DEPARTMENT OF MINES AND ENERGY

SOUTH AUSTRALIA

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RESEARCH FOR INDUSTRY

006

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

CONYNGHAM STREET - FREWVILLE - SOUTH AUSTRALIA
TELEPHONE 79 1662 - TELEGRAMS 'AMDEL' ADELAIDE

Please quote this reference in your reply:
IC 1/1/103

26th October, 1967

Your reference:

The Director,
Department of Mines,
169 Rundle Street,
ADELAIDE.

RECOVERY OF WATER FROM THE ATMOSPHERE

PROGRESS REPORT NO. 1

Period ending 30th September, 1967

Investigation and Report by: M.J. Story

Officer in Charge, Industrial Chemistry Section: R.E. Wilmshurst

R.E. Wilmshurst
for P.A. Young
Director.

PROJECT NUMBER:	1/1/103
PROJECT PROPOSED:	12/7/67
PROJECT AUTHORISED:	30/8/67
AMOUNT AUTHORISED:	$8,000
AMOUNT EXPENDED:	$2,697 to 27/9/67

RECOVERY OF WATER FROM THE ATMOSPHERE

1. REVIEW OF PROGRESS

1.1 Introduction

The basis of this investigation was a paper written by P. Dixon[1] which discussed the idea of recovering water from the atmosphere, (i) by condensation on a surface that is cooled by radiation to the night sky, and (ii) by adsorption of atmospheric water vapour on silica gel during the night with regeneration of the silica gel during the day, the released water vapour being condensed on a suitable cool surface.

Condensation on a cooled surface during the night was ruled out as unsuitable due to the low productivity per unit area of the surface exposed to the night sky. This left silica gel as the alternative to be examined, bearing in mind the possibility of extracting water from the atmosphere by mechanical cooling (e.g. refrigeration) of the air below its dew point during the night, causing moisture to condense from the air. This process would be similar to the dehumidification of air in a room as used in some tropical countries.

1.2 Examination of the Feasibility of Using Silica Gel

The paper of Dixon did not discuss whether kinetics were important in the adsorption and desorption processes. This point was checked by assembling an apparatus that could follow the rate of adsorption (or regeneration) of a bed of silica gel under controlled conditions of air flow rate, and dewpoint and dry bulb temperature of the air entering the bed (see Sections 3 and 4).

It was found that the silica gel will take on water during regeneration at an adequate rate if the air throughput is sufficiently high, i.e. initially the air is almost completely dried and the rate of uptake is roughly proportional to the air flow rate. The regeneration rate of the silica gel is also roughly proportional to the air flow rate, as the exit air from the bed cannot carry more water vapour than that approaching saturation.

These points lead to the following conclusions:

(i) If there is no circulation of air through the bed it will not adsorb at night, nor will it regenerate during the day.

(ii) If there is circulation of air through the bed it will be beneficial during the night as it keeps the incoming air at relatively constant humidity and serves to remove the heat evolved during the adsorption process.

(iii) If there is circulation of air through the bed during regeneration, it will have to be recirculated in order that the water vapour will be kept in the system and not lost to the atmosphere. This would entail the silica gel being laid out in beds such that there will be sufficient collection area for the solar radiation. There must also be a condensing surface at a temperature about that of the ambient temperature. The circulating air must be passed through the bed where it is heated and takes up moisture, passed to the condensing surface where it is cooled and releases the moisture as liquid water, and then passed back to re-enter the bed. This process involves heat losses which will now be examined.

The air leaving the condenser will be saturated at the condenser temperature, i.e. the dew point of the air entering the silica gel bed will be the temperature of the condenser. The air entering the silica gel bed will be heated by the bed and will therefore remove a portion of the heat from the bed as sensible heat. A rough calculation based on a $10^{o}F$ rise in temperature of the bed will now be presented.

Initial experiments (see Section 4) show that an air flow rate of at least 4 ft.min.$^{-1}$ for an 0.8 in. bed depth, is required.

$$\text{Assume } T = 10^{o}F$$
$$Cp = 0.25 \text{ Btu lbs}^{-1}\ {}^{o}F^{-1} \text{ (for air)}$$
$$= 0.08 \text{ lbs ft}^{-3} \text{ (for air)}$$

The sensible heat removed from the bed per sq. ft. is therefore

$$q = 4\ (\text{ft min}^{-1}) \times 1\ (\text{ft}^2) \times 0.08\ (\text{lbs ft}^{-3}) \times 10\ ({}^{o}F) \times 0.25\ (\text{Btu lb}^{-1}\ {}^{o}F^{-1}) \times 60 (\text{min hr}^{-1})$$
$$= 48 \text{ Btu hr}^{-1}$$

for an 0.8 in bed depth

or $q = 24$ Btu hr^{-1} for an 0.4 in. bed depth.

A calculation based upon the solar radiation data of Brice[2], which applies to the climate of San Diego, will now be given in order to estimate the effective heat collected in a solar still after allowing for heat losses to the atmosphere and to the ground.

Consider the month of June in San Diego:

TABLE 1

Time of day	Incident Radiation (Btu ft^{-2} hr^{-1})	Collector Temperature (^oF)	Heat gain at Collector Temperature (Btu ft^{-2} day^{-1})	Efficiency of Collection (%)	Available Collected Radiation (Btu $ft^{-2}hr^{-1}$)
6-7	63	71	1400	70	44
7-8	109	80	1300	65	71
8-9	154	100	1100	55	85
9-10	194	120	900	45	87
10-11	228	138	700	35	80
11-12	250	147	600	30	75
12-1	250	150	475	24	60
1-2	228	150	475	24	55
2-3	194	150	475	24	47
3-4	154	144	600	30	46
4-5	109	129	800	40	44
5-6	63	100	1100	55	35
Total	1996				749

The Collector Temperature has only been estimated and is therefore very approximate. The Heat Gain has been estimated from Figure 5 of Price[2] for the daily heat gain at the given Collector Temperature. The Efficiency of Collection has been calculated by dividing the Heat Gain by the Total Incident Radiation (1996 Btu ft^{-2} day^{-1}). The Available Collected Radiation is that available to the silica gel bed, and is computed by multiplying the Efficiency of Collection by the Incident Radiation.

From Table 1 it can be seen that with a 10^oF rise in temperature required by the air entering the silica gel bed, even if the bed depth was halved (i.e. to 0.4 in., and the air flow rate halved to 2 ft min^{-1}) there would only be 749-288 = 461 Btu $ft^{-1}day^{-1}$ available for regeneration of the silica gel. It must be appreciated that even if suitable heat exchange was available to heat the air passing to the silica gel bed by the air passing from the bed to the condenser, an approach temperature difference of better than 10^oF could not be expected due to the low heat transfer coefficients of gases.

A sample calculation can be performed to estimate the area required for collection of 10 gallons of water per day in ideal summer conditions (i.e. an incident solar radiation of the order of 2000 Btu $ft^{-2}day^{-1}$). Assume an optimistic water content differential of 15% (weight per centage of water relative to activated weight of silica gel) between the charged and regenerated states of the silica gel.

bed depth = 0.4 in (i.e. air flow rate of 2 ft min^{-1})
silica gel density = 40 lbs ft^{-3}
heat required to regenerate 1 lb water = 2500 Btu lb^{-1} (3)
heat available for regeneration = 460 Btu ft^{-2} day^{-1}

$$\text{Water regenerated per sq. ft.} = \frac{460}{2500} \text{ lb ft}^{-1} \text{ day}^{-1}$$

$$= 0.184 \text{ lb ft}^{-1}$$

$$\therefore \text{ for 100 lb of water, require } \frac{100}{0.184} = 540 \text{ ft}^2$$

This calculation assumes an ideal thickness of silica gel such that there is sufficient to promote the water requirement.

For 15% water content in silica gel, and an 0.4 in. bed depth, the area required is

$$\frac{100 \times 100 \times 12}{15 \times 40 \times 0.4} = 500 \text{ ft}^2 \text{ of silica gel.}$$

This area would not be sufficient as it does not receive sufficient radiation, and a bed of 540 sq. ft. would be necessary.

A similar calculation for a bed depth of 0.4 in, and an approach temperature difference of 20°F, yields an effective heat for regeneration of 177 Btu ft^{-2} day^{-1}, and hence a required area of 1410 sq. ft. Similarly an approach temperature difference of 33°F and bed depth of 0.4 in. gives zero water production.

It must be noted that for winter conditions the situation would be hopeless as the energy available for regeneration would be negligible after sensible heat losses had been accounted for.

On the basis of the above calculations (which are optimistic, i.e. for ideal summer conditions) it can be appreciated that the use of silica gel with regeneration by solar energy is at present not feasible, especially when considering the large areas involved, the large weight of silica gel required, and the fact that auxiliary power is required to provide the relatively high air circulation rate.

With the above comments in mind it has been decided that an investigation of the different methods of manufacture of silica gel would be in order, with the hope that a type of gel may be found that is more useful under the prevailing conditions. This investigation is at present in hand.

1.3 Dehumidification of Air by Refrigeration

At this stage only a preliminary survey of the situation has been made. Nebbia[4] has done some experimental work with a 100 watt dehumidifier and he found that without heat recovery he could obtain 2 litres of water per day with an energy consumption of 0.7 kWh per litre of water. This energy consumption is equivalent to 1000 Btu per lb of water produced.

By using a diesel motor to drive the dehumidifier, and a fuel of calorific value 19000 Btu lb^{-1}, and a thermal efficiency of about 0.3, it can be seen that about 6 lbs of water will be produced per lb of fuel, with the set-up as used by Nebbia. This method seems to have possibilities as the system can be used irrespective of weather conditions. Additional advantages lie in its smaller size and mobility.

It is proposed to investigate further the technique of obtaining water from the atmosphere by refrigeration. The power input could be either from a diesel motor or from wind power.

An estimate of wind requirements will now be calculated.

Assumptions:

Wind velocity = 10 mph
Hours per week of 10 mph winds = 70 hr (i.e. approx. 3 days)
Efficiency of wind energy collection = 40%
lbs water per week = 700 lb $week^{-1}$
Density of air = 0.08 lb ft^{-3}

For 1000 Btu lb^{-1} water, the blade diameter would be given by the relationship:

$$1000 \times 700 = 0.0057 \times d^2 \times 10^3 \times 70$$

$$\text{i.e. } d = 42 \text{ ft.}$$

This means a very large and expensive unit with lack of mobility, and complete dependence upon wind velocity.

A more reliable source of power would be a diesel motor, and it remains to investigate an improvement in the performance of the refrigeration system with a view to increasing heat recovery.

2. WORK IN HAND

As mentioned in Section 1, the different ways of manufacturing silica gel will be investigated, with a view to finding a type that has a high moisture content differential between the adsorbed and regenerated states under the prescribed physical conditions. A literature survey is in hand and the various techniques of manufacture will be tried. If a satisfactory type of silica gel is made then a solar "still" will be built to test it under suitable working conditions.

3. EQUIPMENT

An apparatus was built to test a sample of silica gel (917 gm activated weight) for adsorption and regeneration rates. An 0.8 in. deep, 10½ in. square, bed of silica gel was contained in a vessel such that air at a metered rate could be passed through the bed. The dry bulk temperature and dewpoint were measured before the air entered the bed, the dew point being determined by means of a Foxboro Dewcel. The humidity of the air could be adjusted by passing the air through a water bath, or by spraying water into the air stream in a suitable chamber. The weight of the bed was determined at appropriate intervals by attaching the bed by a wire to the hook projecting from the bottom of a Sartorius Kilomat.

4. EXPERIMENTAL RESULTS

The experimental results can be summarized as follows:

Run No.	Process	Initial Water Content (%)	Final Water Content (%)	Water Content Difference (%)	Time (hr)	Inlet air Conditions to bed Dry bulk temp (°F)	Dew-point (°F)	Airflow rate (ft min^{-1})
1	Regeneration	25.0	15.0	10.0	10.0	150	81	0.51
2	Regeneration	15.4	7.0	8.4	7.0	152	81	4.4
3	Adsorption	7.5	20.5	13.0	8.0	65	52	4.4
4	Regeneration	24.8	8.5	16.3	7.5	122	55	4.4

The adsorption capacity of the silica gel was found to be about 25% at atmospheric conditions. The regeneration was carried out until the rate of regeneration was less than 0.5% w/w (of activated weight of silica gel) per hour.

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1. DIXON, P., Amdel Bulletin, 3, 47 (1967).

2. BRICE, D.B., "Saline Water Conversion - II", Advances in Chemistry Series, 38, 99 (1963).

3. KIRK, R.E. and OTHMER, D.F, Editors, "Encyclopedia of Chemical Technology", 1st Ed., Interscience Publishers, New York - London, 1954.

4. NEBBIA, G., International Conference on Water for Peace, Washington, D.C., May 23-31, 1967.

CONYNGHAM ST. FREWVILLE SOUTH AUSTRALIA 5063 TELEPHONE 79 1662 TELEGRAMS 'AMDEL' ADELAIDE

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

PLEASE ADDRESS ALL CORRESPONDENCE TO THE DIRECTOR.

OUR REFERENCE: IC 1/1/103
YOUR REFERENCE:

6th December, 1967

The Director,
Department of Mines,
169 Rundle Street,
ADELAIDE. 5000.

RECOVERY OF WATER FROM THE ATMOSPHERE

PROGRESS REPORT NO. 2

Period ending 30th November, 1967

Investigation and Report by: M.J. Story

Officer in Charge, Industrial Chemistry Section: R.E. Wilmshurst

R.E. Wilmshurst
for F.A. Young
Director.

016

PROJECT NUMBER:	1/1/103
PROJECT PROPOSED:	12/7/67
PROJECT AUTHORISED:	30/8/67
AMOUNT AUTHORISED:	$8,000
AMOUNT EXPENDED:	$4,922 to 26/11/67

RECOVERY OF WATER FROM THE ATMOSPHERE

1. REVIEW OF PROGRESS

In Progress Report No. 1 it was stated that a solar still was to be constructed in order that a conclusive test could be performed to evaluate the feasibility of using silica gel for recovery of water from the atmosphere. It was also stated that an attempt would be made to make a type of silica gel that had a high absorptive capacity for water vapour without necessarily reducing the night air to a very low dew point. Commercial silica gels are manufactured with the property of drying air (and gases) to very low dew points, which is not a property that is required in this instance.

The design of the solar still is similar in type to that used in the conventional Coober Pedy installation. The design incorporates a bed area of silica gel of four square feet, and simplicity was the aim in order that a successful result of the tests may lead to an economic design of larger installations. More complex designs, utilising lower temperature condensing surfaces, would lead to larger sensible heat losses with a resulting reduction in efficiency. The still is in the final stage of construction and results will be available in the next Progress Report.

Silica gel has been made by precipitating copper silicate from a sodium silicate solution by addition of copper sulphate solution, filtering off the clear liquor, drying the resulting mass, and then leaching out the copper by treatment with excess acid. The gel is then washed, dried, and activated. This operation was performed for three copper sulphate/sodium silicate mixtures: under acid, neutral and basic conditions by varying the ratio of the components. The only type that compared with commercial silica gel was the acid type. The results of the tests performed in the apparatus described in Progress Report No. 1 may be summarised as follows:

Type of Gel	Adsorbed State (% water/ activated wgt.)	Regenerated State (% water/activated state)	Differential (%)
Acid Copper	20.6	4.6	16.0
Commercial	20.5	7.5	13.0

The acid copper silicate gel therefore gave a differential that was 23% better than the commercial silica gel.

2. WORK IN HAND

Another method of preparing silica gel is the precipitation of ferric silicate from a solution of sodium silicate by the addition of ferric chloride solution. This was done for the basic and neutral cases; the acid case yielded a fine colloidal suspension with negligible precipitate. These samples have yet to be tested for the adsorbed-regenerated differential as they are still in the final stages of precipitation. The results for these gels will be available in the next Progress Report.

The solar still is to be tested initially with commercial grade silica gel, and if positive results are forthcoming it will be used to test the best of the metallicion precipitated gels.

CONYNGHAM ST. FREWVILLE SOUTH AUSTRALIA 5063 TELEPHONE 79 1662 TELEGRAMS 'AMDEL' ADELAIDE

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

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OUR REFERENCE: IC 1/1/103
YOUR REFERENCE:

8th January, 1968 016

The Director,
Department of Mines,
169 Rundle Street,
ADELAIDE. 5000.

RECOVERY OF WATER FROM THE ATMOSPHERE

PROGRESS REPORT NO. 3

Period ending 31st December, 1967

Investigation and Report by: M.J. Story

Officer in Charge, Industrial Chemistry Section: R.E. Wilmshurst

R.E. Wilmshurst
for P.A. Young
Director.

PROJECT NUMBER:	1/1/103
PROJECT PROPOSED:	12/7/67
PROJECT AUTHORISED:	30/8/67
AMOUNT AUTHORISED:	$8,000
AMOUNT EXPENDED:	$5,886 to 31/12/67

RECOVERY OF WATER FROM THE ATMOSPHERE

1. REVIEW OF PROGRESS

1.1 Solar Still Results

A solar still has been constructed to evaluate experimentally the feasibility of using silica gel to recover water from the atmosphere. The still is of the conventional type (viz. of a similar design to that of the Coober Pedy installation) but with a wooden framework. Commercial silica gel (15 lb) has been spread on a 3.5 sq. ft. tray, which can be taken out of the still at night for the adsorption part of the cycle, and replaced in the day for solar regeneration and water recovery. A door has been built into one end of the still to provide easy access.

The still has been in operation for about 3 weeks, but overcast conditions and the holiday period have given only a few clear hot days. The maximum production from the still in one day has been 325 ml. water, with the bed temperature rising to a peak of 180°F.

1.2 Silica Gel Manufacture

As was stated in Progress Report No. 2, different methods of making silica gel were being investigated. No better product could be made than that mentioned in P.R. No. 2, i.e. the acid copper gel. A large quantity of this gel (about 15 lb) is at present being made, with the addition of powdered charcoal to the early stages of manufacture to make the final product black. It is anticipated that this product will give significantly better yields of water, due to its higher uptake of solar energy (the blackened condition of the gel) and the lower water holding capacity in the regenerated state.

2. WORK IN HAND

A second solar still has been built in order that modifications to one still may be compared with the other, under identical atmospheric and solar conditions. The new still has a door built into each end so that the night-half of the cycle can be evaluated. The take up of water with the tray removed from the old still can be compared with the tray remaining in situ in the second, the doors being left open to permit atmospheric circulation of air.

The planned approach is to make a modification to one still, keeping the other unchanged as a reference. If there is an improvement in performance of the first still then the modification will be made to the second still. By this process the design should be optimised. The proposed modifications include:

a. Placing a polished aluminium sheet beneath the silica gel bed to restrict radiation from the hot bed to the base of the still. Conduction of heat through the base yields a significant loss of heat economy.

b. Varying the bed depth to optimise the quantity of silica gel that is required.

c. Testing the use of the black "acid copper" gel.

d. Varying the orientation of the still with respect to the sun.

e. Treatment of the glass condensing surface with an agent that will cause film-wise condensation in preference to drop-wise. It is anticipated that the latter causes scattering and reflection of the incident sun rays with consequent heat losses. A preliminary trial will be made using a car windscreen demisting agent that prevents drop-wise condensation.

It is planned to build a further still of such a design that the condensing surface will not have the sun's rays incident upon it. The object of this exercise is to determine the effect on the overall performance of the use of a cooler condensing surface. This still will be checked alongside the present stills in their optimised state.

Conventional solar stills for the desalination of water have an output of the order of 1 lb of water per square foot per day. The present indications are that optimisation and improvement of design of the silica gel stills give a daily yield of better than 1lb/sq ft.

CONYNGHAM ST. FREWVILLE SOUTH AUSTRALIA 5063 TELEPHONE 79 1662 TELEGRAMS 'AMDEL' ADELAIDE

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

PLEASE ADDRESS ALL CORRESPONDENCE TO THE DIRECTOR.

OUR REFERENCE: IC 1/1/103 020
YOUR REFERENCE:

12th March, 1968

The Director,
South Australian Government
Department of Mines,
169 Rundle Street,
ADELAIDE.

RECOVERY OF WATER FROM THE ATMOSPHERE

PROGRESS REPORT NO. 4

Period ending 29th February 1968

Investigation and Report by: M.J. Story and [illegible] Waters

Officer-in-Charge, Industrial Chemistry: R.E. Wilmshurst

for [illegible].A. Young
Director.

0213

PROJECT NUMBER:	1/1/103
PROJECT PROPOSED:	12/7/67
PROJECT AUTHORISED:	30/8/67
AMOUNT AUTHORISED:	$8,000
AMOUNT EXPENDED:	$6,643

RECOVERY OF WATER FROM THE ATMOSPHERE

1. REVIEW OF PROGRESS

The two experimental units described in earlier Progress Reports, have been completed and tested. Four tests were carried out under as nearly identical conditions as possible, and these showed that the water production from the two units was similar.

To minimise the effect of changing weather conditions on the experimental results, conditions were changed in one unit but not the other and the water production from the two units was compared.

1.1 It was considered that the heat loss through the bottom of the units might be contributing to the low water yields obtained, and two methods were adopted in an attempt to reduce this heat loss. Initially aluminium sheets were laid in the bottom of one unit and later these were replaced by a layer of polystyrene foam slabs one inch thick. The foamed plastic was expected to show an advantage since the tray of absorbent was raised and the shadowing effects were therefore expected to be less severe. Both the aluminium sheet and foamed plastic insulant gave increased yields of water compared to that from an uninsulated unit, but the increase was relatively small and approximately equal in both cases.

1.2 Altering the orientation of the unit from North-South to East-West, did not significantly affect yields of water obtained. The design of the still is such that one must tolerate daily shadowing before 1030 and after 1330 hours or else poor utilisation of solar energy at noon. The results suggest that these disadvantages affect water production to a similar degree.

1.3 Silica gel incorporating carbon black was substituted for commercial silica gel in the hope that better utilisation of solar energy would be possible. However, the still containing the black silica gel produced less water (about half) than did the still containing the commercial gel. This is attributed to an excess of carbon black in the initial batch of gel produced, resulting in poor water adsorption capacity and low physical strength.

The performance of a still on a hot clear sunny day is shown in Figure 1. For this run the tray was removed and exposed to the air during the previous night. At 0645 hours when the tray containing the silica gel was placed in the unit the air temperature was 19°C. A total of 357 ml of water was collected from a silica gel bed area of 3 square feet. This is equivalent to 0.26 lb of water per square foot per day.

2. WORK IN HAND

Experimental work has shown that the existing units suffer from a number of defects. These include:

(1) Partial shadowing of the gel bed or ineffective use of solar energy as described in Section 1.3, and permanent shadowing of 5 percent of the area in both cases due to the upper support for the glass.

(2) The gauze supporting the gel in the tray is of so fine a gauge that the flow of air through the bed is restricted.

(3) The air space in the still is far too great resulting in large sensible heat losses.

(4) Condensation of water occurs on the bottom of the unit and makes it impossible to obtain quantitative results.

(5) The gel bed should be inclined from the horizontal so that it is normal to the solar radiation.

A design for a pair of new units having separate condensing surfaces has been drawn up and these two units are currently being constructed.

Experimental work is being carried out to assess the loading characteristics of silica gel under static and flowing air conditions. The performance of the current still is also limited by the poor absorption rates resulting from restricted air flow through the bed. Work will also be carried out to determine the effect of using silica gel of various particle sizes. It is expected that the new units will be completed shortly and results of preliminary tests with these units should be available for inclusion in the next Progress Report.

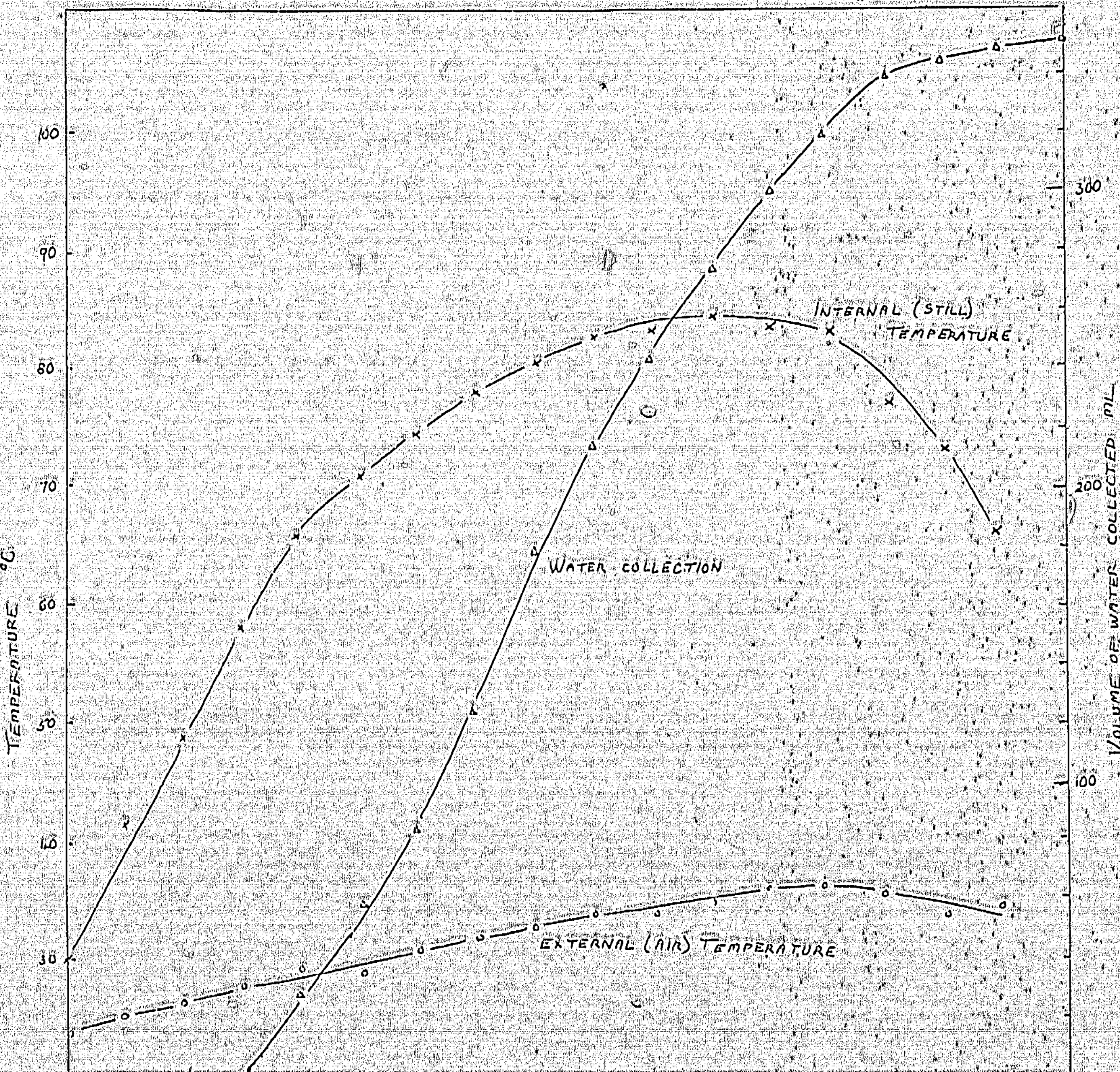

FIG. 1. STILL PERFORMANCE ON A CLEAR DAY

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THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

PLEASE ADDRESS ALL CORRESPONDENCE TO THE DIRECTOR.

OUR REFERENCE: IC 1/1/103
YOUR REFERENCE:
4th April, 1968

025

The Director,
South Australian Government
Department of Mines,
169 Rundle Street,
ADELAIDE.

RECOVERY OF WATER FROM THE ATMOSPHERE

PROGRESS REPORT NO. 5

Period Ending 31st March, 1968

Investigation and Report by: [illegible] H.J. Waters

Officer-in-Charge, Industrial Chemistry Section: N.E. [illegible]

[illegible] Young
Director.

PROJECT NUMBER: 1/1/103

PROJECT PROPOSED: 12/7/67

PROJECT AUTHORISED: 30/8/67

AMOUNT AUTHORISED: £8,000

AMOUNT EXPENDED: £7,500 to 31/3/68

RECOVERY OF WATER FROM THE ATMOSPHERE

1. REVIEW OF PROGRESS

1.1 Water Absorption by Silica Gel

Since the performance of the still in earlier tests appeared to be limited among other things by the rate of water absorption, a series of experiments was carried out to determine the effect of silica gel particle size, bed depth and air flow rate through the bed, on the amount of water absorbed. Three circular trays approximately five inches in diameter with 14 mesh gauze on the bottom were used for these experiments. The trays were filled with 150, 300 and 450 g of silica gel respectively corresponding to bed depths of approximately ½, 1 and 1½ inches. The trays were suspended to provide easy access of air to the top and bottom, and a fan was used to induce an air movement through the bed in the appropriate tests. The weight of gel, air temperature and air humidity were recorded each half hour for the first eight hours, and in some cases readings were taken at 12 and 24 hours. The results are shown in Figure 1 (for static air conditions) and Figure 2 (for induced air flow conditions). Air temperature was 20-25°C and the humidity was such as to give a water vapour partial pressure of approximately 10mm mercury (i.e. 55-65% relative humidity) except in the test using fine gel and induced air flow when the water partial pressure was about 12mm mercury.

Figure 1 illustrates the effect of gel particle size and bed depth under static conditions. The results show that in no case was effective loading achieved in 12 hours, but it is clear that the smaller the particle size of the gel the greater was the quantity of water taken up in unit time. There was no significant difference between the 0.5, 1.0 and 1.5 inch beds indicating that the absorption rate was limited by surface area rather than volume.

Figure 2 shows the effect of gel particle size and bed depth under induced air flow conditions. Air flow rates of approximately 24 ft/min through the ½-inch bed, 12 ft/min through the 1-inch bed and 6 ft/min through the 1½-inch bed were maintained through the coarse and medium sized gel beds and somewhat less through the finer gel. The exact values for the latter were not measured.

An increase in bed thickness resulted in a somewhat less than proportional increase in the weight of water absorbed. A comparison of the gels of different particle sizes shows that the finer gels absorb water more rapidly. For the medium gel size and a 1½-inch thickness the results are somewhat lower than would be expected. However, it is evident that if the graphs were extrapolated to 12 hours, the weight of water absorbed by the 1½-inch thick bed would exceed that absorbed by the 1-inch bed. Particle size distribution of the various grades of silica gel is shown in Table 2.

The following general conclusions may be drawn:

(a) Without inducing an air flow, satisfactory absorption of water by the gel bed at night will not be achieved irrespective of the particle size of the bed. For the particle size of gel used in the earlier solar still experiments, the amount of water absorbed and available for regeneration would only be 3% by weight of the gel or for the prototype still 230 ml over a 12 hour period. (That 350 ml were obtained on some occasions only illustrates that on some nights absorption conditions were more favourable than those adopted for the current series of tests.) By using the finer particle size gel under the same conditions, 6% by weight of the gel or 460 ml of water could be expected.

(b) If an air flow were induced through the bed then the loadings given in Table 1 should be attainable (assuming a 12 hour absorption period).

TABLE 1: EFFECT OF GEL BED DEPTH AND PARTICLE SIZE ON WATER UPTAKE

Water uptake - per cent

Particle Size	Bed depth inches 0.5	1.0	1.5
Fine	32	24	16
Medium	27	(21)[a]	(16)[a]
Coarse	18	14	13

a - ( ) Values obtained by extrapolation are somewhat uncertain.

TABLE 2: PARTICLE SIZE DISTRIBUTION OF SILICA GEL

	+¼ inch	-¼ inch + 6 mesh	-6+8	-8+10	-10+12	-12+14	-14
	Mesh size per cent						
Fine	-	3	32	21	16	17	11
Medium	-	43	49	8	-	-	-
Course	22	78	-	-	-	-	-

Assuming regeneration at 200°F the theoretical maximum loading values to be expected are about 27% for the medium and coarse gels and 32% for the fine gel.

The results given in Table 1 show that near theoretical loading can be obtained with the medium size silica gel for bed depths of ½-inch and for the fine gel for bed depths of ¾ to 1-inch at air velocities approximating to $\frac{12}{\text{bed depth in inches}}$ foot per minute. Although much better loadings could have been obtained on the gel used for earlier experiments if a flowing air system had been used, the slower response and smaller total loadings achieved lead to the conclusion that the smaller particle size gels are to be preferred.

If one assumes an optimistic situation for regeneration, namely 2,000 Btu per ft^2 incident solar energy available and 2,000 Btu required per pound of water regenerated, the maximum productivity of a still would be 1 lb water/ft^2/day. For a 1-inch bed depth the weight of gel is approximately 5 lb/ft^2 hence this would mean that a 20% change in weight is the most that could be utilised. On this basis, a ½-inch bed depth would be insufficient since more solar energy is available than can be utilised in liberating the maximum amount of water the gel could hold. For a 1-inch bed the gel bed water content would vary between 24% water content at the end of absorption and 4% water content at the end of regeneration. Since the data are probably optimistic the capacity of a 1-inch thick gel bed would probably be sufficient if the full productive capacity could be used. If the amount of energy required to liberate the water first absorbed is appreciably less than that required to liberate the water held when the water content of the silica gel is low, then a 1½-inch bed would be preferred. In this case the water content would vary between 24% and 11%. The results in Table 1 show that the loading of a 1½-inch bed over 12 hours is only 16% at the air flow rates used. Consequently it would be necessary to increase the air flow rate if any advantage was to be gained.

1.2 Operation of New Stills

On the basis of the conclusions reached in the previous section, it was decided to use a 1-inch gel bed depth. However, the design and slope of the tray was such that a ¾-inch thick bed was the deepest which could be conveniently used. This corresponded to 3¾ lb of gel per square foot. However, as the gel was loaded to 0.28 lb of water per pound of gel the quantity of gel present was not a practical limitation. The gel used was 100% coloured (blue when regenerated, pink when containing absorbed water) in the hope that better utilisation of solar energy might be obtained in the later stages of regeneration because of its darker colour. The fine particle size gel was used.

The single test carried out showed that under similar conditions the two new units produced almost identical quantities of water (350 and 355 ml) of which approximately 25% was collected from the rear (condensing) surface.

The bed temperature reached a maximum of 170°F. However at a condensing surface temperature of 120°F the equilibrium water content of the gel is 0.14 lb water per pound of gel. The rate of water production is probably limited by the high temperature of the condenser, therefore it is intended to replace the glass condensing surface with one of aluminium. The condensing surface should then closely approach air temperature resulting in a consequent increase in water output.

2. WORK IN HAND

The units are at present being modified to allow circulation of the air through the bed rather than over it. It is hoped thereby to carry out loading in situ and also improve regeneration during daytime operation. The glass condensing surface of one unit is being replaced with a sheet of aluminium. On the basis of the results obtained following this modification other changes will be made, including the addition of a second glass cover to improve efficiency. The experimental work will be completed in the coming month and a final report written.

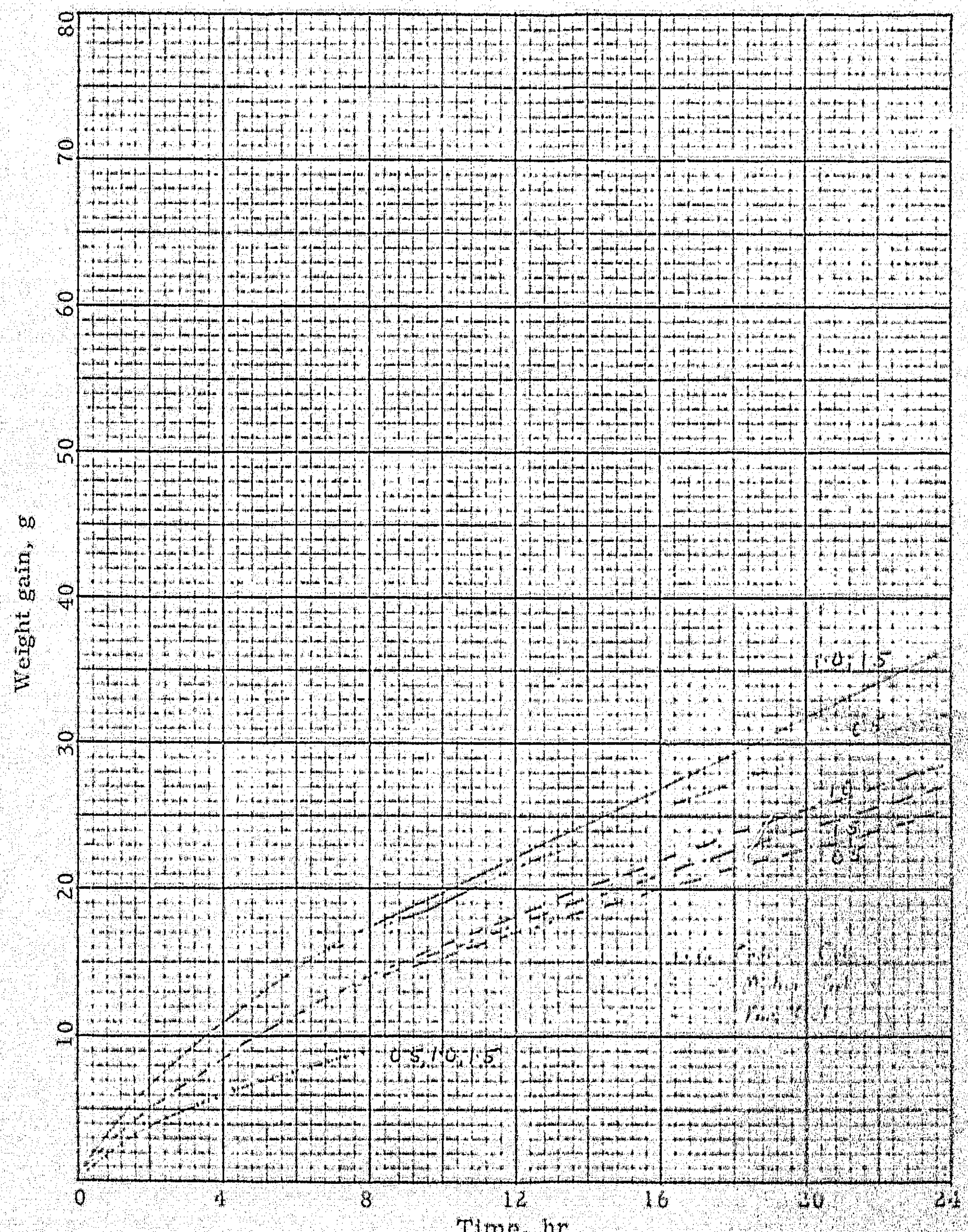

FIG. 11: WEIGHT GAIN OF SILICA GEL AS A FUNCTION OF BED THICKNESS AND PARTICLE SIZE - STATIC AIR

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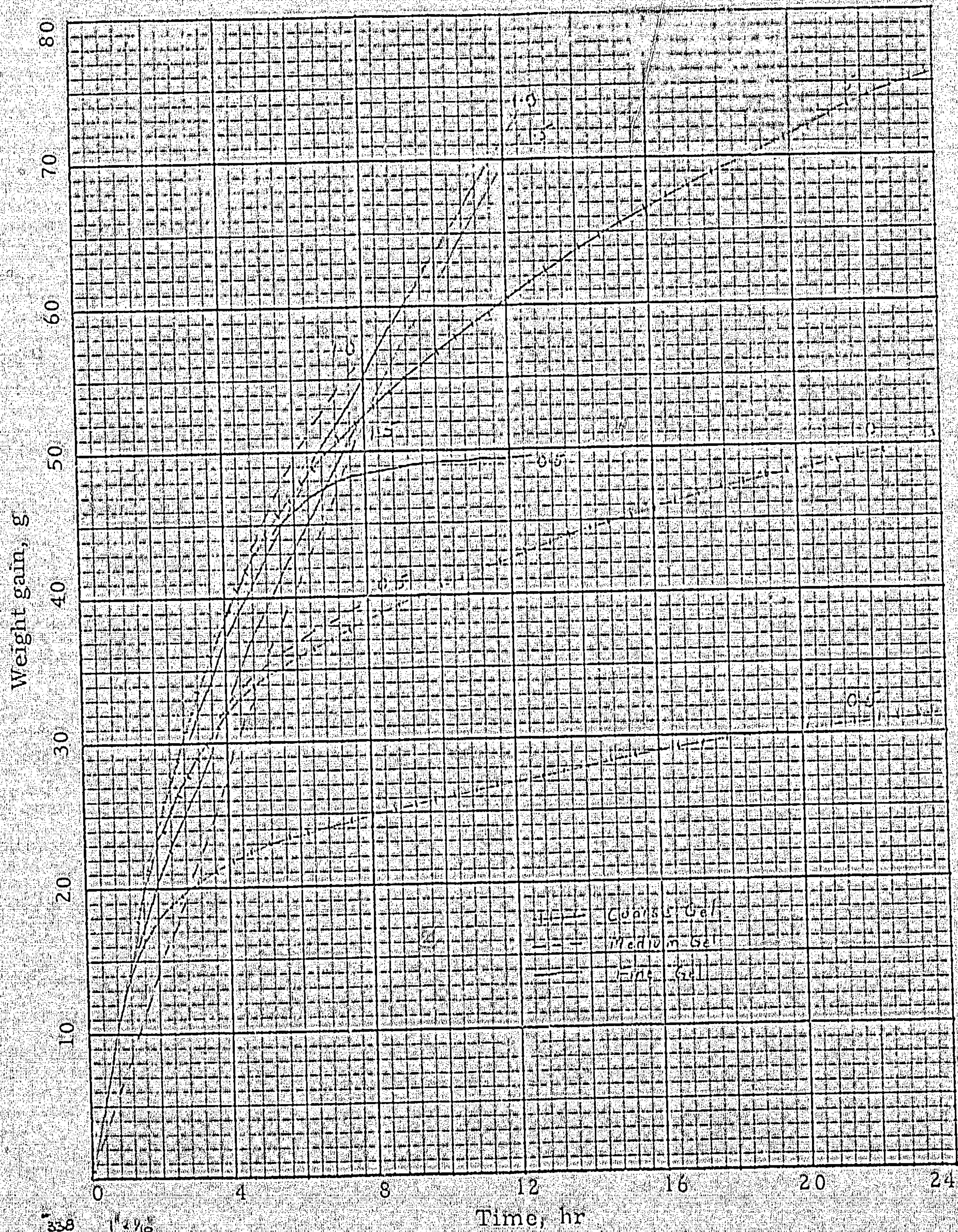

FIG. 2. WEIGHT GAIN OF SILICA GEL AS A FUNCTION OF BED THICKNESS AND PARTICLE SIZE - FLOWING AIR