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An Experimental Investigation of the Performance of a Pilot Plant for Drying Air by Solid Granular Adsorbents

By

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An experimental investigation of the performance of a pilot plant for drying air by solid granular adsorbents

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SUMMARY

An investigation was undertaken to measure the performance on a pilot plant scale of uncooled beds of granular adsorbent when drying air to the low humidities required for supersonic wind tunnel operation.

Two size grades of activated alumina and one of silica gel were tested in a bed $2\frac{1}{2}$ ft x $2\frac{1}{2}$ ft in plan, and of various depths between 12 and 25 inches. The bed was worked throughout at about atmospheric pressure and air was drawn from atmosphere without treatment for humidity or temperature.

The results are presented, in the main, as graphs of mean bed concentration $\left(\frac{\text{mass of water adsorbed}}{\text{mass of activated adsorbent}}\right)$ against inlet humidity for two values of the outlet humidity, 0.0005 and 0.0002 lb water/lb air.

It is shown that over the ranges of the variables encountered the mean bed concentration decreases with increasing inlet humidity, increases with increasing bed depth at a fixed contact time, and decreases with increasing grain size. Although a definitive comparison is not possible there does not appear to be much difference in the performance of silica gel and activated alumina of the same grain size.

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1 Introduction

Present day opinions favour air drying in some form to eliminate condensation in supersonic wind tunnels, and the doubt expressed[1] some years ago on the need for such moisture removal has now receded Consequently an interest is being taken in the problem of drying air to low humidities on a large scale. Hitherto experience has been available mainly on industrial plants drying to moderate humidities or in the laboratory drying to low humidities, so in order to facilitate the design and costing of large scale low humidity plant a programme of experimental work was initiated on a pilot plant scale. Unfortunately the almost complete lack of data, the large range of conditions to be investigated and the long duration of a drying cycle make the collection of information a slow process.

However, one hundred and fifty drying cycles have been observed yielding information on one grade of silica gel and two grades of activated alumina, when using atmospheric inlet air, and the relative importance of several criteria has been assessed.

The symbols used for various quantities in this note are given in the Appendix.

2 Fundamental Adsorption Process

Although adsorption is usually defined as being a selective surface attraction exerted by the adsorbent for the adsorbate, this may be misleading unless the adsorbent is considered to be extremely porous, since grain size appears to have very little effect on the equilibrium moisture content.

The nature of the surface forces involved is not clearly understood and forms a complex study discussed at some length by several authors including C.L. Mantell in his book "Adsorption"[2]. The process of adsorption is used extensively industrially in the separation of all kinds and phases of substance, but in this report it is the behaviour of the two principal water vapour adsorbents, activated alumina and silica gel, which is considered.

Both activated alumina and silica gel are used in the granular form and in the tests described the alumina was used in two grades viz. 2/4 and 4/8, whilst the silica gel was used only in the 6/10 grade. The alumina grains are white and chalky and the silica gel grains are more crystalline with a faint pink to yellow hue.

There is a marked resemblance in basic physical properties between the two substances as is shown by the Table below.

Property	Activated Alumina	Silica Gel
Apparent Density lb/ft^3	39-42	38-40
True Specific Gravity	2.5-2 7	2.1-2.3
Thermal Conductivity Btu/ft^2/hr/$^\circ$F/in	0.85	1 0
Specific Heat	0.21	0 22

More detailed lists of physical properties are obtainable from the manufacturers handbooks.

The adsorption process of activated alumina and silica gel for water vapour has been extensively investigated in many respects but for engineering purposes may be defined simply by stating that the dry adsorbent will take up moisture from the surrounding air in exothermic process until an equilibrium is reached. This equilibrium capacity of the adsorbent is dependent upon the temperature and the vapour pressure of the moisture, decreasing with increasing temperature and increasing with increasing vapour pressure. The heat of adsorption liberated is found to be roughly equivalent to the latent heat of sublimation. Many attempts have been made[2] to deduce these properties theoretically but for design purposes experimental data is most dependable. Constant water vapour pressure curves (sometimes called isobars, or isopiestics) for the two adsorbents appear in Figs.1 and 2 (drawn from data published by Aluminum Ore Co. (U.S.A.) for alumina, and from Ref 2 for silica gel); from which it appears that silica gel has the greater capacity from the reactivated state at all vapour pressures under static equilibrium conditions, although some manufacturers claim that activated alumina has the greater capacity at very low humidities.

As may be expected from these data the moisture may be driven off by heating and so reactivating the material; the amount of heat required usually being considered as equivalent to the sum of the heat required to heat the adsorbent and the heat of sublimation of the moisture.

However, the dynamic air drying process is not so much concerned with the slow arrival at equilibrium conditions as with the rate at which moisture is abstracted from a moving stream of vapour-laden gas with the adsorbent holding less than its equilibrium capacity. Information concerning the properties of adsorbents under such conditions is very scarce and much of what is published tends to be contradictory. It is agreed however that equilibrium is reached sooner with finer grains and at higher temperatures. For static equilibrium conditions to be reached some observers quote time measured in minutes and others measured in fractions of seconds. For these reasons a quantitative deduction of adsorbent dryer performance could not be made from the data available. The experimental method of approach using a moderately large scale pilot plant was consequently considered to be able to provide the most reliable data on the performance of a dynamic air drying bed, especially since the economic performance of a bed also depends on the physical properties associated with durability, pressure drop, strength and cost.

3 R.A.E. Pilot Plant

3.1 Adsorbent Bed

The general layout of the plant, shown in Fig.4, comprises a bed of square cross section with $2\frac{1}{2}$ ft side capable of taking adsorbent up to a depth of 6 ft loaded on to a grid formed of 20 mesh 28 gauge wire netting over 2" mesh 10 gauge wire netting supported on steel slats $1\frac{3}{4}$" deep and $\frac{3}{4}$" thick. The bed is insulated externally with about 2 inches thick "Stillite".

Thirty-four Cambridge resistance thermometers, adjustable for penetration, were fitted in one vertical face of the bed and removable doors were fitted in the adjacent face to facilitate loading and unloading the adsorbent charge.

Moisture laden atmospheric air was taken via a 6" pipe from an outdoor entry 9 feet above the ground and led to the top of the bed. An outlet pipe also 6" diameter was arranged to give a straight run of

15 feet to a standard air measuring orifice[4] before going to exhauster pumps in an adjoining Pump House. This pipework was fitted with by-pass control cocks to enable the flow through the bed to be accurately controlled

3.2 Reactivating Circuit

A 30 KW electric heater controlled by a thermostat was used for reactivation, with a centrifugal fan circulating air around a circuit having an atmospheric inlet and outlet bleed to carry off the water vapour as it was liberated on heating.

A water cooled heat exchanger was also incorporated in the regenerating system in order to cool the reactivated bed, diverting valves being used to circulate the reactivating air either through the heater or the cooler as required.

3.3 Instrumentation

Great care was taken with all instrumentation, keeping to simple absolute instruments wherever possible in order to ensure accuracy.

The absolute humidity of the incoming atmospheric air λ_1 was obtained from the vapour pressure deduced from a standard wet and dry bulb hygrometer set up in an air stream of 13 ft/sec, generated by a calibrated electric fan, using the equations.-

$$\lambda = 0.6213 \frac{P_{p_s}}{(P_B - P_{p_s})} \text{ lb water/lb air}$$

where

$$P_{p_s} = P_s - 0.000367\, P_B\, (t - t_s) \left(1 - \frac{t_s - 32}{1571}\right) \text{"Hg}$$

given that

P_B = barometric pressure in "Hg

P_s = saturation pressure in "Hg

t = dry bulb temperature ^{o}F

t_s = wet bulb temperature ^{o}F

P_{p_s} = vapour pressure of moisture in air "Hg

The absolute humidity of the dried air leaving the adsorbent bed was deduced from frost point readings obtained by a modified aircraft type meteorological hygrometer[5]. This instrument enables the temperature of an aluminium thimble to be measured as frost is formed on it due to cooling by liquid oxygen. Frost point vapour pressures were taken from the Psychrometric Tables and Charts by Zimmerman and Lavine[6].

The airflow was measured in the outlet pipeline from the bed by means of a sharp edged orifice $4\frac{1}{2}$" diameter with corner taps installed in accordance with the recommendations laid down in B S S. 1042 entitled "Flow Measurement".

In order to ensure accuracy of readings all pressures were measured on manometers and temperatures were taken from calibrated platinum resistance thermometers.

3.4 Adsorbents Tested

Two materials were tested, activated alumina and silica gel. The activated alumina was obtained on loan from Messrs Peter Spence in two grain size gradings 2/4, 4/8. The silica gel was obtained from Messrs Silica Gel, the grain grading, 6/10, being that previously selected for the dryer of a new wind tunnel.

4 Experimental Work

4.1 Test Method

In all tests atmospheric air was drawn through the bed without adding heat or altering the absolute humidity so that the air entering the bed would be close to atmospheric temperature and at a slightly reduced pressure due to the friction loss in the inlet pipe. Although this does not give control of inlet humidity and temperature it has the advantage of making more accurate measurement possible since variations of conditions take place much more slowly than the rate of response of the instrumentation.

After the reactivation of the bed test runs were carried out by setting the valves to give the desired airflow and recording inlet and outlet humidities, bed temperatures and air pressures, at frequent intervals initially, then as conditions became stabilized, less frequently, the valves being constantly adjusted to maintain the desired airflow and the test continued until the outlet frost point rose to $+20^{\circ}F$. This method ensured covering an adequate range of wind tunnel requirements since the usual maximum humidity (λ_o) for such use occurs at a frost point of $-9^{\circ}F$.

4.2 Reactivation

To reactivate the bed the inlet and outlet valves (V_a) are closed, the valves to the reactivation circuit opened and air circulated through the heater and bed by a centrifugal fan. From this circuit air and steam are blown off through a valve at the bottom of the bed and fresh air drawn in through a make up valve at the fan intake. By manipulation of these valves and the throttle between them the amount of interchange is regulated, being reduced as the reactivation proceeds and steam generation decreases. Reactivation is continued until the bed air outlet temperature reaches $240^{\circ}C$ (the bed air inlet temperature is then around $300^{\circ}C$), this temperature being standardized to ensure that all tests start with the same initial water content in the bed. Following this hot air is blown through the main circuit outlet pipes for about 10 minutes to ensure that they are free of moisture.

Cooling the bed is effected by closing the interchange valves and diverting the circulating air from the heater to a water cooled heat exchanger. Circulation is continued until the bed outlet temperature falls below $20^{\circ}C$.

Circulation air flow and interchange flow were not measured. Pressure drop readings across the bed indicated that the face velocity was about 50 ft/min.

4.3 Range of Tests

1st Series: The first series of tests was carried out using activated alumina of 2/4 grade, with the bed filled to a depth of 25". This quantity of adsorbent was found to weigh 534 lb in the reactivated condition. In this series 56 tests were carried out at five face velocities corresponding to contact times of 2.5, 1.7, 1.25, 0.83, 0.42 secs and over inlet humidity range λ_1 of 0.35 to 1.2 x 10^{-2} lb/lb.

2nd Series: The charge of activated alumina was replaced by an equal depth of silica gel of 6/10 grade, weighing 520 lb in the reactivated condition. In this series of tests 27 runs were carried out covering an inlet humidity (λ_1) range of 0.58 to 1.45 x 10^{-2} lb/lb and contact times of 2.5, 1.25 and 0.83 secs. An attempt to reach a contact time of 0.42 secs was abandoned when the bed pressure drop reached 105" H_2O at a contact time of 0.5 secs

3rd Series: For this series about one half of the silica gel was removed from the bed in order to obtain bed resistances equivalent to those obtaining in the first series of tests (alumina) for equivalent contact times, thus making the performance of the adsorbents comparable on a pressure drop basis. This resulted in a bed 1 foot in depth and containing an activated mass of 254 lb With this bed filling 23 tests were done at contact times of 1 20, 0.8 and 0.4 secs, the manometer deflection being too small to be satisfactory at a contact time of 2.5 secs. The range of inlet humidity λ_1 covered was 0.8 to 1.13 x 10^{-2} lb/lb.

4th Series: In the fourth series of 13 tests, 4/8 grade activated alumina was used in a bed 25" deep containing 585 lb in the reactivated state. This series of tests was used principally as a "sighting shot" for the following series and so only one contact time was used viz. 1.25 secs covering an inlet humidity range of 0.35 to 0.96 x 10^{-2}.

5th Series: For the fifth series of tests 91 lb of activated alumina was removed from the bed giving a bed depth of 21" and bringing the bed resistance for a given contact time down to that of the first and third series of tests in order to allow direct performance comparison. The range of absolute inlet humidity covered in this series was 0.32 to 0.72 x 10^{-2} lb/lb, all runs being at 1 35 sec contact time.

6th Series: A sixth and final series of tests was then made with 254 lb of silica gel to extend the third series of tests to lower humidities (λ_1) to cover similar humidity ranges to those encountered in the 1st and 5th series of tests.

Table I summarizes the conditions for the several series.

5 Results

During any test run conditions were kept as nearly constant as possible so that each test is defined by its inlet humidity (λ_1 lb/lb), contact time $\left(\frac{L}{v} \text{ sec}\right)$, adsorbent grade, bed depth and bed pressure drop The principal quantities observed, varying with time, were the temperatures at various points and the outlet humidity (λ_o) ; and the significant deduced variable, the mean bed moisture concentration $\frac{x}{m}$, is defined as:-

$$\frac{x}{m} = \frac{LA}{m} \cdot \frac{v}{L} \int_{o}^{t} (\lambda_1 - \lambda_o)\ \rho_a \ . \ dc \ .$$

The whole of the results obtained, except those from the runs with un-matured alumina (see 7.6) are summarized in Table II, which gives for three values of outlet humidity (λ_o) the corresponding values of $\frac{x}{m}$, T_5 (air outlet temperature) and t (time from start of run) Also given are the point of maximum bed temperature and the average value of λ_1, T_1 (inlet temperature), contact time, pressure drop.

For each test, characteristic records were plotted for the absolute humidity of the outlet air λ_o and for temperatures at specified points in the bed, both being plotted against the mean bed concentration $\frac{x}{m}$ as abscissa.

Figs 5 and 6 give some typical test record curves for outlet humidity against bed concentration, while Figs.7, 8, 9 and 10 give some typical curves showing full records of the temperatures at various points also plotted against bed concentration. To these latter, curves of outlet humidity have been added for reference.

To simplify comparison of the performance under various conditions two significant values of the outlet humidity were selected, namely 0.0005 and 0.0002 lb/lb, (between which requirements for wind tunnel air driers normally lie) at which the value of x/m was picked off from the test characteristic. The resulting $\frac{x}{m}$ values plotted against inlet humidity are shown in Figs.11 - 15 for $\lambda_o = 0.0005$, and in Figs.16 - 20 for $\lambda_o = 0.0002$.

Figs.21 and 22 show the maximum temperature rise, i.e. the difference between the incoming air temperature and the highest bed temperature recorded during the run, also plotted against inlet humidity.

The specific pressure drops through the bed have been plotted against flow in Figs.23 and 24. The result for the 2/4 grade alumina agrees with the maker's data but the 4/8 grade was found to offer about $\frac{3}{4}$ of the resistance stated by the maker.

6 Work done by other investigators

6.1 Work done by Derr[3]

Some of the scarce recorded experimental work on drier performance includes a graph given by Derr of temperatures taken in an uncooled bed of 3.14 sq.ft cross sectional area and $2\frac{3}{4}$ feet depth. The alumina grain size is not stated but it is given that air at dry bulb temperature of 24°C containing 9 grains of moisture per cu.ft (almost saturated) was supplied at a rate of 5.2 cu.ft per hour/lb alumina, so that,

$$\lambda_1 = 0.0185 \text{ lb moisture/lb air}$$

$$\text{Contact time, } \frac{L}{v} = \frac{3600\ L\ A}{5.2\ m} = \frac{3600}{5.2 \times 40} = 17.3 \text{ secs,}$$

this giving a mean face velocity v of $9\frac{1}{2}$ ft/min.

These conditions are dissimilar to those used in the series of tests described in this report, the humidity λ_1 being much higher and the contact time far longer. The graph shows a duration of 8 hours for a λ_o of 0.7×10^{-3} lb/lb to be reached, resulting in a mean bed capacity of.-

$$\frac{9 \times 5.2 \times 8}{7000} = \underline{5.35\%}$$

Although we have no experimental figure with which to compare this bed capacity it is interesting to compare the temperature rise of 83°C at an inlet humidity of 1.8×10^{-2} lb/lb with the curve observed and plotted on Fig.21, which would suggest a temperature rise some 20°C smaller.

A second set of tests was carried out by Derr on a bed 0.78 sq.ft in cross sectional area and $3\frac{1}{2}$ ft deep with cooling to 35°C. These tests were reported using contact time of 4.56 secs, 5 8 secs and 4.46 secs respectively giving mean face velocities of 45.8 ft/min, 36.2 ft/min and 46.8 ft/min, with inlet humidities of 0.0107, 0.0115 and 0.00346 lb/lb. The resulting mean bed concentrations were given as 9.8%, 10.3% and 9% respectively. These results are again well outside the range of the experimental work reported herein and can probably be accounted for by the much greater contact time permitting equilibrium conditions to be more nearly approached.

6.2 Dehler's Method of Adsorber Design (Ref.2)

In a paper presented at George Washington University. Washington D.C. on June 23rd 1940, Dehler demonstrated a method of drier design using the static equilibrium charts (known variously as isobars and isopiestics) In this method it is assumed that the temperature rise across the bed is directly proportional to the difference in inlet and outlet humidities.-

$$\Delta t = k \ (\lambda_1 - \lambda_o)$$

and that the rise enables the outlet temperature to be deduced. Then the bed capacity is computed as being the simple mean of the adsorptive capacities obtained if the bed were in equilibrium with the incoming air at the entrance and with the exit air at the end of the bed. This infer that there is a linear distribution of bed moisture concentration from front to rear, and further that in the case where extreme dryness of the outlet is required the effective bed capacity is one half of the static equilibrium capacity of the adsorbent in equilibrium with the incoming air. This implies that a higher inlet humidity λ_1 results in a greater mean bed concentration, but this is shown to be untrue by reference to the experimental results shown in Figs.11 - 20.

Unfortunately such a view of dynamic drying is untenable, failing to account for many factors influencing performance such as bed proportions, grain size, contact time, inlet humidity

6.3 Spence's Dynamic Test

Messrs Peter Spence have standardized a dynamic test on a laboratory scale, which is designed to pass air saturated at 20°C at the rate of 0.8 cu.ft/hr through a sample of 10 grams of alumina in a long thin cylinder ' A second cylinder of alumina is used to detect when moisture is first passed over by frequent weighing. Thus, quoting these figures in more general terms.-

$$\lambda_1 = 1.474 \times 10^{-2} \text{ lb/lb}$$

$$\text{Contact Time } \frac{L}{v} = 2.46 \text{ secs.}$$

The mean bed capacity as shown by such tests is optimistic when compared with large scale beds since the temperature rise is more easily suppressed.

7 Discussion of Present Results

7.1 Repeatability

It was found that the degree of repeatability of results was not great and consequently accurate mean results necessitated a large number of tests. In some series of tests it was not considered necessary to spend time covering a wide range of conditions and the results of these tests are recorded as a number of points with a mean performance characteristic plotted through them.

7.2 Bed Temperature Rise and Capacity

The inlet air humidity gives a measure of the rate at which water is supplied to the bed, and since the adsorption of moisture generates heat the ratio of moisture to air determines the temperature rise because the air flow is the medium for carrying away the heat generated. Figs. 21 and 22 show the observed maximum temperature rises observed in the bed plotted against the incoming air humidity λ_i for activated alumina and silica gel respectively. It will be seen that the temperature rise in the case of silica gel is somewhat less than that for activated alumina but it is remarkable that with both materials the temperature rise is not sensitive to grain size, bed depth or contact time. This feature was apparently noticed by Dehler[2] (see 6.2) since he claims it is possible in designing a drier to calculate the temperature rise in an adsorbent bed of silica gel from

$$\Delta T = k \ (\lambda_1 - \lambda_o)$$

where

$$k = 10^{\circ}F \text{ per grain moisture/ft}^3 \text{ air}$$

$$= 30^{\circ}C \times 10^2 \text{ per lb/lb}$$

It will be seen that this figure agrees exactly with the mean slope of Fig. 22

A general review of all tests shows that the performance of the adsorbent bed at the high duties required for wind tunnel use is very much dependent on the inlet absolute humidity λ_1 and that over the fairly wide range of relative inlet humidities encountered the slight improvement in bed capacity to be expected from an increase in vapour pressure is always, apparently, overwhelmed by the much larger fall in capacity due to the greater temperature rise. This feature may also be seen from Figs 11 to 20

The temperature variation across the bed perpendicular to the direction of flow was small (about $\frac{1}{2}$ to $1\frac{1}{2}^{\circ}C$) which suggests that the bed flow is quite uniform. It was found that in practice very little information could be drawn from the position of the temperature peak. In very fast flows the outlet humidity reached the "break point" (see Appendix) before the peak temperatures were reached and in the case of slower flows peak temperatures were reached much earlier in the cycle.

7.3 Air Inlet Temperature

The range of air inlet temperature encountered was 0 to 20°C. No relationship could be detected between air temperature and adsorptive capacity. It should be remembered that, in the range of atmospheric relative humidity experienced, increase of atmospheric air temperature usually implies higher absolute humidity.

7.4 Depth of Bed and Grain Size

The influence of bed depth as a factor in drier performance has not been seriously considered in previous experimental work and it had been assumed that for a given contact time a deep bed results in a high face velocity and pressure drop, whereas a shallow bed permits a low face velocity and pressure drop and better heat dissipation with otherwise no effect. However, the results of tests in this report show that the deeper bed is more efficient i.e. has a greater moisture capacity, at the expense of the greater pressure drop. This is illustrated for silica gel in Fig.25 where the adsorptive capacity of the double-depth bed is seen to be considerably more than twice as great as that of the shallow bed at the higher inlet humidities, the superiority diminishing at the lower inlet humidities. This is achieved at the cost of increasing the air propelling power about 600%. Figs.12 and 13 for activated alumina 4/8 grade, show the same tendency, the deeper bed, despite the slightly shorter contact time used, having a noticeably greater capacity.

Much of the work by other investigators has stressed that adsorptive capacity is not greatly affected by grain size. This is possibly true for static equilibrium conditions and for very slow dynamic laboratory tests, but the work now reported shows that it is not true for commercial scale plant where performance depends so much on the rate of adsorption of moisture from a comparatively rapidly moving air stream. Fig.26 compares the performance of the two grain sizes of alumina tested when bed depth and contact time are identical. The smaller grains are superior for inlet humidities above 0.3×10^{-2} to 0.5×10^{-2} although at lower inlet humidities the reverse may be true. The smaller grains, of course, result in a higher air propulsion loss.

The choice of bed depth and grain size for a drier depends on economic considerations. Thus a low pressure drop bed has higher drier capital cost and running costs for regeneration than a high pressure drop bed, but the latter entails fan or compressor plant of greater capital and running costs. No attempt has been made at cost comparison but, as already noted, some tests were made to evaluate the performance of the various adsorbents under conditions of equal pressure drop.

7.5 Comparative Performance of Adsorbents

Comparison of the performance of the adsorbents under various conditions can be made from the graphs in the report. For example Fig.27 compares them for conditions of equal bed depths and equal contact times. The superiority of the silica gel is no doubt partly due to the smaller grain size but whether this is the sole cause it is not possible to decide from this comparison.

Fig.28 illustrates the comparative performances when the bed depths are adjusted for equal pressure drops. The adsorptive capacities are now much closer together and the curves suggest that for equal grain sizes the performances of silica gel and alumina would be very nearly equal, at least over part of the range. The reversal of curvature of the silica gel line

makes it dangerous to extrapolate the other curves The relative sensitivity of the adsorptive capacity to inlet humidity does not correlate with the sensitivity of bed temperature rise to inlet humidity. As already noted the slope of the relation $\frac{\text{maximum bed temperature rise}}{\text{inlet humidity}}$ is the same for both grades of alumina while for silica gel it is, if anything, slightly less steep, (Figs.21 and 22).

7 6 Maturing of Adsorbent

Both grades of activated alumina showed a slightly better performance on the first eight to twelve cycles than the steady performance which it sustained subsequently. The alumina performances quoted in this note are the "mature" or lower values. Silica gel did not exhibit this tendency.

7.7 Dusting

It was found that both of the adsorbents produced a fine dust in operation a proportion of which was carried over into the hygrometer where it could be seen; otherwise no means of assessing the magnitude of dusting was provided. As far as it was possible to judge from these observations it appeared that there was little difference between the two adsorbents and that the rate of dust formation increased with the air velocity through the bed.

7.8 Settlement

Several observations were made to assess the degree of bed settlement during use and it was found that a 7-9% shrinkage in depth occurred soon after filling causing an increase in apparent density from 38 lb/cu.ft to 41 lb/cu.ft

In this report contact times have been considered on the bed depth after settling down.

7.9 Method of Regeneration

The method of regeneration used in these tests, wherein a part of the hot air and generated steam is recirculated, reduces the energy requirements for regeneration. It has been criticised as leading to a possible deterioration of the adsorbent. No such effect was observed, although the number of cycles undergone by any one adsorbent was small compared with that occurring in the life of a plant.

8 Conclusions

The tests reported provide quantitative results for an uncooled bed, obtained with two size grades of activated alumina and one of silica gel for a variety of conditions of bed depth, contact time and inlet humidity. The relationships between adsorptive capacity and these conditions can be deduced for the ranges tested from the figures in the report. Qualitatively the effect of changes may be summarized as follows:

Inlet humidity : Although when drying air with adsorbents at constant temperature the adsorptive capacity increases with increase of vapour pressure, these tests show that increases in inlet humidity i.e. vapour pressure, result in diminished adsorptive capacity due to the consequent bed temperature rise

Contact time : Over the range tested longer contact time results in increased specific adsorption. There appears to be no sharp break in this relationship.

Bed depth : At constant contact time increased bed depth results in marked increase in adsorption, the effect decreasing with decreased inlet humidity. Since the pressure drop across the bed appears to be proportional to (bed depth x velocity^2), increase of bed depth at constant contact time causes a rapid increase of pressure loss

Grain size : Smaller grains result in higher specific adsorption although there is some evidence that this trend may reverse at low inlet humidities. When the 4/8 grade alumina bed was reduced in depth for equality in pressure drop with the 2/4 bed it was still superior at inlet humidities above about 0.4 or 0.5 x 10^{-2} lb/lb.

Adsorptive material : Despite the difficulties of extrapolation the results do appear to indicate that with equal grain size and bed proportions there is little difference in the adsorptive capacities of silica gel and activated alumina at least over part of the range of inlet humidity used.

Further Work

(1) In view of the important economy of heat for regeneration that can be achieved by using a recirculatory system it would be useful to determine whether this system has a deleterious effect on the adsorbent. This could be done on a laboratory scale.

(2) Since some projected wind tunnel driers are intended to work with very low inlet humidities, i.e. about 0.0006 lb/lb, this region should be explored. The present rig could be adapted quite simply.

(3) Owing to the marked loss of adsorption capacity that occurs with inlet humidities corresponding to the upper part of the range of atmospheric humidity in this country, it is clear that it is not economic to use plain beds only. Alternatives are to use refrigerated pre-cooling or beds with embedded cooling coils. As general information is not available on the performance of cooled beds some work is advisable.

A rig on a laboratory scale is being set up to investigate (1) above, and it is also proposed to modify the pilot plant to permit tests with very low inlet humidities as for (2).

It is hoped to obtain data on cooled beds at a later date.

REFERENCES

No.	Author	Title, etc.
1	J. Lukasiewicz	Humidity Effects in Supersonic Flow of Air. R & M 2563 June, 1948
2	C.L. Mantell	"Adsorption". Publ. McGraw Hill Book Co.
3	Derr	Ind. Eng. Chem. 30, 384 (1938).
4	-	Fluid Flow Measurement. B.S.S. 1042
5	A.W. Brewer, B. Cwilong and G.M B. Dobson	Measurement of Absolute Humidity in Extremely Dry Air. Proc. Physical Society, Vol 60, Part 1, Page 52.
6	Zimmermann and Lavine	Psychrometric Charts and Tables Published by Industrial Research Service, Dover, New Hampshire.

Previous R.A.E. Memoranda

Interim note on tests of experimental activated alumina air drier :
R.A.E. Technical Memorandum No. Aero/SD/No.5

Second interim note of tests of experimental activated alumina air drier :
R.A.E. Technical Memorandum No Aero/SD/No 13

Interim note on tests of experimental air drying bed using silica gel :
R.A.E. Technical Memorandum No. Aero/Sup.23

Attached:-

Appendix I.

Tables I and II.

APPENDIX I

1 Symbols Used

λ_i = humidity of inlet air, lb water/lb air

λ_o = humidity of outlet air, lb/lb

m = mass of reactivated adsorbent in bed, lb

x = mass of moisture adsorbed, lb

v = mean face velocity of inlet air, ft/sec

L = depth of bed, ft

A = cross sectional area of bed, sq.ft

ρ_a = density of inlet air, lb/ft^3

ρ_g = density of adsorbent, lb/ft^3

2 Expressions used in some adsorbent manufacturers' handbooks

Percentage adsorption = $\left(\frac{x}{m} \times 100 \right)\%$

Adsorptive efficiency = $\left(\frac{\lambda_i - \lambda_o}{\lambda_i} \times 100 \right)\%$

Percentage break point = Percentage adsorption at stated adsorptive efficiency (e.g. 20% at 99% adsorptive efficiency)

Break Point : The break point in the performance of a dynamic drying plant occurs when the outlet air from such a plant first contains moisture. The expression probably results from use of gravimetric laboratory methods to measure the outlet humidity from small test columns, giving rise to performance curves such as Fig.3 and suggesting that the bed gives perfectly dry air until a certain "percentage adsorption" has been reached and then fails very rapidly doing no drying at all on addition of a small further quantity of moisture. A similar impression would arise from the use of insensitive or slow response instrumentation to measure the outlet humidity, or from the use of extremely slow air flows, resulting in more nearly static or equilibrium conditions being reached.

3 Terms used in the report

Capacity : In the case of the high duty dynamic beds in which we are interested there is no sharply defined "Break Point" (compare Figs.7 and 8 with Fig.3) and to convey a test performance by means of a single figure, for say $\frac{x}{m}$, requires that some standard value of outlet humidity be adopted. The humidity usually specified for supersonic wind tunnels

is 0.5×10^{-3} lb/lb but the drier connected to such a tunnel is, in some instances, required to deliver air at 0.2×10^{-3} lb/lb. In this report bed capacity $\left(\frac{x}{m}\right)$ is given for the above two values of humidity, thus Figures 9-13 are for humidity 0.5×10^{-3} lb/lb and Figures 14-18 are for humidity 0.2×10^{-3} lb/lb

Mean bed concentration : The mean bed concentration is similar to the manufacturer's "percentage adsorption" $\frac{x}{m}$ excepting that in this report m is clearly defined as the mass of adsorbent in the reactivated state, i.e. with the residual moisture, and x is the increase in weight of the bed due to the adsorption of x lb of moisture. Since the reactivated adsorbent is not anhydrous but contains some 5-10% residual moisture depending on the reactivation conditions, m is referred to not as the dry weight but as the reactivated weight.

Contact Time : The contact time is quoted in seconds derived from $\frac{L}{v}$ sec, and is a measure of the volume airflow duty or loading of the bed, being inversely proportional to the commercial expression given as volume airflow per lb of adsorbent, thus

$$\text{cu.ft of air/hour/lb of adsorbent} = \frac{A \cdot v \cdot 3600}{\rho \cdot g \cdot A \cdot L}$$

$$= \left(\frac{3600}{\rho g}\right)\left(\frac{L}{v}\right)^{-1}$$

Wt.2078.CP79.K3. Printed in Great Britain.

TABLE I

Summary of Tests Made with Adsorbents Drying Air

Series of Tests	Adsorbent	Grade (mesh)	Depth of Bed inches	Weight of Reactivated Adsorbent lb	No. of Tests	Contact Times seconds	Range of inlet humidity, λ_1 lb moisture per lb air x 10^2	Notes
1st	Alumina	2/4	25	534	56	2.5 , 1.7 , 1.25, 0.83, 0.42	0.35 to 1.2	Maximum pressure drop 18.5" H_2O
2nd	Silica Gel	6/10	25	520	27	2.5 , 1.25, 0.83	0.58 to 1.45	Pressure drop at 0.5 sec = 105" H_2O
3rd	Silica Gel	6/10	12	254	23	1.2 , 0.8 , 0.4	0.8 to 1.13	Bed resistance as for Series 1
4th	Alumina	4/8	25	585	13	1.25	0.35 to 0.96	
5th	Alumina	4/8	21	494	18	1.35	0.32 to 0.72	Bed resistance as for Series 1 and 3
6th	Silica Gel	6/10	12	254	8	1.35	0.28 to 0.61	To extend λ_1 range to cover Series 1 and 5

TABLE II

Test Results Adsorbents Drying Air . Principal Readings

Series	Run No	λ_1 lb/lb	T_1 °C	$\frac{L}{v}$ secs	Δp "H_2O	λ_o = 0 2 x 10^{-3} lb/lb			λ_o = 0.5 x 10^{-3} lb/lb			λ_o = 0.10 x 10^{-2} lb			Maximum bed temperature		
						$\frac{x}{m}$	T_5	t_{mins}	$\frac{x}{m}$	T_5	t_{mins}	$\frac{x}{m}$	T_5	t_{mins}	°C	$\frac{x}{m}$	t_{mins}
1st	12	0 87 x 10^{-2}	15.5	2.5	0 7	3.4	42	97	4.5	41.5	128	5.8	39.0	166	46.5	0 9	25
	18	0 64 x 10^{-2}	13.0	"	"	6 3	28.2	235	8 1	25 3	303	9 6	23	368	34.5	0 65	30
	22	0 6 x 10^{-2}	11.0	"	0.75	4.25	29.0	178	5.8	26.7	248	7 3	24.0	316	29.5	0.5	23
	38	0 5 - 0 55 x 10^{-2}	11.5	"	0 8	5.9	24.5	260	7.6	23 0	320	8.8	21.0	380	28.0	0 63	30
	39	0 69 x 10^{-2}	13.0	"	"	4.25	35.0	146	5 3	33.4	182	6.3	31 0	220	37.0	1 1	38
	42	0 53 x 10^{-2}	11.5	"	"	6.2	23	264	7.7	21 5	334	9.3	18.8	406	27.5	0.55	25
	47	0.63 x 10^{-2}	12.0	"	"	4.8	29.0	172	5.8	28	212	6.5	26.5	243	33.5	0 83	32
	48	0 55 - 0 65 x 10^{-2}	12.0	"	"	5.3	27.0	209	6.6	26.0	259	7 7	25 5	298	29.0	0 58	24
	50	0 69 x 10^{-2}	14.0	"	"	4.6	32.0	152	5.8	30 5	190	6.9	27.5	226	36.0	1.02	36
	56	0.72 x 10^{-2}	15.0	"	"	3.9	35.5	125	5.0	33.5	158	5.9	31.4	188	38.0	1.16	38
	11	1.0 x 10^{-2}	16.5	1.7	1.55	3.0	48	50	4.3	48	72	5.3	45	90	53.0	1.3	23
	17	0.58 x 10^{-2}	11.5	"	"	5.3	27	148	6.9	25.5	195	8.6	22.7	245	30	0.7	18
	49	0.59 x 10^{-2}	11.5	"	"	3.9	29	100	5.1	27.0	131	6.3	24.5	163	31.5	1.05	27
	23	0.55 x 10^{-2}	7.0	1.25	2.4	3.0	22.7	90	4.2	23.5	117	5.6	23.8	145	24.5	0.33	12
	25	0.57 - 0.65 x 10^{-2}	10 5	"	"	3.3	27.9	67	4.6	27.0	94	5.6	26.5	117	34.0	0 75	15
	26	0.78 x 10^{-2}	13 0	"	"	2.7	38.2	41	3.7	36.4	57	5.0	33.5	80	44 0	1.0	15
	27	0.57 x 10^{-2}	11.0	"	"	4.1	26.4	84	5.5	24 5	115	7.0	21.7	152	30.5	0 95	19
	29	0.73 x 10^{-2}	13.5	"	"	3.1	36.6	52	4.2	34.5	69	5.3	31.8	88.5	39.5	1.35	21
	30	0 73 x 10^{-2}	14.5	"	"	2.9	37.4	47	3.9	36.9	62.5	5.1	33	74	41.5	1 2	18
	31	0.44 x 10^{-2}	6.5	"	"	4.4	19.0	120	6.1	17.4	168	8.0	14.7	228	23.0	0.58	16
	32	0.64 x 10^{-2}	11.5	"	"	3.6	30.8	68	4.8	28.8	91	6.0	26.5	118	34.0	1 04	19
	33	0 51 x 10^{-2}	10.0	"	"	4 3	23.4	101	5 /	21.7	135	7 1	20 6	172	27 5	0 69	16
	34	0.57 x 10^{-2}	10.0	"	"	4.1	27.5	86	5.4	24.5	112.5	6.75	22 2	146	31.5	0.76	16
	41	0.57 x 10^{-2}	11.5	"	"	4.0	27.6	85	5.1	26.6	103	6.5	24 5	135	29.0	0.8	17
	55	0.89 x 10^{-2}	14.5	"	"	1.9	42 5	25	2.6	43.7	34.2	3.3	42 0	450	46.5	1.6	21
	19	0.55 x 10^{-2}	8.5	0.83	4.9	2.9	24.0	51	4.1	24.1	72.0	5.1	23.5	90	26.5	0.62	11
	21	0.55 x 10^{-2}	9 0	"	"	2.6	26 2	37	3.9	24.0	57.5	5.1	22.2	67	29 0	0.8	11
	24	0.77 x 10^{-2}	11.5	"	"	1.5	-	-	2.3	39	24	-	-	-	41.5	1.0	10
	35	0.53 x 10^{-2}	8 0	"	"	2.0	26.0	30	4.2	24.0	64	5.35	22.0	94	28.0	0.9	15
	36	0.35 x 10^{-2}	2.0	"	"	4.3	13.8	96	5.25	14.0	118	6.6	14	149	17.5	0.9	7
	40	0.52 x 10^{-2}	10 0	"	"	3.1	23.0	47	4.2	23.5	66	5.3	22 4	82	27.5	0 9	14
	43	0.46 x 10^{-2}	10.0	"	"	5.2	18.5	87	7.2	17	122	10.4	13.5	186	22.5	0 7	11
	44	0 46 x 10^{-2}	7.0	"	"	3.3	21.4	55	4.25	20.5	72	5.3	19.0	92	22.5	0 8	12
	46	0 43 x 10^{-2}	7.0	"	"	3 5	18.5	64	4.7	17.4	84	6.2	16.4	113	21.5	0.59	11
	20	0 65 x 10^{-2}	12.0	0 43	18.5	-	-	-	1.7	31 2	11	2.6	29	19	33.0	1.06	7
	37	0 43 x 10^{-2}	11.0	"	"	2.1	19	19	4.6	18.0	43	7.5	15.4	73	21 0	0.7	6
	45	0.39 x 10^{-2}	6 5	"	"	2.8	14.5	30.0	4 1	13.0	44.0	6.2	11.5	70	20.7	0.47	5
	51	0.52 x 10^{-2}	10 0	"	"	1.3	27	10 5	1.7	26.7	13 0	2.4	24.6	24 5	28 5	1.14	9
	52	0 68 x 10^{-2}	15.0	"	"	1.5	30.7	9.0	2.0	32.0	12.0	2.8	29.5	17 25	34.5	1.4	8
	54	0.8 x 10^{-2}	16 0	"	"	0.6	21	3.3	1.1	29	6.0	1.7	36.0	9.0	38.5	1.5	8
2nd	69	1.0 x 10^{-2}	18 5	2.5	7.9	7.6	41.2	180	8.9	38.9	208	10.2	37 4	240	43.5	1.48	35
	70	1.0 x 10^{-2}	18.5	"	"	6.6	45.7	144	7.7	45 1	166	8.6	44.2	185	46 0	1.05	25
	78	1 0 - 1.2 x 10^{-2}	21 5	"	"	6.8	44.8	143	7.8	43.8	163.5	13.8	-	-	46.0	1.15	23
	79	1.2 - 1.3 x 10^{-2}	22.0	"	"	5.4	48.0	104	6.6	46.8	126.5	7.7	45 3	148	54 5	1.37	28
	80	0 95 - 1.05 x 10^{-2}	21.5	"	"	8.0	38.5	190	9.0	38.2	215	10.0	36.0	243	41.5	1.00	25
	57	0 6 x 10^{-2}	13.0	1.25	20.0	9.0	26.0	176	11 8	24.7	228	14.7	24.0	280	26 4	0.85	18
	58	0 69 x 10^{-2}	15.5	"	"	11.3	28.5	188	12 9	27.5	213	14.8	26 8	232	31 5	1.2	20
	59	0 65 x 10^{-2}	15.5	"	"	13.5	27.0	236	15.0	26.0	260	16.95	25.2	293	27.7	1.2	23
	60	0 61 x 10^{-2}	12.0	"	"	12.1	23.7	228	14.3	23.0	275	16.4	21.7	335	30 2	1.0	9
	61	0.59 x 10^{-2}	13.0	"	"	14.2	24.0	268	15.9	23 5	302	18.5	20.5	358	26 0	0.8	17
	62	0 73 x 10^{-2}	14 0	"	"	10 0	27.0	157	11.5	26.0	180	12.85	25 0	200	30.5	1.36	22
	72	0.88 x 10^{-2}	18 0	"	"	7.9	35.6	100	9.3	34.9	119	10.9	33.5	141	37.5	1.60	23
	75	1.45 x 10^{-2}	25.0	"	"	3.1	56.0	25 5	3.8	56.5	31.5	4.85	55.3	42.5	60.5	2.91	24
	76	1 1 x 10^{-2}	23	"	"	5.9	44	63	7.3	42.5	78	9.10	39	101	46	1.90	21
	63	0.75 x 10^{-2}	15 5	0.83	39.0	8.9	28.2	79	10.4	27.2	107	11.8	26.0	122	28.5	4.60	50
	64	0 73 x 10^{-2}	14 5	"	"	9.4	26.0	99	11.0	25.0	114	12.75	23.0	132	28.5	1.20	14
	65	0 83 x 10^{-2}	14.5	"	"	7.35	35.0	71	8.45	34.3	82	9.8	32.2	96	39.5	2.10	21

TABLE II (Continued)

Series	Run No	λ_1 lb/lb	T_1 °C	$\frac{L}{v}$ secs	Δp "H_2O	λ_o = 0 2 x 10^{-3} lb/lb			λ_o = 0 5 x 10^{-3} lb/lb			λ_o = 0 10 x 10^{-2} lb			Maximum bed temperature		
						$\frac{x}{m}$	T_5	t_{mins}	$\frac{x}{m}$	T_5	t_{mins}	$\frac{x}{m}$	T_5	t_{mins}	°C	$\frac{x}{m}$	t_{mins}
2nd Contd	66	0 73 x 10^{-2}	11 5	0 83	39 0	8 6	29 4	91	10 1	27.5	110	11.8	26 7	130	34 5	1.09	12
	67	0 71 x 10^{-2}	13 5	"	"	9 01	31 4	97	10.5	29 0	115	12 2	26 5	134	32 0	1 9	10
	68	0 74 x 10^{-2}	13 0	"	"	9 3	28 0	101	10 7	27 0	113	12 35	25 5	134	30 5	1 33	15
	71	0 73 x 10^{-2}	14 5	"	"	9 2	30 8	97	10.3	30 0	108	11 65	28 5	167	33 0	1 2	13
	73	0 98 x 10^{-2}	21 5	"	"	7.35	37 8	58	8 6	36 5	69	10 4	33.0	85	41 5	0 9	21
	74	1 25 x 10^{-2}	22.5	"	"	3.9	51.5	24	4 5	51.0	28 5	5 5	50 2	36	55 5	3 18	20
	77	0 75 x 10^{-2}	14.5	"	"	8 2	31 7	83 5	9 4	30.5	96	10 9	29 2	112 5	33 5	1 4	10
	83	1 0 x 10^{-2}	22 5	"	"	7 5	36 5	59	8 5	36 0	68	10 2	36 0	80 5	43 5	1.5	12
3rd	89	1 1 x 10^{-2}	21.0	1 2	2 9	0 65	23.0	7 0	0 95	28.0	11 0	2 4	44 2	27 0	47 0	2 3	26
	90	0 92 x 10^{-2}	19 5	"	"	1 2	35 7	15 5	3.8	42.5	49	5 4	40 2	70 0	45.0	1 6	21
	91	1 33 x 10^{-2}	34 5	"	"	2.2	50	20	3 3	53 4	30	4 2	53 5	39	59 0	2 1	20
	92	0 92 x 10^{-2}	18 0	"	"	-	-	-	2 8	41.5	37.5	5 4	40.5	71	44 0	1 4	18
	97	0 84 x 10^{-2}	16 0	"	"	5.0	37.0	68	6.4	36.2	87 5	7 7	34 4	108	40 0	1 8	24
	98	0 95 x 10^{-2}	16 5	"	"	4 1	40 7	52	5 4	39 2	68	6 7	38 0	85	43 5	1 61	20
	99	1.12 x 10^{-2}	19 0	"	"	1 1	28	7.5	2.3	43 8	24	4 0	45 6	42	49 0	1 9	20
	100	0.95 x 10^{-2}	17.0	"	"	4.1	41 9	49.25	5.3	49.9	65	6 2	41 2	76	46 0	2.0	25
	101	0 99 x 10^{-2}	18 0	"	"	0.9	23.0	11	3 0	42 7	36	4 8	42 2	58	46.5	1 7	21
	103	0 83 x 10^{-2}	16 0	"	"	5 0	37 5	70	5.9	37 1	82	6.9	36 5	113	39 0	1.6	23
6th	139	0 61 x 10^{-2}	13 5	1 35	"	6 8	29 0	136	8 0	28 90	164	9.10	27 5	188	33.0	1 16	20
	140	0.51 x 10^{-2}	11.5	"	"	7.5	26.5	175	8.4	26 25	193	9 4	25 6	223	26 5	0.84	21
	141	0 30 x 10^{-2}	9 0	"	"	7.8	17.5	300	8 8	16 7	315	9 55	15.25	420	19 5	0.77	25
	142	0 29 x 10^{-2}	10 0	"	"	7 1	19 5	298	7 85	19.25	335	8.8	17 25	400	20 5	0 34	15
	143	0.54 x 10^{-2}	12 5	"	"	7 1	28.0	150	8 2	27.0	184	9 3	26 5	209	31 0	0 90	22
	144	0 52 x 10^{-2}	12.0	"	"	7 1	29.0	160	8 0	28 5	179	9 10	26 0	208	29	3 95	90
	145	0 51 x 10^{-2}	16.0	"	"	4 6	30 5	117	5.8	31 0	142 5	6 75	30 0	165	31 5	1 75	31
	146	0 34 x 10^{-2}	10 0	"	"	7 8	19 0	284	8 7	18 0	317	10 15	16 7	371	22	0 8	20
4th	107	0.96 x 10^{-2}	16 0	1 25	4 7	4 7	47	60	6 5	46 3	84	8 0	41	99	49.0	1 9	26
	108	0.76 x 10^{-2}	16.0	"	"	6 6	37 7	107	8 2	36 0	132	9 6	33 5	155	38 0	2 0	30
	109	0 65 x 10^{-2}	15 0	"	"	6 4	33 5	122	8 2	31 7	156	10.0	28.5	189	35 0	0 93	19
	110	0 44 x 10^{-2}	8 0	"	"	8 4	22.1	225	9.8	20.3	265	10 7	18 5	291	22 0	0 55	18
	111	0 39 x 10^{-2}	5-10	"	"	6 7	25 7	206	8 1	23.4	245	9 4	20 5	292	19 0	0 4	14
	112	0 49 x 10^{-2}	12 0	"	"	6 6	29 5	194	7 3	28 5	185	8 25	26 5	208	27 0	0 8	16
	113	0 49 x 10^{-2}	11 0	"	"	6 3	27.0	163	7 7	24 2	204	8 7	21.5	253	28 5	0 9	23
	114	0 58 x 10^{-2}	14.0	"	"	5.9	32 2	126	7 0	30 0	152	7 4	29.0	161	34.0	1 1	24
	115	0 46 x 10^{-2}	10 0	"	"	6 5	25.0	172	7 5	23 3	201	8 3	21.0	239	26 0	0.7	18
	116	0 79 x 10^{-2}	15 0	"	"	5.3	39 5	85	6 5	36 8	106	7 55	33.0	125	43 0	1.3	20
	117	0 68 x 10^{-2}	13 0	"	"	5 8	33.7	120	6.9	32	133	7.7	29.7	151	37 0	1 5	28
	118	0 45 x 10^{-2}	8 5	"	"	6 6	23 5	180	7 5	22	204	8 4	20.4	251	26 0	0.70	20
	119	0 58 x 10^{-2}	11 5	"	"	6.4	28 7	135	7 4	27.0	168	8 4	25 4	244	32 5	0 95	20
5th	121	0 48 x 10^{-2}	10 5	1 35	2 6	6 2	24 2	178	7 2	22.9	203	8 0	21 2	230	29 5	0.56	15
	122	0 32 x 10^{-2}	7 0	"	"	6 6	16.8	263	7 5	15.7	308	8 4	13 3	352	16 5	0 2	8
	123	0 53 x 10^{-2}	11 0	"	"	5.5	28 2	139	6 6	26.0	169	7.6	23.0	200	30	0 6	15
	124	0.43 x 10^{-2}	11 0	"	"	5.5	25.8	168	6 4	24.5	195	7 15	23 0	231	26 5	0.6	18
	125	0.50 x 10^{-2}	10 0	"	"	5 5	28 9	143 5	6 4	27 0	166	7 10	26.1	184	27.0	0 64	18
	126	0.72 x 10^{-2}	13.5	"	"	4 2	37 5	78	6 0	35.0	113	6.85	32 0	136	41 0	1 4	25
	127	0 59 x 10^{-2}	11.5	"	"	4 8	31.4	112	5 7	30.5	132	6 4	29.0	146	34 0	0 9	21
	128	0 58 x 10^{-2}	11 0	"	"	5 5	30 5	128	6 6	27.8	154	7 10	26 8	166	33 0	0 8	19
	129	0 47 x 10^{-2}	8.5	"	"	6.0	25	157.5	6 9	24.5	180	7.6	23 5	200	28 5	0 63	18
	130	0 46 x 10^{-2}	9	"	"	5 8	24 0	165	6 8	21.6	195	7.5	20 3	215	27 0	0.67	20
	131	0.37 x 10^{-2}	6.0	"	"	6.0	19.0	210	7 0	18 7	244	8.1	16.0	280	21 5	0 4	17
	132	0 41 x 10^{-2}	8 0	"	"	6 1	19.7	188	6.9	17.8	218 5	8 0	16.0	256	25 0	0 56	16
	133	0 28 x 10^{-2}	5 0	"	"	6 6	15	303	7 3	14	343	8.1	12 5	393	15 5	0 22	13
	134	0 55 x 10^{-2}	10.0	"	"	5 9	29 1	143	6.7	28.6	163	7 6	26.5	185	30 0	5 12	125
	135	0 48 x 10^{-2}	8.0	"	"	6 1	23.5	168	7.0	21 3	196	7.7	19	222	26.5	0 8	23
	136	0 52 x 10^{-2}	8 0	"	"	5 8	24 0	160	6.6	23 7	181	7 7	22	212	25 5	0 4	12
	137	0.51 x 10^{-2}	9 0	"	"	5 8	24.5	157	6 8	21 8	186	7 7	20	211	28 0	0.85	23
	138	0.65 x 10^{-2}	13 5	"	"	5 1	35 4	103	6.0	33 5	123	6 7	31	138	38.0	1 0	20

FIG. 1 & 2.

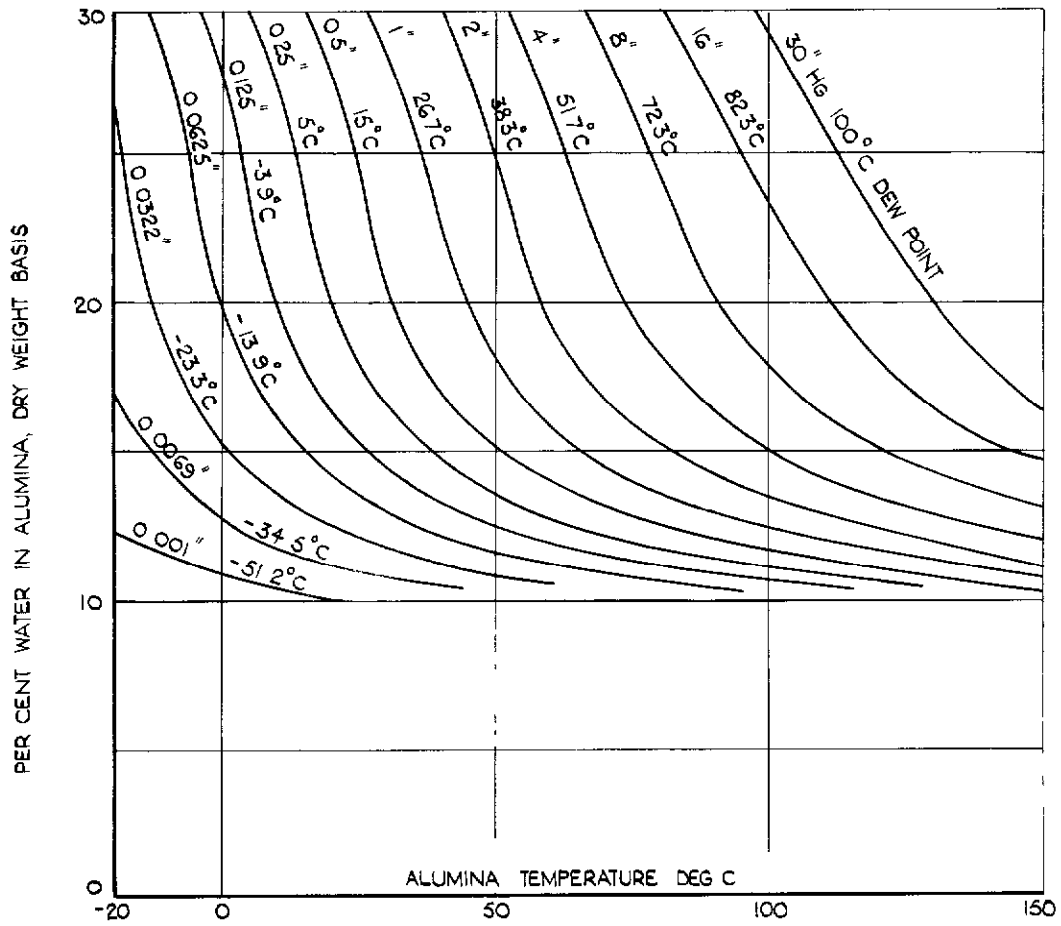


FIG. 1. CONSTANT WATER-VAPOUR PRESSURE LINES FOR ACTIVATED ALUMINA AGAINST TOTAL WATER CONTENT AND ALUMINA TEMPRE

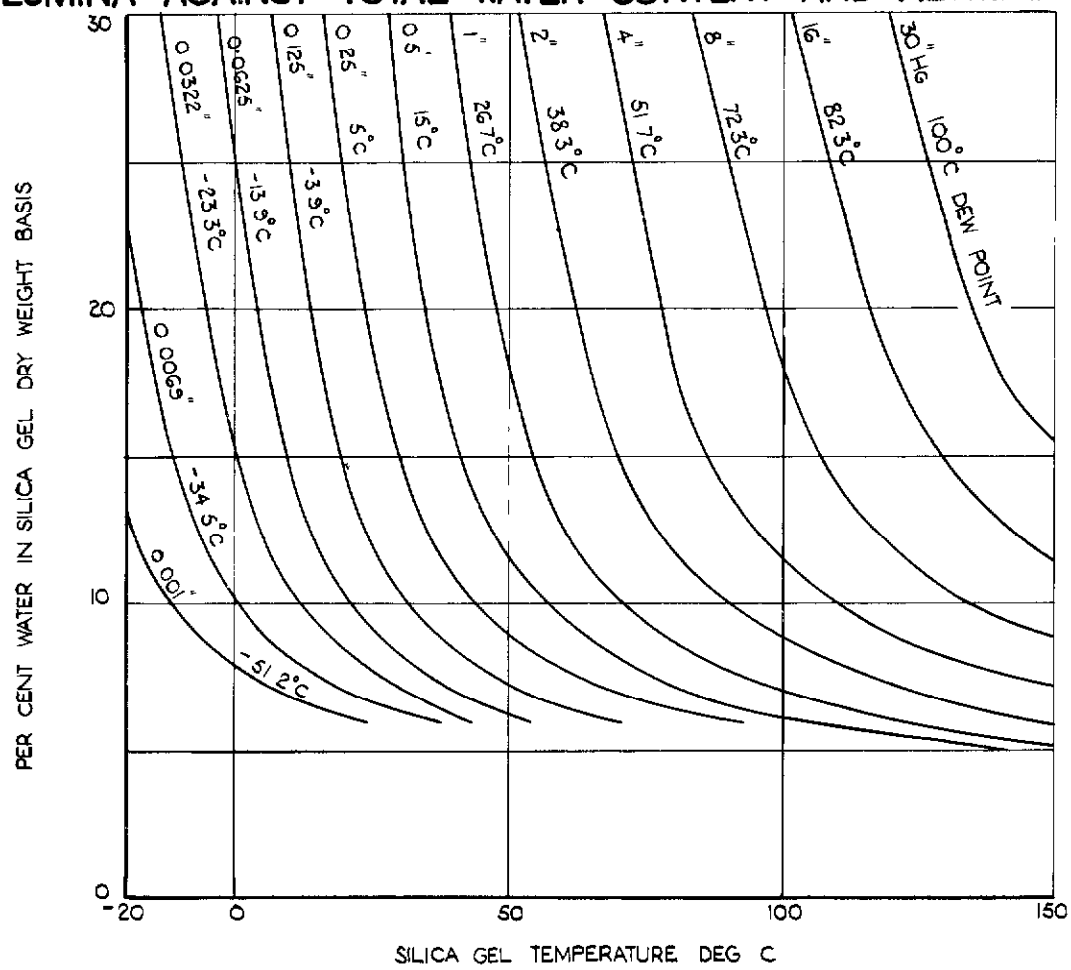


FIG. 2. CONSTANT WATER-VAPOUR PRESSURE LINES FOR SILICA GEL AGAINST TOTAL WATER CONTENT & SILICA GEL TEMPERATURE.

FIG. 3.

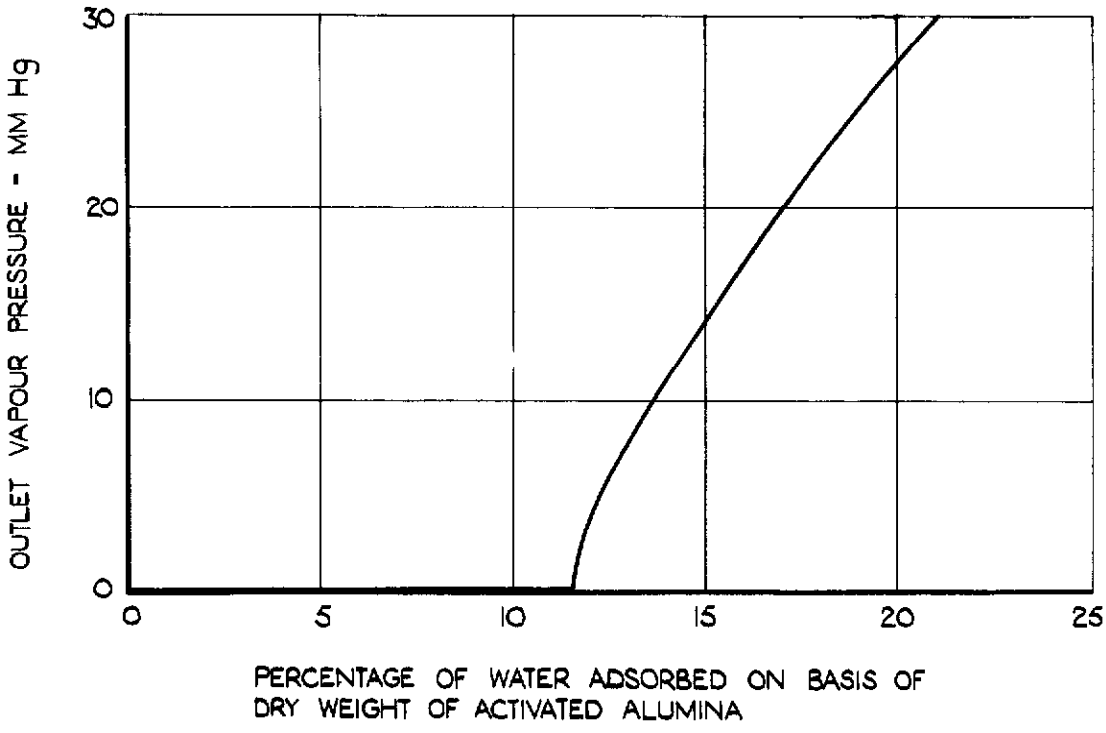
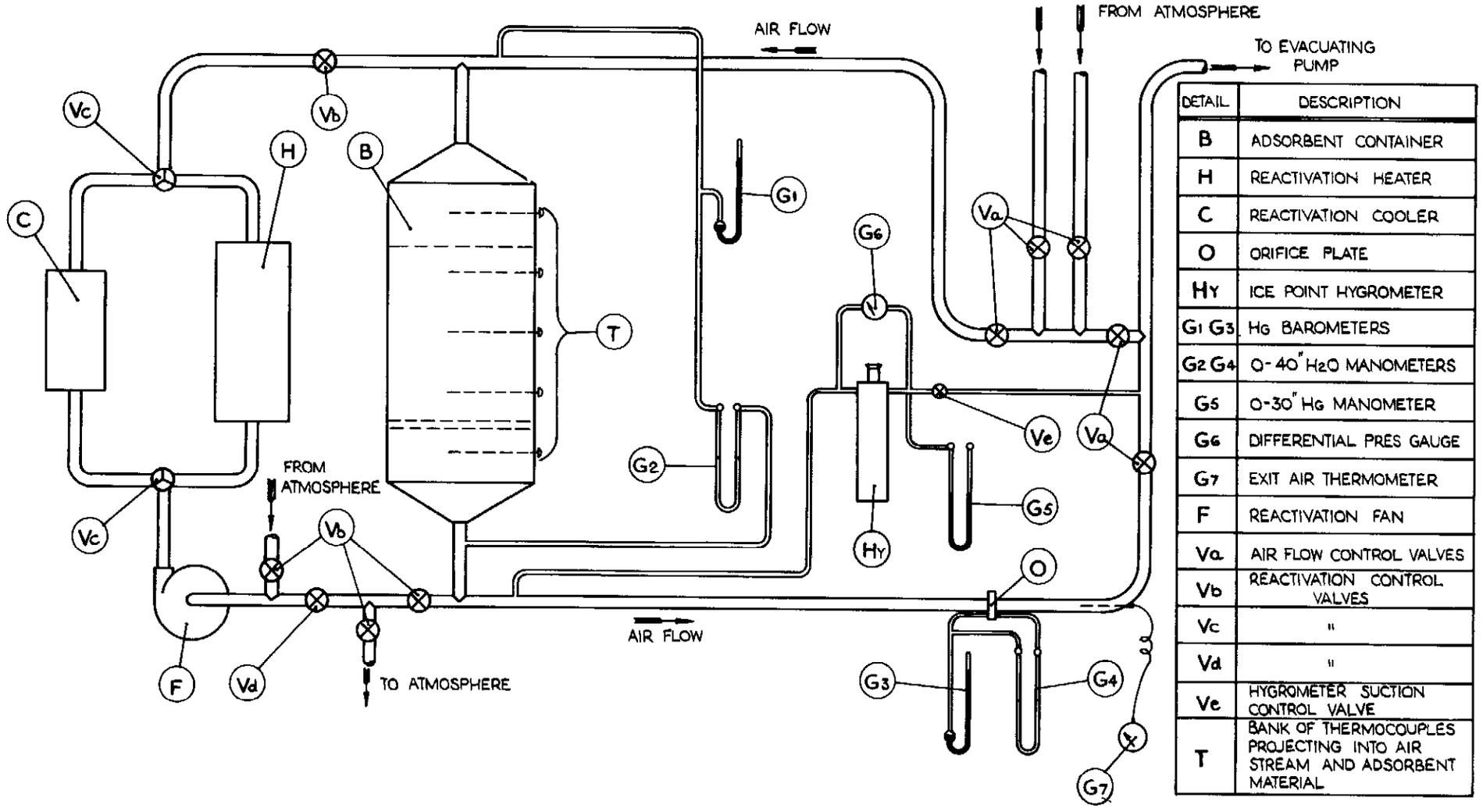


FIG. 3. SIMPLIFIED CURVE OF VAPOUR PRESSURE WITH PERCENTAGE ADSORPTION FROM AIR AT 30°C. & 90% RELATIVE HUMIDITY FOR 8-14 MESH ACTIVATED ALUMINA BY THE DYNAMIC METHOD.



DETAIL	DESCRIPTION
B	ADSORBENT CONTAINER
H	REACTIVATION HEATER
C	REACTIVATION COOLER
O	ORIFICE PLATE
Hy	ICE POINT HYGROMETER
G1 G3	Hg BAROMETERS
G2 G4	0-40" H_2O MANOMETERS
G5	0-30" Hg MANOMETER
G6	DIFFERENTIAL PRES GAUGE
G7	EXIT AIR THERMOMETER
F	REACTIVATION FAN
Va	AIR FLOW CONTROL VALVES
Vb	REACTIVATION CONTROL VALVES
Vc	"
Vd	"
Ve	HYGROMETER SUCTION CONTROL VALVE
T	BANK OF THERMOCOUPLES PROJECTING INTO AIR STREAM AND ADSORBENT MATERIAL

FIG.4. DIAGRAMMATIC LAYOUT OF ADSORPTION DRYING PILOT PLANT.

FIG.4.

FIG. 5.

CURVE No	ADSORBENT		INLET HUMIDITY $\lambda_i \times 10^2$ LB/LB	CONTACT TIME SECS	BED DEPTH INCHES	PRESSURE DROP THROUGH BED INCHES H_2O
1	ACTIVATED ALUMINA	4-8 GRADE	·46	1·35	21	2·53
2		2-4 GRADE	·63	2 50	25	0·8
3		2-4 GRADE	·73	1·25	25	2 4
4		2-4 GRADE	89	1 25	25	2 6
5		2-4 GRADE	1·00	·42	25	17·5

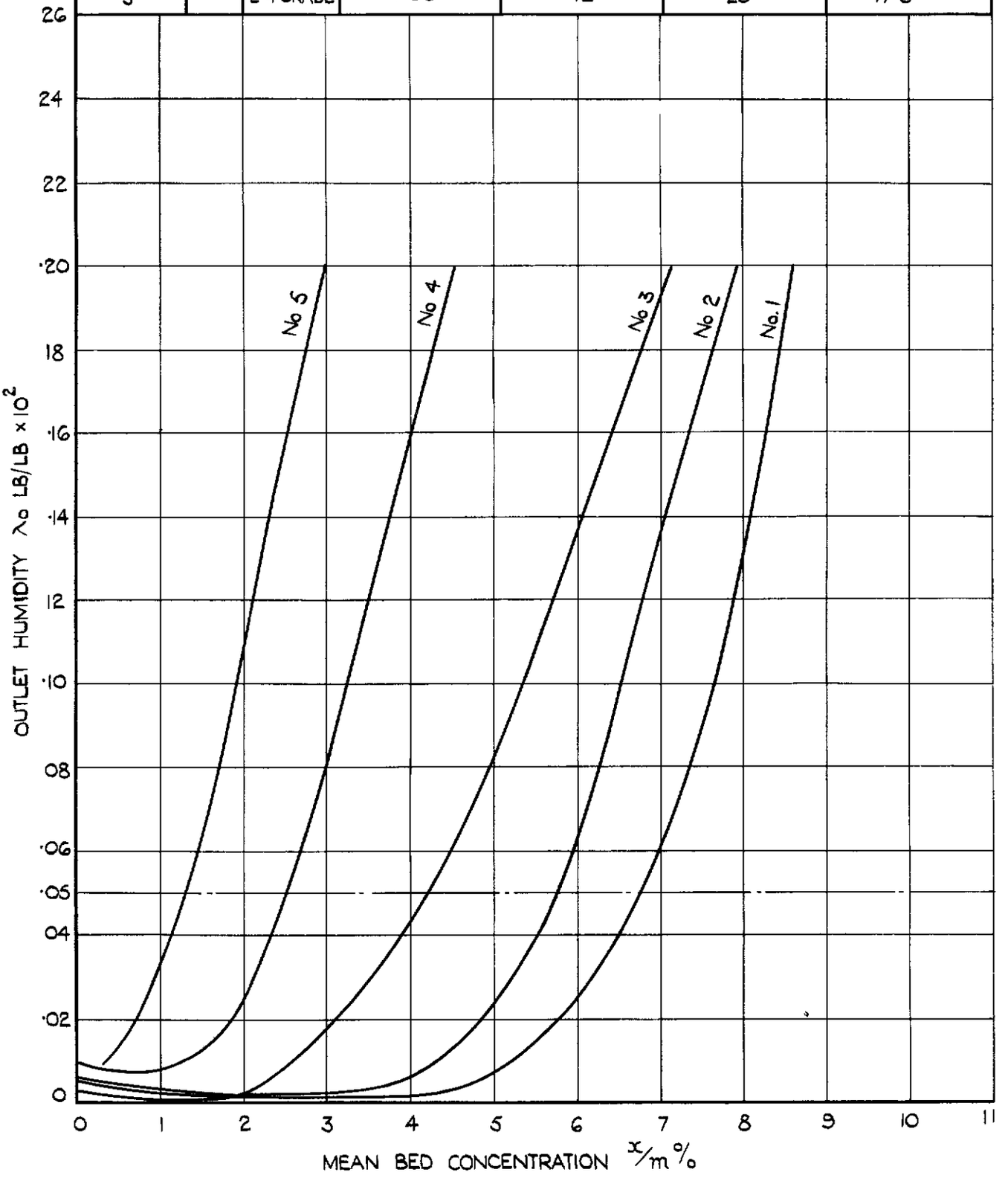


FIG. 5 TYPICAL TEST BED PERFORMANCE CURVES FOR ACTIVATED ALUMINA.

FIG. 6.

CURVE No	ADSORBENT	INLET HUMIDITY $\lambda_i \times 10^2$ LB/LB	CONTACT TIME SECS	BED DEPTH INCHES	PRESSURE DROP THROUGH BED INCHES H_2O
1	SILICA GEL 6-10 GRADE	595	1·25	25	20·0
2		·73	1·25	25	20·5
3		·88	1 25	25	20 0
4		·84	1 20	12	3 8
5		1·02	·40	12	18 0

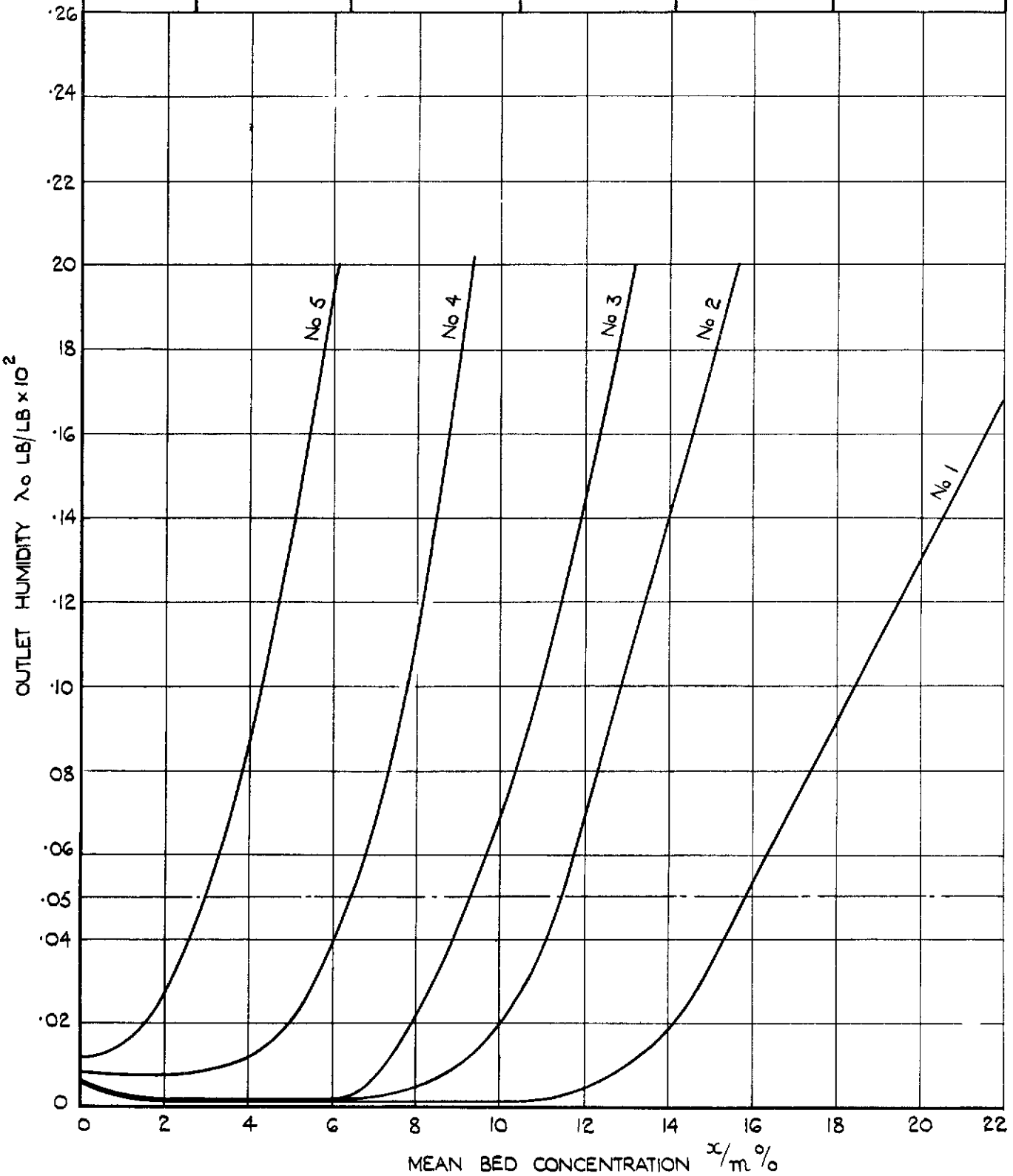


FIG. 6. TYPICAL TEST BED PERFORMANCE CURVES FOR SILICA GEL.

FIG. 7 & 8.

ADSORBENT	ACTIVATED ALUMINA
GRADE	2 - 4
BED DEPTH	25 INCHES
CONTACT TIME	1 25 SEC
INLET HUMIDITY λ_i	73×10^{-2} LB/LB
PRESSURE DROP THROUGH BED	2 4 IN H_2O

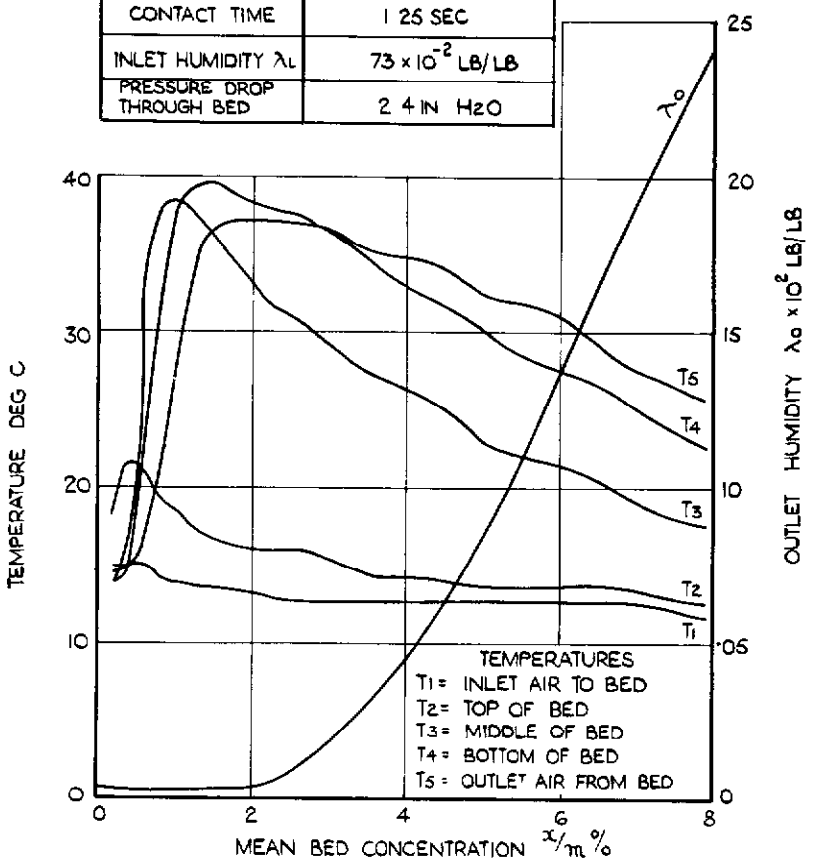


FIG. 7.

ADSORBENT	ACTIVATED ALUMINA
GRADE	4 - 8
BED DEPTH	25 INCHES
CONTACT TIME	1 25 SEC
INLET HUMIDITY λ_i	45×10^{-2} LB/LB
PRESSURE DROP THROUGH BED	4 6 IN H_2O

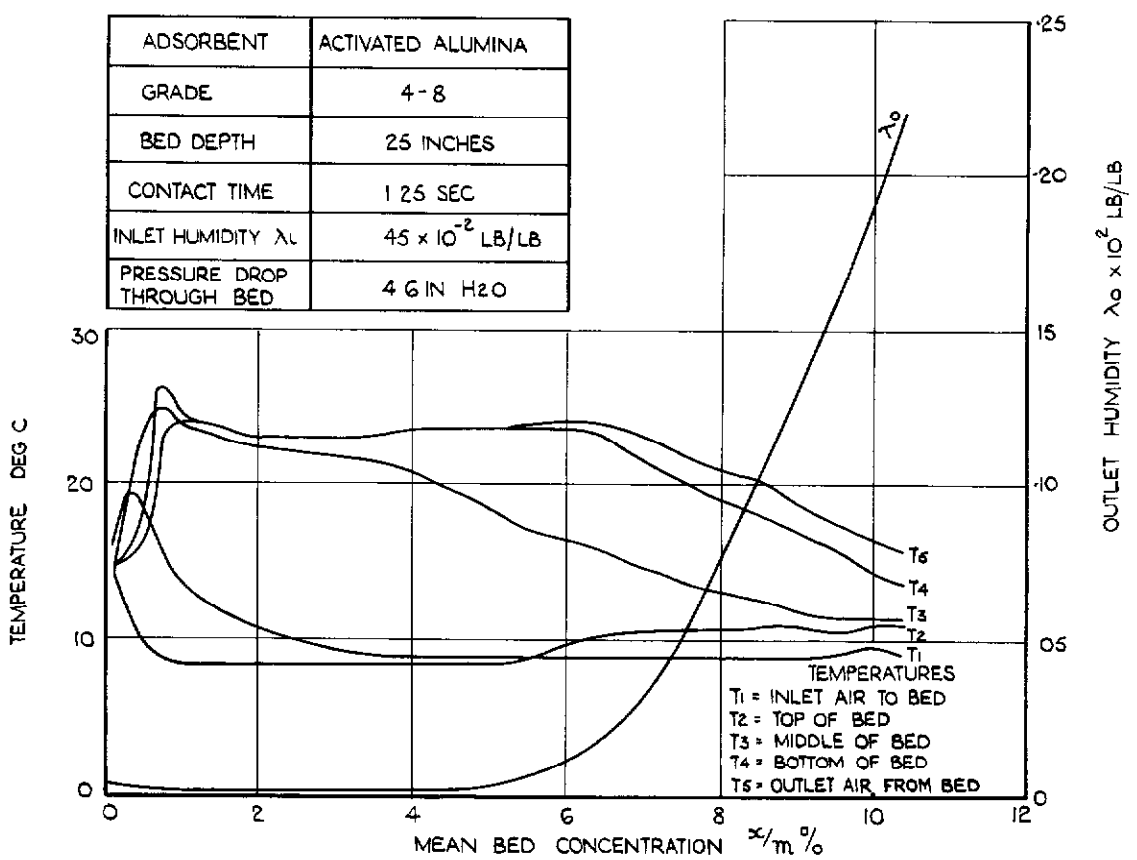


FIG. 7 & 8. BED TEMPERATURES AND OUTLET HUMIDITY λ_o PLOTTED AGAINST x/m %.

ADSORBENT	SILICA GEL
GRADE	6 - 10
BED DEPTH	25 INCHES
CONTACT TIME	1·25 SEC.
INLET HUMIDITY λi	$(\cdot 58 \text{ TO } 61) \times 10^{-2}$ LB/LB
PRESSURE DROP THROUGH BED	20 IN H_2O

TEMP	POSITION
T1	INLET AIR TO BED.
T2	TOP OF BED.
T3	MIDDLE OF BED.
T4	BOTTOM OF BED
T5	OUTLET AIR FROM BED.

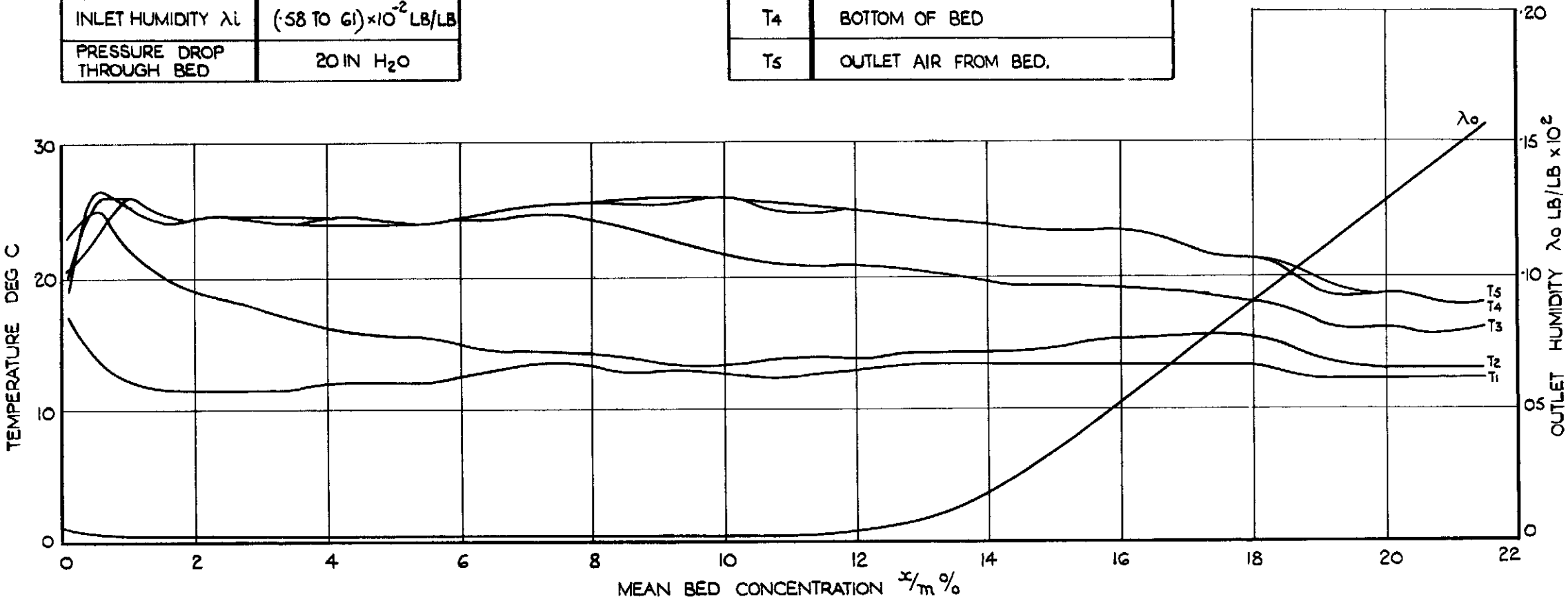


FIG. 9. BED TEMPERATURES AND OUTLET HUMIDITY λ_o PLOTTED AGAINST x/m %

FIG. 9.

FIG.10.

ADSORBENT	SILICA GEL
GRADE	6-10
BED DEPTH	25 INCHES
CONTACT TIME	1·25 SEC
INLET HUMIDITY λ_i	$1{\cdot}45 \times 10^{-2}$ LB/LB
PRESSURE DROP THROUGH BED	21·5 IN. H_2O

TEMP	POSITION
T_1	INLET AIR TO BED
T_2	TOP OF BED
T_3	MIDDLE OF BED
T_4	BOTTOM OF BED
T_5	OUTLET AIR FROM BED

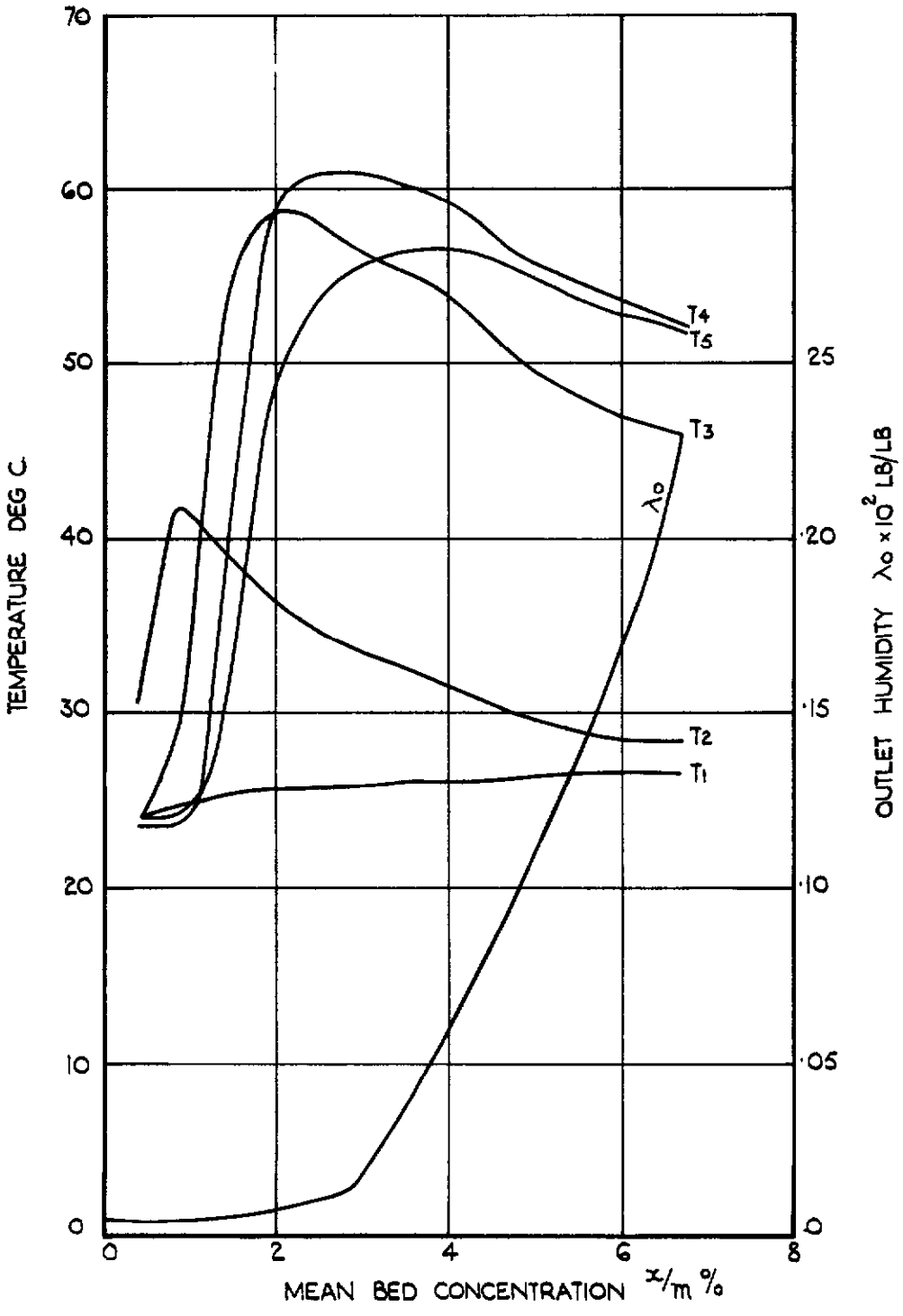


FIG. 10. BED TEMPERATURES AND OUTLET HUMIDITY λ_o PLOTTED AGAINST x/m %.

FIG.11.

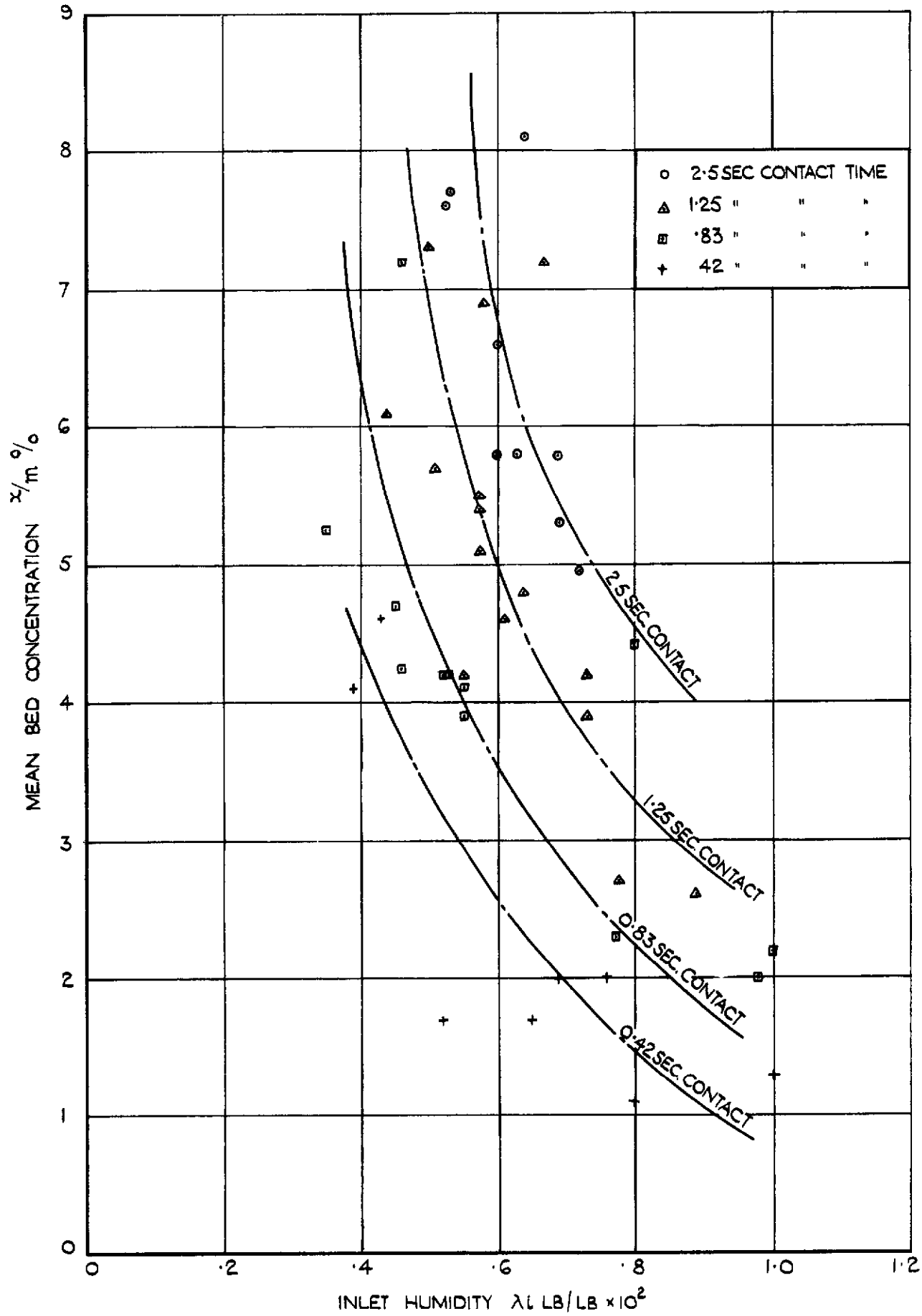


FIG.11. $\frac{x}{m}$ PLOTTED AGAINST λ_i, WHEN OUTLET HUMIDITY $\lambda_o = \cdot 0005$ LB/LB. ACTIVATED ALUMINA, 2/4 GRADE. 25 IN. DEPTH OF BED.

FIG. 12 & 13.

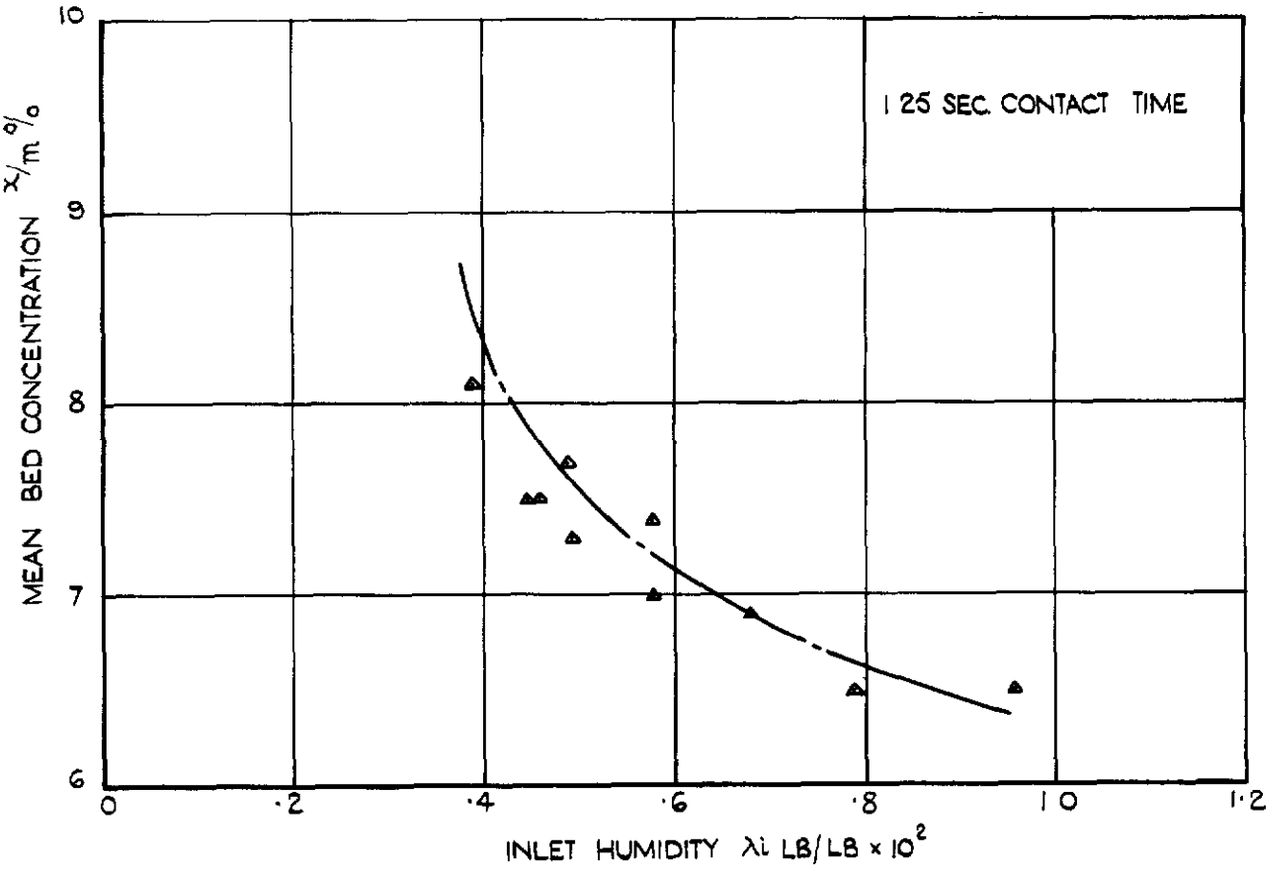


FIG. 12. x/m PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0005 LB/LB. ACTIVATED ALUMINA 4/8 GRADE. 25 IN. DEPTH OF BED.

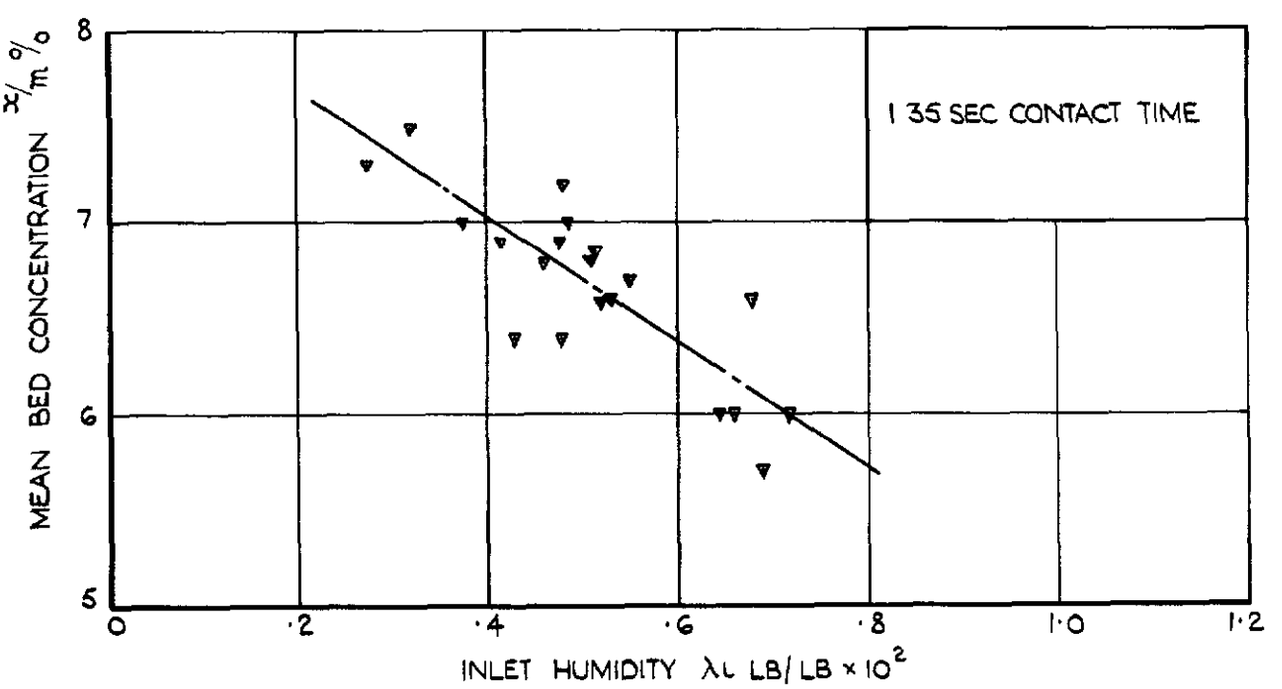


FIG. 13. x/m PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0005 LB/LB. ACTIVATED ALUMINA 4/8 GRADE 21 IN. DEPTH OF BED.

FIG.14.

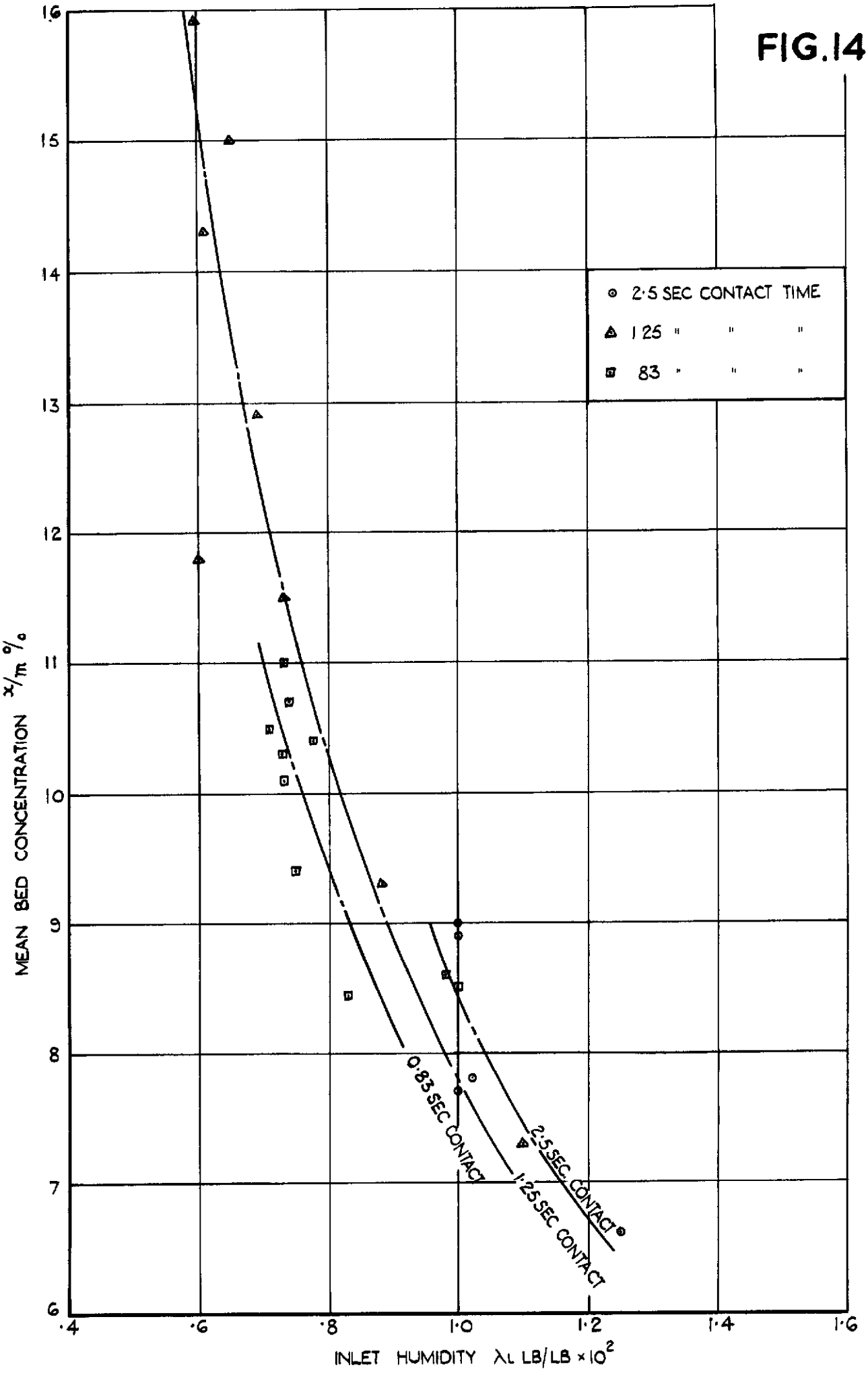


FIG.14. $\frac{x}{m}$ PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0005 LB/LB.
SILICA GEL 6/10 GRADE.
25 IN. DEPTH OF BED.

FIG.15.

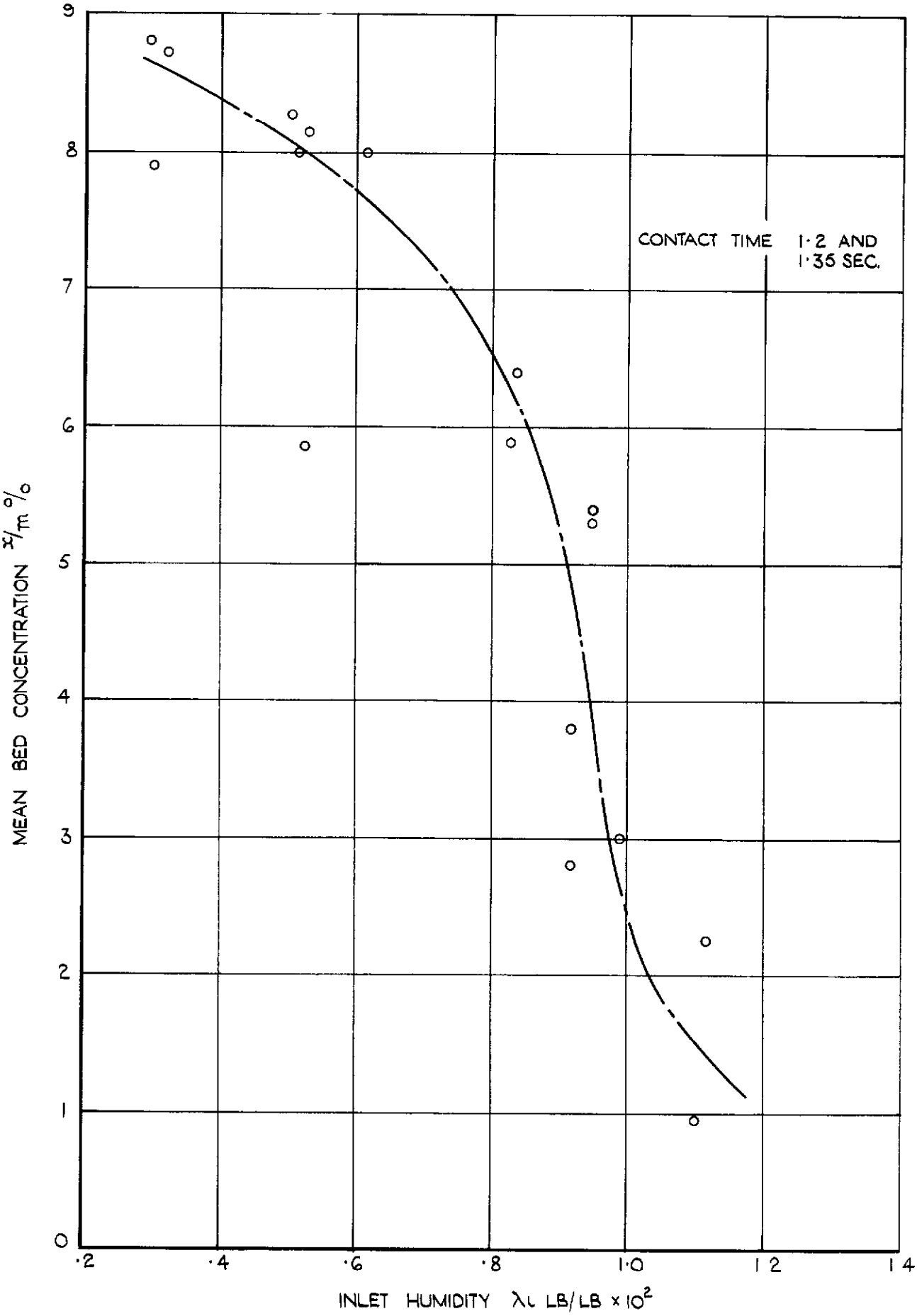


FIG.15. x/m PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY $\lambda_o = \cdot0005$ LB/LB.
SILICA GEL 6/10 GRADE.
12 IN. DEPTH OF BED.

FIG.16.

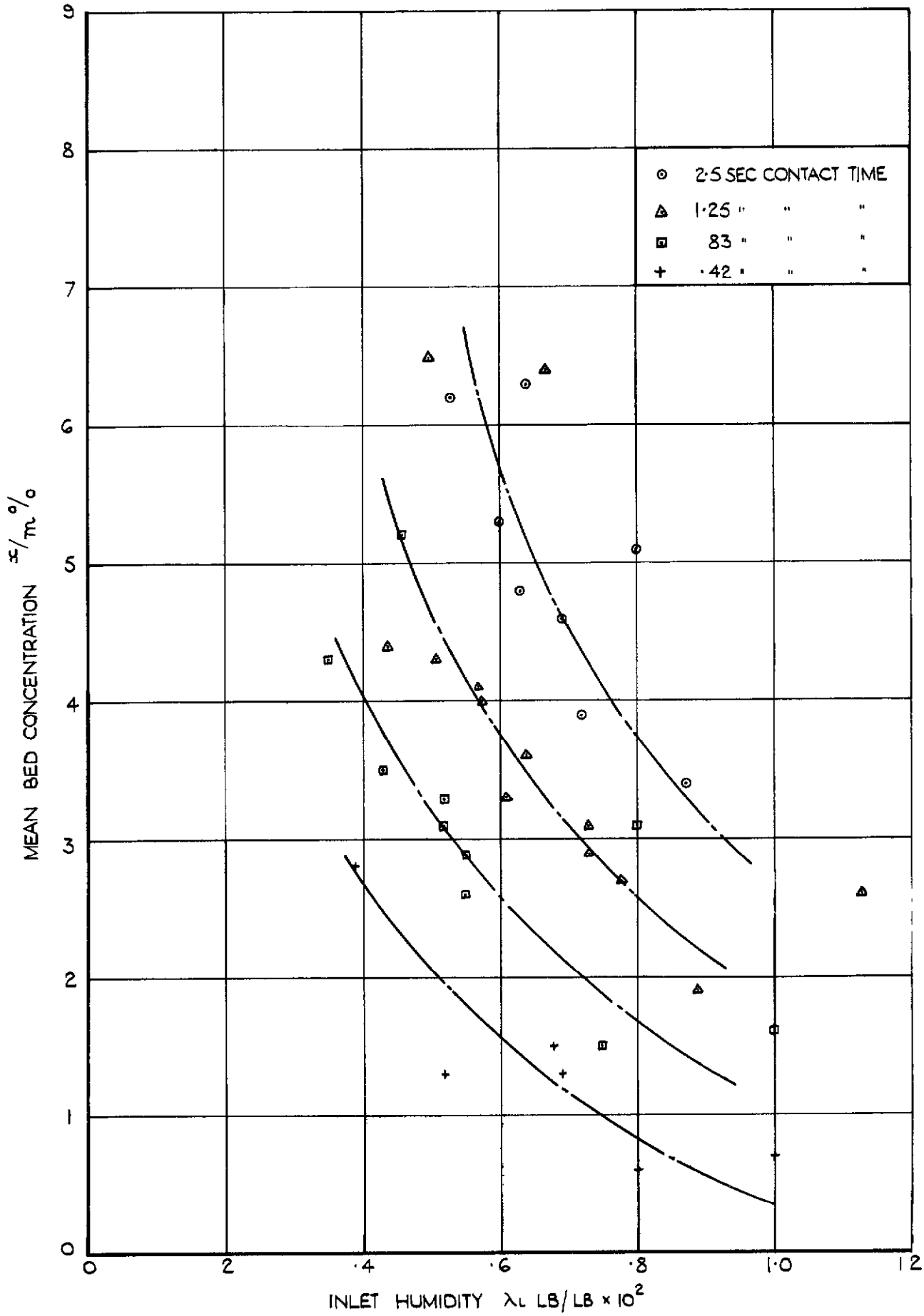


FIG.16. x/m PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY $\lambda_o = \cdot0002$ LB/LB. ACTIVATED ALUMINA 2/4 GRADE. 25 IN. DEPTH OF BED.

FIG. 17 & 18.

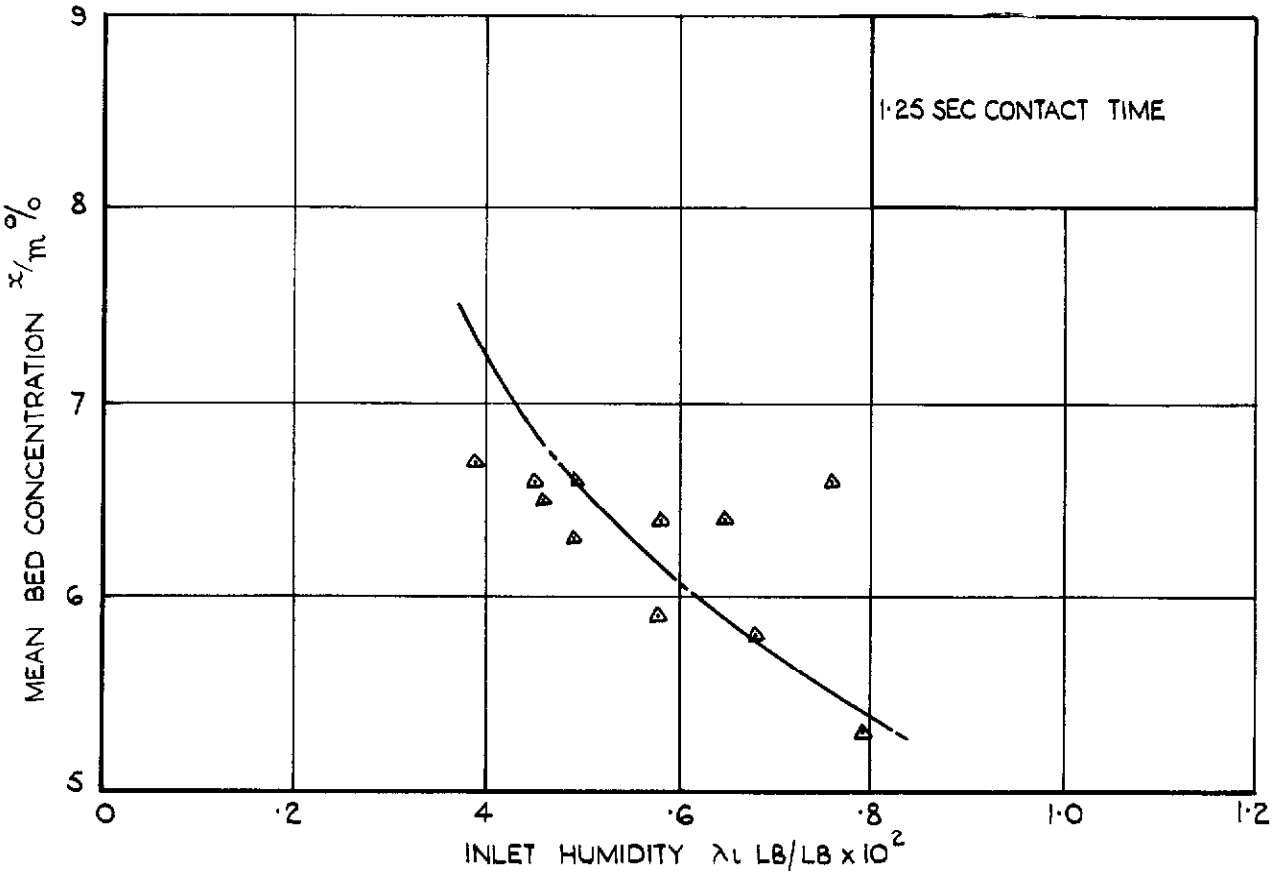


FIG. 17. $\frac{x}{m}$ PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0002 LB/LB.
ACTIVATED ALUMINA 4/8 GRADE.
25 IN. DEPTH OF BED.

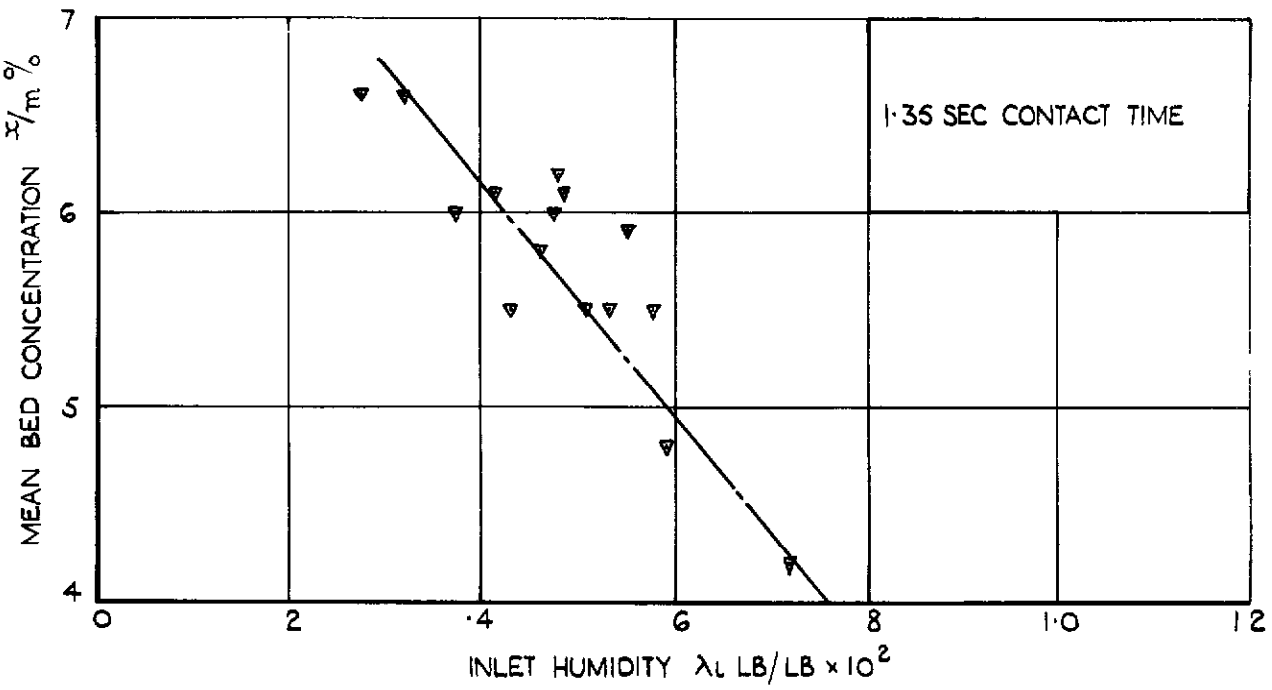


FIG. 18. $\frac{x}{m}$ PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0002 LB/LB.
ACTIVATED ALUMINA 4/8 GRADE.
21 IN. DEPTH OF BED.

FIG.19.

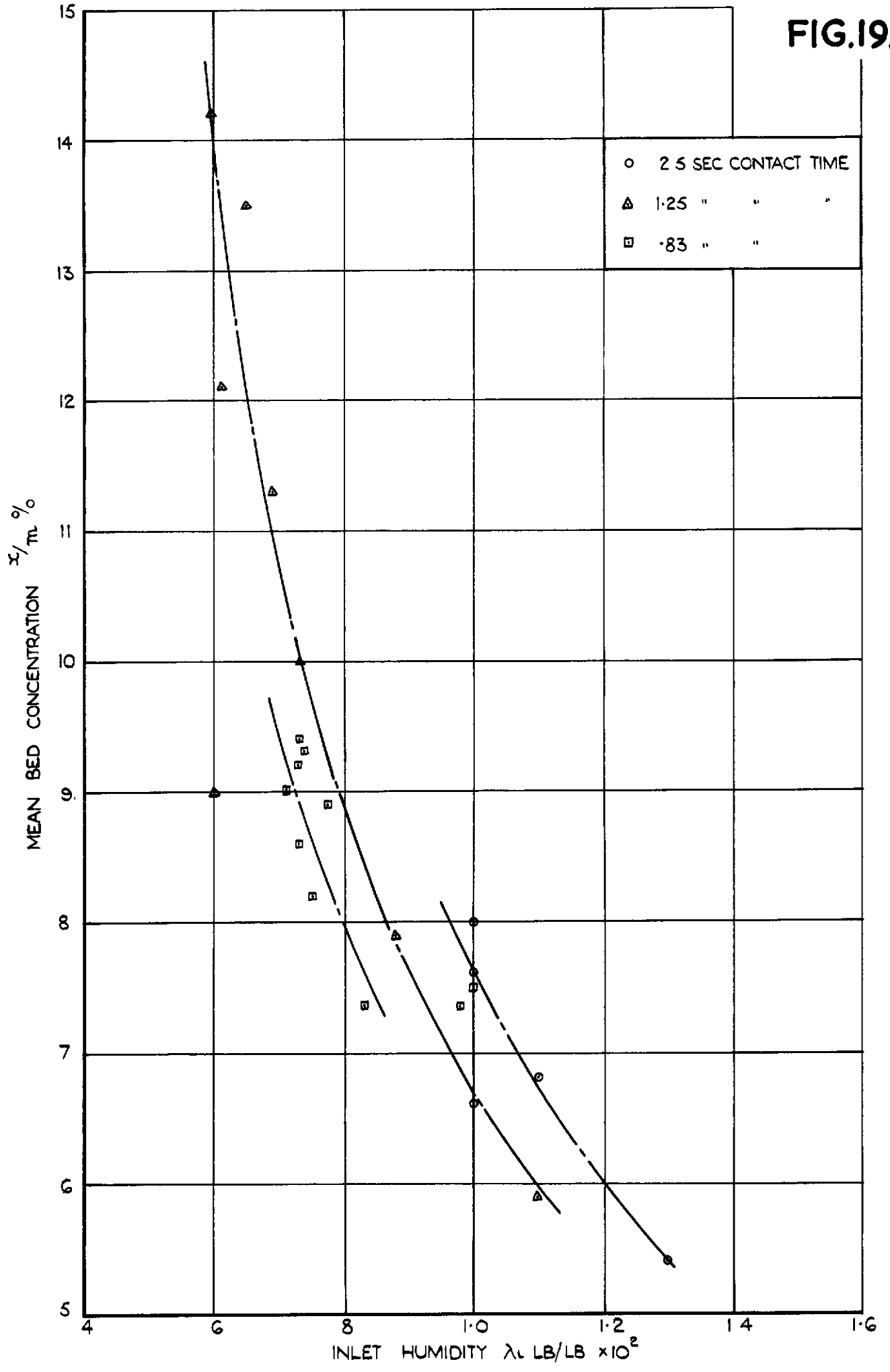


FIG.19. $\frac{x}{m}$ PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY λ_o = ·0002 LB/LB.
SILICA GEL 6/10 GRADE.
25 IN. DEPTH OF BED.

FIG.20.

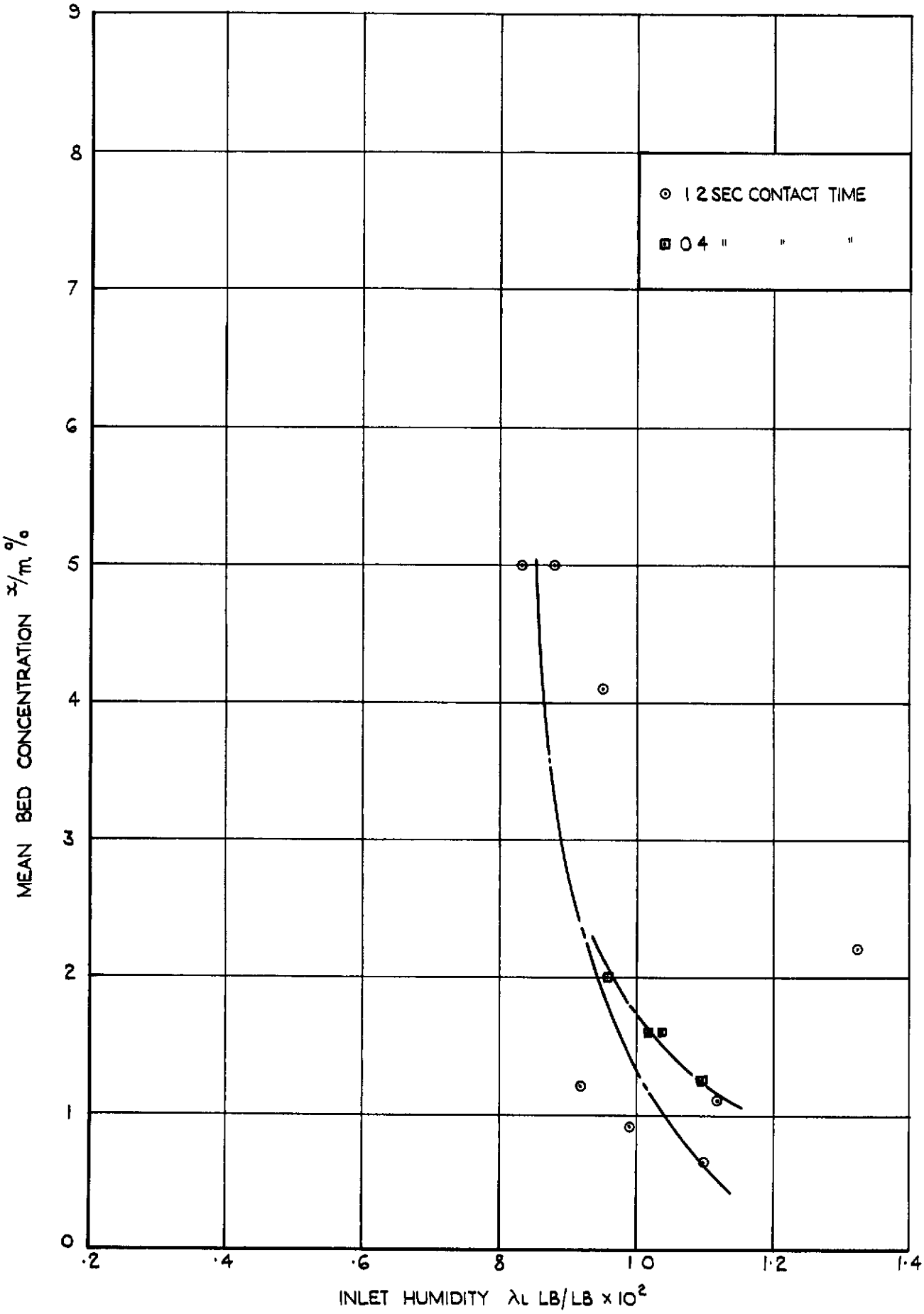


FIG.20. $\frac{x}{m}$ PLOTTED AGAINST λ_i WHEN OUTLET HUMIDITY $\lambda_o = \cdot 0002$ LB/LB.
SILICA GEL 6/10 GRADE.
12 IN. DEPTH OF BED.

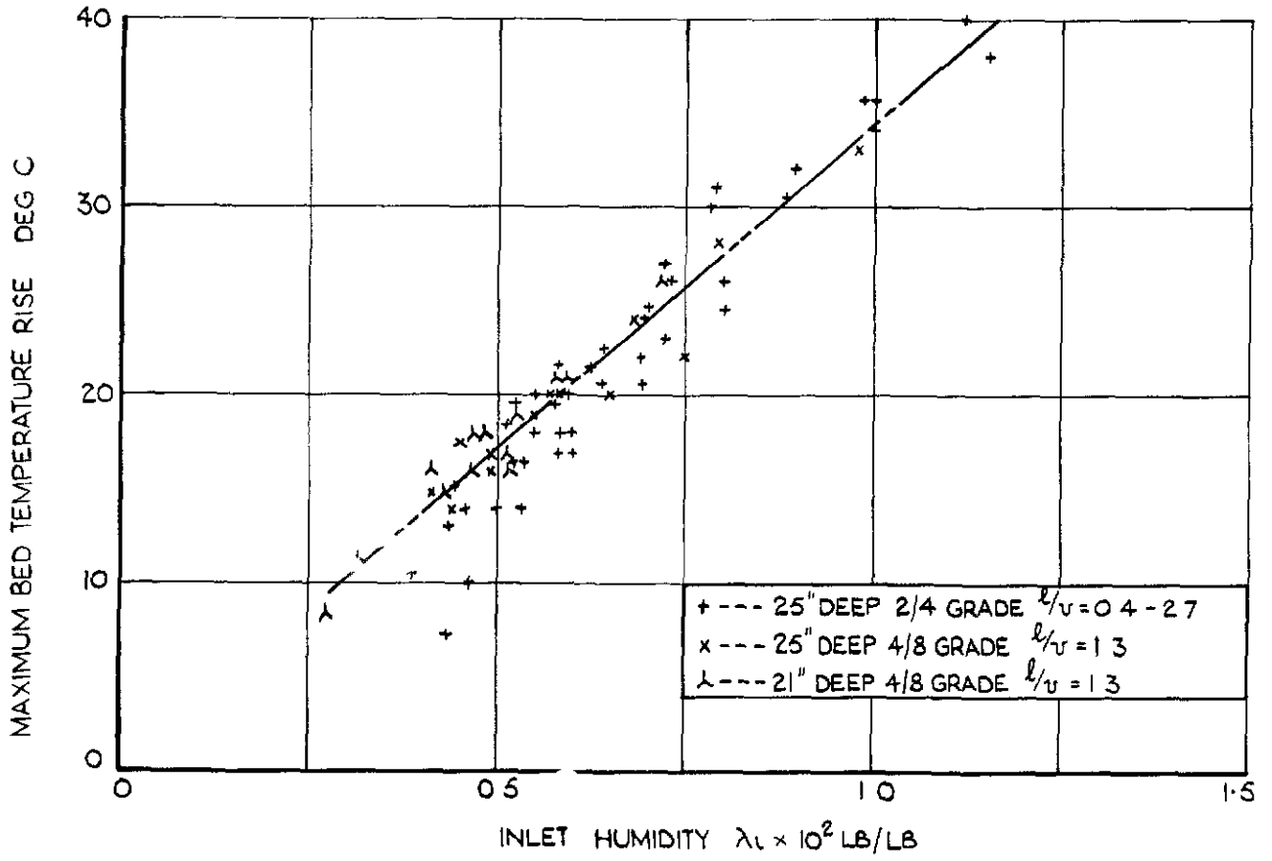


FIG. 21. MAXIMUM ADSORBENT BED TEMPERATURE RISE USING ACTIVATED ALUMINA.

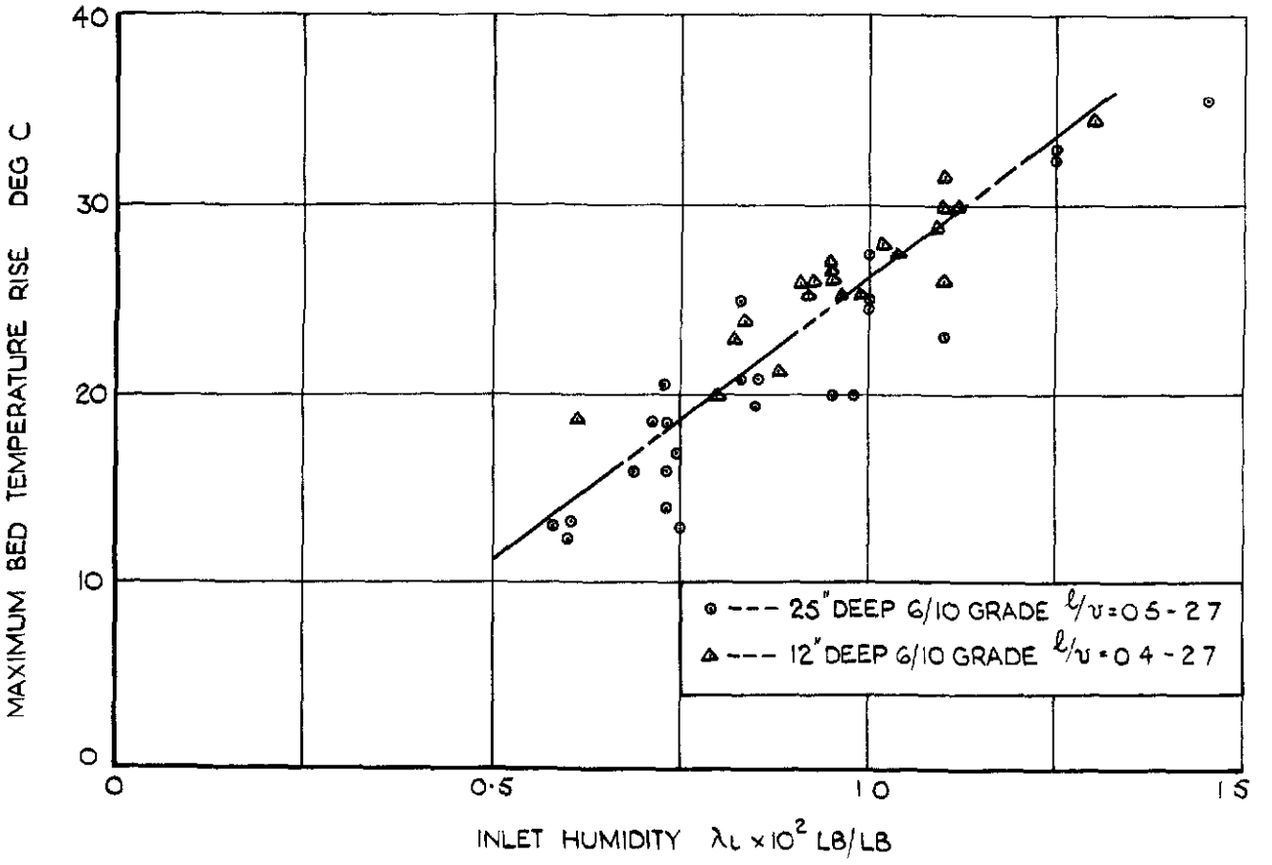


FIG. 22. MAXIMUM ADSORBENT BED TEMPERATURE RISE USING SILICA GEL.

FIG.23.

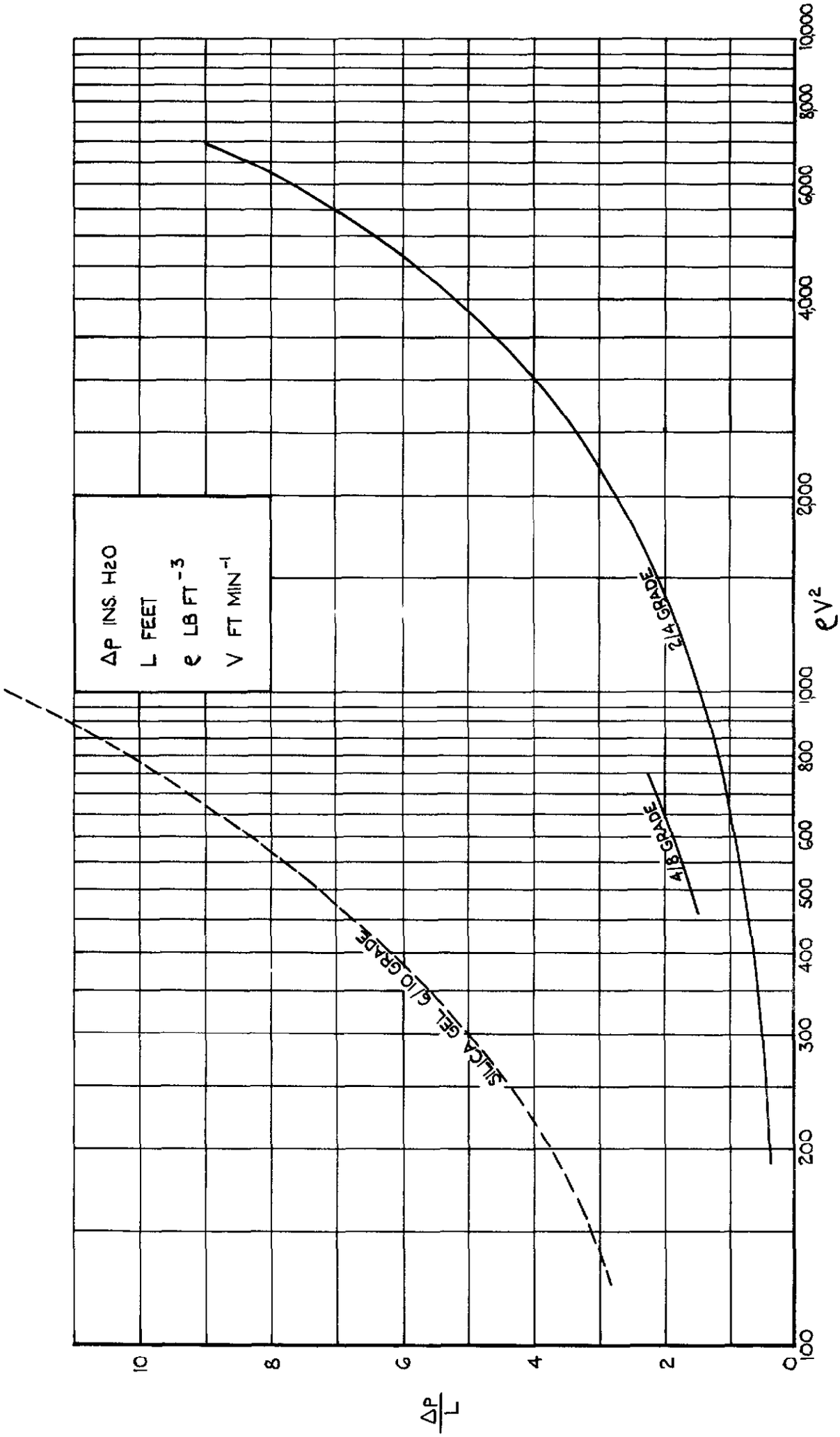


FIG.23. SPECIFIC PRESSURE DROP FOR ACTIVATED ALUMINA, 2/4 AND 4/8 GRADES AND SILICA GEL 6/10 GRADE.

FIG. 24.

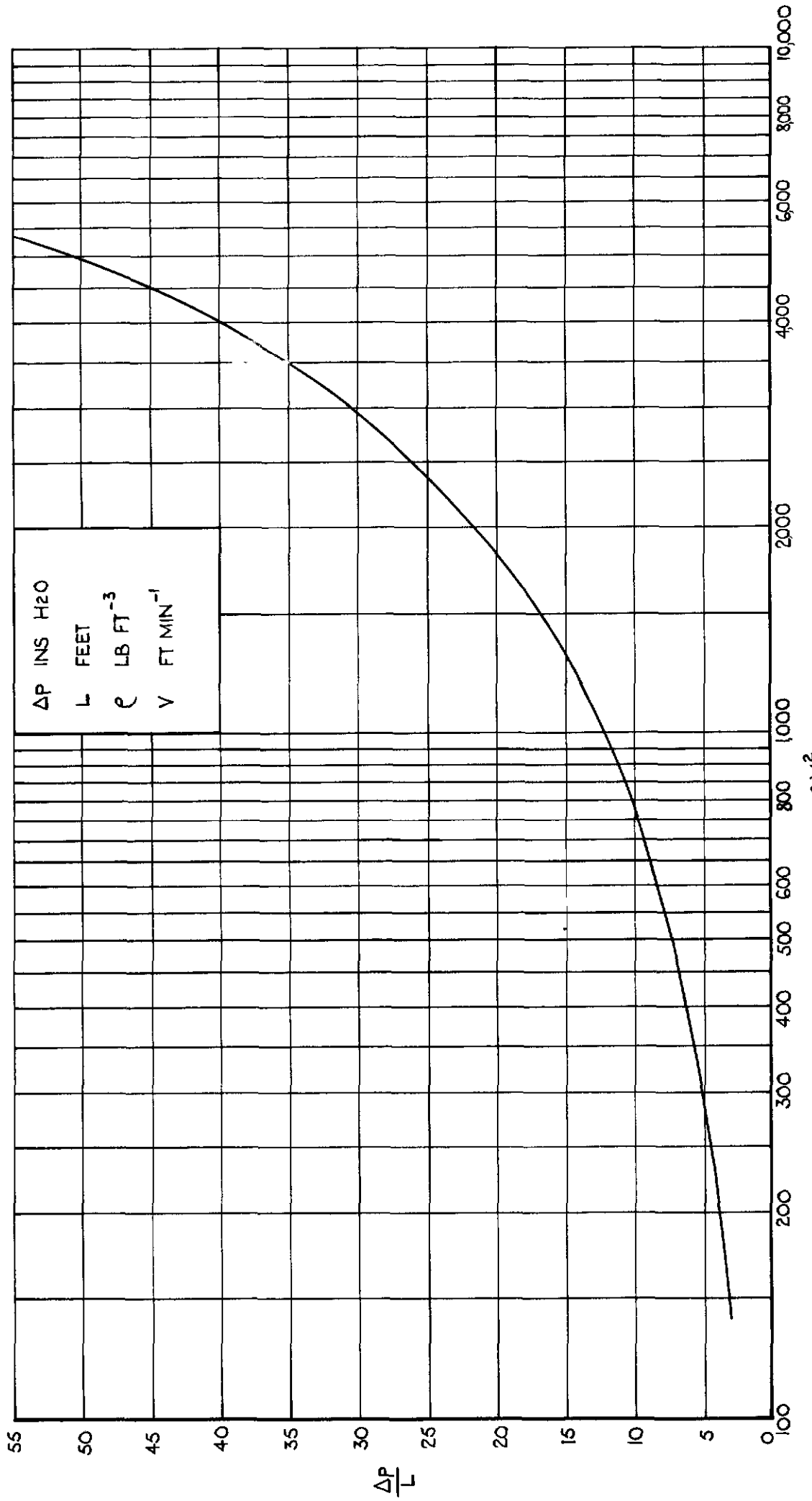


FIG. 24. SPECIFIC PRESSURE DROP FOR SILICA GEL, 6/10 GRADE.

FIG.25.

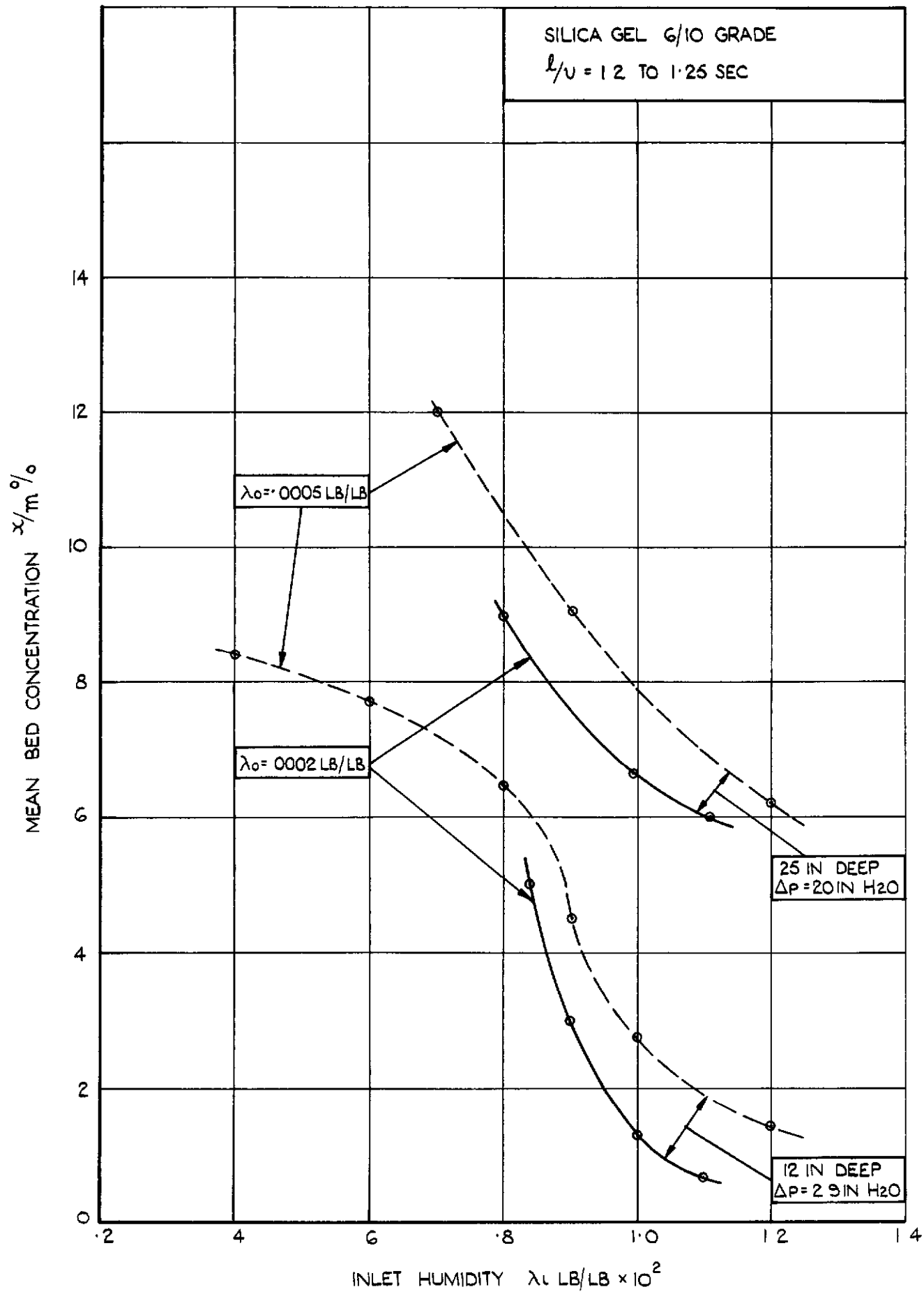


FIG.25. EFFECT OF BED DEPTH AT CONSTANT CONTACT TIME AND GRAIN SIZE.

FIG.26.

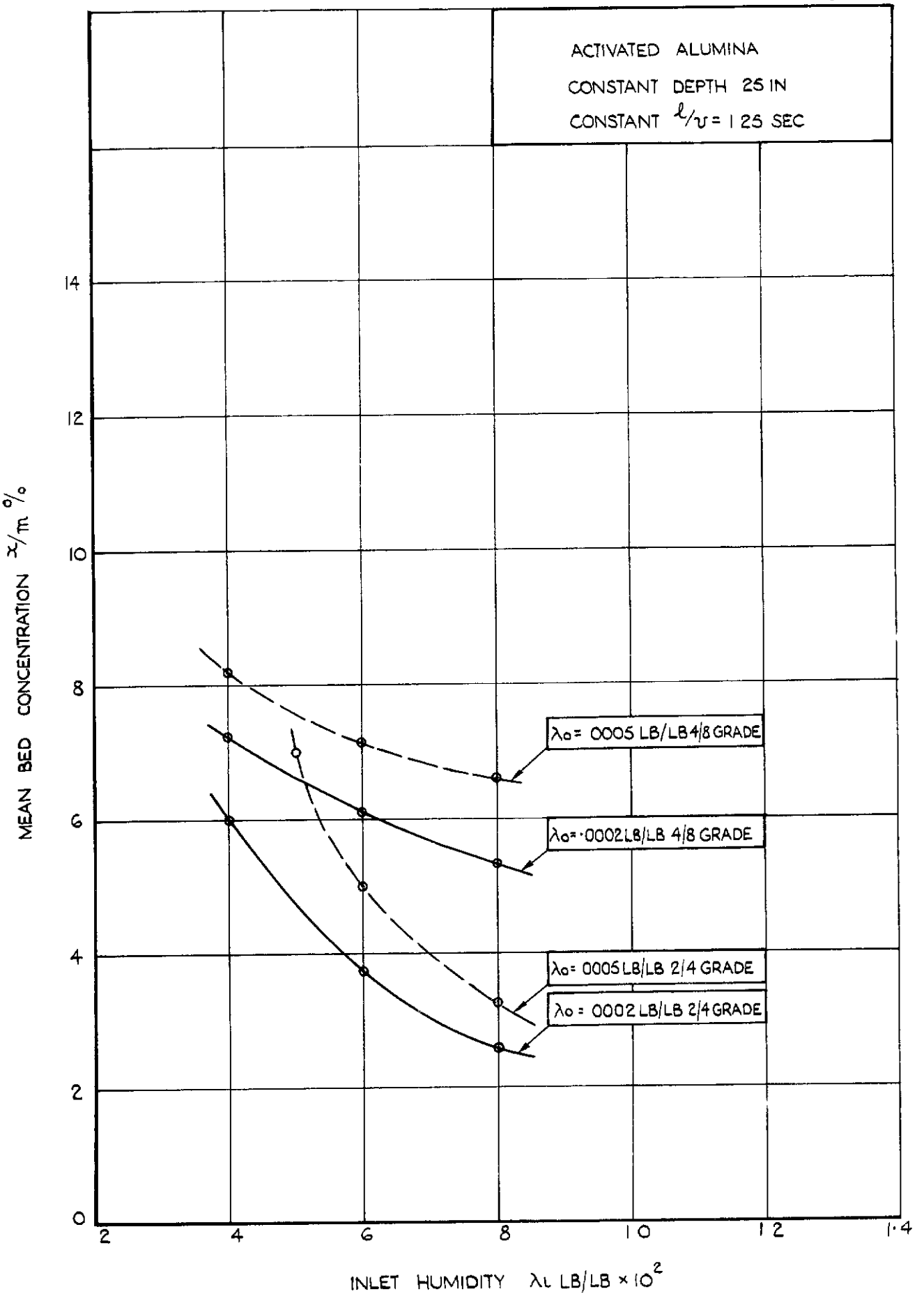


FIG. 26. EFFECT OF GRAIN SIZE.

FIG. 27.

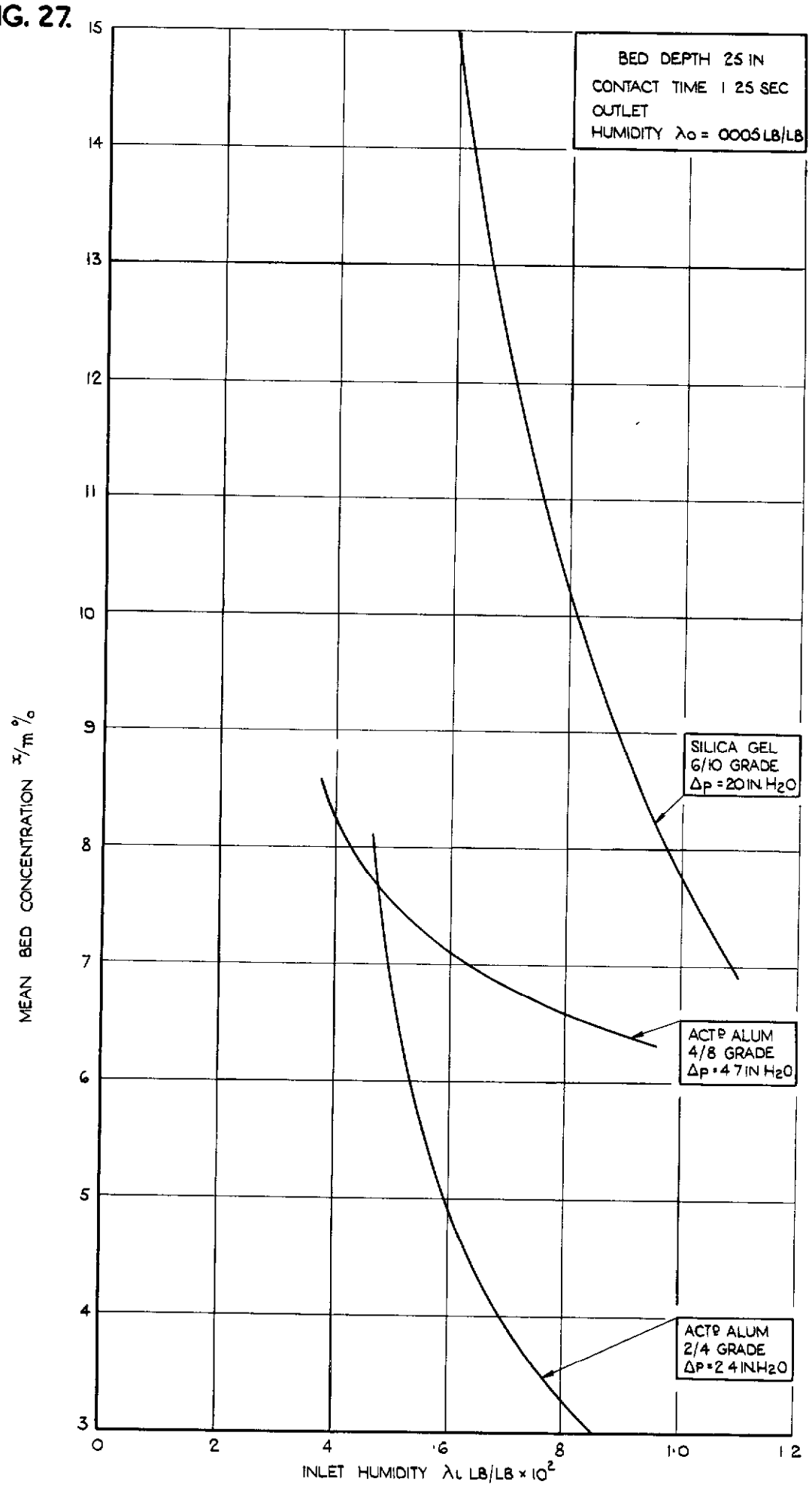


FIG. 27. COMPARISON OF ADSORBENTS AT CONSTANT BED DEPTH.

FIG.28.

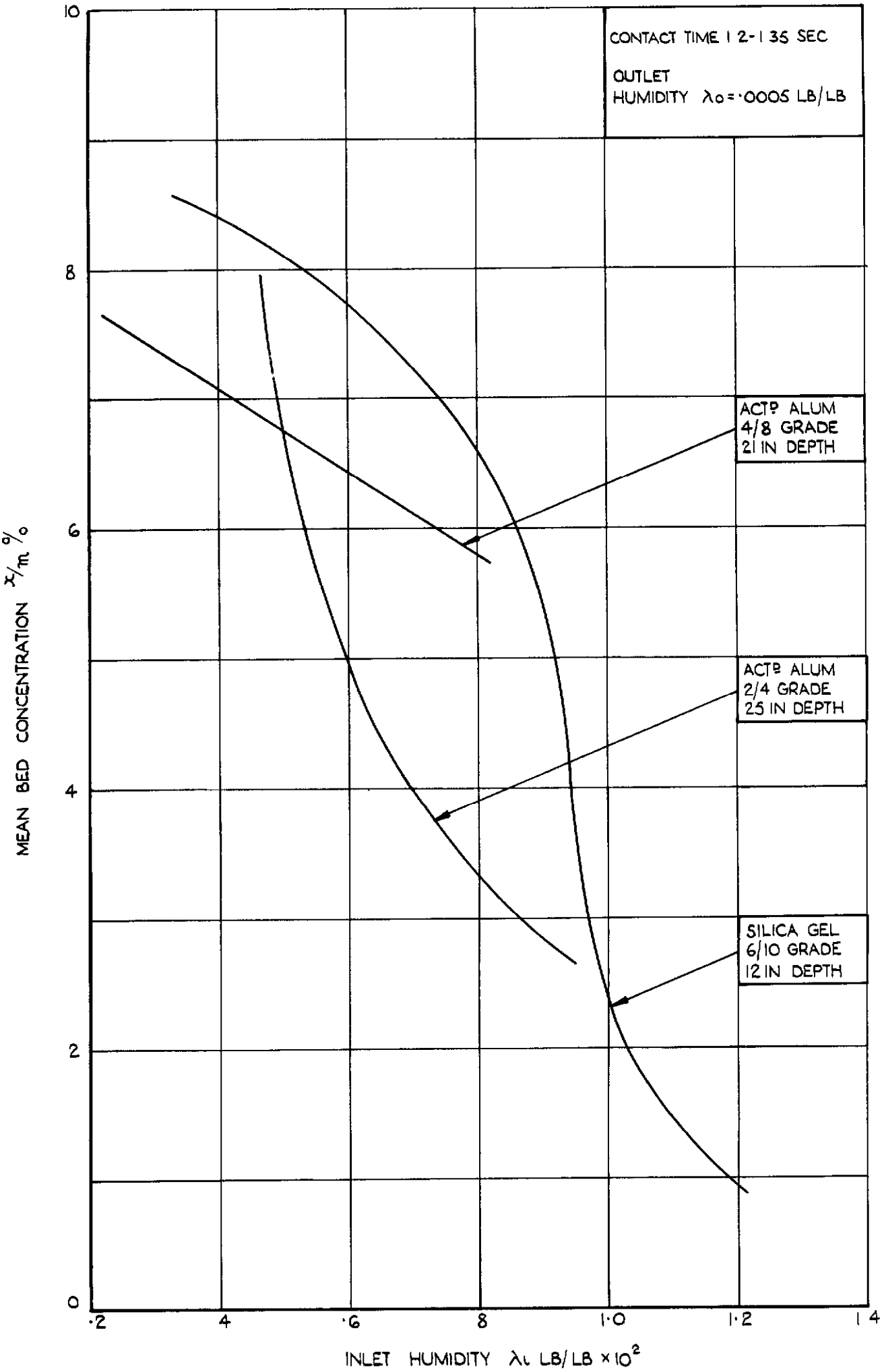


FIG. 28. COMPARISON OF ADSORBENTS AT CONSTANT PRESSURE DROP.

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