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SUMMARY STATEMENT

We have investigated the regenerative properties of silica gel after successive use and regeneration steps on farm conditions. The research was aimed at developing a simple and inexpensive regeneration method for silica gel used in grain drying.

A series of experiments were conducted. Silica gel was wetted to 30% moisture level by adding water with a sprayer while mixing. It was then divided into four batches. Each batch was dried five times using different fireplaces (closed, open), containers (big pan, small pan, rotating drum) and fuels (wheat, straw, charcoal). Following five successive regenerations as stated above, each batch was subjected to an equilibrium moisture test and compared with the original sample. A decrease in adsorption due to high temperatures and smoke was noted.

The damage to silica gel during drying was minimized by using a thick (14 gauge metal sheet) with a $\frac{1}{2}$ " sand bed underneath the containers. Due to reduction in temperature and smoke contamination, the equilibrium moisture content of these samples were the same after five successive regeneration steps when compared to the original sample.

REGENERATION CAPACITY OF SILICA GEL
FOR GRAIN DRYING

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PREFACE

This report is a copy of a thesis prepared by V.G. Rao to complete his studies for a Master of Science Degree. It deals with the problem of grain storage which has been studied extensively in recent work at Kansas State University by Dr. Do Sup Chung.

Mr. Rao was supported by the Agency for International Development during the semester when he was performing this research. His research was supervised by Dr. Do Sup Chung and Dr. Harry B. Pfost, both from the Department of Grain Science and Industry; both of them are members of the group assigned to the AID Contract.

The result of this research should be of interest to grain storage engineers who are concerned with the drying and storage of grain in tropical areas.

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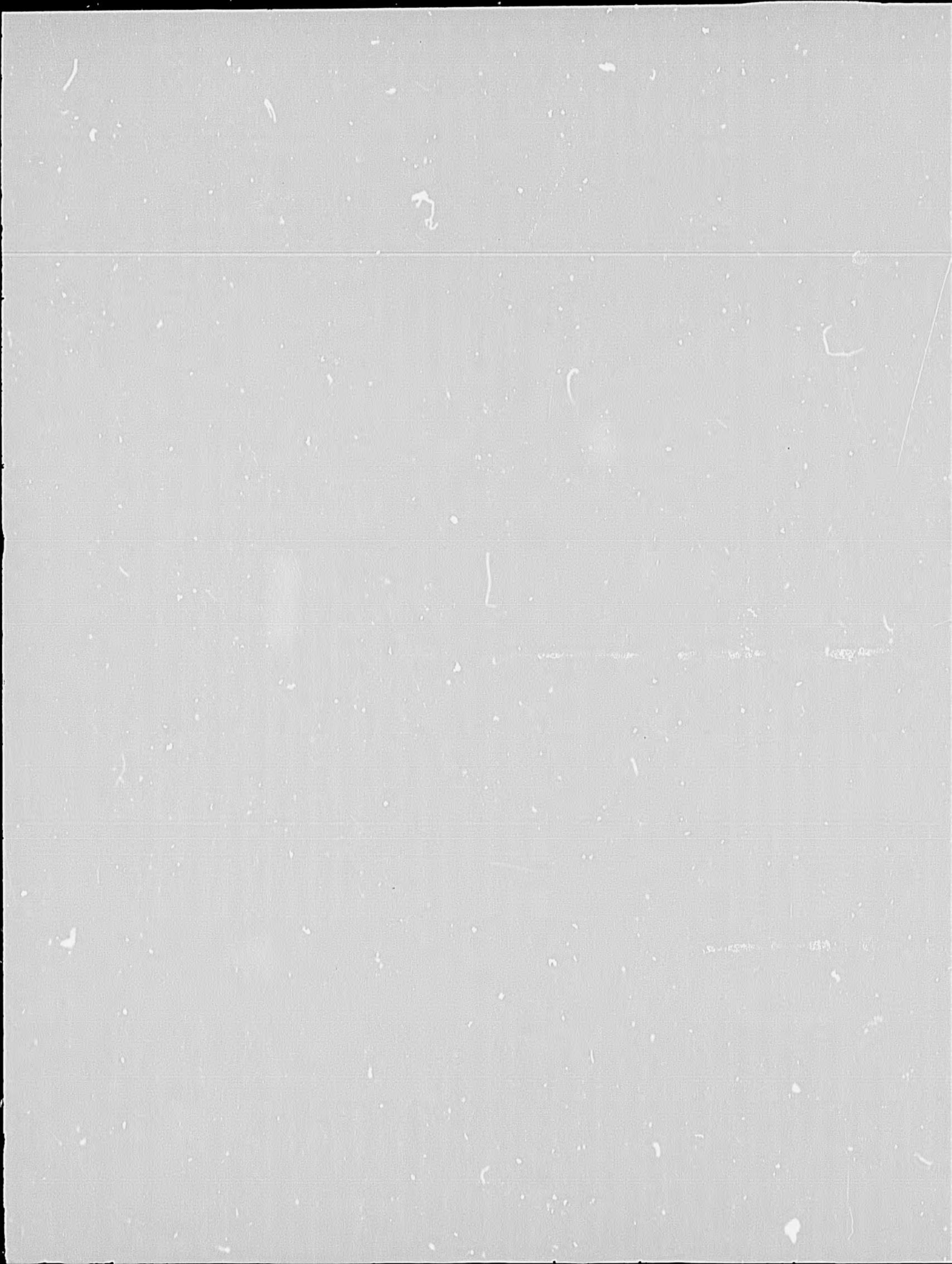
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INTRODUCTION

The moisture content of grain affects processes such as harvesting, storage, feeding, germination and milling of various kinds. Matured grain contains less moisture compared to unripened grain and needs drying to prevent the growth of micro-organisms. The moisture content affects the trading value of the grain.

It is essential to maintain the moisture content of grain at the optimum level during storage. An equilibrium moisture content of above 70 percent relative humidity at room temperature is not suitable for grain storage (7). The equilibrium moisture content is different for each commodity.

The following methods have been used to improve storability and to maintain marketable quality in grains harvested with a high moisture content: 1. Drying to a moisture content safe for storage. 2. Aeration to maintain a low and uniform temperature to prevent moisture migration.

There are several grain drying methods such as sundrying, field drying, mechanically forced heated air, mechanically forced unheated air, etc. Sundrying and field drying depend on climatic conditions. The other artificial drying methods may cause damage to the grain like brittleness, heat damage and reduced nutritive value. Grains are hygroscopic, so by whatever means drying is done they can later gain moisture from high humidity. The Food and Feed Grain Institute at Kansas State University is trying to establish a simple and inexpensive storage unit suitable for humid areas. In their work, silica gel (a drying agent) was placed in the grain mass to dry the grain and to maintain optimum moisture content.

Once the silica gel reaches the maximum adsorbing capacity it needs regeneration for further use. The purpose of the research is to find out how many times the silica gel can be regenerated without losing its adsorbing capacity. Also, to develop a simple and inexpensive regeneration method which does not effect the quality of silica gel.

LITERATURE REVIEW

History:

Silica gel was first known in its hydrogel form. In 1640 Van Helmont reported that amorphous silica becomes liquid in contact with alkali, which later can be precipitated by addition of acid. In 1861 Sir Thomas Graham discovered that the hydrogel may be formed when a hydrosol is destabilized by dialyzing out the electrolyte. He prepared silica gel by dialyzing dilute silica sols obtained by mixing aqueous solutions of sodium silicate and hydrochloric acid (11).

Dr. Walter A. Patrick brought the silica gel into use during the First World War as a possible adsorbent in gas-mask canisters (15). Silica gel production was commercialized in 1920 in the USA.

Preparation:

Silica gel is commercially prepared by mixing sodium silicate solution with a mineral acid. This reaction leads to the formation of hydrosol. Hydrosol is converted into silica gel due to polymerization of silica molecules. Various types of silica gel can be prepared by modifying the reaction conditions such as temperature, concentration and pH. Each variety exhibits specific physical properties (5).

Properties:

Silica gel is classified as: 1. Regular density 2. Intermediate density 3. Low density.

Regular density silica gel has extremely fine pores, which allows higher adsorption of water. It is hard and glassy. Intermediate density silica gel is characterized by larger average pore diameter; it lacks fine

pores which reduce adsorption capacity of water. This type of silica gel is more friable. Low density silica gel is characterized by an even larger pore diameter (11). The full description of properties is given in Table 1 (11).

Silica gel has a capacity to adsorb sulfur dioxide, acetone and benzene. Also, silica gel shows specific and selective adsorption for water. It retains its adsorptive capacity even below 100°F (11, 15, 19). The specific heat of silica gel is .22 B.T.U./lb/°F (2, 15). Figure 1 shows the isotherms of silica gel and other adsorbents.

Table 1

Representative Properties of the Three Main Types of Silica Gel

Properties	Regular density	Intermediate density	Low density
density, g/cc			
apparent (bulk)	0.67-0.75	0.35-0.40	0.12-0.17
particle	1.10-4.20	0.65-0.75	
true	2.20	2.20	2.20
surface area m ² /g	750-800	300-350	100-200
pore volume, ml/g	0.37-0.40	0.90-1.10	1.4-2.0
average pore diameter, A ^o	22-26	120-160	180-220

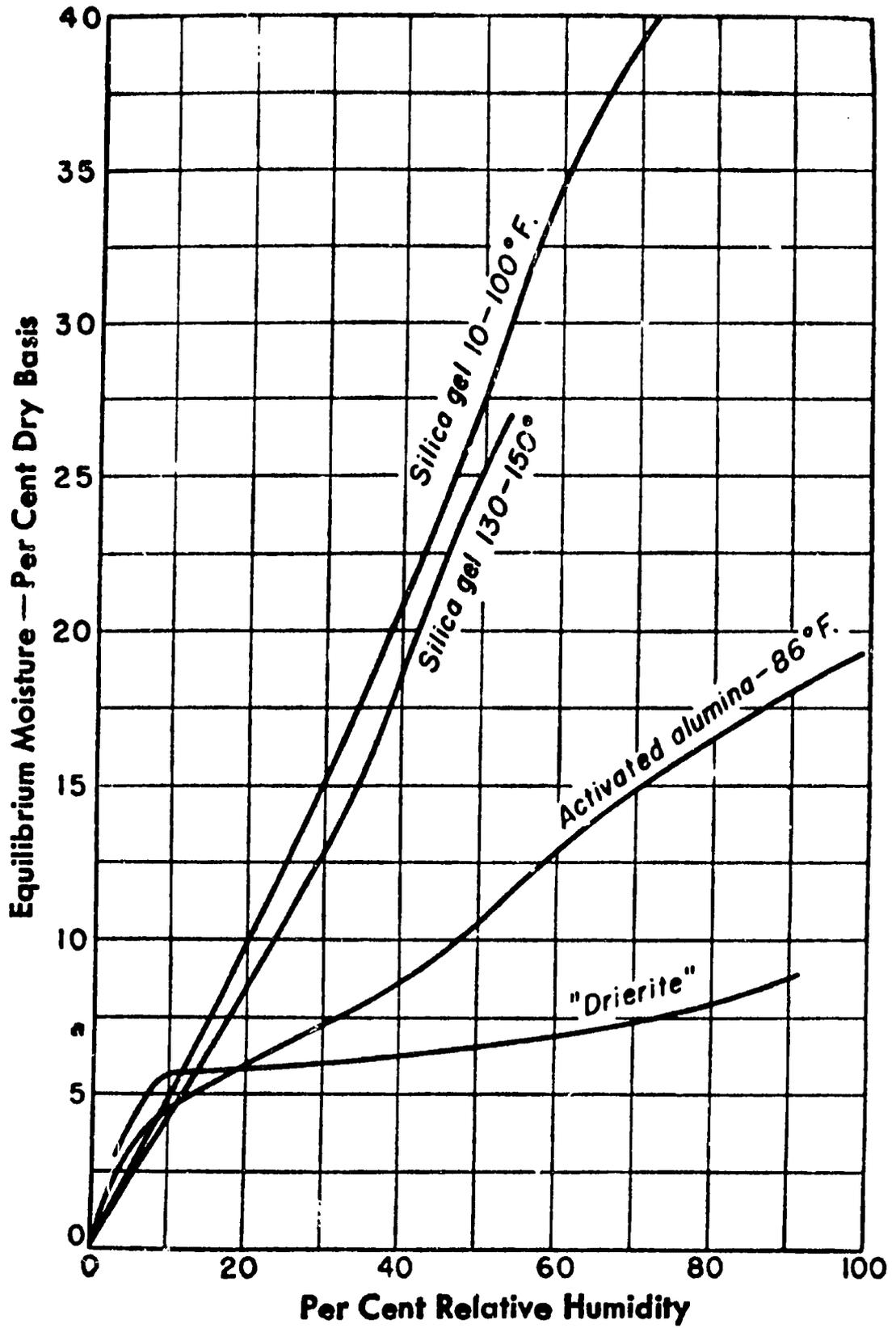


Figure 1. Equilibrium moisture for solid desiccants, Chemical Engineer's Handbook.

Applications:

Silica gel has been used in many industrial and pharmaceutical applications. Table 2 shows its application in industry. The commercial application of silica gel includes: refining of petroleum distillates, desulfurizing motor oils, dehydrating and purifying industrial gases, and serving as catalysts in the preparation of sulfuric acid and hydrogenation of oils (5, 11, 15).

Chemical adsorbents have been used for grain drying for nearly 3 decades (1). Recently, research was conducted by Fleske (1973) on the use of silica gel as a grain drying agent. Several factors were examined in his research. The results indicate that silica gel is a better adsorbent for grain drying than other adsorbents (6).

The ratio of grain to adsorbent required for drying depends inversely on the initial moisture content of grain. The grain to adsorbent ratios for corn with 12%, 15% and 20% initial moisture content were 140:1, 50:1, 35:1 respectively. Furthermore, his data on grain temperature, rate of drying, germination and mold invasion indicated that silica gel can be used for grain drying without adversely affecting the grain quality (6).

Silica gel has other advantages for grain drying. It is chemically inert and in no way reacts with the grain being dried. The drying process with silica gel is relatively slow and hence does not damage the grain (6).

Research is still in progress at Kansas State University to increase the drying rate by aeration while using silica gel. Small bins which can hold 300 lbs. of grain (corn) are used. Silica gel is placed in the grain at different positions. The air movement in the grain mass is brought about by a wind-powered fan placed on top of the bins.

Table 2

Silica Gel Use Chart (Davison Chemicals)

<u>Use Code</u>	<u>Grade</u>	<u>Application</u>
A	01	Dehydration of gases, trace hydrocarbon removal. Usually recommended for special applications where particle size is critical.
B	03	For natural gas and other industrial gases. 1) Bulk dehydration 2) Hydrocarbon recovery
D	05	Liquid and gas dehydration--special because of controlled particle size distribution.
E	12,15	Chromatographic gels.
F	13	Drying of flowers.
H	35	Packaging--because of size they could be used in selected liquid applications.
I	40	Liquid and gas dehydration.
J	41	Gas dehydration--because of particle size it is also recommended for hydrocarbon recovery.
K	42,43,44	Indicating--blue to pink.
N	59	Nondecrepitating--mainly used to top off beds of other gels in order to protect them from entrained liquid water.
P	31	Selective separation.
S	407,408	Bulk liquid dehydration such as refrigerants; air-drying in insulating glass.
T	923,950	Ultrahigh purity chromatographic gels.

Once silica gel reaches 70% of its total adsorbing capacity, it needs to be regenerated for further use. Laughlin et al. (12) and Robert et al. (9) discussed commercial methods of regeneration of silica gel.

The regenerative capacity of silica gel is affected by several factors. High temperatures and impurities affect the physical properties of silica gel like capillary volume, bound water, and surface area (8, 11).

The Encyclopedia of Chemical Technology (11) and Markrides (13) indicate that silica gel loses its "bound water" on exposure to 400°F for 3 hours (11). The results in Markrides experiment (13) show that the surface area of silica gel is reduced upon exposure to 700°F.

Patrick et al. (17) indicated that the adsorption capacity drops to a minimum if silica gel is heated to 1000°C for two hours. This drop is due to loss of capillary space.

Maroya et al. (16) studied the effect of various kinds of inorganic salts on physical properties (water adsorption capacity) of silica gel. The cationic impurities such as Na⁺, K⁺, Ca⁺², Pb⁺², Zn⁺² exert a strong effect on the water adsorptive capacity of silica gel.

Mantell (15) describes twenty-nine static laboratory tests conducted by Deschner, Hammerschmid and Capell. The results show that the adsorptive capacity of silica gel declines with continued use and reactivation. The results of this investigation are not in agreement with the statement by the Encyclopedia of Chemical Technology (11) that silica gel can be regenerated 1000 times.

Therefore, research was conducted to investigate a simple, efficient and inexpensive method of regeneration of silica gel on farm conditions.

MATERIALS AND METHODS

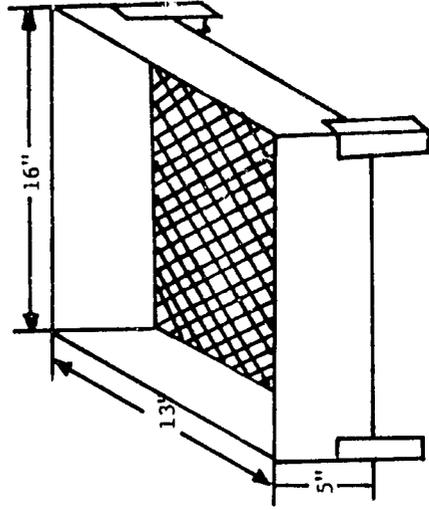
The experiments were conducted under a shed in an open area. The purpose of the shed was for protection against wind and rain. The shed has a corrugated steel roof with 8' x 16' floor space. The sides were uncovered to give plenty of ventilation to carry the smoke away from the experiment.

The method for regeneration of silica gel investigated by us was economical and could be operated by unskilled persons. Wheat straw and charcoal were used as fuels. Open and closed fireplaces were designed to burn the fuels. An open fireplace was built with three bricks at 90° angles to hold the containers. Two types of closed fireplaces were studied. One was made out of a metal can (diameter: 11", height: 13") and the other one out of 18 gauge galvanized steel as shown in Figure 2.

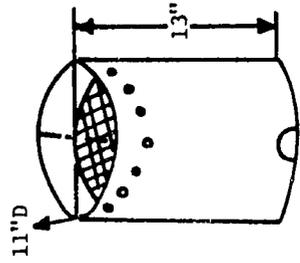
A big pan, a small pan and a rotating drum were used to hold the silica gel over the source of heat. The rotating drum was made out of a metal can (diameter: 11", height: 13") as shown in Figure 2. The big pan and the small pan were made out of 18 gauge black steel with dimensions of 18" x 18" x 6"; 12" x 12" x 6" respectively (Figure 2). Later the height of the big pan was raised from 6" to 15" to prevent the smoke from entering the silica gel. A special jacket-type container was also made as shown in Figure 3.

In addition to the above containers, two sacks (8 in. x 18 in.) were made out of 36 mesh stainless steel bolting cloth, to hold silica gel from direct exposure to heat.

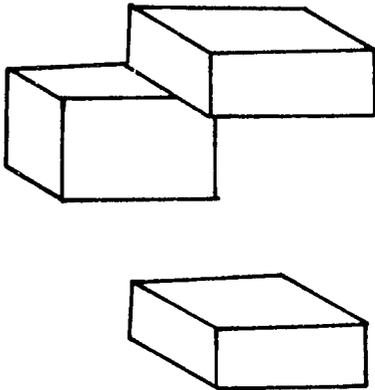
Figure 2 Types of Fireplaces and Containers



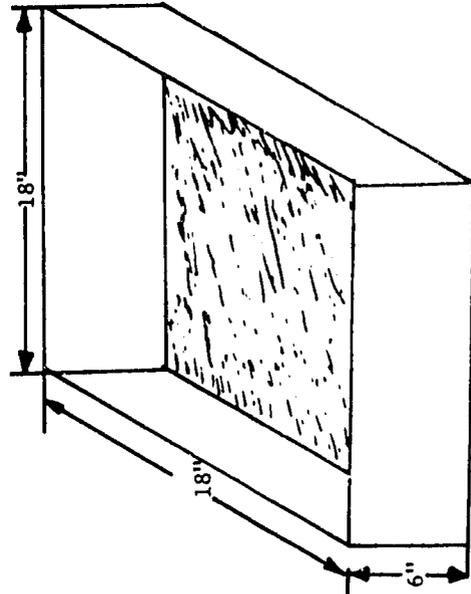
Closed-Type II



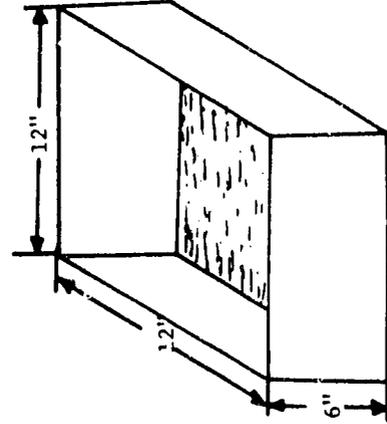
Closed-Type I



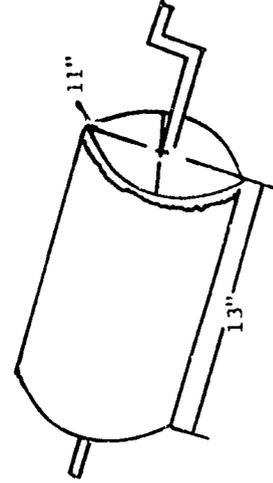
Open-Type



Large Pan

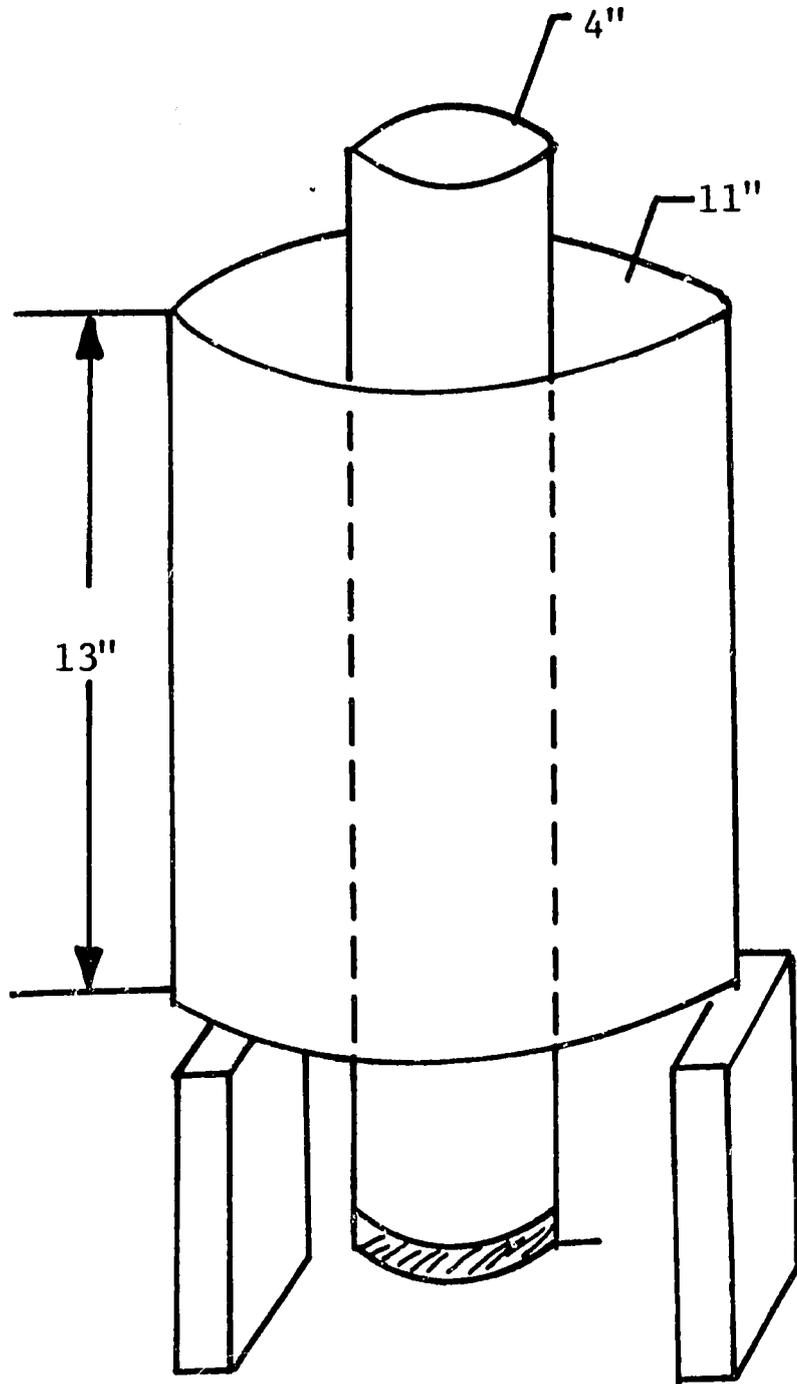


Small Pan



Rotating Drum

Figure 3 Jacket-Type Container



The silica gel used in these experiments was a commercial product (TEL-TALE) of The Davison Chemical Division, Baltimore, MD. 21203, USA. It is a regular density silica gel of 42 grade. It contains a colored pigment which will give several reproducible color changes at specific relative humidities. The original color of the silica gel is dark blue and it has a capacity to adsorb 40% of water by weight. As it starts adsorbing moisture it turns from dark blue to light blue; light blue to dark pink; and dark pink to light pink; when it reaches its maximum adsorbing capacity, it turns to light pink. At this stage it needs to be regenerated.

Preliminary laboratory tests were conducted to find the adsorptive capacity and time required to dry the silica gel using a hot air oven. Two kilograms of silica gel were taken in a sieve (diameter: 8", Tyler screen no.: 20). The bed depth was two inches. The sample was placed in a humidifying chamber set at 85°F and 90% relative humidity. Small samples were taken in an aluminum container at 8 hour intervals and dried at 190°C in a hot air oven. The time required to dry the sample to get a uniform weight was 60 minutes. The moisture adsorbed by the sample was 20% by weight after 52 hours. Since it takes a week, or so, to get the silica gel to 30% moisture content, the following method was used for faster wetting of the silica gel.

Hudson's Clipper 6215 Sprayer and a small mixer designed by the Grain Science Department of Kansas State University were used for wetting the silica gel. All the samples were wetted to 30% (75% of its adsorptive capacity) moisture level by adding water with the sprayer while mixing the sample. It is the same as keeping the sample in a humidifying chamber or in the grain mass to be dried.

After wetting, the silica gel was divided into four batches A, B, C, and D. Batch A, weighing 10 lbs., was dried and wetted alternately five times, each time using a different container but the same fuel. The samples were stirred while drying to prevent heat damage to the bottom layer. A big pan was used three times, a rotating drum once and a small pan once. The fuel used was wheat straw. Only open fireplaces were used since the closed fireplace did not allow enough air to burn the wheat straw.

Batch B was subjected to the same conditions as Batch A, except that the fuel was charcoal. Charcoal was burned in both open and closed type fire situations. The closed fireplace was made out of a metal can.

Three pounds each of Batch C and D were dried five times in the steel screen sacks by exposure to direct fire. The fuels used for C and D were wheat straw and charcoal respectively.

The data recorded in each experiment included the amount of water added (adsorbed), the amount of water evaporated, the time taken to dry the sample and the amount of fuel used.

Following the five regeneration steps each batch (A, B, C and D) was subjected to the equilibrium moisture test for a week (at 80°F and 90% R.H.), and the particle size analysis. The results were then compared with the original sample.

A method for the equilibrium moisture test was described by Dunstan et al. (4). The particle size analysis was described by Pfoest (18).

After observing the physical characteristics of silica gel and the results of the equilibrium moisture test, it was felt that the high temperatures of flame and smoke were destroying the adsorbing capacity

of silica gel. Temperatures were measured by a pyrometer (Eimer and Amend NYC No. 30-38) which has a chromel alumel thermocouple and can read temperatures up to 2200°F.

Two more experiments were conducted (Batch E and F) as before. The weights of Sample E and F were 4 lbs. 6 ozs. and 6 lbs. respectively. Both of them were dried five times. This time the side walls of the big pan were raised to 15" to reduce the smoke contamination. Sample E was dried on an open fireplace. Wheat straw was used as fuel. A 12 gauge metal sheet was placed under the pan to reduce the temperature. Sample F was dried in the small pan on the closed fireplace (the one which was made out of galvanized steel). Charcoal was used as a fuel. The temperature was reduced by placing a ½" sand bed on the 14 gauge steel in between the fireplace and the pan. In other words, the pan was in contact with the sand but not with the fire.

Again, the equilibrium moisture test and the particle size analysis were run on the samples from batches E and F. The results were compared with the original sample and with the batches A to D.

RESULTS AND DISCUSSION

The main objective of the project was to investigate the regenerative capacity of silica gel using simple, efficient and inexpensive methods.

Tables 3 to 8 show the type of containers used (small pan, large pan and rotating drum), the time required to dry the sample and the amount of the fuel used. Also, they show the percentage of water adsorbed (added) and evaporated. Under all drying conditions, the amount of water that evaporated was similar with certain minor variations.

The amount of fuel used depended on the drying time and the drying time depended upon weather conditions (temperature and wind velocity).

Drying a material involves a) vaporization of moisture contained in the material at or beneath the surface and then diffusion of the vapor into the air, and b) the movement of water and/or vapor from the interior to the surface of the material before it can diffuse into the air (3).

The time required for the first phase of drying was about 2/3 of total time required for drying and at this stage silica gel becomes loose and dry without much change in the color. The second phase was about 1/3 of total time required for drying. The second phase is very important because the color changes are very fast. Since all the water is evaporated at this stage the bottom layer of silica gel is more prone to heat damage if left unstirred.

Table 3 shows the results of Batch A, silica gel dried five times on an open fireplace, using wheat straw as a fuel. Table 4 indicates the results of Batch B, silica gel dried five times on open and closed fireplaces, using charcoal as fuel. Tables 5 and 6 show the results of Batches C and D silica gels dried in steel screen sacks by direct exposure to fire.

Table 3

Regeneration of silica gel (Batch A) using wheat straw as a fuel

Test No.	Fireplace	Container	Initial weight of gel	Final weight of gel	Water adsorbed (added)		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
					weight	%	weight	%		
1	open type	small pan (3" bed depth)	10 lbs	7 lbs	3 lbs	30	3 lbs	30	48.33 min.	1 bale
2	open type	rotating drum	10 lbs	7 lbs 8 ozs	3 lbs	30	2 lbs 8 ozs	25	37.6 min.	3/4 bale
3	open type	big pan (1 1/2' bed depth)	10 lbs	7 lbs 3 ozs	2 lbs 13 ozs	28.12	2 lbs 13 ozs	28.12	26.59 min.	1/2 bale
4	open type	big pan	8 lbs 10 ozs	6 lbs 1 oz	2 lbs 10 ozs	30.40	2 lbs 9 ozs	29.71	17.59 min.	1/2 bale
5	closed type	big pan	8 lbs 8 ozs	6 lbs 1 oz	2 lbs 8 ozs	29.59	2 lbs 7 ozs	28.67	18.51 min.	1/2 bale

Table 4

Regeneration of silica gel (Batch E) using charcoal as fuel

Test No.	Fireplace	Container	Initial weight of gel	Final weight of gel	Water adsorbed (added)		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
					weight	%	weight	%		
1	open type	big pan	10 lbs	7 lbs 4 ozs	3 lbs	30	2 lbs 12 ozs	27.5	36.36 min.	10 lbs
2	open type	small pan	10 lbs	7 lbs 4 ozs	3 lbs	30	2 lbs 12 ozs	27.5	47.27 min.	10 lbs
3	closed type	small pan	9 lbs 14 ozs	6 lbs 14 ozs	3 lbs	30.37	3 lbs	30.37	33.33 min.	10 lbs
4	closed type	big pan	9 lbs 13 ozs	6 lbs 15 ozs	2 lbs 15 ozs	29.94	2 lbs 14 ozs	29.30	21.53	8 lbs
5	closed type	rotating drum	9 lbs 10 ozs	6 lbs 13 ozs	2 lbs 14 ozs	29.87	2 lbs 13 ozs	29.20	43.77	8 lbs

Table 5

Regeneration of silica gel (Batch C) by direct heating using wheat straw as a fuel
and steel screen sack as a container

Test No.	Fireplace	Initial weight of gel	Final weight of gel	Water adsorbed (added)		Water retained		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
				weight	%	weight	%	weight	%		
1	open type	3 lbs	2 lbs	1 lb	33.3	-	-	1 lb	33.3	30. min.	2/3 bale
2	open type	2 lbs 12 ozs	1 lb 14 ozs	12 ozs	27.27	-	-	-	-	50.67 min.	1/2 bale
3	open type	2 lbs 8 ozs	1 lb 12 ozs	10 ozs	25.00	-	-	12 ozs	30.0	46.67 min.	1/4 bale
4	open type	2 lbs 4½ ozs	1 lb 12 ozs	12 ozs	32.87	8½ ozs	23.28	8½ ozs	23.28	69.81 min.	1/4 baie
5	open type	2 lbs 3½ ozs	1 lb 12 ozs	13 ozs	36.61	6½ ozs	18.3	6½ ozs	18.3	75. min.	1/4 bale

Table 6

Regeneration of silica gel (Batch D) by direct heating using charcoal as fuel
and steel screen sack as a container

Test No.	Fireplace	Initial weight of gel	Final weight of gel	Water added		Water retained		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
				weight	%	weight	%	weight	%		
1	open type	3 lbs	2 lbs 3 ozs	13 ozs	27.0	-	-	13 ozs	27.00	37.04 min.	2 lbs
2	open type	2 lbs 14 ozs	2 lbs 6 ozs	11 ozs	29.73	-	-	8 ozs	21.62	64. min.	2 lbs
3	open type	3 lbs	2 lbs 2½lbs	13 ozs	27.0	-	-	13½ ozs	28.12	38.27 min.	1½lbs
4	closed type	3 lbs	2 lbs 1 oz	13½ozs	28.12	-	-	15 ozs	31.00	26.88 min.	1½lbs
5	closed type	2 lbs 11 ozs	1 lb 15 ozs	15 ozs	34.8	10 ozs	23.25	12 ozs	27.9	33.33 min.	1½lbs

The results in Tables 3 to 6 indicate that a lb. of water from silica gel (30% water) can be evaporated in 17 to 75 minutes.

But the other important factor to be considered is the adsorbing capacity of silica gel after five successive regenerations.

Table 9 shows the results of the equilibrium moisture test of batches A, B, C, D, E and F indicating the adsorbing capacity of silica gel after five successive regenerations, in comparison to the original silica gel. The loss in adsorption capacity of silica gel dried on wheat straw, charcoal (indirect fire), wheat straw, charcoal (direct fire) is 2.56%, 4.06%, 7.53%, 4.30% respectively.

It was felt that this loss might be due to high temperature and/or smoke contamination. Table 11 shows the temperature readings of wheat straw and charcoal at different bed depths.

Table 7 shows the results of Batch E silica gel dried on an open fireplace using wheat straw as fuel. Table 8 shows the results of Batch F, silica gel dried on a closed fireplace using charcoal as fuel. In these experiments (E and F) the temperature was reduced from 1300^o - 1600^oF to 200^o - 300^oF by placing a sand bed below the container.

The results of Table 7 and 8 indicate that the time required to dry the sample of silica gel (Batches E and F) are not much different from Batches A, B, C and D. The equilibrium moisture test indicates that adsorption capacity is similar to the original sample of silica gel. There is a change in the color of silica gel (blue with a black tinge) when compared to the original sample (dark blue). But it does not affect either the adsorption capacity or the identification of color change at different humidities.

Table 7

Regeneration of silica gel (Batch E) using wheat straw as fuel with a
12 gauge metal sheet underneath the container

Test No.	Fireplace	Container	Initial weight of gel	Final weight of gel	Water added		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
					weight	%	weight	%		
1	open type	Big pan	4 lbs 4 ozs	3 lbs 1 oz	20 ozs	29.4	19 ozs	27.5	42.37 min.	1/2 bale
2	open type	Big pan	4 lbs 6 ozs	3 lbs 1 oz	21 ozs	30.0	21 ozs	30.0	49.51 min.	1/2 bale
3	open type	Big pan	4 lbs 6 ozs	3 lbs 1 oz	21 ozs	30.0	21 ozs	30.0	34.27 min.	1/3 bale
4	open type	Big pan	4 lbs 6 ozs	3 lbs	21 ozs	30.0	22 ozs	31.42	32.73 min.	1/3 bale
5	open type	Big pan	4 lbs 5 ozs	3 lbs	21 ozs	30.4	21 ozs	30.4	45.70 min.	1/4 bale

Table 8

Regeneration of silica gel (Batch F) using charcoal as fuel
with a $\frac{1}{2}$ " sand bed underneath the container

Test No.	Fireplace	Container	Initial weight of gel	Final weight of gel	Water adsorbed (added)		Water evaporated		Time required to evaporate a lb. of water	Amount of fuel
					weight	%	weight	%		
1	closed type	small pan	6 lbs	4 lbs 4 ozs	28 ozs	29.16	28 ozs	29.16	22.86 min.	5 lbs
2	closed type	small pan	6 lbs	4 lbs 4 ozs	28 ozs	29.16	28 ozs	29.16	42.86 min.	5 lbs
3	closed type	small pan	6 lbs	4 lbs 2 ozs	28 ozs	29.16	30 ozs	31.25	32.00 min.	4 lbs
4	closed type	small pan	6 lbs	4 lbs 3 ozs	28 ozs	29.16	29 ozs	30.20	33.15 min.	4 lbs
5	closed type	small pan	5 lbs 15 ozs	4 lbs 3 ozs	28 ozs	29.47	28 ozs	29.47	22.86 min.	4 lbs

Table 9

Equilibrium moisture content of all batches
at 80°F and 90% relative humidity (a week period)

Initial wt. of all samples was 5 grams

No.	Sample	Net weight		Average wt.	Average moisture content	Decrease in adsorption
		1	2			
1	original	6.75	6.70	6.72	25.56	0
2	A	6.60	6.40	6.50	23.00	2.56
3	B	6.40	6.35	6.37	21.50	4.06
4	C ₂	6.15	6.20	6.17	18.96	6.60
5	C ₅	6.10	6.10	6.10	18.03	7.53
6	D ₂	6.45	6.45	6.45	22.48	3.08
7	D ₅	6.40	6.30	6.35	21.26	4.30
8	E	6.70	6.70	6.70	25.37	0.19
9	F	6.70	6.70	6.70	25.37	0.19

C₂: Sample taken from batch C after 2nd regeneration

C₅: Sample taken from batch C after 5th regeneration

D₂: Sample taken from batch D after 2nd regeneration

D₅: Sample taken from batch D after 5th regeneration

Table 10

Comparison of particle size with adsorption capacity

No.	Sample	Geometric mean particle size	Geometric mean standard deviation	Surface area sq cms/gram	No. of particles per gram	Moisture adsorbed
1	A	1070.27	1.307	24.292	182.84	21.87
2	B	1188.97	1.513	41.000	1186.09	21.25
3	C	1112.75	1.368	35.574	621.38	18.03
4	D	1074.50	1.439	38.672	885.22	20.63
5	E	917.82	1.435	40.002	972.99	25.37
6	F	1047.65	1.379	46.203	1382.63	25.37
7	original	1708.49	1.417	40.850	1009.93	25.56

The particle size analysis of all batches is shown in Table 10. The purpose was to show whether the particle size affects the adsorption capacity because in the process of drying, the silica gel particles become smaller compared to the original. The results indicate that the particle size within the limits of these tests does not have any effect on adsorption capacity.

Tables show the sieving data used for particle size analysis (Table 12) and the drying and adsorption rate of silica gel (Table 13).

Table 11

Temperature readings measured by the
Pyrometer with a chromel Alumel Thermocouple

Wheat straw flame temp. = 1400° - 1600°F

Charcoal flame temp. = 1600° - 1800°F

When silica gel was wet the temperature of the
whole mass was = 100° - 200°F . As soon as it gets
dried the temperature readings are as follows:

Fuel: charcoal:

silica gel (2" bed depth) temperature in a 18 gauge
container:

Bottom layer = 600° - 800°F

Top layer = 220°F

By placing a 14 gauge metal sheet below the container:

Bottom layer = 400° - 600°F

Top layer = 200° - 220°F

By placing a $\frac{1}{2}$ " sand bed in between 14 gauge metal
sheet and 18 gauge metal container:

Bottom layer = 200° - 300°F

Fuel: wheat straw:

silica gel (3/4" bed depth) temperature after placing
a 12 gauge metal sheet below the 18 gauge metal
container

= 200° - 300°F

Table 12

Data Sheet Used for Tabulation of Sieving Data and
Calculation of Geometric Particle Size or Diameter by Weight

Tyler Screen No.	Diameter in micron	Weight in gms						
		Original	A	B	C	D	E	F
3	6730	-	-	-	-	-	-	-
4	4760	-	-	-	-	-	-	-
6	3360	-	-	-	-	-	-	-
8	2380	10.5	0.5	0.5	0.5	0.5	-	0.3
10	1680	45.8	11.8	11.0	10.5	8.0	1.8	7.0
14	1190	42.0	32.5	41.3	36.0	34.0	10.3	32.0
20	841	6.3	28.5	34.0	33.5	33.5	41.0	38.5
28	595	0.5	17.8	11.5	17.0	18.8	30.0	21.0
35	420	-	7.5	1.5	3.5	5.0	8.0	5.0
48	297	-	1.2	-	0.5	0.5	0.5	0.5
65	210	-	0.3	-	0.3	-	-	-
100	149	-	-	-	-	-	-	-
150	105	-	-	-	-	-	-	-
200	74	-	-	-	-	-	-	-
270	53	-	-	-	-	-	-	-
PAN	-	-	-	-	-	-	-	-

Table 13

Preliminary Lab Tests Showing the Rate
of Adsorption (at 85°F and 90% R.H.) and Rate of Drying (190°F)

Sample No.	Adsorption Time	Drying Time	Total Wt in gms	Container Wt in gms	Sample Wt in gms	Moisture by Wt in gms
1 (Top layer)	½ hr	Initial	27.905	14.065	13.840	-
		30 min	27.760		13.695	1.048
		45 min	27.700		13.635	1.480
		1 hr	27.680		13.615	1.620
2	8 hrs	Initial	30.385	15.350	15.035	-
		30 min	29.323		13.973	7.064
		45 min	29.250		13.900	7.549
		1 hr	29.248		13.898	7.562
3	18 hrs	Initial	36.666	15.292	21.374	-
		30 min	33.968		18.676	12.623
		45 min	33.845		18.553	13.198
		1 hr	33.805		18.513	13.385
4	24 hrs	Initial	38.872	15.362	23.510	-
		30 min	35.545		20.183	14.151
		45 min	35.415		20.053	14.700
		1 hr	35.400		20.038	14.768
5	47 hrs	Initial	37.790	15.345	22.445	-
		30 min	33.500		18.155	19.113
		45 min	33.465		18.120	19.269
		1 hr	33.460		18.115	19.292
6 (Top layer)	47 hrs	Initial	39.327	15.500	23.827	-
		30 min	34.500		19.000	20.025
		45 min	34.385		18.885	20.674
		1 hr	34.370		18.870	20.800
7	52 hrs	Initial	39.265	15.495	23.770	-
		30 min	34.753		19.259	18.982
		45 min	34.672		19.177	19.323
		1 hr	34.650		19.155	19.415
8	52 hrs	Initial	1883	470	1413	-
		3½ hrs	1619		1149	18.680
		5½ hrs	1589		1119	20.800

CONCLUSION

From the results of the investigation it was concluded that the silica gel can be regenerated by a simple and inexpensive method. In this method a farmer can use either wheat straw or charcoal as a heat source to dry the silica gel after using it for grain drying. To avoid the smoke contamination and high temperatures he should follow the following procedure.

The container needs to be placed on a half-inch sand bed on a 14-gauge metal, instead of placing it on direct fire. The wall of the container should be high enough (24") to avoid smoke contamination. The batch needs to be stirred every 10 minutes while drying the sample. The color changes observed while drying silica gel are pink to light blue; light blue to dark blue; dark blue indicates that it is completely dried.

We hope this regeneration method of silica gel for grain drying will help to solve the problems of grain drying in developing countries and the energy crisis in developed countries.

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