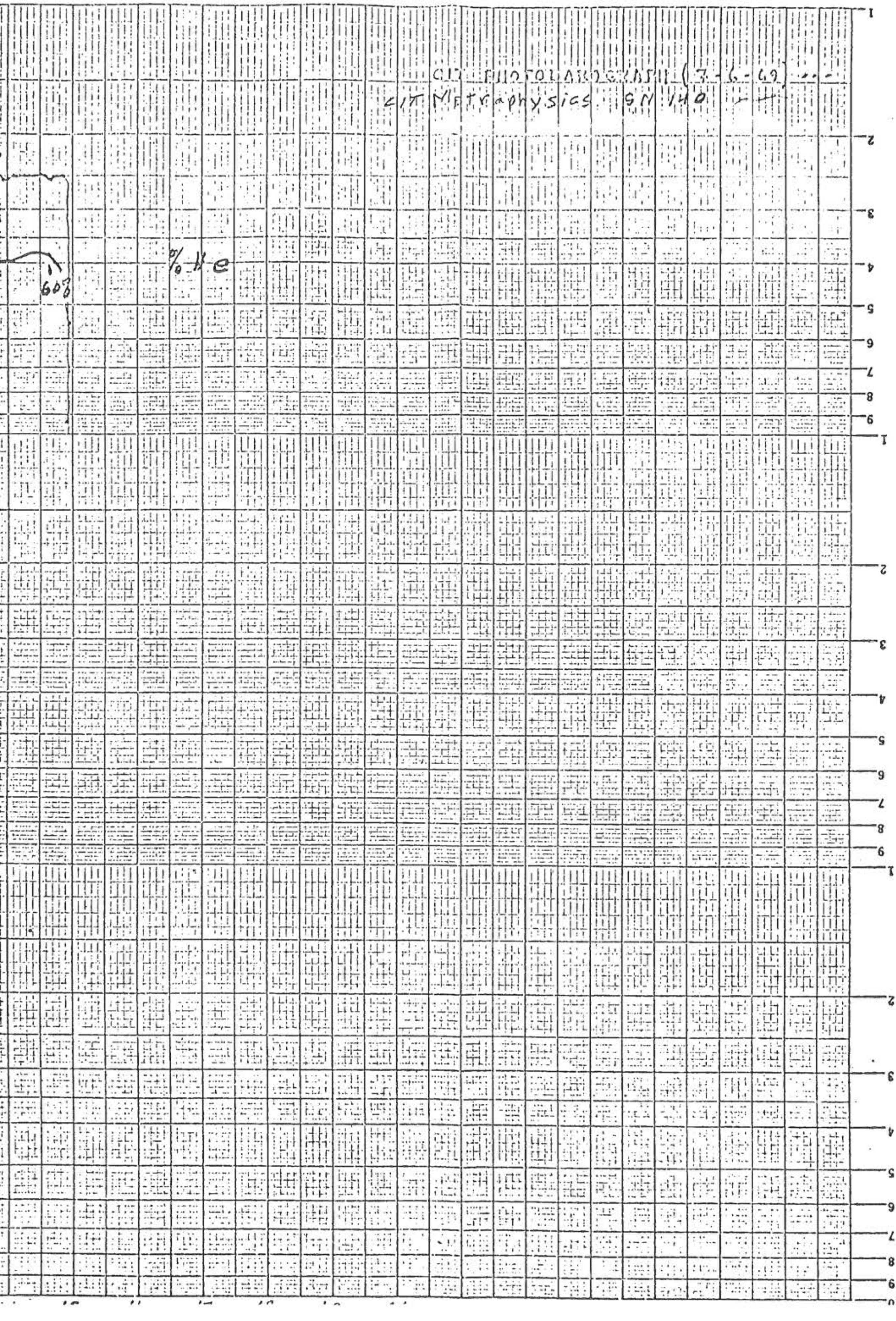


Fig. 3

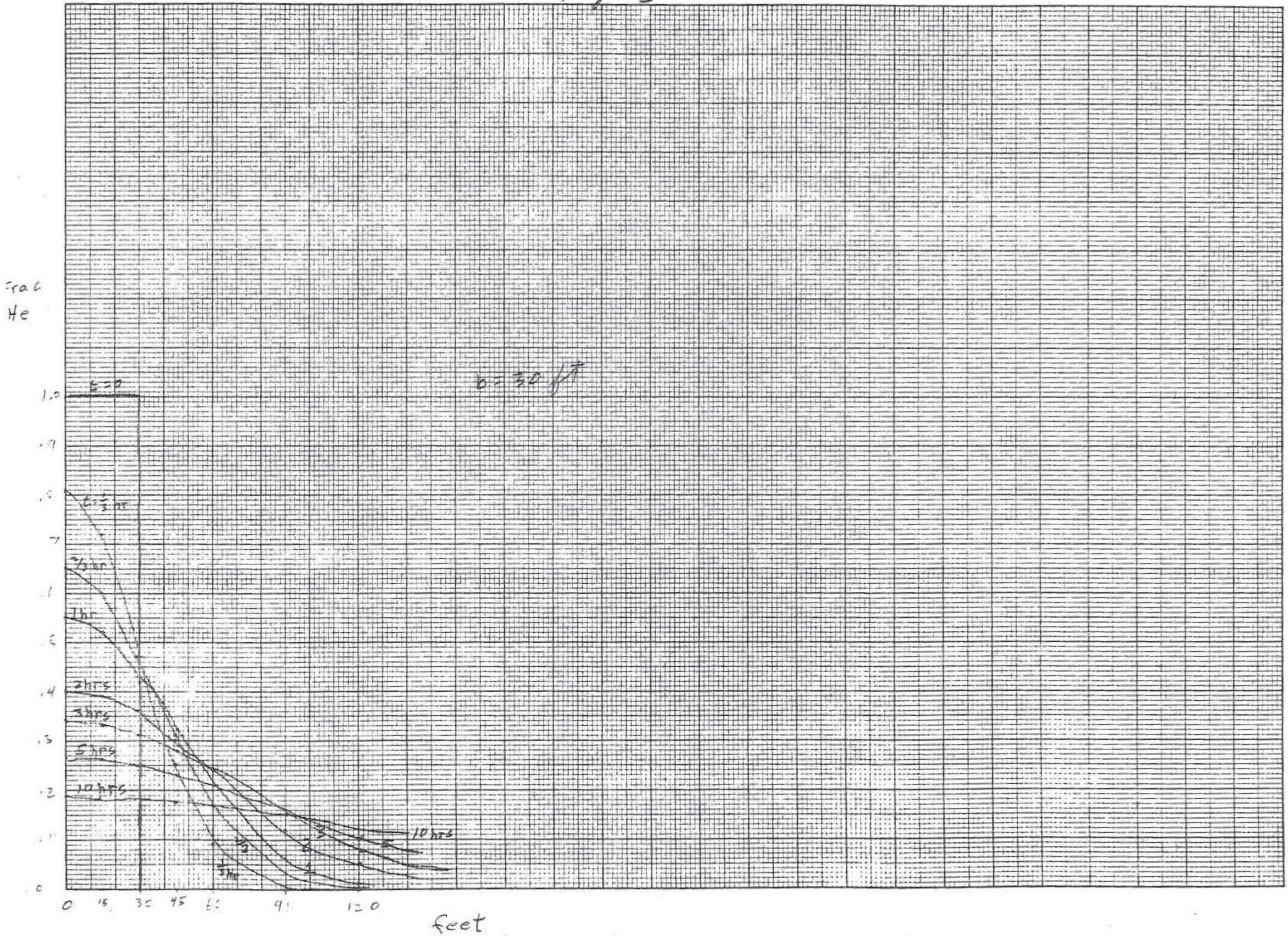

Frac He
b = 30 ft
t = 0
t = 1/3 hr
2/3 hr
1 hr
2 hrs
3 hrs
5 hrs
10 hrs
1/3 hr
2/3
1
2
3
5
10 hrs
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
15
30
45
60
90
120
feet

Fig. 4

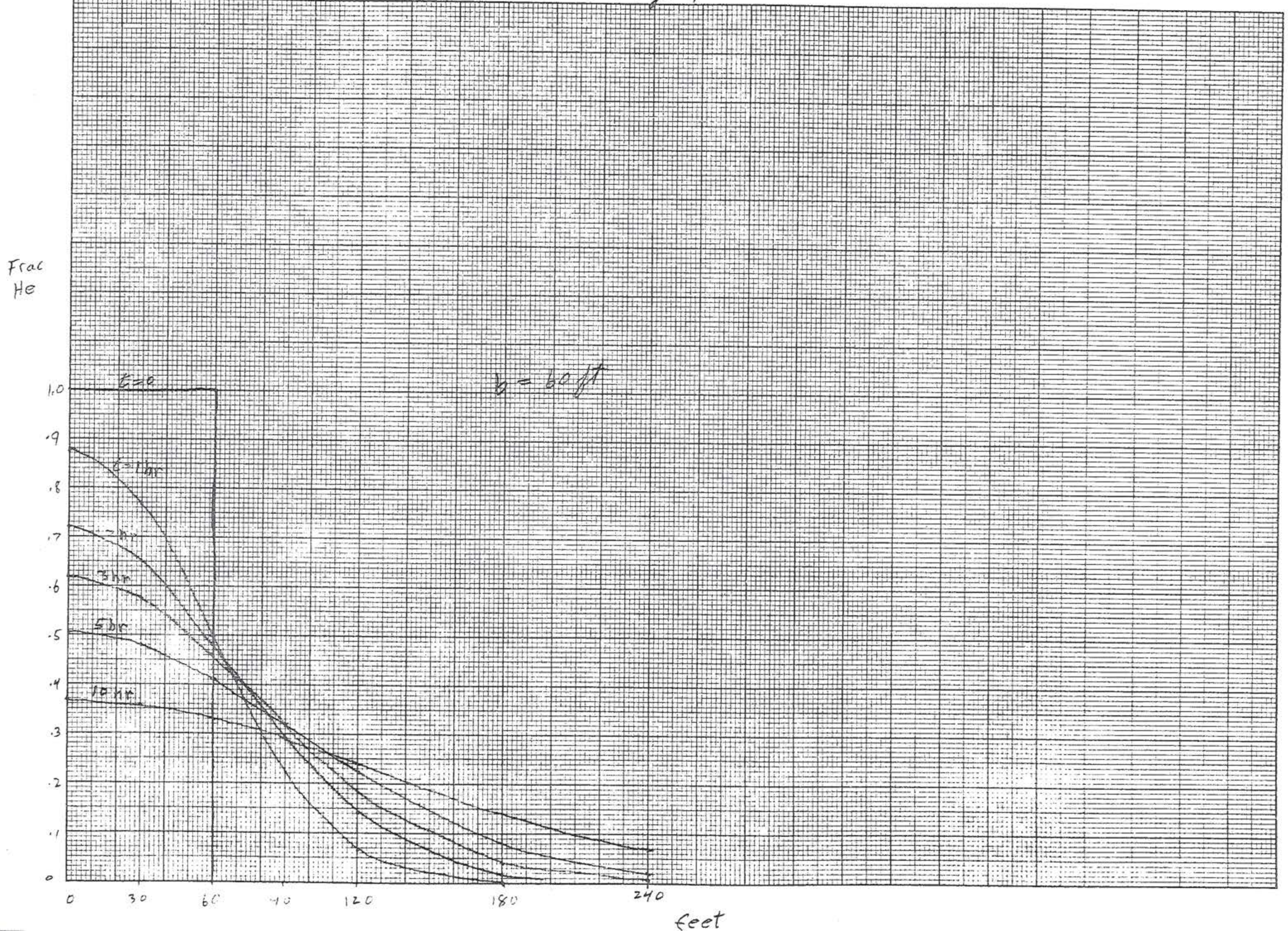

Frac He
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
t=0
t=1hr
2 hr
3hr
5hr
10hr
b = 60 ft
0
30
60
90
120
180
240
feet

Fig 5

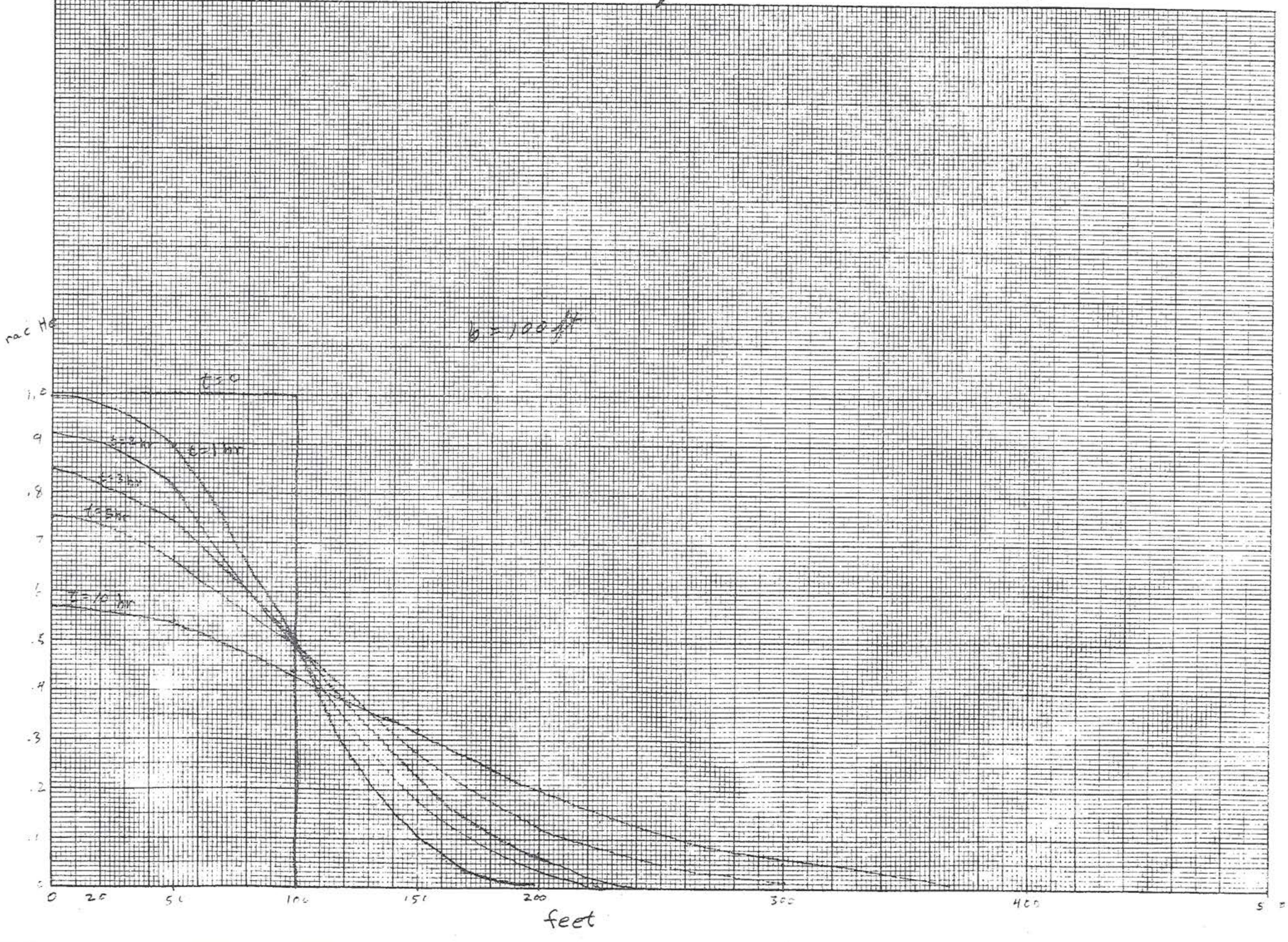

b = 100 ft
rac He
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
t = 0
t = 1 hr
t = 2 hr
t = 3 hr
t = 5 hr
t = 10 hr
0
20
50
100
150
200
300
400
500
feet

Fig 6

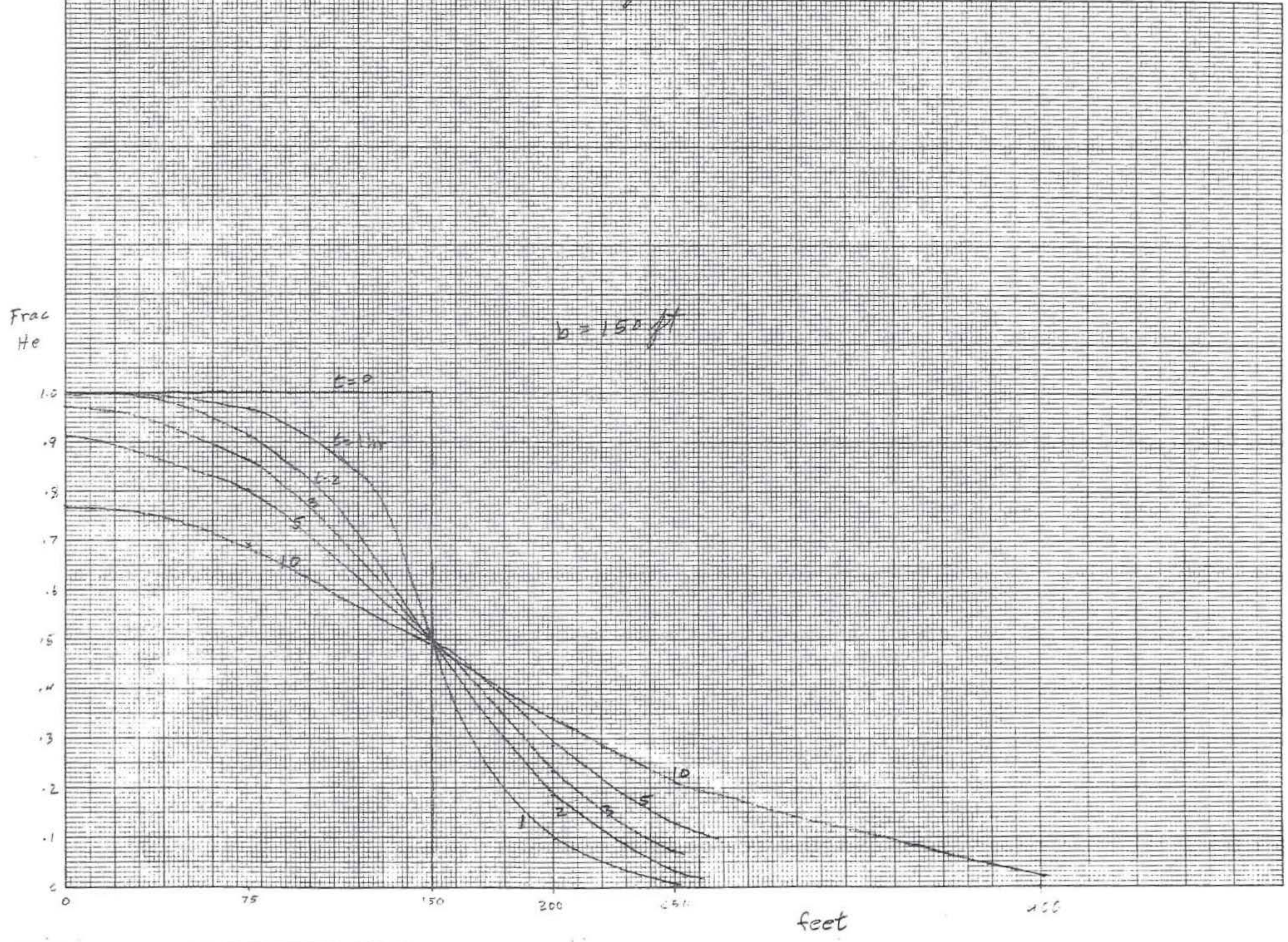

b = 150 ft
Frac He
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
t=0
t=1hr
t=2
3
5
10
1
2
3
5
10
0
75
150
200
250
400
feet

Fig 7

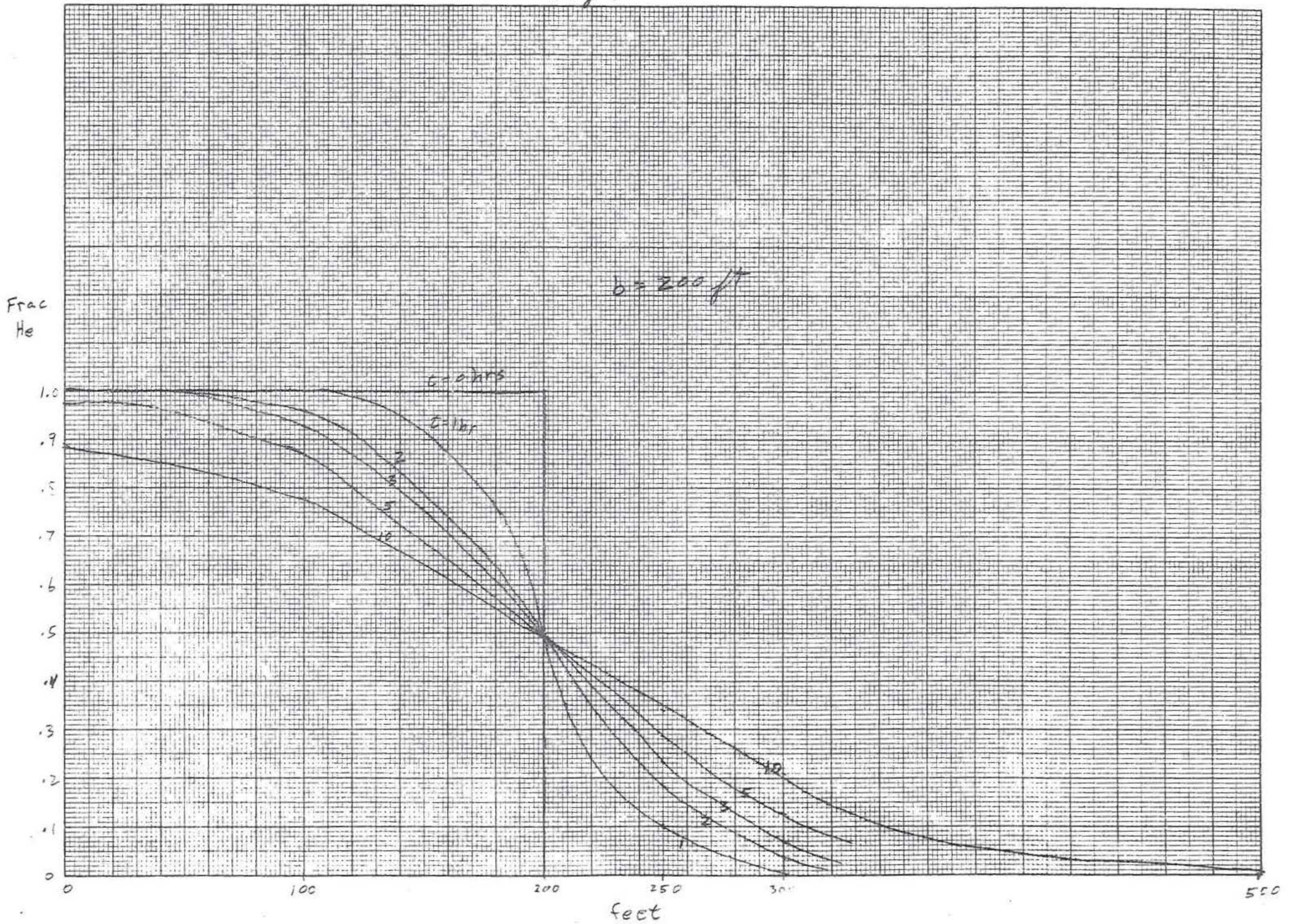

b = 200 ft
Frac He
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
100
200
250
300
550
feet
t=0 hrs
t=1hr
2
3
5
10
1
2
3
5
10

Fig 8