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THE EFFECTS OF AGING AT ELEVATED TEMPERATURES ON
CERTAIN PHYSICAL PROPERTIES OF DRILLING FLUIDS

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ABSTRACT

There has been a trend toward deeper drilling in the oil industry over the past twenty years. Since formation temperature increases with depth and reaches 300°F or more in existing wells, the effect of elevated temperature on drilling fluid has become an important problem. Elevated temperatures may have a detrimental effect upon drilling fluid, especially during periods of shut-down when the drilling fluid stays in the well and ages at high bottom-hole temperature for hours or days.

This study was undertaken in order to determine the effect of aging at elevated temperature on the physical properties of drilling fluids. The work is based on the results of laboratory investigations of three kinds of clay-water-base drilling fluids, each of which was heated at four different temperatures and aged for considerable periods. It was found that the physical properties of drilling fluids subjected to temperature and aging change in the following ways. The viscosity of Montmorillonite fluid decreases as the temperature is raised. The rate of filtration through the filter cake on the wall of the well increases with temperature rise and the thickness of filter cake will tend to increase. Meanwhile, the gel strength of

the montmorillonite fluid decreases with temperature rise. However, for the Aquagel fluid, and 30% Aquagel-70% Baroid fluid, it was found that after heating at elevated temperature the density is decreased, viscosity and gel strength are increased, and the rate of filtration and thickness of filter cake are decreased.

From this laboratory work, it is apparent that suitable chemical or physical reagents are needed to improve the properties of drilling fluids in order to make them satisfactory for deep oil well drilling wherever abnormally high temperatures are encountered.

THE EFFECTS OF AGING AT ELEVATED TEMPERATURES ON
CERTAIN PHYSICAL PROPERTIES OF DRILLING FLUIDS

INTRODUCTION

The relative success of drilling operations depends to a large extent upon the properties of the drilling fluid employed. Drilling fluid may vary from a simple mixture of native earth minerals and water to a very complex, closely controlled fluid compound containing special clays, heavier minerals, and organic colloids. The liquid phase of the complex drilling fluid may be water, water-in-emulsion, oil-in-water-emulsion, or oil.

The first rotary drilling fluid used was water. Its primary functions were to transport the cuttings to the surface and cool the bit. Water is admirably suited for this purpose and in addition has proved to be the fluid which least retards drilling rate. Thus, clear water remains as the ideal drilling fluid where no other function must be performed. The use of water is almost entirely confined to drilling through hard

formations which have very low permeability and which do not cave or promote the deposition of a filter cake on the wall of the bore hole of the well. However, most rotary wells have been drilled through unconsolidated formations made up of hydrated shales, highly permeable sands, gravels, and limestone. They may also contain fluids and gases which may migrate into the bore hole.

One of the first observations to suggest the usefulness of drilling fluids was that less hole trouble was encountered as the drilling water became muddy with ground-up formation clays. This muddy slurry was described as mud. It is also called drilling fluid.

The use of formation and surface clays was the first step in which colloids were intentionally used in drilling fluid. Clay forms rigid platelike particles with very large ratio of length to thickness. When dry, the individual clay particles are bound closely together but, when hydrated, the water molecules migrate in between adjacent clay lamina and force them further apart so that the mixture assumes plasticity. When still further dispersed in water, the individual clay particles display Brownian movement; but if the fluid gels, this motion ceases. The extent to which clay expands or is dispersed on hydration depends upon its origin and the chemical and colloidal natures of other substances present.

As mentioned previously, one function of drilling fluid is to transport cuttings to the surface. If however, the circulation is temporarily stopped, the fluid must be thixotropic

and capable of holding the cuttings in suspension. The high hydrostatic pressure of drilling fluid prevents other fluids such as oil, gas, water, and brine from coming into the holes. Yet the fluid itself would be lost by entering into the formation if it were not for its wall-building property, that is, the building up of a more or less impervious filter cake on the wall of the bore hole. This cake also strengthens the wall and minimizes caving, heaving, and sloughing. Furthermore, the drilling fluid cools the bit and drill pipe, carries part of its weight, and brings samples of the formation, oil or other materials encountered to the surface. Although drilling fluid must be sufficiently thixotropic to suspend the cuttings, its yield value under agitation must be sufficiently low, so that then the fluid flows horizontally in ditches at the surface gas can be released and cuttings dropped out from the fluid. Also the filter cake on the wall of the bore hole must remain a very thin layer so as not to obstruct the hole to passage of drill pipe and bit. Because it is satisfactory in most cases, clay-water-base fluid is often used in the present petroleum industry.

No special drilling fluid was employed for high temperature well drilling prior 1930. Up to that time the depths of wells were not great, and high-temperature formations were not encountered. As well depth became greater and abnormally high temperature was encountered, more trouble in drilling operation occurred. Accordingly, drilling engineers began to study the effect of temperature on the properties of drilling fluid. Investigators in this field during the past two decades have

included Sawdon (1931), who first described that drilling fluid is an important factor in deep well drilling; Baker (1932), who found that the importance of drilling fluid is increased with the increase of depth of oil well; and Byck (1939), who has tested several drilling fluids and found that the rate of filtration was increased and the viscosity was decreased with temperature rise. Recently, Gilkenson (1952), who found some factors affecting the solidification of lime-treated muds at high temperature. Coffey (1953) used lime-treated mud without its inherent limitations, it is resistant to contaminants such as anhydrite, gypsum, cement, and salt water and does not gel at high temperature. Watkins (1953) did a successful work of testing several treated-drilling-fluids at high temperature. The fluids were as follows:

- (1). Lime-treated fluid which contains five pounds per barrel high grade bentonite; five pounds per barrel caustic soda; two pounds per barrel lignitic emulsion stabilizer; two pounds per barrel quebracho; one pound per barrel CMC polyacrylonitrile or similarly stable organic water-loss reducing materials; some barite to yield the desired weight; and ten volume per cent of diesel oil and lime added when necessary to maintain a pH of 10.5 to 12.
- (2). Low pH red drilling fluid, a fluid whose pH is not greater than 12, containing natural tannins and lignitic materials, or a combination of those or equivalent materials as dispersing agents.
- (3). Lime-base fluid similar to the foregoing but containing

caustic soda and lime. The pH value of such fluid will be in excess of 12.5 and the content of solid (undissolved) lime in the circulating system will be on the order of one to fifty pounds of lime per barrel of drilling fluid.

(4). Low pH red fluid, which has been treated with a relatively small amount of lime so that little or no insoluble lime is present in the drilling fluid system.

These special drilling fluids have performed well in deep oil well drilling where higher than normal temperatures are encountered.

THE PHYSICAL PROPERTIES OF DRILLING FLUID

The main physical properties of drilling fluid discussed in this paper can be described as follows:

1. **Density:** The density of drilling fluid is significant in lifting drilling cuttings and offsetting high formation pressure. It can be represented by weight, in pounds per gallon or pounds per cubic foot. The primary function of weighted fluid is to control gas, oil, and water pressure in the formation penetrated within the well. This is accomplished by using a fluid heavy enough to furnish a positive hydrostatic differential against the contents of the formation. A second function of weighted fluid is to prevent caving and is accomplished through two effects of heavy fluids: the first one applies a positive differential pressure against the formation to hold it in place; the second utilizes the bouyant effect of heavy fluid and lessens the tendency of unconsolidated or fractured formation to gravitate into the hole. Formation solids and surface clays were the first materials used to add weight to drilling fluids. The higher the percentage of inert solids, the higher the density of the fluid. The inert solids

have a specific gravity of about 2.5, and they are capable of making fluid weighing 11 and 12 pounds per gallon; but at higher densities such a fluid becomes too plastic to use. Such fluids are usually low in colloids and have undesirably high filtration loss and thick filter cake. Many blow-outs have been caused by a combination of light weight and high viscosity, with resultant of recycling of gas and swabbing of hole. In order to make a heavy fluid it is necessary to use materials having specific gravity greater than clays, sands and limestone.

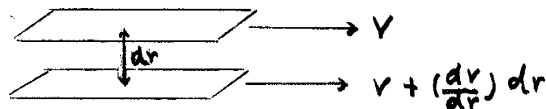
2. Viscosity: The viscosity of drilling fluid influences its fluidity and its resistance to flow through the circulating system. The simplest viscosity effect, known as Newtonian flow, is that in which the rate of deformation is directly proportional to the magnitude of applied force; all other viscosity effects are surperimposed on the Newtonian or fundamental condition of flow. The well-grounded formulation of viscosity is that of Einstein, who applied the ordinary formula of hydrodynamics to Brownian motion, viscosity and diffusion of colloidal particles. However, Einstein assumed that the particles were spherical and large as compared with a molecule of solvent; that they were unchanged, and there was no slip between them and the solvent with which they were actually in contact ; and, finally, that turbulence was avoided. By this procedure a well-known formula for relative viscosity, η_r or $\frac{\eta}{\eta_0}$ was obtained, where the viscosity η is referred to that of the solvent η_0 as unity. If v is the fraction of total

volume occupied by the suspended molecules, then Einstein's formula is:

$$\eta_r = 1 + 2.5 v$$

It should be noted that this theoretical viscosity is independent of the degree of subdivision, or size of the particles, as long as the latter are separate, unchanged spheres.

By definition, viscosity is a measure of the frictional resistance that a fluid in motion offers to an applied shearing force. The nature of this resistance may be illustrated by the following figure.



If a fluid is flowing past a stationary plane surface, the layer of fluid adjacent to the plane boundary is stagnant; successive layers have increasingly higher velocity. The frictional force f , resisting the relative motion of any two adjacent layers is proportional to S , the area of the interface between them. This is Newton's law of viscous flow:

$$f = S\eta \, dv/dr$$

The proportional constant η is called the coefficient of viscosity; the unit is g/cm-sec, called Poise.

Generally speaking, the viscosity of drilling fluid depends upon the amount and character of the suspended solids; the greater the percentage of suspended solids contained, the greater will be the viscosity. Usually, the plastic clays develop higher viscosity than noncolloidal materials; for

example, bentonite has well developed colloidal and thixotropic properties.

3. Gel Strength: Whereas viscosity is a measure of the resistance of fluid to infinitesimal uniform shear, the gel strength of fluid can be defined as a measure of the minimum shearing stress necessary to produce sliplike movement; in other words, it is the resistance to shear of a fluid and is a measure of plasticity and thixotropy. In drilling fluid, the gel strength is responsible for the ability of the fluid to transport cuttings upward, but also for the ability of the fluid to hold the cuttings in suspension when circulation is suspended. Noncolloidal particles will eventually sink in a true fluid having zero gel strength, regardless of its viscosity.

With respect to gel strength, drilling fluids have two important characteristics not exhibited by some plastic fluids. These are the following:

(1). Gel strength increases as the time of quiescence increases.

(2). Agitation restores the original fluidity of the gelled fluid, which again gels if it is allowed to return to quiescence. This characteristic is known as thixotropy.

Due to the characteristic of increasing gel strength with increase of time, it becomes necessary to obtain a measure this increase. This is done by comparing the zero-time or initial gel strength with the ten-minute gel strength. The difference is the measure of thixotropy of the drilling fluid. The thixotropic character of drilling fluid performs the

function of suspending cuttings in the bore hole of the well during periods of shut-down. It also allows the cuttings and sands to settle out from the drilling fluid in the pit or ditch. These seemingly opposite functions are performed because the fluid, upon cessation of circulation, develops a definite gel strength which supports entrained particles, whereas the cuttings are free to settle in ditches and pits; the movement of the fluid in its passage through the surface system prevents the gel from forming, and the fluid approaches the character of nongelling fluid.

4. Colloidal Property: The colloidal properties of drilling fluid determine its ability to form a suitable cake on the wall of the well, to seal the pores of the wall formations, and to lubricate the bit and drill pipe. The wall-building properties of drilling fluid are of great importance. As the clay-laden fluid is circulated over the wall of the bore hole, there is a tendency for the fluid either to enter the pores of formation, or, if the pores are large enough, to permit the solid particles to enter. There is also a tendency for the liquid phase of drilling fluid to be squeezed from the fluid into the surrounding formation, and leaving the solid matter to deposit as a cake on the wall of the well. The thickness and permeability of the cake may exercise considerable influence on the drilling of the well. If the formation and cake permeabilities are both high, then a thick filter cake will be developed. This cake may become so thick that it interferes seriously with movement of the drill pipe.

The fluid which enters into the formation may encounter shales and clays susceptible to hydration, and the swelling which results may cause heaving or slipping of shales or clay into the hole. The hydration or swelling of clay in producing sands may impair production through the loss of permeability of the formation.

There is no unit of the colloidal property of drilling fluid, and the colloidal value cannot be measured quantitatively. However, relative colloidal value and its effect on the properties of drilling fluid are indicated by the thickness of filter cake and the rate of filtration.

LABORATORY WORK AND RESULTS

The laboratory work performed in connection with this study consisted of the following three steps:

First step: Preparation of Drilling Fluid.

The clay was used to make drilling fluid samples for laboratory study. The procedure was to grind the clay to about 40 or 50 mesh and then mix it with distilled water in a five-liter jar provided with an agitator. The density of fluid depends upon the relative amounts of clay and water; the density was made to vary from 64 to 70 pounds per cubic foot. The fluid was stirred thoroughly in the jar and its physical properties were then observed at room temperature.

Second step: Measurement of Physical Properties.

1. **Density:** The density of the drilling fluid was measured by means of a Baroid Balance. The procedure was to fill the cup on the balance arm with fluid to be tested and seat the lid slowly with a twisting motion, making sure that some of the fluid ran out of the hole on the cover of the cup. All fluid was wiped from the lid, cup, and beam of the balance. Then the knife edge was set on the fulcrum, and the rider was moved along the graduated beam until the cup and beam

were balanced. The density of the tested fluid was then given by the value which was recorded on the beam. It was read in pounds per cubic foot or pounds per gallon.

2. Viscosity: The Stormer Viscosimeter was used for measuring viscosity. The procedure used was as follows: First the coarse materials were removed from the fluid to be tested. Next the cup of the viscosimeter was filled to within one quarter inch of the top and placed in the water bath. This assembly was then raised as far as it would go on the support rods of the viscosimeter and was held in place by means of set screw. Free rotation of the spindle was obtained by releasing the brake screw located on the gear case.

After the drilling fluid in the cup was thoroughly agitated the spindle was revolved by turning the reel. Metric weights were added to or subtracted from the plumb line until the spindle rotated at a speed of 600 RPM.

The viscosity of the fluid to be tested was determined by means of the weights attached on the plumb line and was converted into centipoises with the calibration chart.

3. Gel Strength: The gel strength of the drilling fluid was also measured by the Stormer Viscosimeter. The procedure was to agitate the fluid thoroughly and pour it immediately into the test cup of the viscosimeter. The initial gel strength measurement was made by determining the minimum weight required to effect a movement of the spindle of approximately one quarter revolution after the brake had been slowly released. Then the total weight in grams required

to obtain this rotation was taken as the initial gel strength of the drilling fluid.

A ten-minute gel strength determination was made after the drilling fluid in the cup of the viscosimeter had been allowed to remain quiescent for ten minutes following the initial gel strength observation. Additional weights were added to the plumb line and the brake was released slowly. If no rotation of the spindle occurred, the brake was set again, more weight was added to the line, and the brake was released again. This procedure was repeated until the minimum weight required to cause rotation was found. This weight was taken as the ten-minute gel strength of the drilling fluid.

4. Colloidal Property: The colloidal properties of drilling fluid may be indicated by the measurement of the rate of filtration and thickness of filter cake formed. These measurements were made by means of a Baroid Filter Press. Which consists of a screw-press frame and filter cell assembly, it is a cylinder fitted with a gasket and a machined cap having a small hole for admission of a pressure medium. The bottom of the cylinder is closed by a sheet of filter paper backed by a wire screen and a bottom cap effectively sealed by means of a gasket. Before measurements were made, the wire screen, filter paper, and bottom cap assembly were wet with water and shaken gently to remove any excess. Then the gasket, wire screen, filter paper, and cylinder were placed on the bottom cap, and the cylinder was filled with fluid to be tested within one inch of the top. Then the top cap and gasket were placed on the reservoir

cylinder, the screw press was tightened, and pressure was applied as soon as possible. With a graduated cylinder in place to receive the filtrate, the volume accumulation in 30 minutes was recorded in cubic centimeter. The pressure used was obtained from an air bomb and regulated to 100 pounds per square inch, applied to the cylinder by means of regulator. At the expiration of the 30 minute test period, the pressure was released through a valve connected to the pressure inlet line, the cylinder and bottom plate were withdrawn from the press intact, excess fluid was poured out, and the filter cake was removed from the bottom plate. After the plate had separated from the cylinder, the filter cake was washed free of excess fluid and its thickness measured in thirty-seconds of an inch.

Third step: Heating the Drilling Fluid.

A 600-cc bronze cylinder having a wall thickness of $3/8$ of an inch and a removable cap fitted with a gasket was used as the fluid container. The cylinder was filled with fluid, and the cap was put in place and tightened. The assembly was put in the electrical oven and heated to the desired temperature.

The temperatures used in the experiment were 90°F , 120°F , 180°F , and 250°F . The heating time at each temperature were periods approximately of 10 hours, 20 hours, 30 hours, and 50 hours, so that sixteen batches of heating (and aging) were needed for each sample of drilling fluid. After the drilling fluid had been heated and aged through each scheduled temperature and heating time, the fluid container was taken

from the electrical oven and immersed in the water to cool to room temperature. Its physical properties were measured as described in the second step.

The first sample, a clay from a deposit near Socorro and identified as montmorillonite mineral by Paul Kintzinger in 1955, was used to make drilling fluid for laboratory study which followed the procedure described above.

The second sample of drilling fluid studied was composed of water and Aquagel, a product of the National Lead Company of Houston, Texas. Aquagel is a specially processed high grade swelling Wyoming bentonite. Laboratory work with this fluid followed the same procedure as described in the foregoing paragraphs.

The third sample was a mixture of 30% Aquagel and 70% Baroid (by weight). Both are the products of National Lead Company. Baroid is a commercial barium sulphate which is a drilling fluid weighting material. The fluid was tested by the same method described above.

Experimental results concerning these three drilling fluids are shown in detail in Tables I through XII.

TABLE I.

Physical Properties of Montmorillonite Fluid

HEATING TEMPERATURE 90° F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 12hr		HEATING TIME 24hr		HEATING TIME 34hr		HEATING TIME 51hr	
DENSITY, LB./CU.FT.	65.4	65.4	65	65	66.2	66.2	66.6	66.7
VISCOSITY, stormer viscosimeter 600RPM IN GRAM IN CENTIPOISE	56.7 1.7	56.4 1.6	45.0 3.0	42.5 2.9	58.5 6.4	57.7 6.0	54.3 5.1	52.8 5.0
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	1.2 2.4	1.1 2.5	1.5 2.6	1.15 2.4	1.2 2.1	1.1 2.0	1.6 5.5	1.4 2.8
RATE OF FILTRATION CC IN 30 MIN. AT 100PSI	42.0	43.0	61.0	66.0	49.0	52.0	75.0	80.0
THICKNESS $\frac{1}{32}$ " OF FILTER CAKE	6	7	7	9	6	7	16	17

TABLE II.

Physical Properties of Montmorillonite Fluid

HEATING TEMPERATURE 120° F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 8.5	HEATING TIME 29.5	HEATING TIME 48hr	HEATING TIME 65hr	HEATING TIME 66.6	HEATING TIME 66.6	HEATING TIME 66.6	HEATING TIME 66.6
DENSITY, LB/CU.FT.	67.6	67.6	67.6	67.6	67.9	68.0	66.6	66.8
VISCOSITY, stomer viscosimeter 600RPM IN GRAM	60.3	59.5	60.5	59.0	60.7	59.0	55.2	55.8
IN CENTIPOSE	6.7	6.5	6.75	6.4	6.9	6.4	5.9	5.1
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	2.1	2.0	2.1	1.7	2.1	1.9	2.4	1.7
	3.5	3.2	3.5	3.4	3.5	3.1	3.2	2.8
RATE OF FILTRATION CC IN 30 MIN. AT 100 PSI	57	61	57	60	57	59	49	53
THICKNESS $\frac{1}{32}$ " OF FILTER CAKE	9.5	10	11	12	7	9	5	7

TABLE III.

Physical Properties of Montmorillonite Fluid

HEATING TEMPERATURE 100°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 11.5	HEATING TIME 20.5	HEATING TIME 36hr	HEATING TIME 56hr	HEATING TIME 67.1	HEATING TIME 67.2	HEATING TIME 67.1	HEATING TIME 50hr
DENSITY, LB./CU.FT.	65.5	65.5	65.8	67.3	65.5	70.0	67.1	67.2
VISCOSITY, stormer viscosimeter 600RPM								
IN GRAM	42.3	41.8	46.7	45.0	45.7	40.6	48.2	45.8
IN CENTIPOISE	2.8	2.4	5.8	3.7	3.0	2.2	4.1	5.8
GEL STRENGTH, INITIAL (IN GRAM)	1.52	1.0	1.7	1.5	1.6	1.1	1.5	1.1
TEN MINUTES	2.3	2.1	3.3	3.1	2.86	2.14	2.7	1.5
RATE OF FILTRATION CC IN 30 MIN. AT 100PSI	68	75	76	82	84	71	66	70
THICKNESS 1/32 OF FILTER CAKE	5	6.5	16	18	12	16	7	7

TABLE IV.

Physical Properties of Montmorillonite Fluid

HEATING TEMPERATURE 250°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 10hr	HEATING TIME 10hr	HEATING TIME 10hr	HEATING TIME 10hr	HEATING TIME 35hr	HEATING TIME 35hr	HEATING TIME 40	HEATING TIME 40
DENSITY, LB/CU.FT.	65.3	66.0	65.7	66.0	67.0	66.8	66.8	67.5
VISCOSITY, stromer viscosimeter 600RPM								
IN GRAM	46.6	42.5	46.3	45.0	45.0	45.5	46.8	44.2
IN CENTIPOISE	5.0	2.8	3.7	3.1	3.6	2.9	3.8	3.2
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	1.7 2.2	1.2 1.8	1.6 3.1	1.2 2.8	1.6 5.0	0.8 2.5	1.9 2.8	1.0 2.0
RATE OF FILTRATION CC IN 30MIN. AT 100PSI	64	66	66	71	70	75	67	70
THICKNESS ¹ / ₃₂ OF FILTER CAKE	7.5	7.9	7.3	7.9	7.3	7.8	7.2	7.9

TABLE V.

Physical Properties of Aquagel Fluid

HEATING TEMPERATURE 90° F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 22.5	64	HEATING TIME 40.5	64	HEATING TIME 64	64	HEATING TIME 70.5	95.5
DENSITY, LB./CU.FT.	64	64	64	64	64	64	64	64
VISCOSITY, stromer viscosimeter 600RPM								
IN GRAM	62.87	65.71	62.87	65.9	62.87	67.43	62.87	70.59
IN CENTIPOISE	7.0	7.9	7.0	8.0	7.0	8.2	7.0	9.2
GEL STRENGTH, INITIAL (IN GRAM)	4.36	4.45	4.56	5.0	4.56	5.7	4.56	5.88
TEN MINUTES	15.9	16.8	15.9	16.7	15.9	17.6	15.9	17.8
RATE OF FILTRATION CC IN 30 MIN. AT 100 PSI	24	25	24	25	24	22	24	22
THICKNESS ¹ / ₃₂ " OF FILTER CAKE	2	2	2	2	2	2	2	2

TABLE VI.

Physical Properties of Aquagel Fluid

HEATING TEMPERATURE 120°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 17hr	HEATING TIME 24hr	HEATING TIME 48hr	HEATING TIME 72hr	HEATING TIME 48hr	HEATING TIME 72hr	HEATING TIME 48hr	HEATING TIME 72hr
DENSITY, LB/CU.FT.	64.1	64	64.1	63.9	64.1	63.8	64.1	63.7
VISCOSITY, stomer viscosimeter 600RPM								
IN GRAM	75.7	79.6	75.7	80.13	75.7	81.8	75.7	86.0
IN CENTIPOISE	10.3	11.7	10.3	11.9	10.3	12.0	10.3	13.0
GEL STRENGTH,								
INITIAL (IN GRAM)	2.55	2.5	2.55	2.67	2.55	2.67	2.55	3.56
TEN MINUTES	16.86	17.65	16.86	18.5	16.86	17.98	16.86	19.7
RATE OF FILTRATION CC IN 30 MIN. AT 100 PSI	21	21	21	20.8	21	19.5	21	14.9.2
THICKNESS $\frac{1}{32}$ " OF FILTER CAKE	3	2	3	2	3	1.0	3	1.5

TABLE VII.

Physical Properties of Aquagel Fluid

HEATING TEMPERATURE 180°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME	9hr	HEATING TIME	17hr	HEATING TIME	28hr	HEATING TIME	46.5
DENSITY, LB/CU.FT.	63.8	63.6	63.8	63.4	63.8	63.5	63.8	63.0
VISCOSITY, former viscosimeter 60ORPM								
IN GRAM	61.4	66.9	61.4	71.5	61.4	80.8	61.4	89.05
IN CENTIPOISE	7.0	8.0	7.0	9.2	7.0	12.0	7.0	14.5
GEL STRENGTH, INITIAL (IN GRAM)	1.88	2.11	1.98	2.34	1.98	2.76	1.98	3.75
TEN MINUTES	9.86	10.42	9.86	11.67	9.86	12.0	9.86	13.8
RATE OF FILTRATION CC IN 30MIN. AT 100PSI	24.5	24	24.5	25.5	24.5	25.0	24.5	22.4
THICKNESS 1/32 OF FILTER CAKE	3	3	3	2.5	3	2	3	1.9

TABLE VIII.

Physical Properties of Aquagel Fluid

HEATING TEMPERATURE 250° F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 7.5		HEATING TIME 20hr		HEATING TIME 32hr		HEATING TIME 45hr	
DENSITY, LB/CU.FT.	65.6	65.5	65.6	65.2	65.6	65.0	65.6	65.0
VISCOSITY, stormer viscosimeter 60ORPM								
IN GRAM	65.1	14.75	65.1	142.0	65.1	148.6	65.1	150.6
IN CENTIPOISE	8.0	15.9	8.0	50.0	8.0	32.2	8.0	33.0
GEL STRENGTH, INITIAL (IN GRAM)	1.86	2.54	1.86	2.68	1.86	2.69	1.86	3.6
TEN MINUTES	4.9	5.5	4.9	5.65	4.9	5.8	4.9	6.8
RATE OF FILTRATION CC IN 30 MIN. AT 100 PSI	24.5	24	24.5	28	24.5	22.5	24.5	21.2
THICKNESS ¹ / ₃₂ OF FILTER CAKE	5	2	3	1.8	5	1.78	5	1.7

50% Aquagel and 70% Baroid Fluid

HEATING TEMPERATURE 90°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 0.5	HEATING TIME 0.5	HEATING TIME 20.5	HEATING TIME 20.5	HEATING TIME 32.5	HEATING TIME 32.5	HEATING TIME 46.5	HEATING TIME 46.5
DENSITY, LB/CU.FT.	69	69	69	69.9	69	68.9	69	68.6
VISCOSITY, stormer viscosimeter 600RPM IN GRAM IN CENTIPOSE	75.85 10.8	60.7 11.9	75.85 10.8	64.6 13.0	75.85 10.8	86.6 13.6	75.85 10.8	67.0 13.8
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	2.7 10.85	2.8 11.2	2.7 10.85	2.9 12.1	2.7 10.85	3.1 15.0	2.7 10.85	5.5 14.2
RATE OF FILTRATION CC IN 30 MIN. AT 100 PSI	19	16.5	19	15.5	19	14.8	19	15
THICKNESS $\frac{1}{32}$ " OF FILTER CAKE	3	3	3	2	3	2	3	2

TABLE X.

50% Aquagel and 70% Baroid Fluid

HEATING TEMPERATURE 120°F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 12.5	HEATING TIME 24hr	HEATING TIME 66.5	HEATING TIME 66.0	HEATING TIME 66.5	HEATING TIME 65.9	HEATING TIME 52.5	HEATING TIME 52.5
DENSITY, LB/CU.FT.	66.3	66.2	66.5	66.0	66.5	65.9	66.5	65.7
VISCOSITY, stormer viscosimeter 60ORPM IN GRAM IN CENTIPOISE	51.6 4.5	55.5 5.6	51.6 4.5	52.0 4.6	51.6 4.5	57.0 5.9	51.6 4.5	58.0 6.0
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	1.9 2.4	2.1 2.6	1.9 2.4	2.1 2.8	1.9 2.4	2.5 2.98	1.9 2.4	2.76 3.25
RATE OF FILTRATION CC IN 30 MIN. AT 100PSI	50.5	50	50.5	29	50.5	28	50.5	27.5
THICKNESS $\frac{1}{32}$ " OF FILTER CAKE	5	2	5	2	5	2	5	2

TABLE XI.

30% Aquagel and 70% Baroid Fluid

HEATING TEMPERATURE 180 F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME 10.5	HEATING TIME 17hr	HEATING TIME 4hr	HEATING TIME 60hr	HEATING TIME 4hr	HEATING TIME 17hr	HEATING TIME 4hr	HEATING TIME 60hr
DENSITY, LB/CU.FT.	68.7	68.6	68.7	68.5	68.7	68.3	68.7	68.0
VISCOSITY, stormer viscosimeter 60ORPM IN GRAM IN CENTIPOISE	65.87 8.0	64.8 15.4	65.75 8.0	66.45 16.6	65.75 8.0	111.5 21.0	65.75 8.0	136.5 28.0
GEL STRENGTH, INITIAL (IN GRAM) TEN MINUTES	2.7 17.9	2.8 18.2	2.7 17.9	3.0 19.8	2.7 17.9	3.7 20.1	2.7 17.9	3.9 23.9
RATE OF FILTRATION CC IN 30 MIN. AT 100PSI	22	21	22	26	23	19	23	19.5
THICKNESS ¹ / ₃₂ " OF FILTER CAKE	4	4	4	3.7	4	3.1	4	3

TABLE XII.

30% Aquasol and 70% Baroid Fluid

HEATING TEMPERATURE 250° F

PHYSICAL PROPERTIES	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING	BEFORE HEATING	AFTER HEATING
	HEATING TIME	HEATING TIME	HEATING TIME	HEATING TIME	HEATING TIME	HEATING TIME	HEATING TIME	HEATING TIME
DENSITY, LB/CU.FT.	66.7	66.5	66.7	66.2	66.7	66.1	66.7	66.0
VISCOSITY, stromer viscosimeter 600RPM								
IN GRAM	60.3	137.5	60.3	151.2	60.3	149.5	60.5	156.8
IN CENTIPOSE	6.6	27.0	6.6	31.0	6.6	32.8	6.6	34.6
GEL STRENGTH, INITIAL (IN GRAM)	1.8	2.8	1.8	5.2	1.8	5.5	1.8	4.6
TEN MINUTES	12.6	13.5	12.6	14.6	12.8	15.0	12.8	20.4
RATE OF FILTRATION CC IN 30MIN. AT 100PSI	51.5	50	51.5	29.5	51.5	29	51.5	28.6
THICKNESS ¹ / ₃₂ " OF FILTER CAKE	4	4	4	3	4	2.8	4	3.7

TABLE XIII. A COMPARISON OF CHANGES OF PHYSICAL PROPERTIES OF THREE DRILLING FLUIDS DUE TO AGING AT ELEVATED TEMPERATURES

PHYSICAL PROPERTIES OF DRILLING FLUID	DENSITY	VISCOSITY	GEL STRENGTH	RATE OF FILTRATION	THICKNESS OF FILTER CAKE
MONTMORILLONITE FLUID	Not appreciably affected, a slight increase at temperature higher than 150 F.	Decreased. Range from 2% to 19%.	Decreased. Range from 1% to 30%.	Increased. Range from 2% to 9%.	Increased. Range from 7% to 34%.
AQUAGEL FLUID	Decreased. Range from 1% to 9.5%.	Increased. Range from 1% to 300%.	Increased.. Range from 5% to 94%.	Decreased. Range from 2% to 11%.	Decreased. Range from 17% to 50%.
30% AQUAGEL AND 70% BAROID FLUID	Decreased, range from 1% to 10%.	Increased, range from 2% to 450%.	Increased, range from 4% to 160%.	Decreased, range from 2% to 22%.	Decreased, range from 6% to 50%.

The results of laboratory work are summarized in Table XIII which gives the comparison of changes of physical properties of three drilling fluids due to aging at elevated temperatures.

Figures I through VI show the relationships between the physical properties of Aquagel fluid and the heating time for different temperatures.

In figure I it can be noted that the density of Aquagel fluid has a linear relation with the heating time. The density is decreased slightly with the increase in heating time.

Figure II shows that the viscosity of Aquagel fluid increased markedly as the heating period was increased at each of the temperatures used, and with a few exceptions, the viscosity at the end of any given period of heating (aging) increased with the heating temperature.

Figure III shows that the rate of filtration of Aquagel fluid decreased rather consistently but not greatly with heating time. Very poor correlation between heating temperature and reduction in filtration rate is shown by the data.

Figure IV and V show the relation of initial and ten-minute gel strength of Aquagel fluid with heating time at different temperatures. The gel strength of this fluid increased with heating time and, in general, with aging temperature, but the variations in gel strength were less marked and not so consistent as in the case of viscosity.

In figure VI it can be noted that the thickness of filter cake of Aquagel fluid was reduced slightly with increase in heating time at different temperatures. Very poor correlation

between heating temperature and reduction in thickness of filter can be seen from this figure.

Figure VII through XII show the relationships of physical properties of the 30% Aquagel and 70% Baroid fluid with the heating time at different temperatures. Generally speaking, it showed the same relationships as the Aquagel fluid with the heating time and temperature. However, due to the existence of Baroid, a quantitative difference can be seen from those figures.

The results obtained from the study of the drilling fluid made from the local clay, montmorillonite mineral, do not show any significant relation between the heating time and temperature on the one hand and the fluid properties on the other. Variations in fluid properties were observed, but no very consistent pattern in these changes is discernible.

FIGURE 1. THE RELATIONSHIP BETWEEN THE DENSITY AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

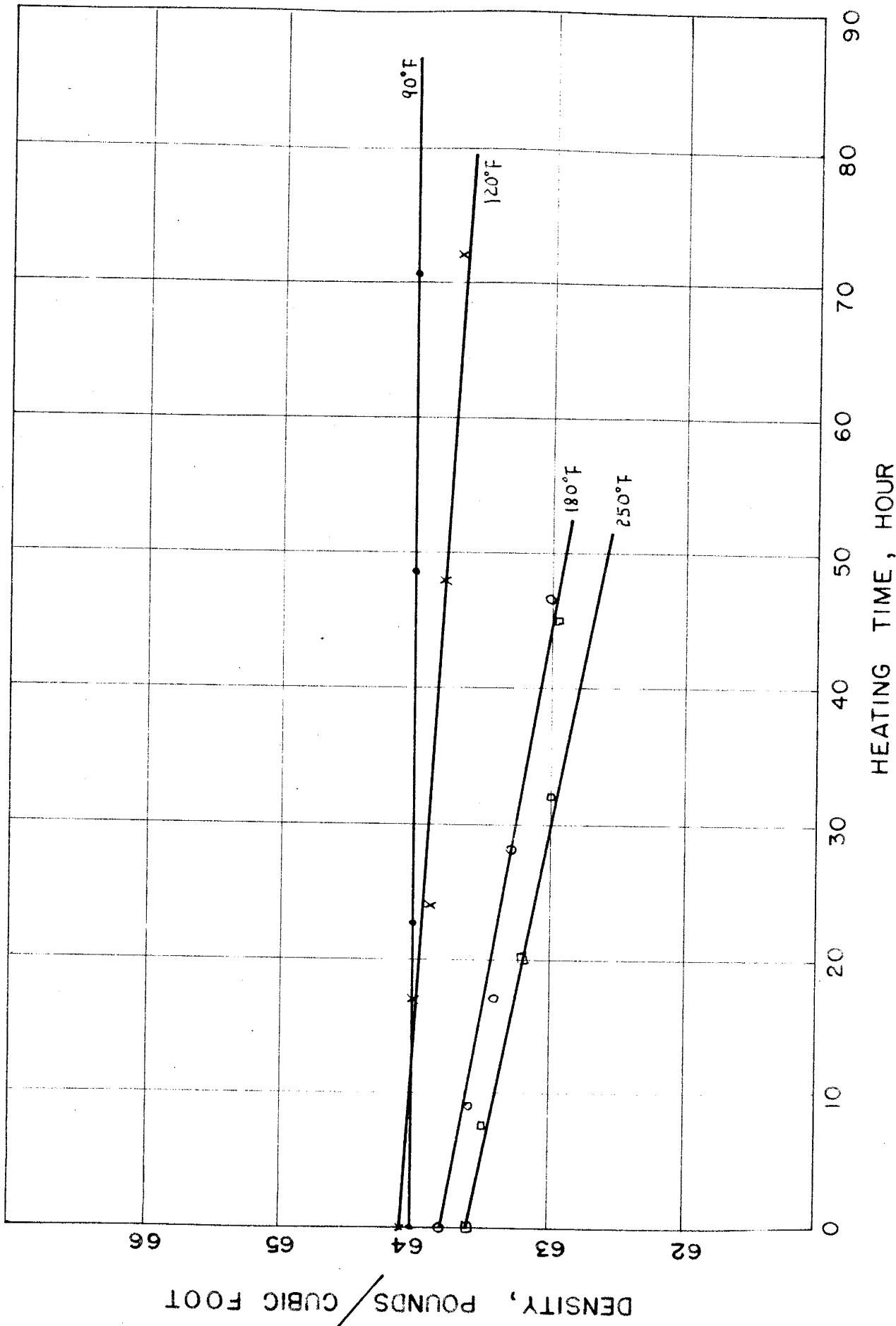


FIGURE II. THE RELATIONSHIP BETWEEN THE VISCOSITY AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

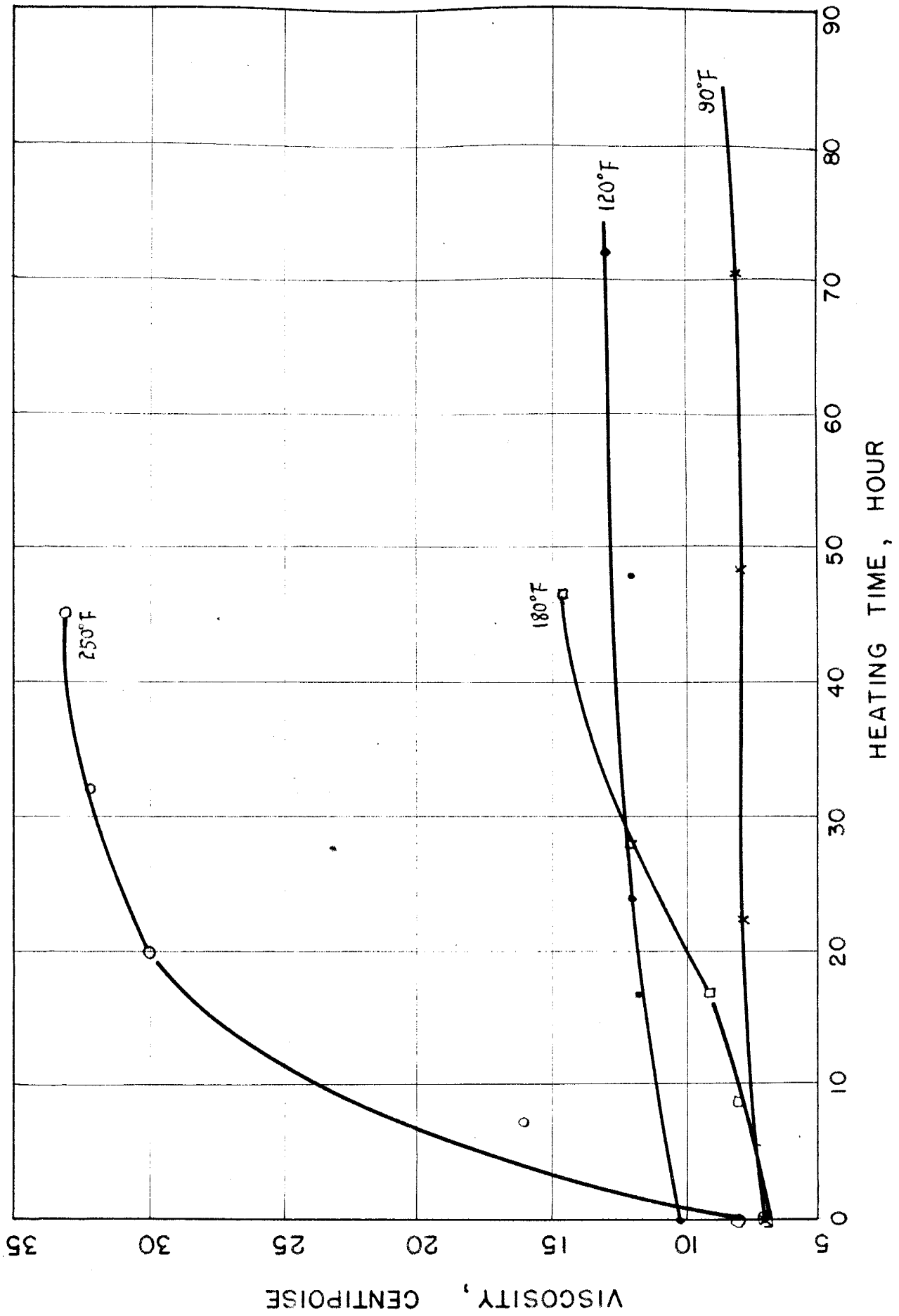


FIGURE III. THE RELATIONSHIP BETWEEN THE RATE OF FILTRATION AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

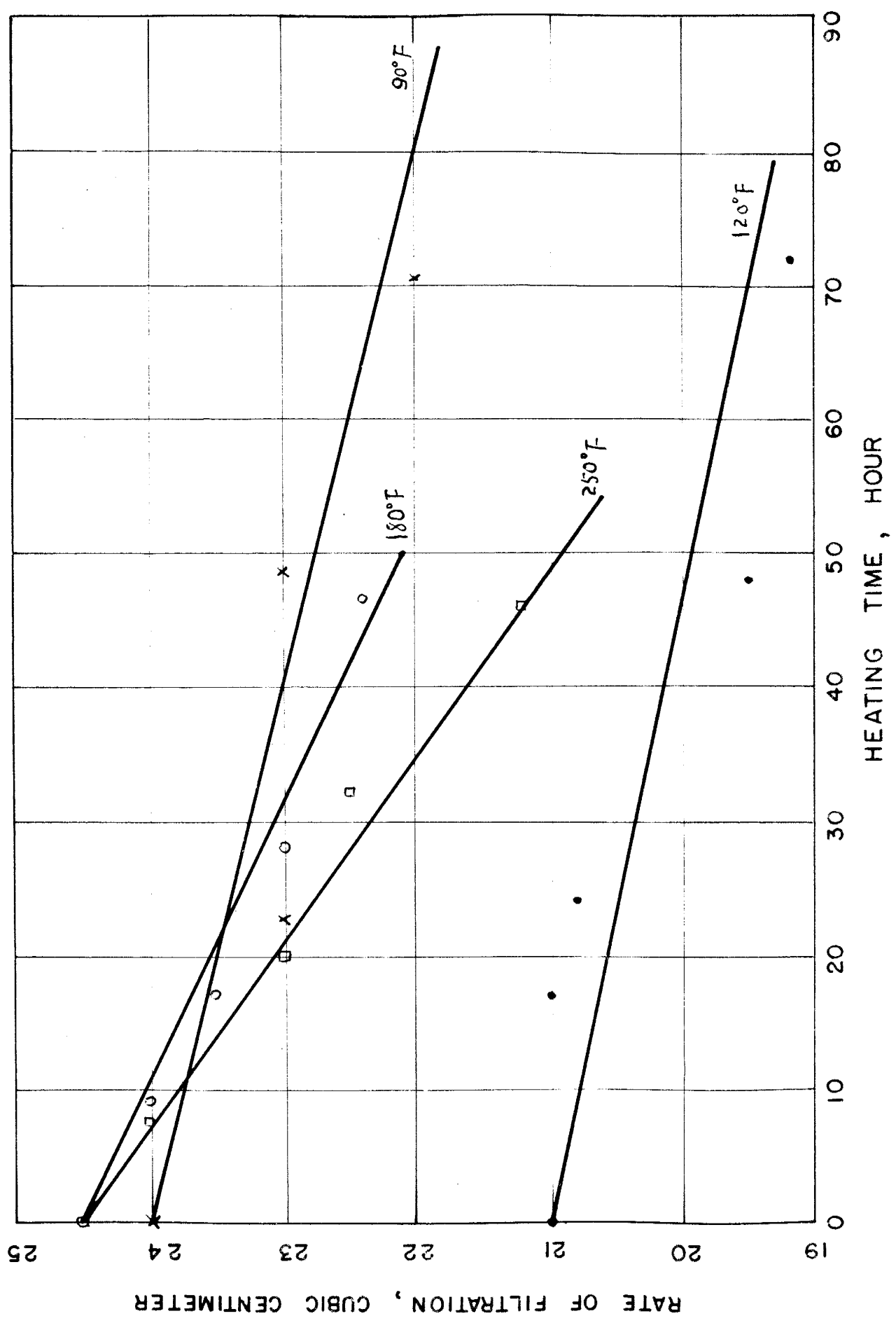


FIGURE IV. THE RELATIONSHIP BETWEEN THE INITIAL GEL STRENGTH AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

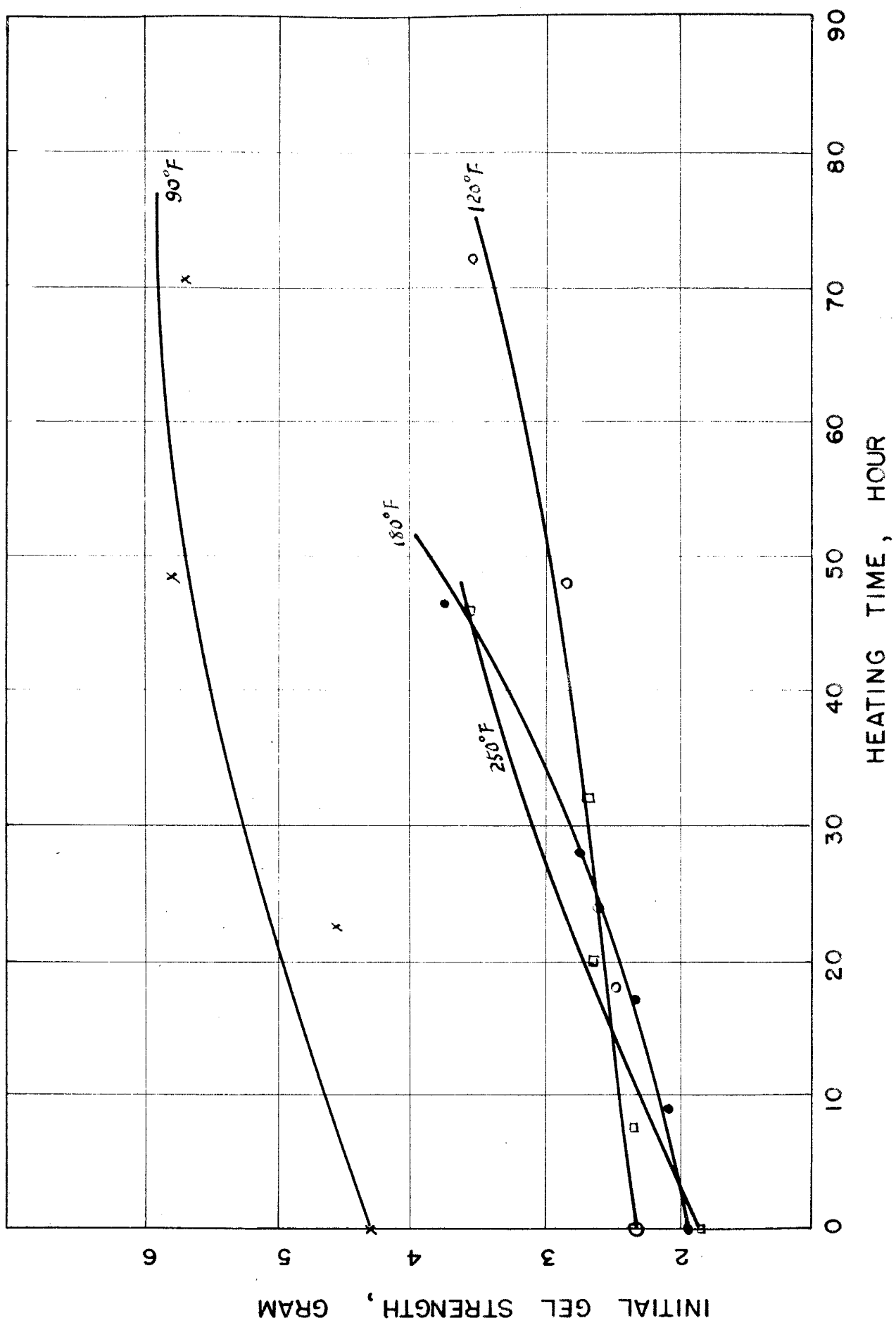


FIGURE V. THE RELATIONSHIP BETWEEN THE TEN MINUTES GEL STRENGTH AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

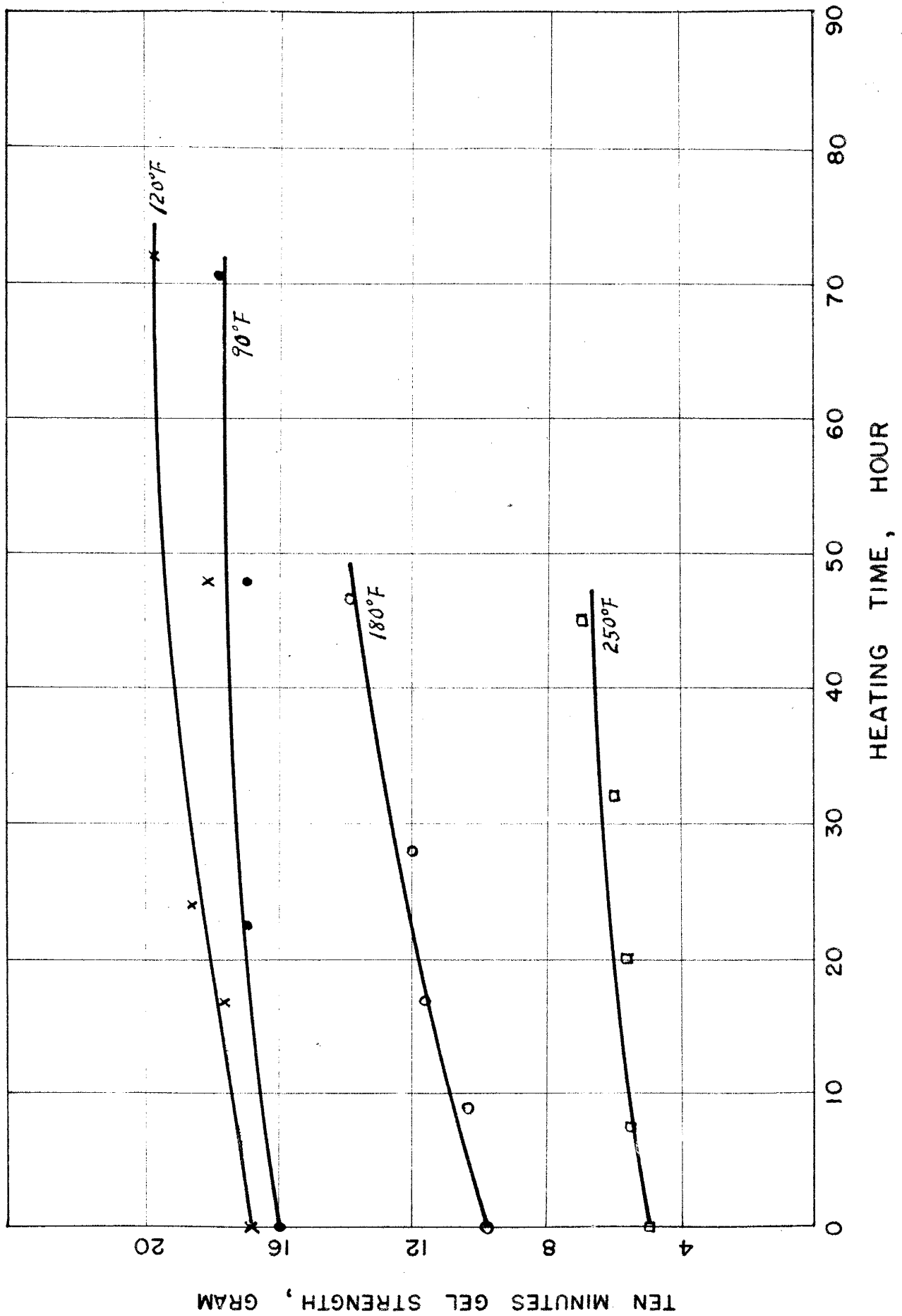


FIGURE VI. THE RELATIONSHIP BETWEEN THE THICKNESS OF FILTER CAKE AND HEATING TIME FOR DIFFERENT TEMPERATURES (AQUAGEL FLUID)

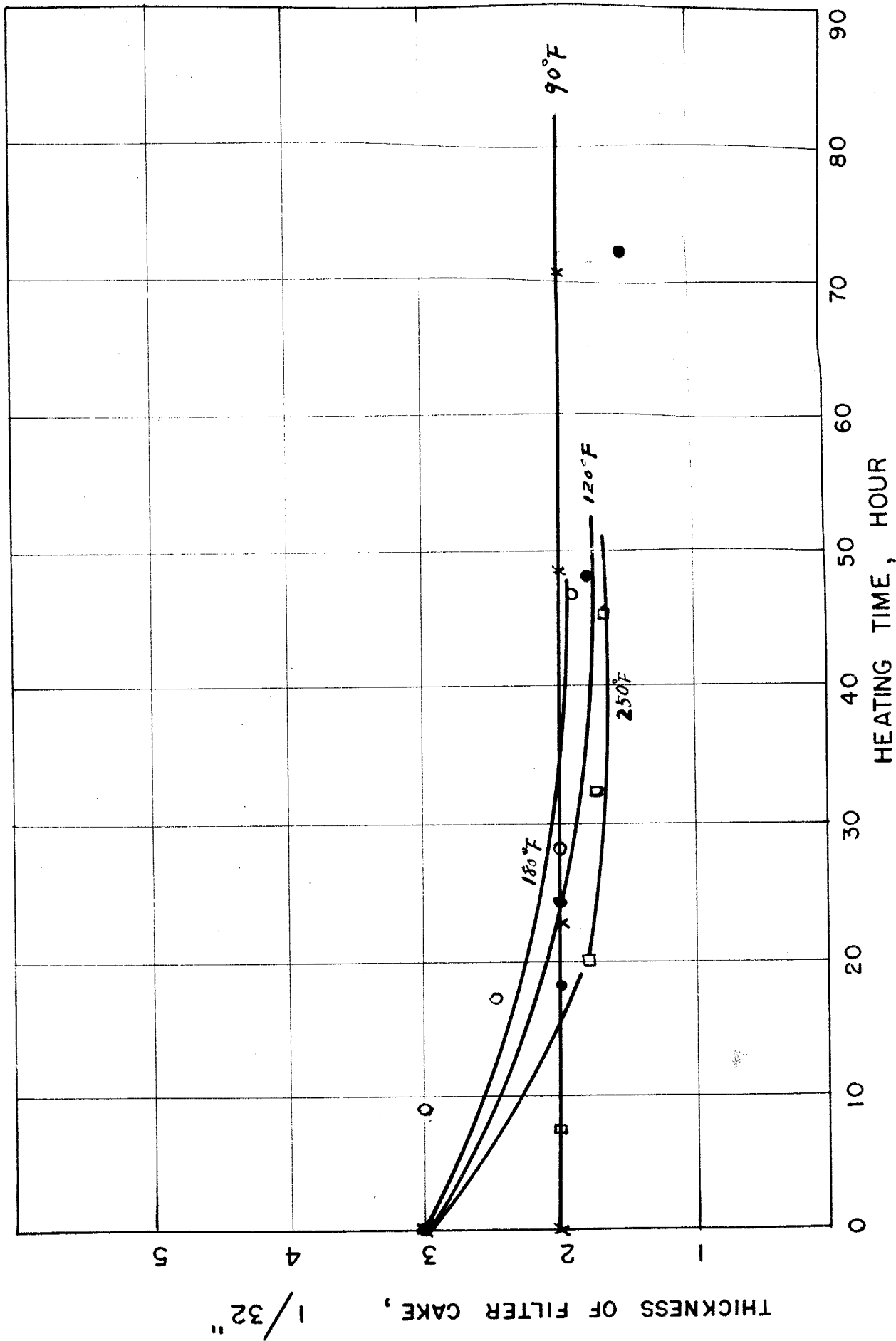


FIGURE VII. THE RELATIONSHIP BETWEEN THE DENSITY AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)

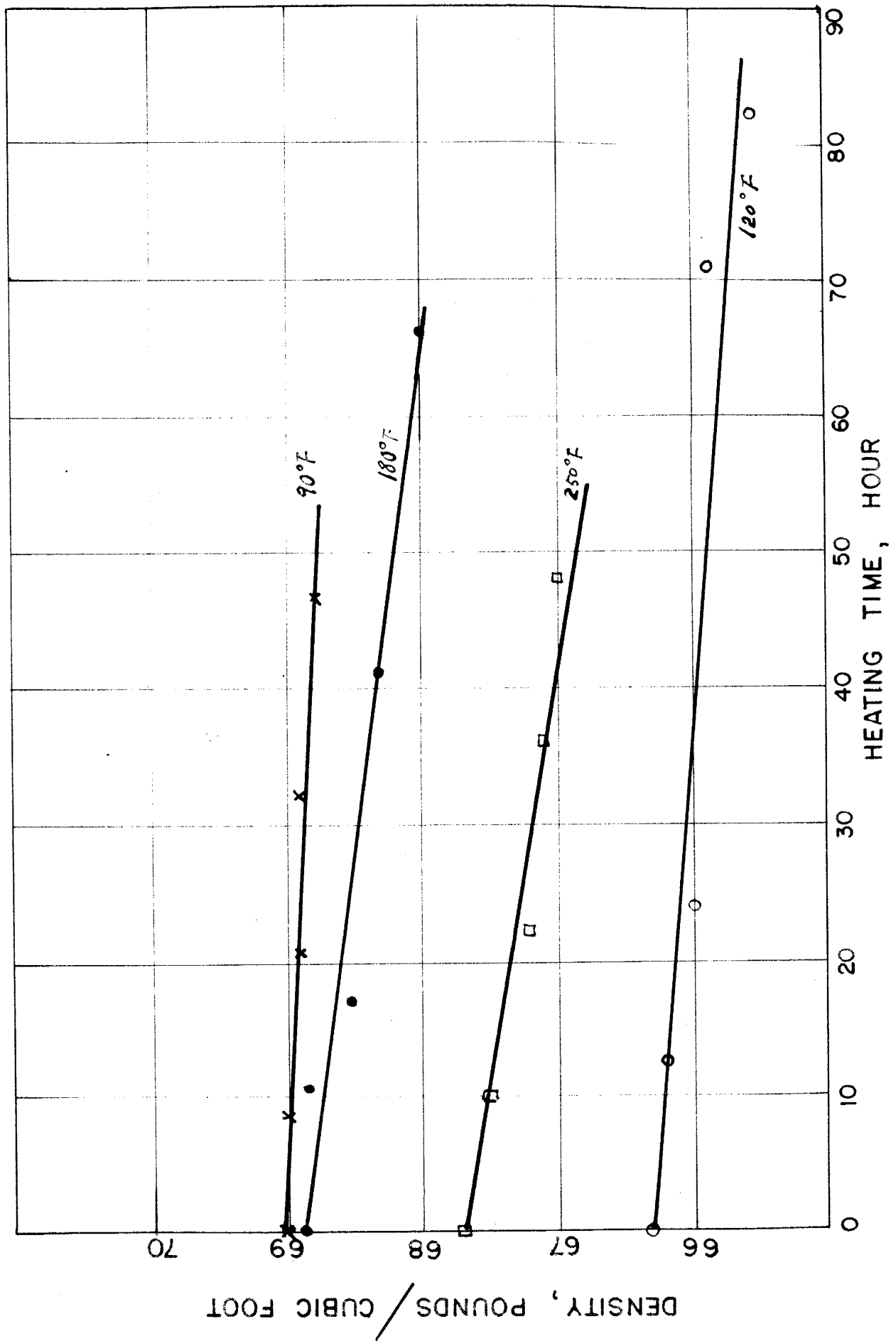


FIGURE VIII. THE RELATIONSHIP BETWEEN THE VISCOSITY AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)

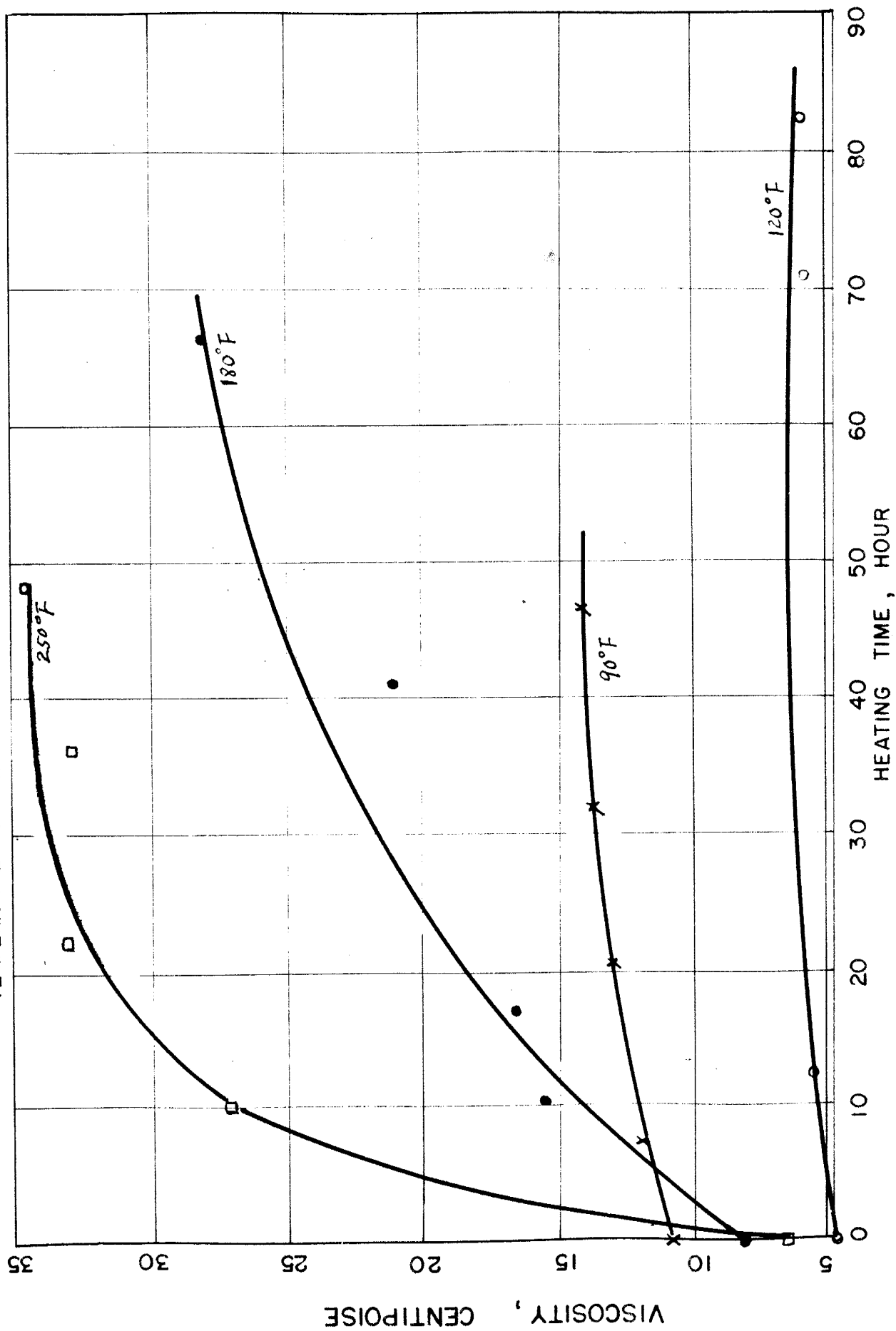


FIGURE IX. THE RELATIONSHIP BETWEEN THE RATE OF FILTRATION AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)

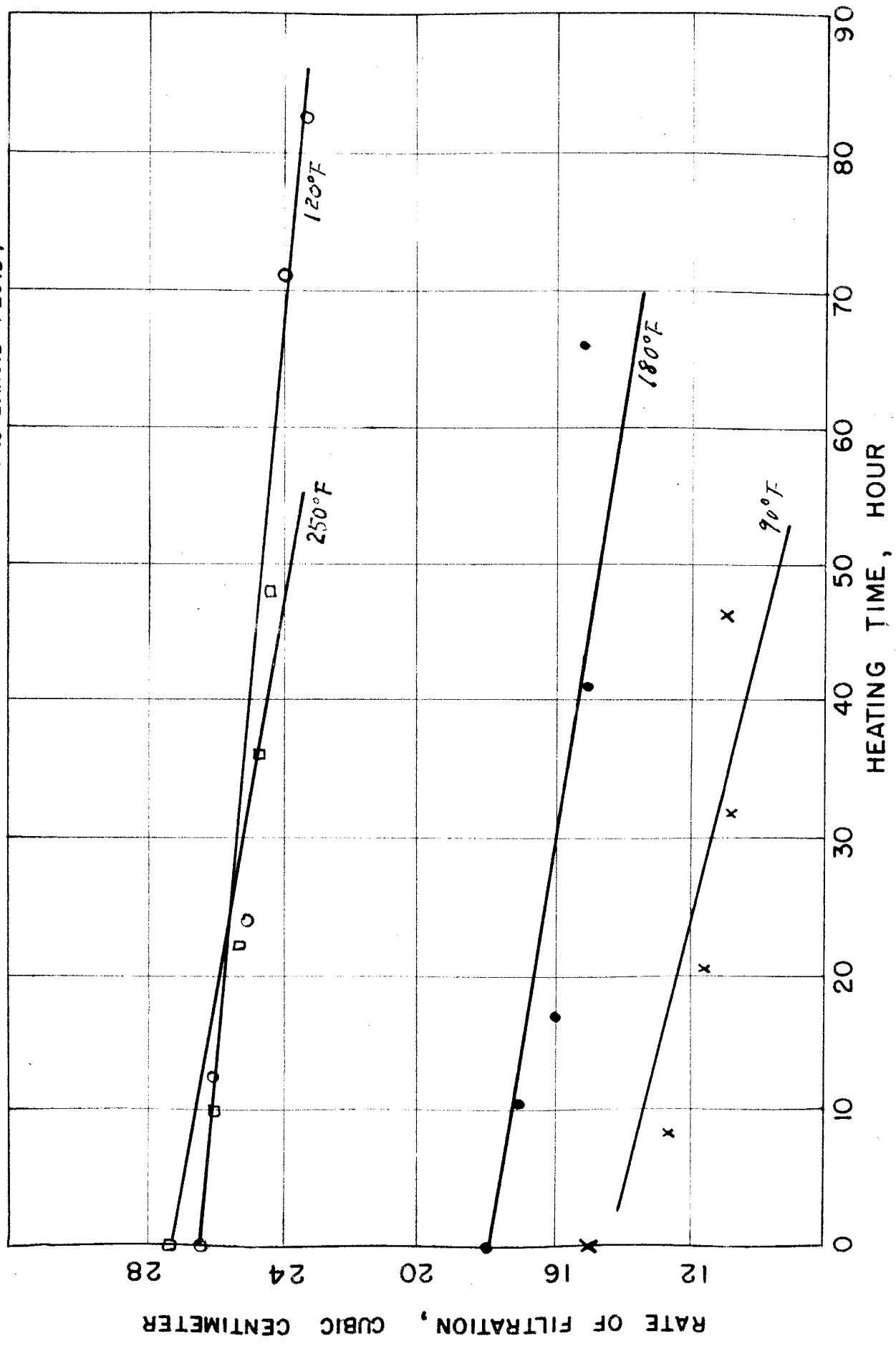


FIGURE X. THE RELATIONSHIP BETWEEN THE INITIAL GEL STRENGTH AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)

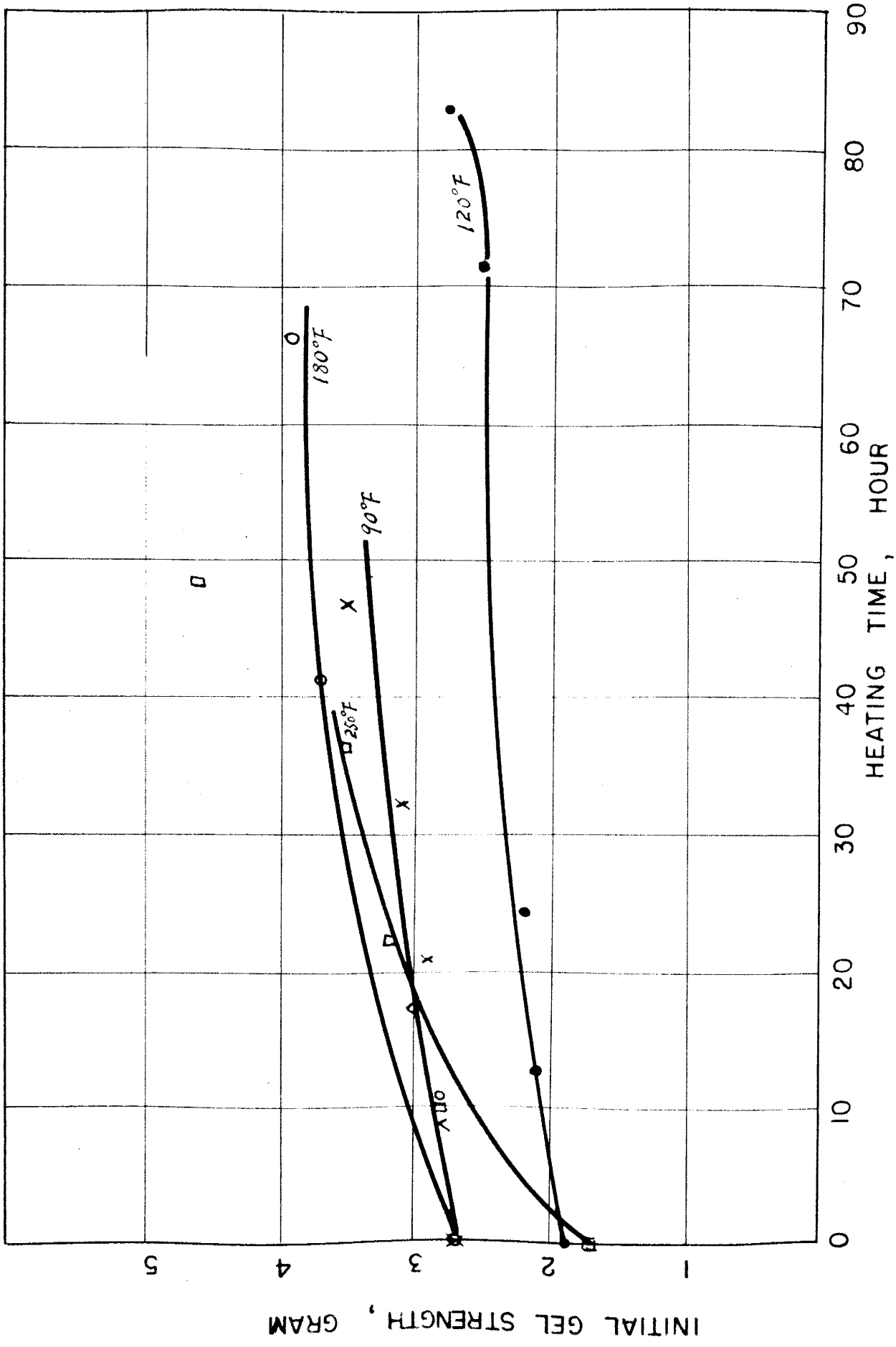


FIGURE XI. THE RELATIONSHIP BETWEEN THE TEN MINUTES GEL STRENGTH AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)

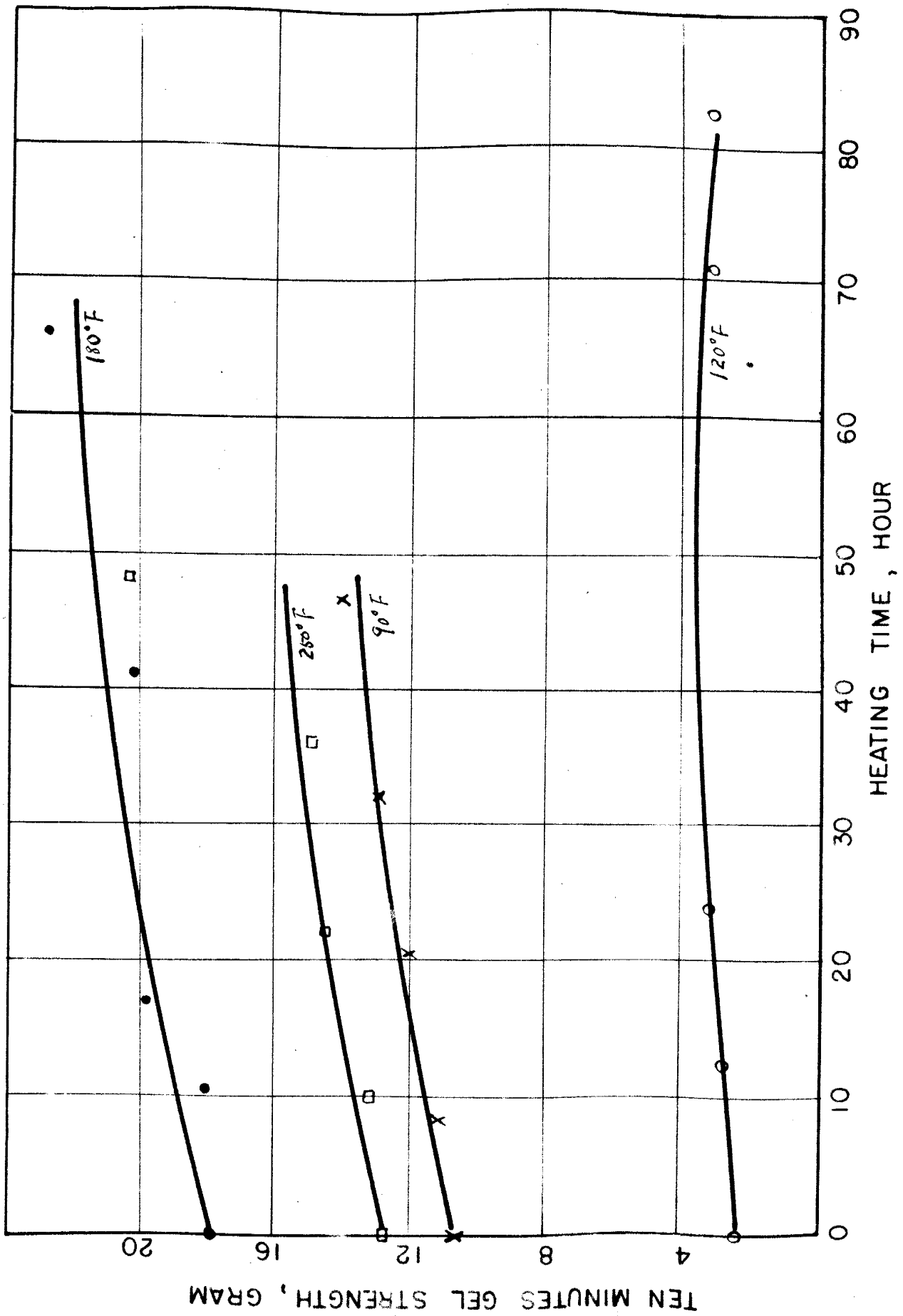
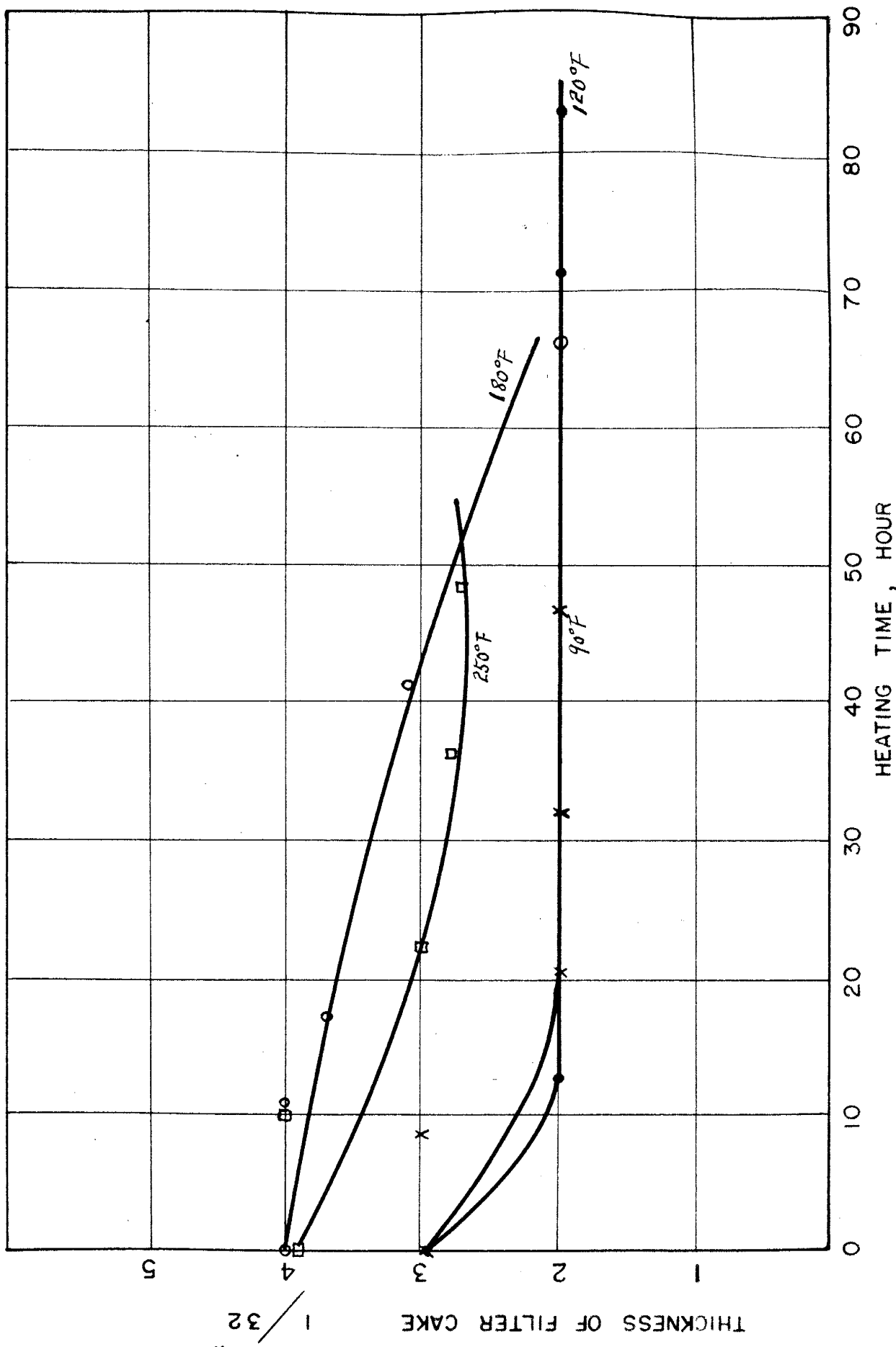


FIGURE XII. THE RELATIONSHIP BETWEEN THE THICKNESS OF FILTER CAKE AND HEATING TIME FOR DIFFERENT TEMPERATURES (30% AQUAGEL AND 70% BAROID FLUID)



DISCUSSION OF RESULTS

The laboratory investigations showed that the physical properties of these three drilling fluids were changed due to aging at different elevated temperatures. These results can be explained as follows:

1. Density.

(1). The Montmorillonite Fluid: Its density was slightly increased with temperature rise.

From the thermal analysis curve of montmorillonite mineral, which was tested by Paul Kintzinger in 1955, it can be seen that the phase change of such mineral's structure begins at a temperature of 284°F (140°C). Hence, the changes of density of montmorillonite fluid cannot be explained due to a phase change of its structure because the heating temperature of such fluid in the laboratory was too low (it was 250°F, lower than 284°F) for a phase change to take place. However, it was found that the volume of the fluid in the container decreased slightly after heating in the electrical oven at 180°F and 250°F respectively. The increase in density at such temperature can be explained as due to the leakage of the gasket of container (since in laboratory work, the gasket of container was found deformed at higher temperatures).

Vaporization of a part of the liquid phase of the fluid probably happened at elevated temperatures. However, the changes of density was very small, about one percent.

(2). The Aquagel Fluid: Its density was decreased with temperature rise.

From laboratory work, it was found that the volume of Aquagel fluid in the container increased slightly after heating. This phenomenon can be used to explain the decrease in density of the Aquagel fluid. The density of the fluid depends upon the specific gravity and amount of the suspended solids in the fluid. For the Aquagel, which is a kind of bentonite, particles sizes are unusually small and it has the unique characteristic of swelling to several times its original volume when placed in water. Some of these small particles are aggregated together, but, after heating such aggregations may be broken down to individual particles; therefore, the total number of Aquagel particles in the fluid increases. The volume of the fluid in the container is increased, and the density of the Aquagel fluid is decreased.

(3) The 30% Aquagel and 70% Baroid Fluid: Its density was decreased with temperature rise.

Since Baroid is a commercial barium sulphate which is a drilling fluid weighting material. It cannot be used alone because it gives very high filter loss and thick cake. The Aquagel-Baroid fluid responded to heating, having the same changes of density as the Aquagel did. This result can be explained by the same line of reasoning given for the Aquagel fluid described above.

2. Viscosity.

(1). The Montmorillonite Fluid: Its viscosity decreased with temperature rise.

As mentioned previously the viscosity of the drilling fluid depends upon the amount and size of the solid particles suspended in the fluid. For the montmorillonite fluid, it is possible that the amount and size of the solid particles in the fluid probably change due to hydration caused by the aging process at elevated temperature. Hence, the viscosity of montmorillonite fluid decreases with temperature rise.

(2). The Aquagel Fluid: Its viscosity increased with temperature rise.

It is known that Aquagel is a specially processed high grade Wyoming bentonite. From laboratory work, it was found that a small amount of Aquagel is required to provide prescribed viscosity. When suspended in water, it will exist in the form of individual clay particles and aggregates of particles. As the temperature is raised, there is a tendency toward a more complete dispersion of the Aquagel particles, and the aggregates will break down to their individual components. Therefore, the total amount of particles of the Aquagel fluid is increased. This is probably the major factor involved in increasing the viscosity of the Aquagel fluid.

(3). The 30% Aquagel and 70% Baroid Fluid: Its viscosity increased with temperature rise.

This result can be explained using the same reason described for the Aquagel fluid.

3. Gel Strength.

(1). The Montmorillonite Fluid: Its gel strength, both initial and ten-minute, decreased with temperature rise.

The gel strength of drilling fluid is a measure of the property of thixotropy which depends upon the size, form, arranging figure, and amount of the suspended solids in the fluid. There is a tendency that these factors in the montmorillonite fluid will be changed due to hydration and dispersion of the solid particles, caused by the aging process at elevated temperatures. This is probably the main reason for the decrease in gel strength of the montmorillonite fluid.

(2). The Aquagel Fluid: Its gel strength, both initial and ten-minute, increased with temperature rise.

As mentioned previously, the total number of finely divided particles in the Aquagel fluid will be increased due to the aging process at elevated temperatures. Therefore, the open space among the dispersed particles in the Aquagel fluid is decreased. In other words, the suspended solid particles in the fluid are closer together. Hence, a thixotropic structure in the Aquagel fluid occurs, and an increase in gel strength will result.

(3). The 30% Aquagel and 70% Baroid Fluid: Its gel strength, both initial and ten-minute, increased with temperature rise.

It can be explained using the same reason described in the foregoing paragraphs.

4. Rate of Filtration and Thickness of Filter Cake.

(1). The Montmorillonite Fluid:

Its rate of filtration and thickness of filter cake were increased with temperature rise.

Generally speaking, the filtration rate and thickness of filter cake are indicative of colloidal properties of drilling fluids. The general filtration behavior of drilling fluid is influenced by the kind, concentration, and particles size of solids present in the fluid. Filtration rates are also influenced by the dispersion of particles in the fluid, the hydration of particles, the presence or absence of hydrated colloidal particles and presence or absence of dispersing or agglomerating chemicals. There are two steps in the process of filtration;

- a. Bridging of openings in the filter medium.
- b. Filtering of fluid through the filter cake that develops on the filter medium as filtration takes place.

Most drilling fluids which do not contain enough finely divided minerals will be unable to bridge the openings and might have poor filter loss properties.

For the montmorillonite fluid, there is a tendency that the size, and amount of fine particles in the fluid will change due to the aging process at elevated temperatures. Then, the possibility of bridging the openings in the filter medium is relatively decreased, and the rate of filtration will increase. The filter cake is made by the deposition of the colloidal particles of the fluid, **these** particles follows, the liquid phase of drilling fluid which being squeezed from the fluid into the surrounding formation, and leaving these colloidal particles to deposit as a cake on the wall of the well. So

that the greater the rate of filtration, the thicker will be the filter cake, and also the greater the permeability of the filter medium, the greater will be the rate of filtration.

(2). The Aquagel Fluid: Its rate of filtration and thickness of filter cake were decreased with temperature rise.

The Aquagel fluid has a tendency toward a more complete dispersion of its colloidal particles resulting from the aging process at elevated temperatures. Some of its aggregates of particles will break down into individual small ones. Therefore, the total number of finely divided particles in the fluid is increased, which means more fine particles are able to bridge the openings in the filter medium. Then the permeability of the filter medium decreases and the rate of filtration will decrease, also the thickness of filter cake will reduce.

(3). The 30% Aquagel and 70% Baroid Fluid: Its rate of filtration and thickness of filter cake were decreased with temperature rise.

It can be explained using the same reason described for the Aquagel fluid.

From the experimental data, there is a marked difference between the montmorillonite fluid and the Aquagel and Aquagel-Baroid fluid in their response to aging at elevated temperatures. It would appear that the montmorillonite particles coagulate on aging while the Aquagel particles break up into finer particles. Since the Aquagel is largely Wyoming bentonite and probably a montmorillonite type clay, how can one explain the difference in physical properties due to aging process at

elevated temperatures?

The montmorillonite clay, extracted from a deposit near Socorro, is a relatively pure clay. It is estimated from data obtained by electrodialysis by Dr. Schufle that less than one out of every four exchange positions carries an exchangeable cation. Particles of this clay should be relatively free of absorbed ions, therefore relatively uncharged, and tend to coagulate on aging at high temperature.

The Aquagel, on the other hand, is a commercial bentonite clay probably treated with salt solution. In water suspension, the Aquagel particles would carry relatively large amounts of absorbed ions, and be relatively highly charged. Therefore, they tend to repel each other. On aging at elevated temperatures the Aquagel particles would break up into smaller particles due to thermal agitation, and the charges carried would prevent these finer particles from coagulating.

CONCLUSION

From the results of laboratory work, some conclusions concerning the effect of aging at elevated temperatures on the physical properties of drilling fluids can be drawn as follows:

1. The density change, either increase or decrease, of clay-water drilling fluids with temperature rise is not an important factor to be considered in the making of special drilling fluids suitable for high temperature formation drilling, because the density of the fluid is not changed enough to influence appreciably the drilling operation.

2. Suitable amount of bentonite must be mixed with the ordinary clay-water fluid for making special fluids for high temperature formation drilling, because bentonite provides proper physical properties which enable the drilling fluid to perform the functions for deep well drilling.

3. Chemical and physical reagents may be used to treat the drilling fluids for deep well drilling; however, they must provide the following important characteristics:

- (1). Suppression of swelling and dispersion of bentonite clays which are used to increase viscosity.

- (2). Retention of good filtration property at high temperatures.
- (3). Suppression of tendencies of the drilling fluids to set at high temperatures.

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