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A STUDY OF INVERT EMULSION DRILLING FLUIDS

BY

EDWARD ROLAND TEGLAND

A

THESIS

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ABSTRACT

Since invert emulsions are being applied as drilling fluids to cope with special drilling and completion problems, evaluations of existing and new types of emulsions are needed. Three types of emulsions are evaluated in this study: (1) type A emulsions prepared with a commercial emulsifier, (2) type B emulsions prepared by adding clay to the external phase, and (3) type C emulsions containing no externally added emulsifier.

Standard testing procedures were used to measure the viscosity and filtration properties of the emulsions studied. Interfacial tension measurements were made using a technique described in the literature. The degree of stability for the emulsions studied was determined by the viscosity ratio method developed during this study.

A discussion of the effects of some of the recognized variables on the properties mentioned above is presented. The three types of emulsions studied are compared on the basis of the effects of the variables and on theoretical considerations.

Type A emulsions as investigated were found to be suitable for all conditions under which the use of an invert emulsion fluid is warranted. Type B emulsions as investigated were found to be suitable only over a narrow range of temperatures and phase volume ratios. Type C emulsions exhibited excessive filter losses over all phase volume ratios investigated and were eliminated from further consideration on this basis.

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INTRODUCTION

In recent years, laboratory work and field experience have shown that a number of the more generally encountered oil producing formations exhibit a decreased permeability to oil after being exposed to water or water base drilling fluids (1,2,3,4).^{1/} In order to eliminate this undesirable effect, oil base fluids of two types are used: (1) fluids originally composed only of oil which is mixed with organophyllic clay material, lost circulation materials, and possibly small quantities of water-in-oil emulsifier, and (2) invert emulsion fluids which contain up to sixty percent water emulsified in either crude oil or a partially refined product such as uncracked diesel oil. Of these two basic types, the invert emulsion may be considered preferable in that it has a very high flash point, low filtration rate, and is much cleaner to handle than a comparable all oil base fluid produced from the same type of oil.

Field and laboratory studies have been conducted to determine the properties and effectiveness of invert emulsion drilling fluids. These studies were conducted under the direction of the companies that supply drilling fluid materials; therefore, most of them represent an evaluation of a specific product or products.

The purpose of the present study was to evaluate the properties of emulsion systems prepared with one of the more common commercial emulsifiers and a specified combination of oil and water (5). Additional investigations were carried on to determine the nature of systems prepared with the same oil and water with no emulsifier added and with a high yield clay added to the oil phase. The results of these investigations were

^{1/}Numbers in parentheses refer to items in the bibliography.

compared and correlations made with established principles of emulsion theory in an effort to determine the applicability of the latter two types of emulsification to drilling fluids. Should the emulsions prepared either with no emulsifier or with clay added to the oil phase prove successful as drilling fluids, a considerable saving on the initial make up costs of a field drilling fluid might be realized.

It was necessary during the course of this study to devise a method other than the commonly used electrical measurement to determine the stability of the systems investigated (3). This was necessary in order to provide a stability measurement which was diagnostic of conditions existing during the use of the emulsion as a drilling fluid.

THEORETICAL CONSIDERATIONS

In general, an emulsion may be formed by simply dispersing the internal phase in droplets fine enough that Brownian movement is sufficient to prevent gravitational separation (6). However, the interfacial tension between the two phases in an unstabilized system as described above is often great enough to bring about coalescence of the dispersed phase. The droplets of dispersed phase eventually enlarge sufficiently to be essentially unaffected by Brownian movement, and gravitational separation takes place. In order to permanently stabilize the system, agents may be added to one or both phases to reduce the interfacial tension to such an extent that coalescence of the dispersed phase is greatly inhibited. Interfacial tension provides a measure of the usefulness of a material as an emulsifier since the better emulsifiers will provide lower interfacial tension between the phases.

In general, the emulsifier forms a thin film about the interface. According to Berkman, this interfacial film should have the nature of a

plastic solid instead of a viscous liquid for conditions of maximum stability (7). She points out that a liquid film would be deformed by a force of any magnitude, while a plastic solid type of film will flow only when subjected to large shearing forces but may withstand readily small forces. Thus the liquid films eventually allow the dispersed droplets to flow together under the force of interfacial tension while the probability of such action when the film is a plastic solid is greatly reduced.

The viscosity of an emulsion is generally conceded to be in direct proportion to the viscosity of the external phase of the system (7,8,9,10, 11). The viscosity of the external phase is assumed to be the viscosity of the liquid itself with any emulsifiers that may be added. The viscosity of the internal phase contributes an indeterminate amount to the viscosity of the system, since the general assumption is that the dispersed phase droplets react as solid spheres to any shear forces imposed on the system (7).

The effect of phase volume ratio (volumetric ratio of the dispersed to the continuous phase) is probably next in importance to the viscosity of the external phase in its contribution to the viscosity of the system. As the phase volume ratio increases, the ability of the dispersed phase droplets to move relative to one another in the external medium, under the influence of shearing stress, is greatly reduced and the viscosity of the system increases. This process continues until the limiting phase volume ratio or inversion point is reached. At this point a sharp decrease in viscosity of the system is often noted, due to the sudden decrease in phase volume ratio which is attendant to inversion (8). If the emulsion does not invert, the limiting phase volume ratio may be marked by the inability of the emulsion to hold any additional quantity of dispersed phase. Theoretically, inversion should occur at a phase

volume ratio of about 74/26, however, this assumes maximum density packing of equal sized spheres of dispersed phase. Such a condition is seldom attained, and in most cases inversion occurs at a phase volume ratio somewhat higher than the theoretical.

Viscosity is to some degree influenced by the nature of the emulsifier film deposited at the interface. The mechanism by which this takes place is not clearly understood and is probably a function of the attraction between the emulsifier film and the continuous phase. As this force of attraction increases, the ability of the dispersed droplets to move under shear stress is decreased (6). The actual magnitude of this effect in a given system, as well as the effect of particle size distribution on viscosity are not readily determined. However, experience has shown that homogenization of the system tends to increase viscosity, while emulsions having a wide range of particle sizes are usually of lower viscosity (11).

The age of any given emulsion system also has an effect on both the stability and viscosity of that system. The effects of age are mainly due to changes in emulsifier films which are not readily defined, changes in particle size distribution towards less homogeneity, and possible variation of phase volume ratio and external phase viscosity.

The viscosity temperature relationship for a given system is believed by some investigators to provide a measure of the stability of that system (7). The logic behind this idea relies on the validity of a relationship in the form of Einstein's equation for emulsion viscosity as stated in slightly modified form in equation 1 (9).

$$\eta_f = \eta_e (1 + A\phi) \dots\dots\dots \text{Equation 1}$$

In this equation, n_f is the viscosity of the emulsion, n_e is the viscosity of the external phase, Q is the phase volume ratio fraction, and A is a constant evaluated experimentally for a given system and is largely dependent on the type and concentration of the emulsifier and on the particle size and size distribution of the dispersed phase.

In using the viscosity ratio method of stability estimation, the viscosity of the emulsion is measured at various temperatures and divided by the external phase viscosity at the same temperatures. The ratio formed in this manner should be essentially constant for a given system under constant conditions of homogeneity and age. If, however, the phase volume ratio is decreased at any temperature step due to a tendency toward instability or there is a decrease in homogeneity, the ratio will decrease and approach one as a limit. Other variations in viscosity ratio might arise from the method of making the viscosity measurement, however, in most cases such changes would be recognized and be taken into account when interpreting the data. In the case of drilling fluid testing, such a method of evaluating stability would be much more applicable than the electrical stability measurements that have been used in the past. The electrical method of determining stability requires that the dispersed droplets possess an electrical charge. This condition is not always met by all emulsions; and Becher states that some investigators are of the opinion that in many cases the droplets of a water-in-oil emulsion have no electrical charge (9). Furthermore, the electrical measurement imposes a number of arbitrary conditions on interpretation of the stability obtained which reflect no conditions present in the borehole during usage of the emulsion as a drilling fluid. The viscosity ratio method, on the other hand, evaluates the effects of temperature conditions which correspond to temperature conditions in the borehole during drilling.

An asphalt base crude oil was selected as the external phase of the systems because the contained asphaltic materials form excellent natural emulsifiers and the crude oil would lend itself well to investigation of systems containing no added emulsifier. Similarly the selected crude oil is well adapted to studies involving addition of finely ground clay to the external phase, since the asphaltic materials tend to be adsorbed on the clay particles creating a colloid within the oil which forms films of greater rigidity about the interfaces of the dispersed water droplets than the films of asphalt itself (6,7,12).

The water phase consisted of a solution of commercial grade sodium chloride in distilled water. In all systems the concentration of this solution was 20,000 parts per million sodium chloride. The electrolyte and relative concentration used have no significance other than they were selected simply to provide a basis for comparison between all systems investigated.

The commercial emulsifier investigated consists of a mixture of clay, emulsifying agents, salts and stabilizers. The exact chemical composition of any of the ingredients is not readily available at the present time. This particular emulsifier was selected merely because more literature pertaining to its performance is available at present. This allows a greater range of comparisons to be drawn between the present work and work already reported.

LABORATORY PROCEDURE

The procedure used to evaluate some of the properties of invert emulsion drilling fluids was selected to provide close correlation with actual field usage and published laboratory information. The physical properties studied in this investigation were: (A) viscosity, (B) stability, and (C) filtration. The variables considered in determining each of the physical properties were:

1. Phase volume ratio.
2. Emulsifier concentration.
3. Mixing time.
4. Aging.
5. Temperature.

Interfacial tension measurements were made to determine this property of the emulsions investigated.

The test emulsions studied were as follows:

Type A:

Oil phase: Asphalt base crude oil as described on page A-2 of the Appendix.

Aqueous phase: Solution of 20,000 ppm. commercial grade sodium chloride in distilled water.

Emulsifier: Commercial emulsifier, described under Theoretical Considerations, added to the oil phase (5).

Type B:

Oil phase: Asphalt base crude oil as described on page A-2 of the Appendix.

Aqueous phase: Solution of 20,000 ppm. commercial grade sodium chloride in distilled water.

Emulsifier: High yield, bentonitic, drilling clay added to the oil phase.

Type C:

Oil phase: Asphalt base crude oil as described on page A-2 of the Appendix.

Aqueous phase: Solution of 20,000 ppm. commercial grade sodium chloride in distilled water.

Emulsifier: No emulsifier was added externally to these emulsions.

All test samples were mixed with a rotary mixer (13). For each mixing, the stirring head of the mixer was placed in the same position, three inches to the left of the center of the mixing container. Mixing was commenced in every case with the water and oil in static contact, which allowed more precise comparisons to be made between various systems. All test samples were 10 bbl. equivalent pilot samples containing 3500 cc. of emulsion.

(A) Procedure used to determine apparent viscosity:

All viscosity measurements were made with a Stormer viscosimeter and units of Stormer grams obtained were converted to centipoise by means of a calibration chart prepared for the instrument.

1. Variations in phase volume ratio were obtained by varying the volume of aqueous phase used relative to the volume of oil phase.
2. Emulsifier types were stated previously in the portion of the Laboratory Procedure relating to composition of the types of systems. The concentration of emulsifier was determined in relation to the number of lb./bbl. that were used in preparing 1 bbl. of a given system.
3. The effect of mixing time on apparent viscosity was determined for 5, 10, and 15 minute periods of mixing.
4. Test systems used to determine the effect of aging on apparent viscosity were aged in glass containers. The range of aging

time considered was from 0 to 100 hours, with four viscosity measurements spaced through this period.

5. Variations in apparent viscosity with temperature were determined using a heated water bath to contain the Stormer viscosimeter cup.

(B) Procedure used in stability determinations:

Stability determinations were made using the viscosity ratio technique described under Theoretical Considerations. The apparent viscosity of the oil showed little change with variation in concentration of the emulsifier used for type A emulsions. Therefore, a single curve was fitted to the entire group of data for apparent viscosity of the oil and added emulsifier. Values of the apparent viscosity of the external phase at various temperatures were then taken from this relationship.

The temperature-viscosity data for the oil phase containing 10 to 20 lb./bbl. of clay were combined to form a single relationship from which values of apparent external phase viscosity for type B emulsions having emulsifier concentrations as stated were determined. The temperature-viscosity data for the oil with 30 lb./bbl. of clay showed large deviation from temperature-viscosity data for 10 and 20 lb./bbl. clay. Therefore, a separate relationship was used to determine the apparent viscosity of the external phase for type B emulsions having an emulsifier concentration of 30 lb./bbl.

Stability determinations were made using the same test systems that were used for viscosity measurements.

(C) Procedure used in filtration studies:

All filtration studies were made with a 350 cc. low pressure Baroid filter press. The standard procedure outlined in API Code 29 was followed in making these filtration studies (15). Temperature-filtration studies were made with the filter press suspended in a heated water bath.

The test systems used in the filtration studies were those used in the viscosity and stability studies.

(D) Procedure used in measuring interfacial tension:

A Cenco Du Nouy tensiometer, modified by adding a short length of platinum wire to connect the beam and ring stirrup, was used to measure interfacial tension between the aqueous and oil phases. The procedure used in making these measurements was discussed by Harkins and Jordan and is standardized for this type of instrument (16). This procedure differed from the normal technique for surface tension measurements in that the stirrup was submerged in the oil phase during the interfacial tension measurements and calibration of the instrument.

DISCUSSION OF RESULTS

The relation between phase volume ratio and apparent viscosity for all the systems studied proved to be similar to that found in studies conducted by others (1,2,3,4). An example of this relation for type A emulsions is shown in Figure 1. Numerous attempts were made to prepare a type A system with a phase volume ratio of 70/30; however, all such attempts resulted in incomplete emulsification of the aqueous phase over the range of emulsifier concentrations from 10 lb./bbl. to 40 lb./bbl. Figure 2 shows the relation between phase volume ratio and apparent viscosity for a typical type B emulsion. The apparent viscosity shown for a phase volume ratio of 65/35 is indicative of the high degree of instability shown by type B systems with this phase volume ratio. Type B systems having phase volume ratios of 70/30 were found to be completely unstable throughout the range of clay concentrations from 10 lb./bbl. to 40 lb./bbl., with gravitational separation of the phases taking place immediately after mixing was ceased.

Increases in emulsifier concentration brought about a general increase in the apparent viscosity of type A systems as shown in Figure 3. Similar results were reported by Lummus (2). On the other hand, increases in clay concentration in the oil phase of type B systems brought about only slight increases in viscosity as shown by Figure 4. In the case of type B systems having phase volume ratios of 60/40 and higher, there was a general tendency toward instability. A clay concentration of 20 lb./bbl. in the oil phase of the 60/40 type B system produced emulsions which were unstable to the point at which the dispersed phase coalesced during the course of the initial viscosity measurements, and no reliable viscosity data were obtained.

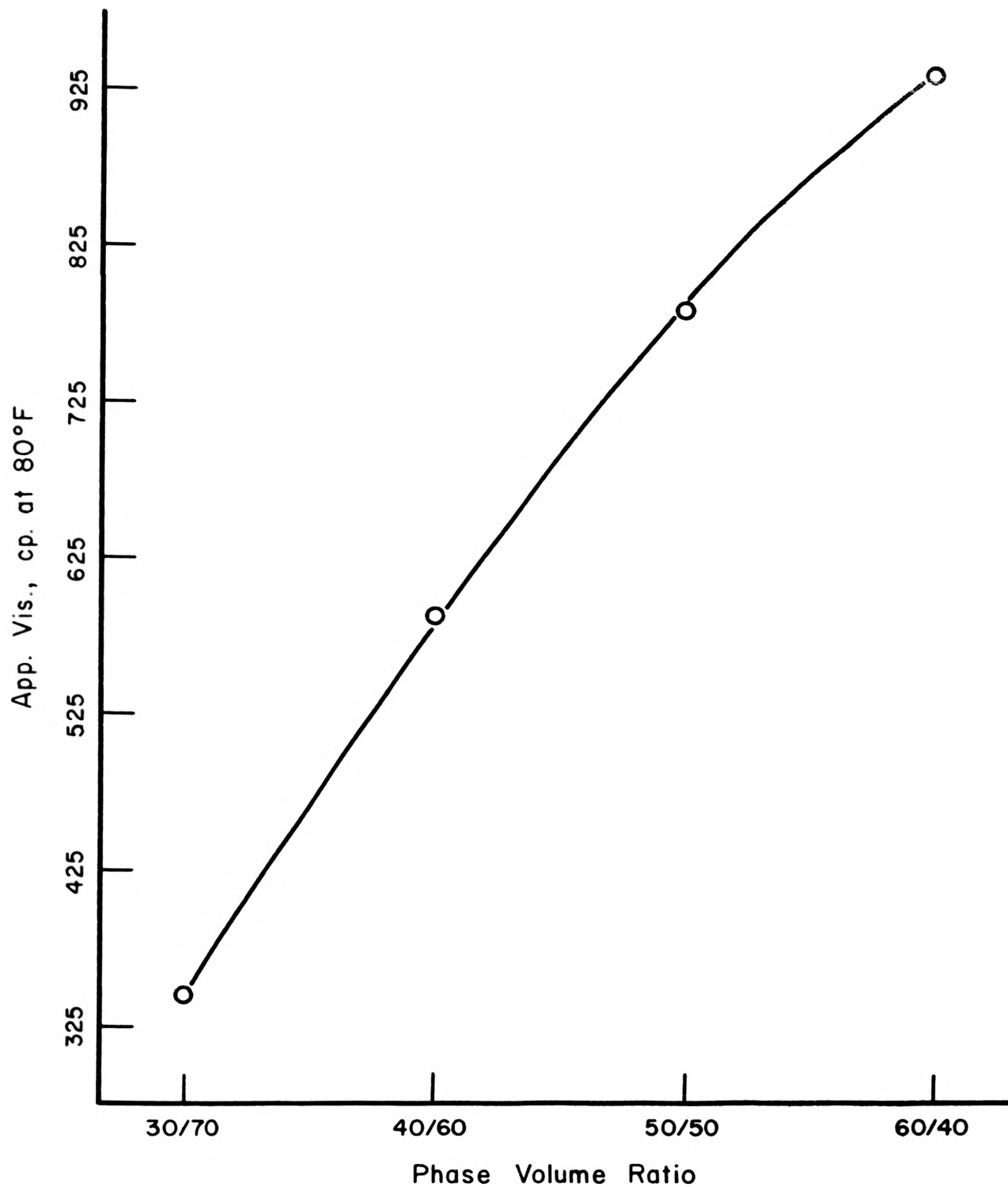


FIG. 1 - EFFECT OF PHASE VOLUME RATIO ON THE VISCOSITY OF TYPE A EMULSIONS

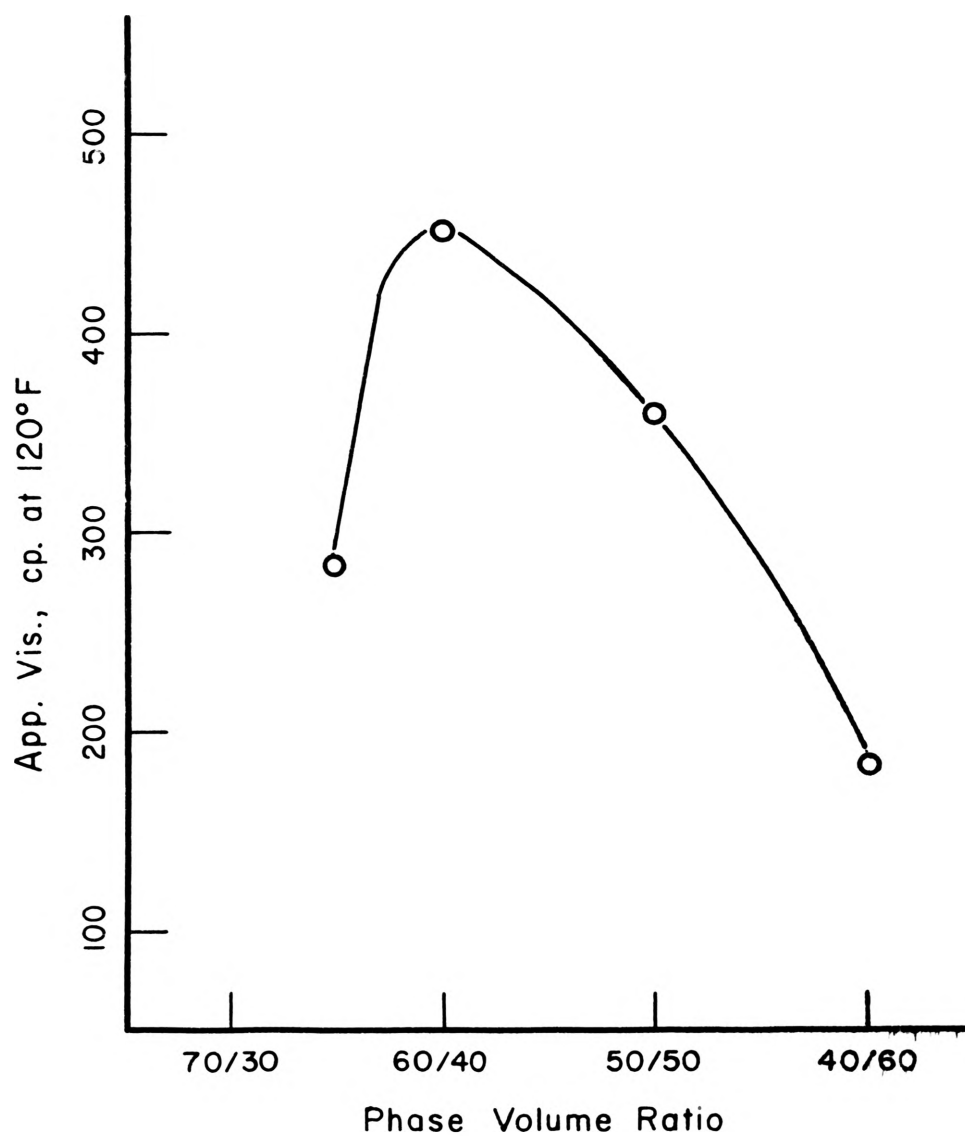


FIG. 2 - EFFECT OF VARYING P. V. R. ON VISCOSITY OF TYPE B EMULSIONS

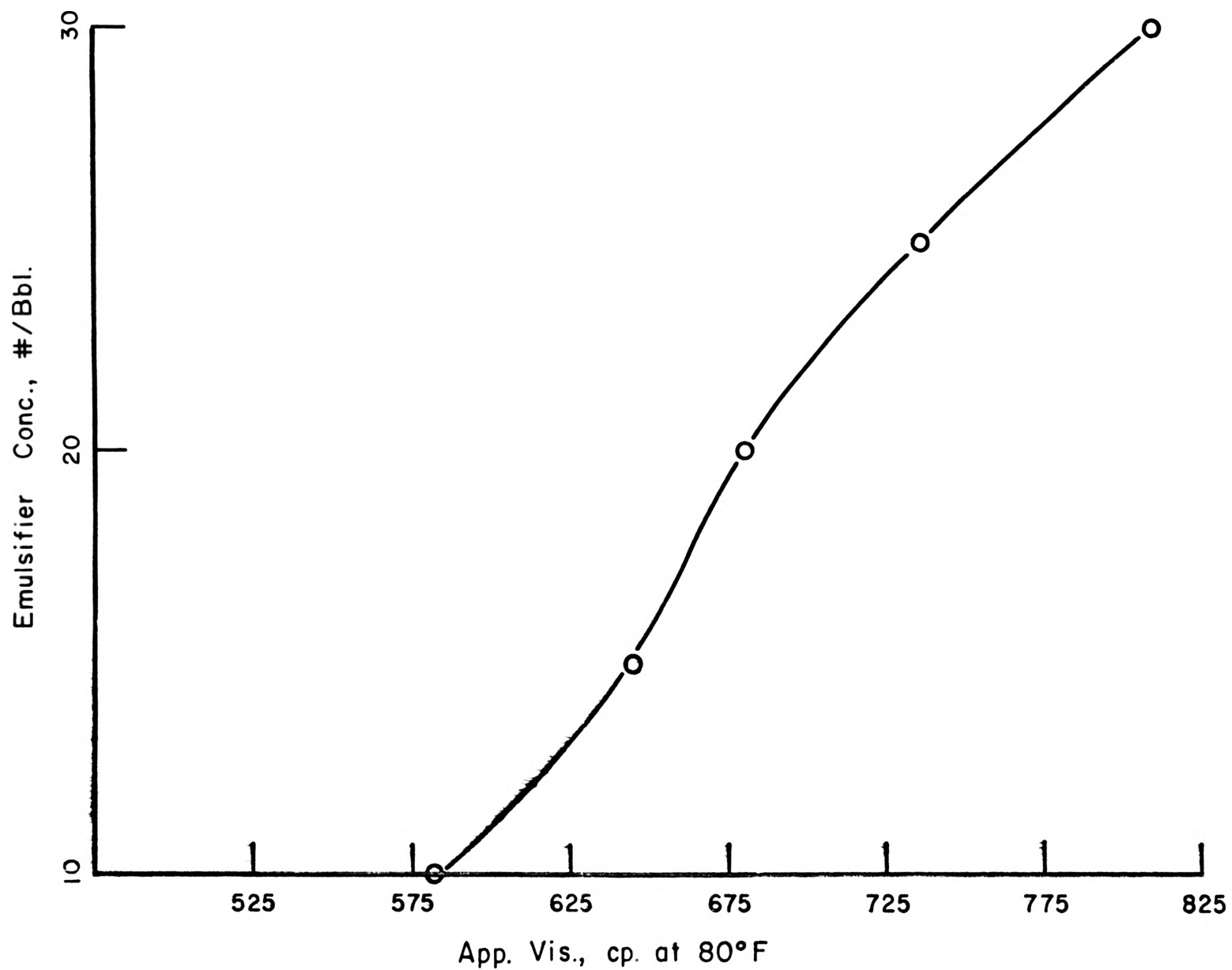


FIG. 3 - EFFECT OF VARYING EMULSIFIER CONCENTRATION ON TYPE A EMULSIONS P. V. R. = 50/50

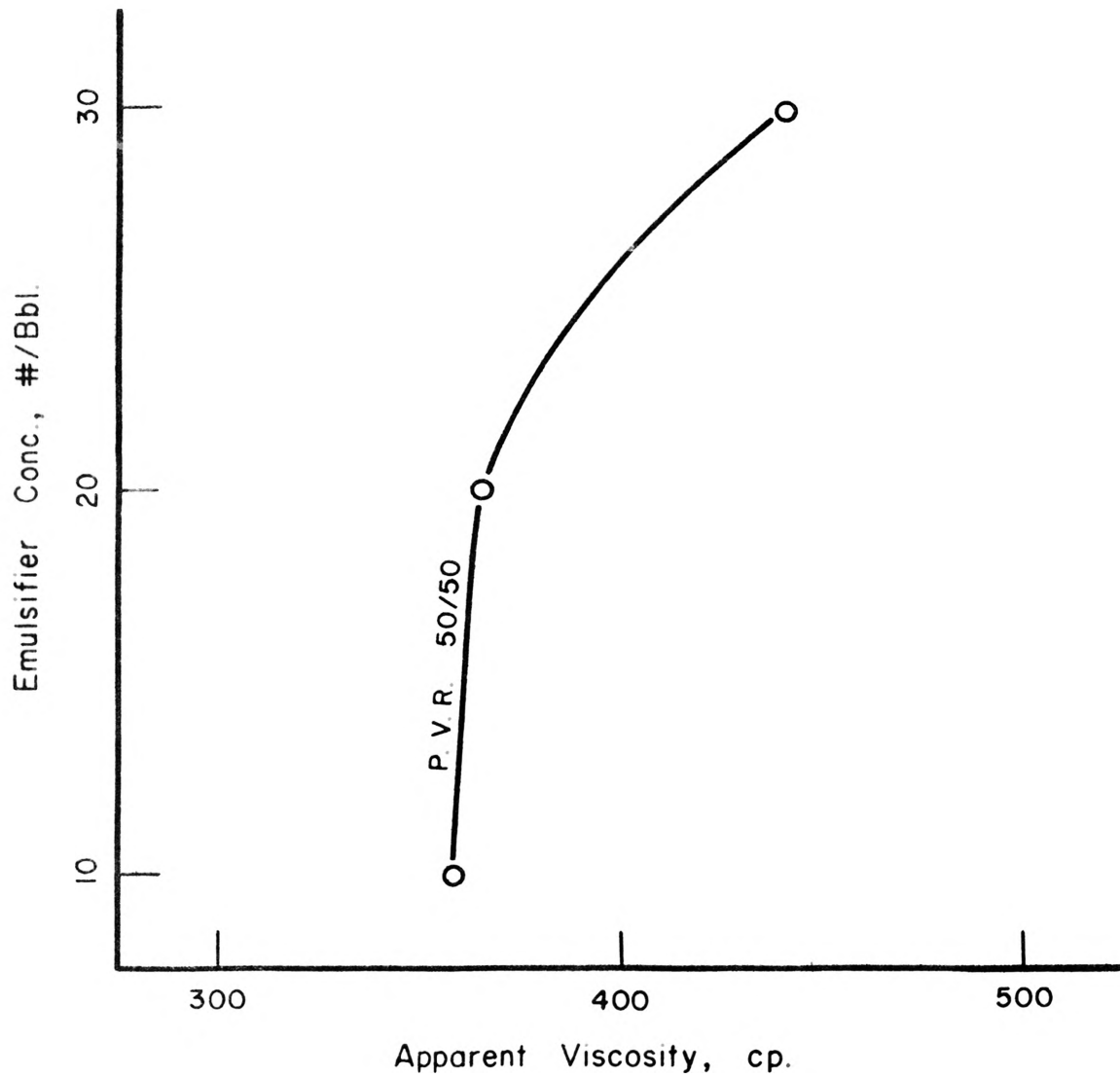


FIG. 4 - EFFECT OF EMULSIFIER CONCENTRATION ON THE VISCOSITY OF TYPE B EMULSIONS

Increased mixing time produced an increase in the apparent viscosity of both type A and type B emulsions. The magnitude of the increase in apparent viscosity was not the same for high and low emulsifier concentrations. As shown in Figure 6, the trend of apparent viscosity with increased mixing time for clay concentrations of 20 and 30 lb./bbl. is a steady increase which would approach a limiting value of viscosity at complete homogenization of the system. However, the trend of apparent viscosity with increased mixing time for clay concentration of 10 lb./bbl. shows no increase up to 10 minutes of mixing time with a rapid increase from 10 to 15 minutes and appears not to approach a limiting value of apparent viscosity. Similar results were obtained with type A emulsions having phase volume ratios of 50/50 as shown by Figure 5 and 40/60 (Appendix, page A-6) and the same emulsifier concentrations. These results indicate that with emulsifier concentrations up to 30 lb./bbl. both type A and B emulsion systems were more readily mixed to a state of near homogeneity when higher emulsifier concentrations were used.

The effects of aging on the viscosity of type A emulsions are shown in Figure 7. The results of investigations involving phase volume ratios of 50/50 and 40/60 were similar except the decreasing trend of apparent viscosity with increased aging time from 50 to 20 hours was not as pronounced. This decrease in apparent viscosity may be interpreted as a readjustment in particle size distribution in the system toward the less homogenous state, due to a coalescence of the dispersed phase droplets during this aging period. This trend was more pronounced in the systems having higher phase volume ratios, due to the closer packing of dispersed phase particles in these systems. The trend toward higher apparent viscosities following the 50 hour aging period may be attributed largely to slight changes in external phase viscosity and phase volume ratio result-

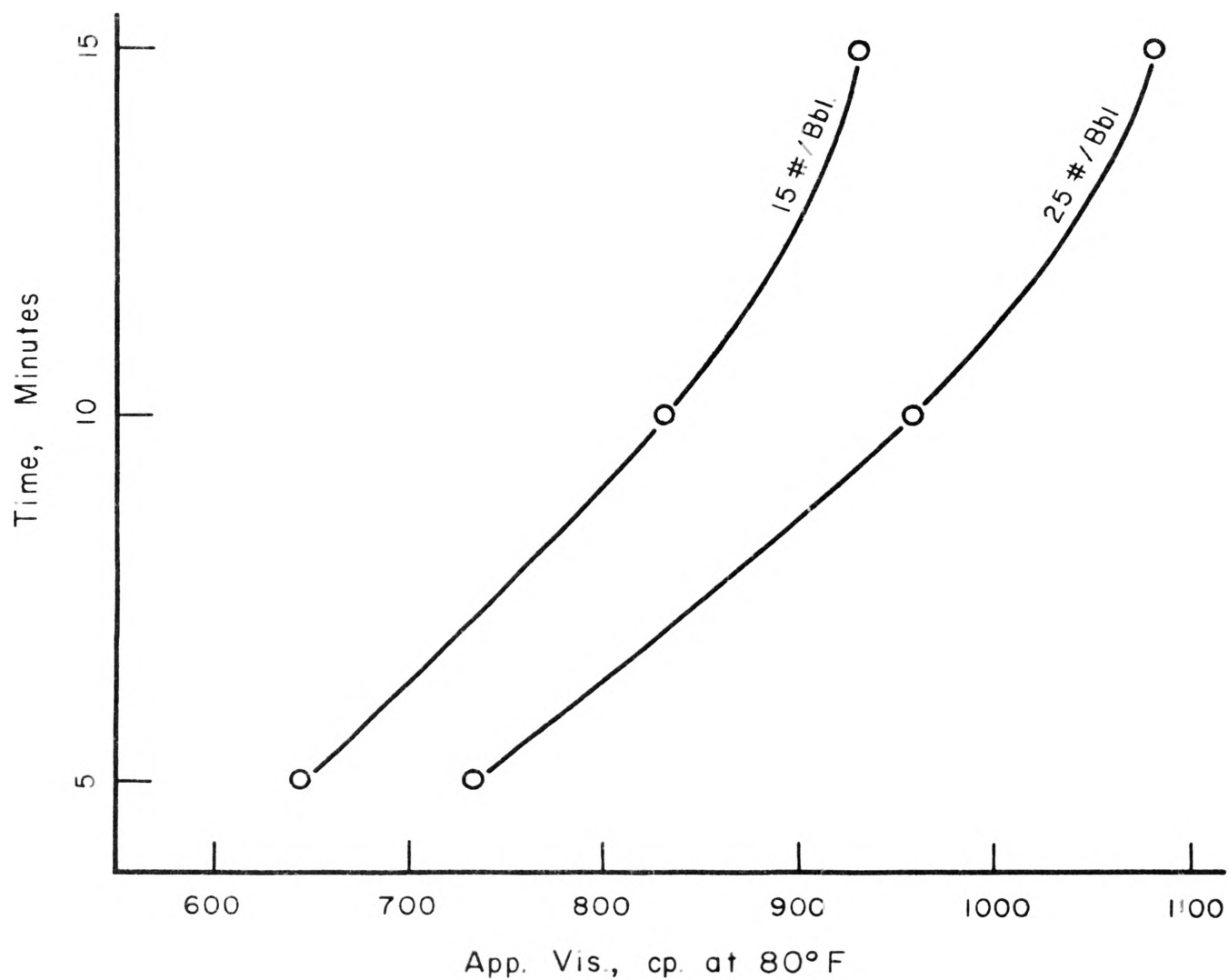


FIG. 5 - RELATION BETWEEN MIXING TIME AND VISCOSITY OF TYPE A EMULSIONS P. V. R. 50/50

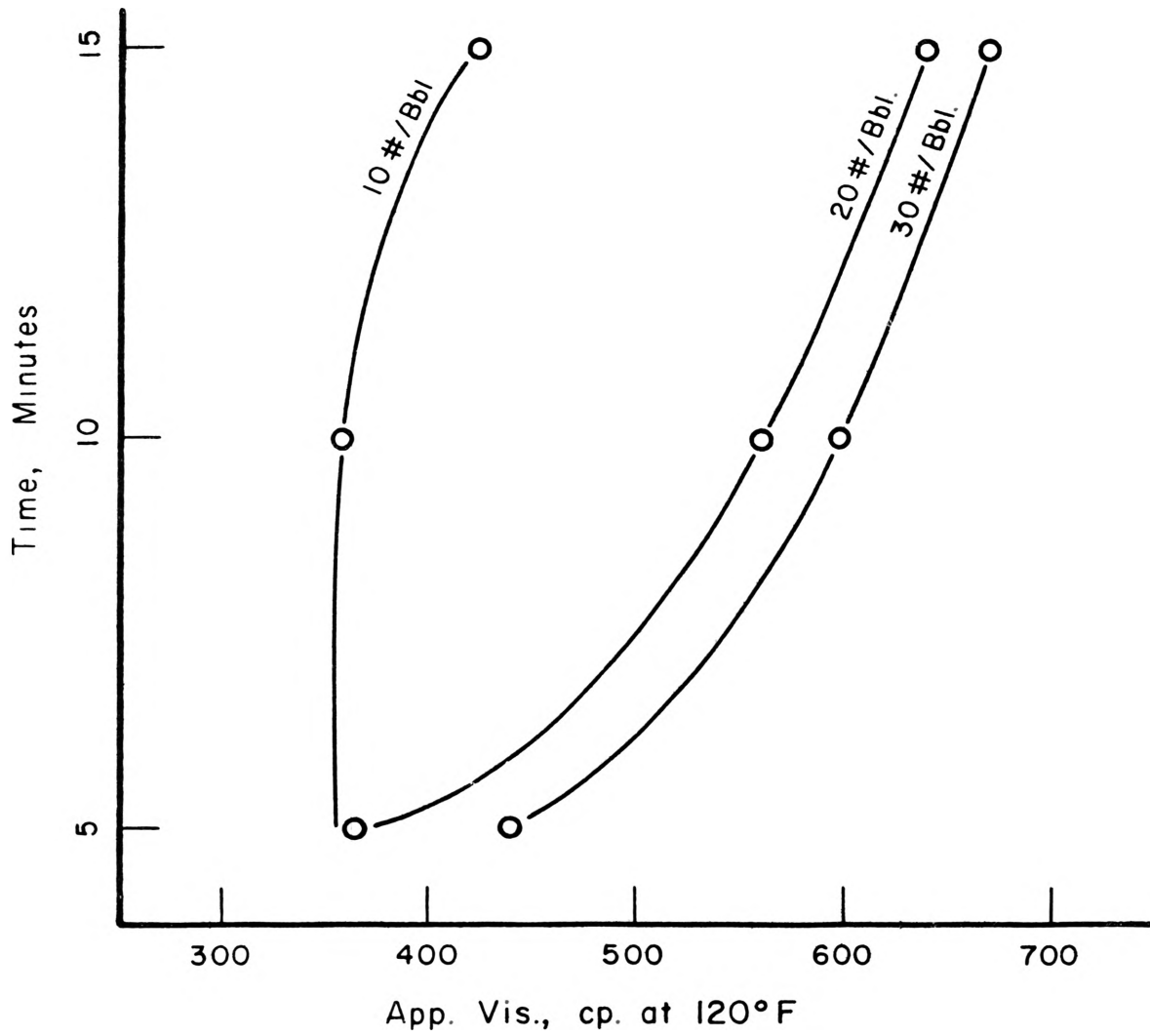


FIG. 6 - RELATION BETWEEN MIXING TIME AND VISCOSITY OF TYPE B EMULSIONS P. V. R. 50/50

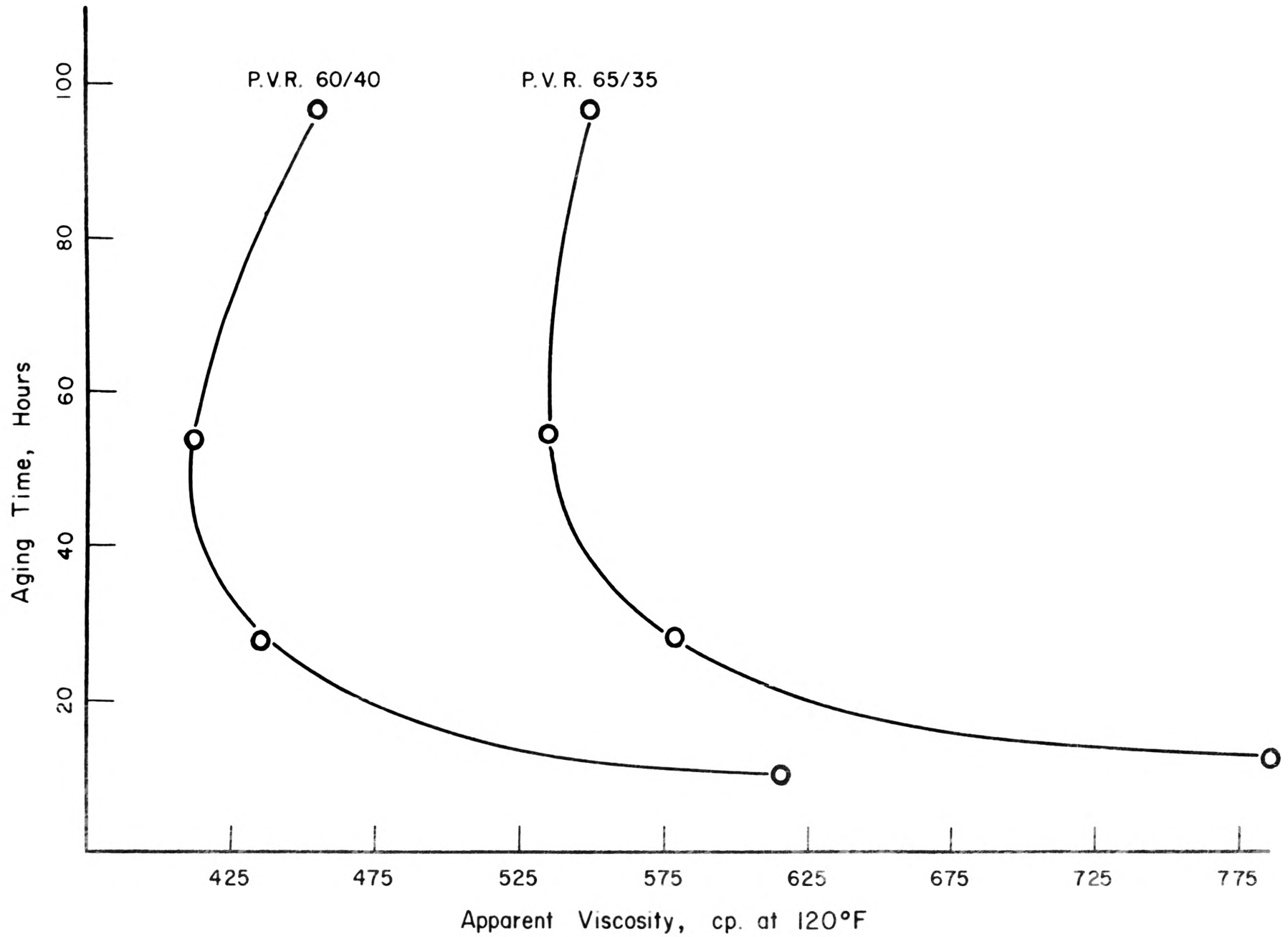


FIG. 7 - EFFECT OF AGING ON THE VISCOSITY OF TYPE A EMULSIONS CONTAINING 30 #/BBL. EMULSIFIER

ing from vaporization of a portion of the lighter components of the crude oil phase. Changes of indeterminate magnitude in the physical characteristics of the emulsifier film surrounding the dispersed phase particles might have caused some of the variations in apparent viscosity noted with aging. Type B emulsions, with a phase volume ratio of 50/50, showed changes in apparent viscosity with aging time as illustrated in Figure 8. The aging characteristics shown here are similar to those exhibited by type A emulsions of the same phase volume ratio. However, this relation between apparent viscosity and aging time for the type B emulsions having a phase volume ratio of 60/40 does not conform to the trend of apparent viscosity with aging time established for type A emulsions having the same phase volume ratio. The precise cause of this reversal in characteristics is difficult to determine but may be due to unstable tendencies of this type B system.

For all stable systems, the viscosity decreased exponentially with temperature increase as shown in Figure 9. Systems which were very unstable exhibited an unpredictable viscosity temperature relationship as shown in Figure 10. An example of the variation between apparent viscosity measured at ascending temperatures and apparent viscosity measured at descending temperatures is shown in Figure 11. This variation in apparent viscosity between measurements made at ascending temperatures and at descending temperatures is caused by changes in external phase viscosity and phase volume ratio resulting from vaporization of a portion of the external phase. The viscosity data used in this study were measured at ascending temperatures to insure proper comparison between various test systems.

The Stormer viscosimeter is a rotating spindle type of viscosimeter, and therefore, during an extended series of measurements such as those made at ascending temperatures, a slight degree of mixing occurs which tends to

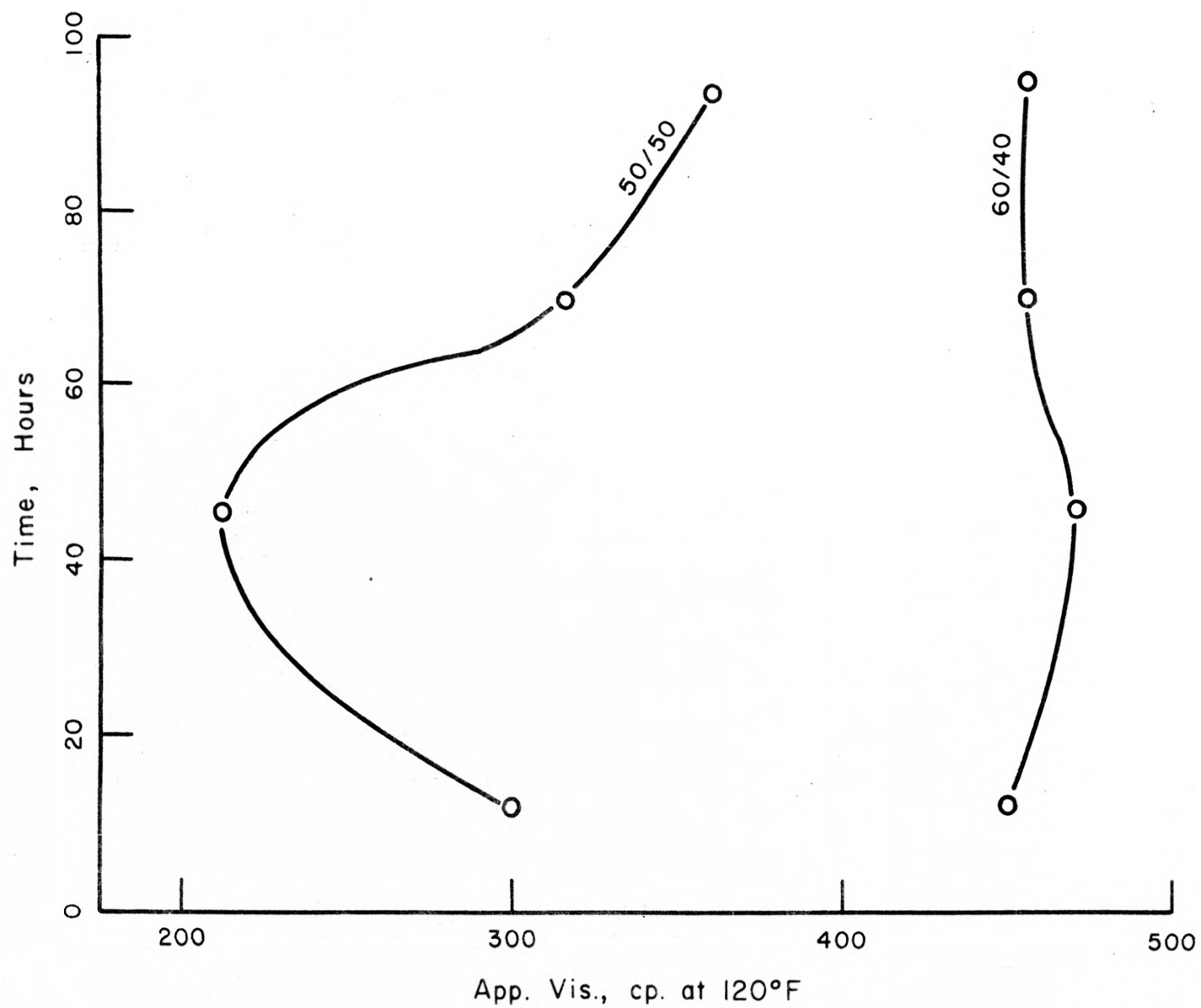


FIG. 8 - EFFECT OF AGING ON THE VISCOSITY OF
TYPE B EMULSIONS CONTAINING 10 #/BBL. EMULSIFIER

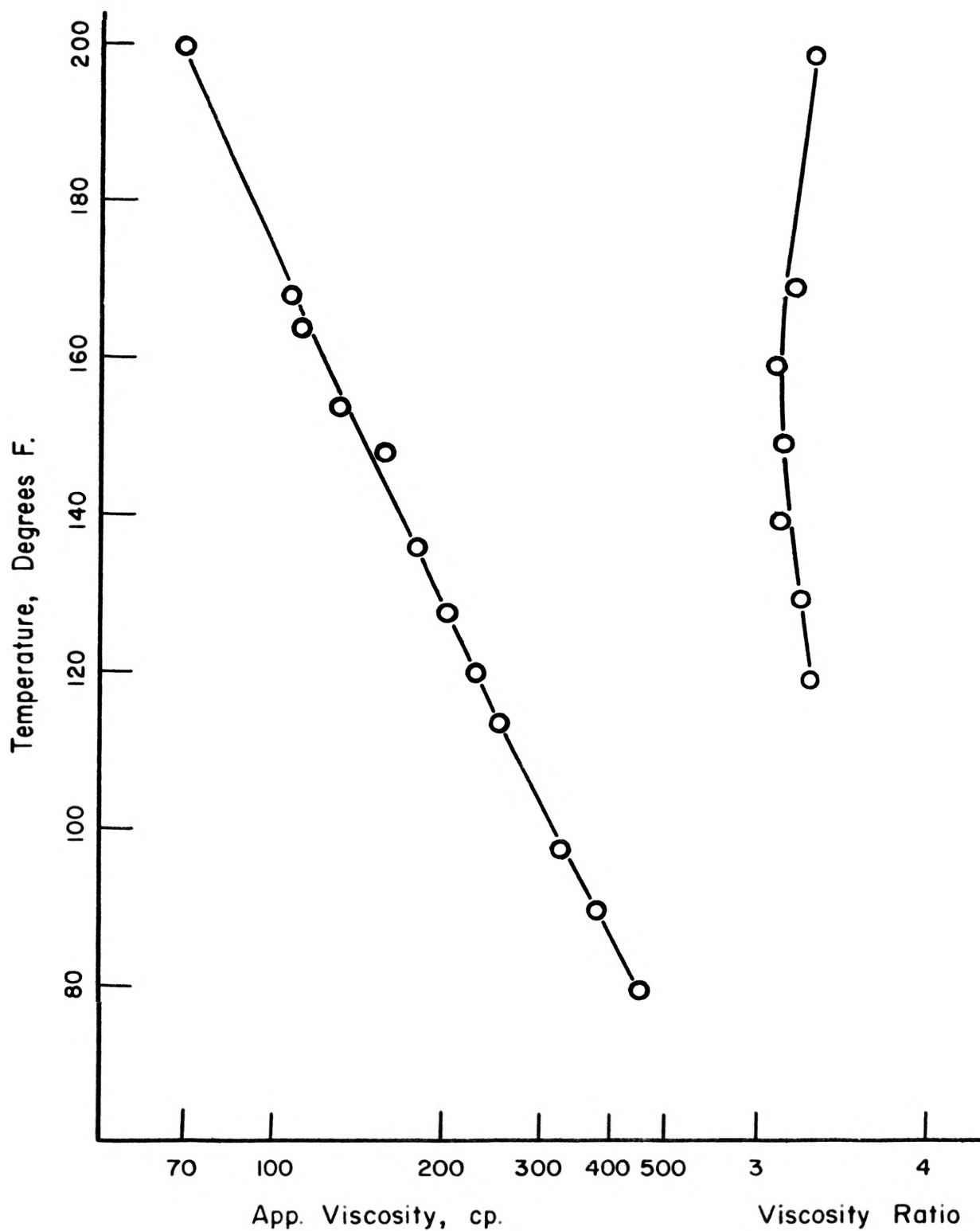


FIG. 9 - VISCOSITY-VISCOSITY RATIO/TEMPERATURE RELATIONSHIPS FOR A TYPICAL STABLE SYSTEM

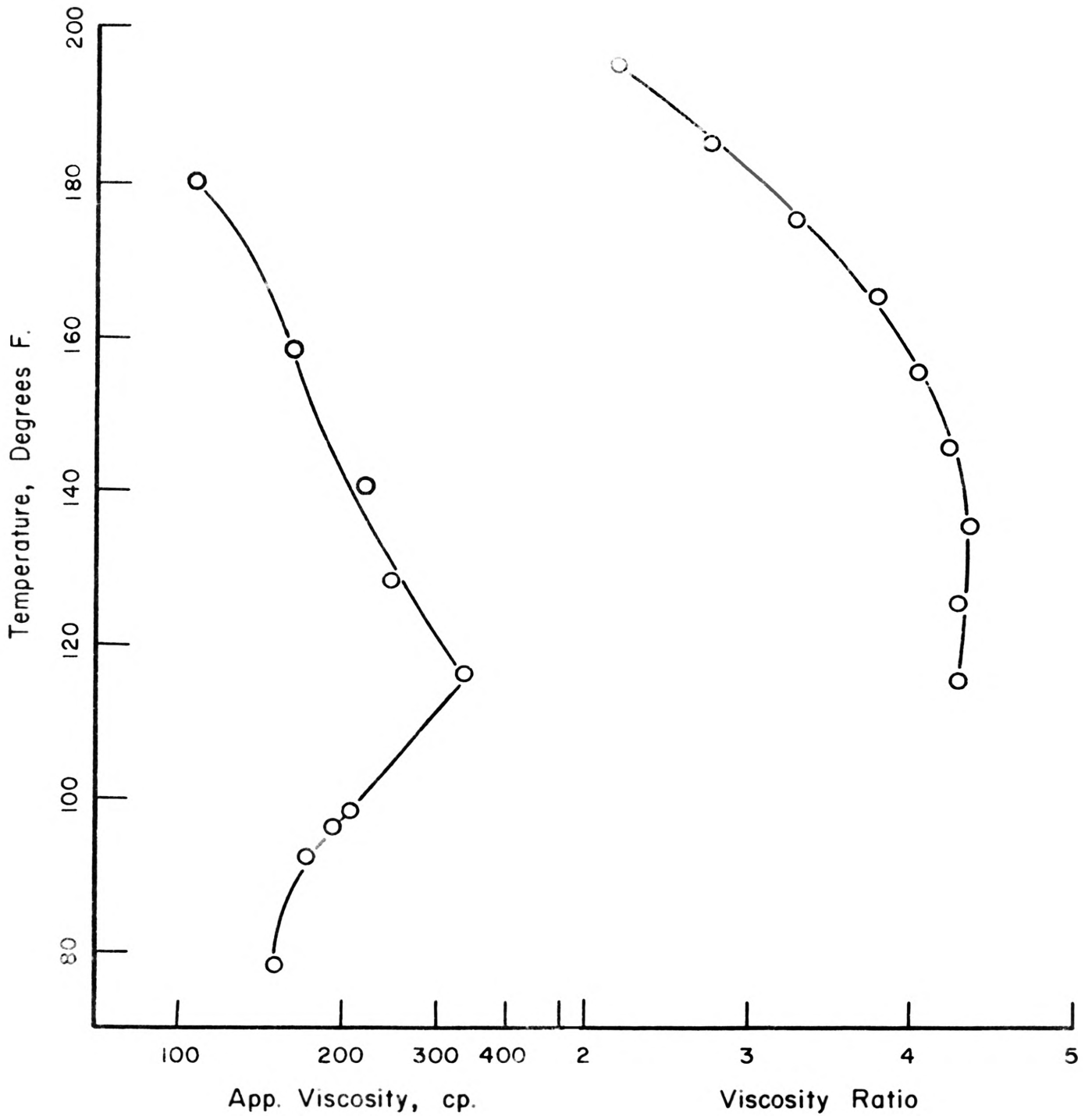


FIG. 10 - VISCOSITY-VISCOSITY RATIO/TEMPERATURE RELATIONSHIPS FOR A TYPICAL UNSTABLE SYSTEM

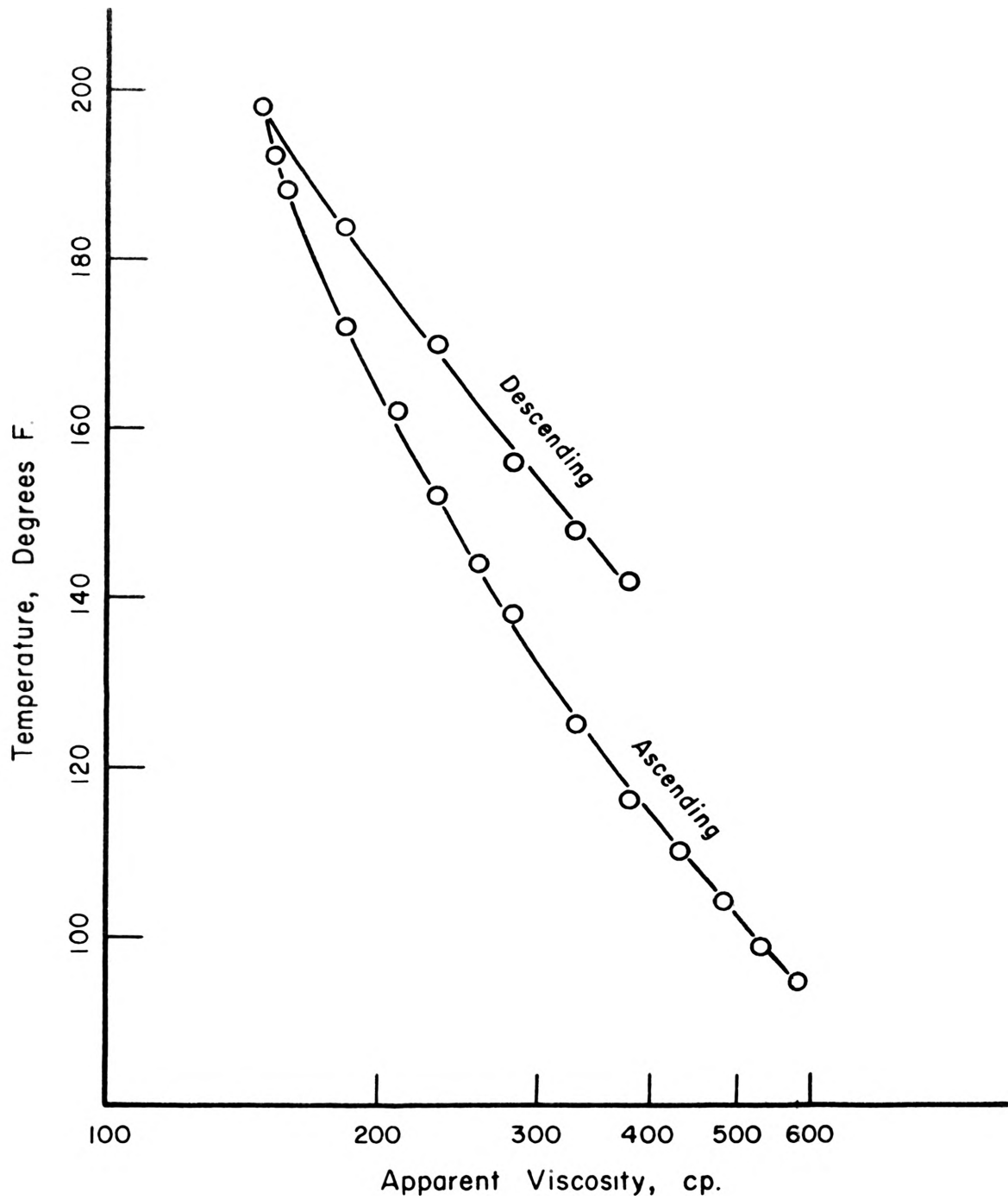


FIG. II - VARIATION IN TEMPERATURE/VISCOSITY RELATIONSHIPS WITH MEASUREMENT AT ASCENDING & DESCENDING TEMPERATURES

increase the apparent viscosity of the system being studied. This slight increase in apparent viscosity along with increases in phase volume ratio of the system being studied due to vaporization of a portion of the external phase complicated the interpretation of viscosity ratio-temperature data to obtain a measure of the stability of the system. However, in systems where instability is inherent, definite trends toward lower viscosity ratios with increasing temperature will be apparent as shown in Figure 10. Figure 9 shows the relation between temperature and viscosity ratio for a typical stable system of either type A or B. Since the magnitude of the viscosity ratio is controlled directly by the phase volume ratio fraction, the degree of stability determined from the viscosity ratio data were interpreted on the basis of the total change in viscosity ratio over a set temperature interval. Systems showing a high degree of stability over a set temperature interval have viscosity ratios which vary only due to changes in apparent viscosity brought about by the method of measurement, such as those previously described. The magnitude of such changes is from 0 to 0.3 in the value of the viscosity ratio.

Type A emulsions were stable over the range of temperatures investigated with the exception of systems having phase volume ratios of 65/35 and above. Type B systems were stable up to phase volume ratios of 50/50 as illustrated in Figure 12. At phase volume ratios of 50/50, the degree of stability of the type B systems above 160 degrees Fahrenheit was not readily defined; and at higher phase volume ratios, the type B systems did not exhibit desired characteristics of stability above 140 degrees Fahrenheit.

Emulsifier concentration in type A emulsions affected stability measurably only at phase volume ratios higher than 60/40 (Appendix, page A-6). Emulsifier concentration did have a measurable effect on the

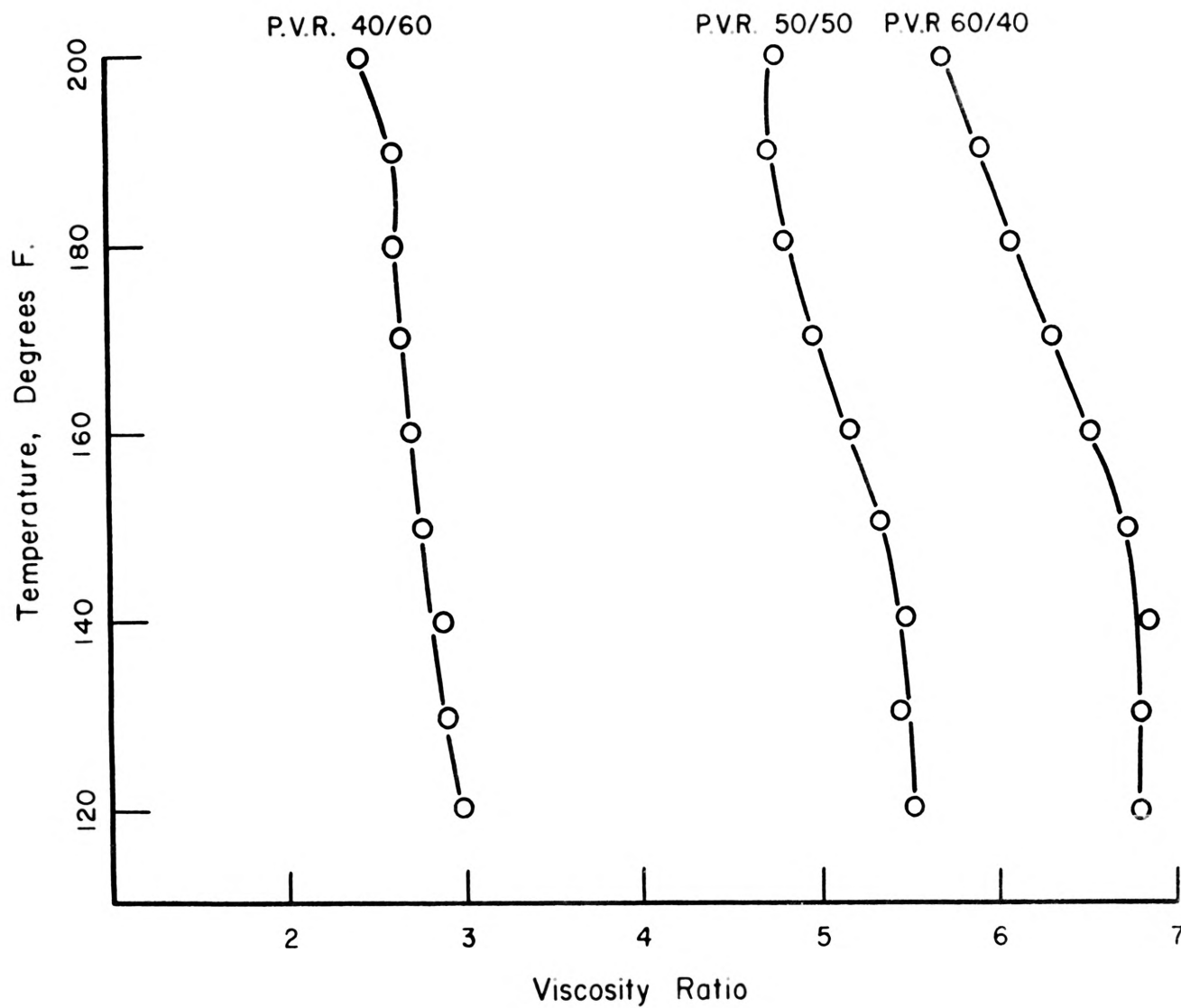


FIG. 12 - EFFECT OF VARYING P.V.R. ON VISCOSITY RATIO/TEMPERATURE RELATIONSHIPS FOR TYPE B EMULSIONS CONTAINING 10 #/BBL. CLAY

stability of type B emulsions as shown by Figure 13. The greatest degree of stability was exhibited by systems containing 30 lb./bbl. clay.

Variations in mixing time did not affect stability greatly. The main effect of increased mixing time was an increase in the value of viscosity ratio at all temperatures as shown in Figure 14.

Aging did not greatly affect stability of either type A or type B emulsions and no definite aging trends could be established from the measurements.

Type C emulsions were characterized by extremely high filter losses. A comparison of the filter losses for representative type A, B, and C systems is shown in Table I. The filtration characteristics of type C systems was such that little or no phase separation occurred across the filter element, and the filtrates were emulsion. Since the range of desirable filter loss has been described by other investigators as 0 or near 0 cc. up to a temperature of 300 degrees Fahrenheit, the type C systems were eliminated from further consideration due to the excessive filter losses which these systems showed (1,2,3,4). The extremely high filter losses exhibited by type C systems can be attributed to lack of solid particles. Type A and B systems contained solid materials added externally and exhibited low filter losses in the range acceptable for field usage.

Type A systems exhibited excellent fluid loss properties throughout the range of emulsifier concentrations and phase volume ratios investigated. Type B systems showed filter losses which were slightly higher than those for type A but were still within the acceptable field range as previously described.

A comparison of the filtration properties of type A and B systems containing various concentrations of emulsifier was made at increased temperatures as shown in Table II. In each case, filter loss increased

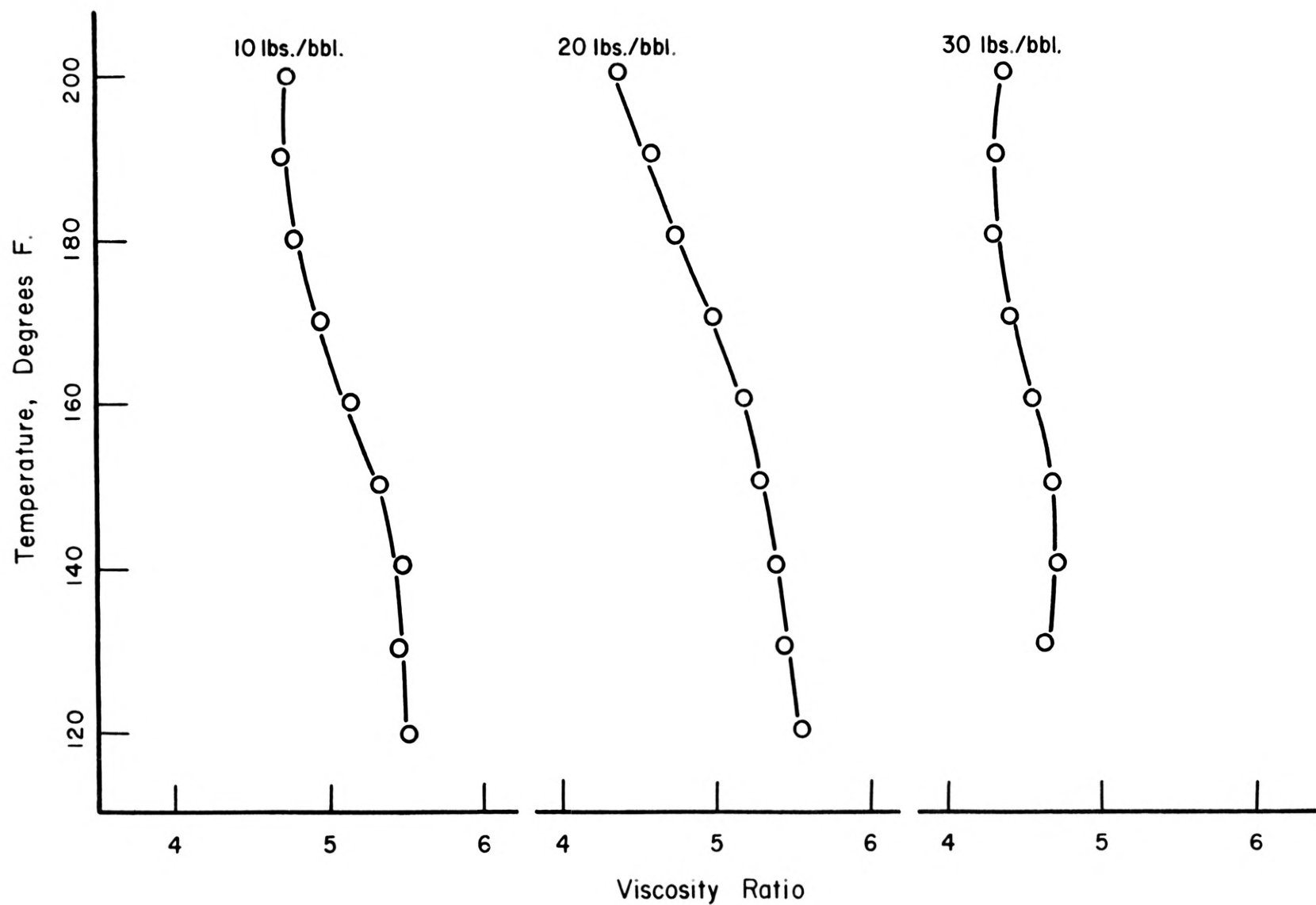


FIG. 13- EFFECT OF VARYING EMULSIFIER CONCENTRATION ON VISCOSITY RATIO/TEMPERATURE RELATIONSHIPS FOR TYPE B EMULSIONS P.V.R. 50/50

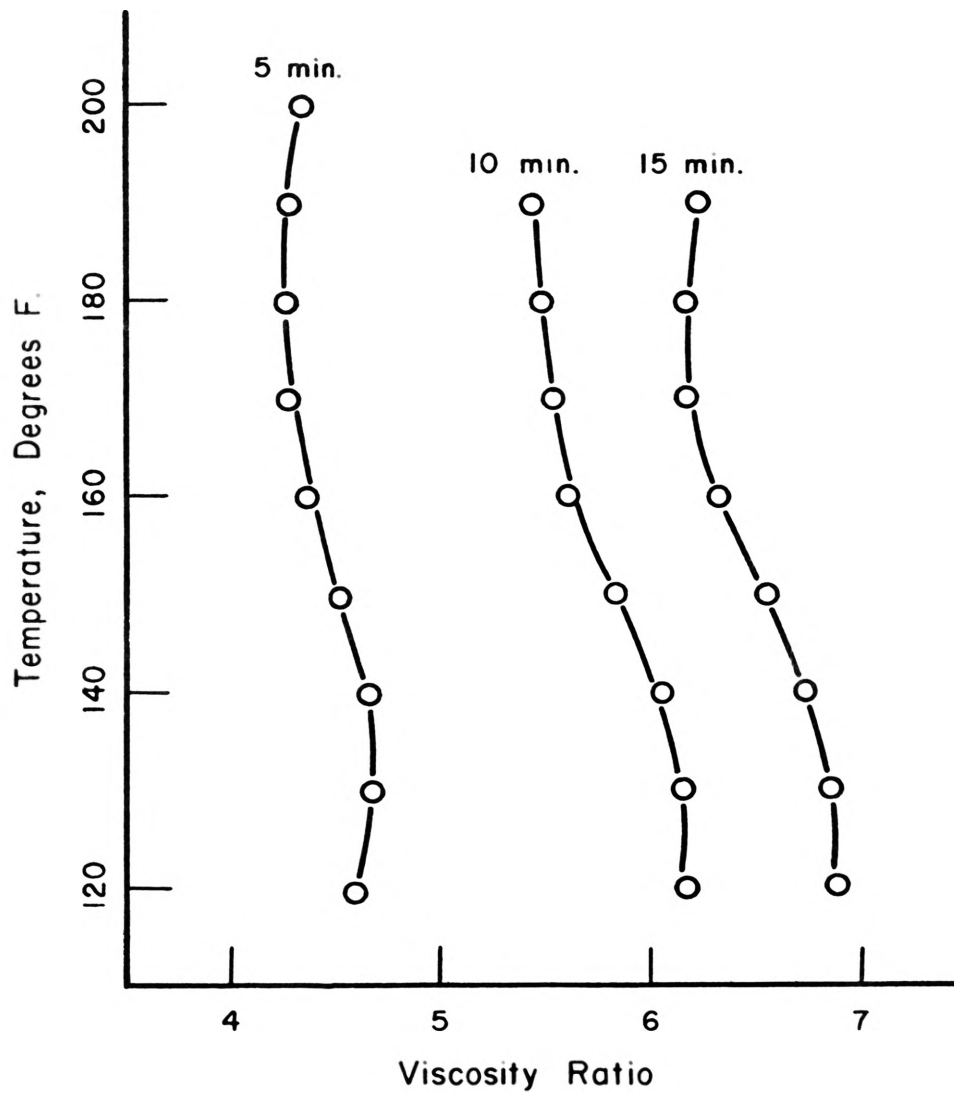


FIG. 14- EFFECT OF MIXING TIME ON VISCOSITY RATIO/TEMPERATURE RELATIONSHIPS, TYPE B SYSTEMS, P.V.R. 50/50, EMULSIFIER CONC. 30 #/BBL.

Table IComparison of Filter Losses for Type A, B, and C Emulsions

<u>Emulsion Type</u>	<u>Phase Volume Ratio</u>	<u>Emulsifier Conc. lbs./bbl.</u>	<u>Filter Loss at 80°F. cc. Filtrate</u>
C	50/50	0*	460 emulsion
C	60/40	0	280 emulsion
C	70/30	0	246 emulsion
A	50/50	30	0
A	60/40	30	0
A	65/35	30	0
B	40/60	10	2.5 oil
B	50/50	30	0.4 oil
B	60/40	30	0.1 oil

*Since type C emulsion utilized the natural emulsifiers present in the crude oil, no emulsifier was added externally.

Table IIEffect of Temperature on Filter Losses of Type A and B Emulsions

<u>Emulsion Type</u>	<u>P.V.R.</u>	<u>Emulsifier Conc. lbs./bbl.</u>	<u>Temp. °F.</u>	<u>Filter Loss cc.</u>
A	50/50	30	120	0.5 oil
			170	1.0 oil
A	50/50	20	120	0.5 oil
			170	1.0 oil
A	50/50	10	120	2.0 oil
			170	2.5 oil
B	50/50	30	150	1.0 oil
			170	2.0 oil
B	50/50	20	150	2.0 oil
			170	3.5 oil
B	50/50	10	150	1.0 oil
			170	2.0 oil

with increasing temperature; however, the filter loss throughout the temperature range was not large compared to stated desirable filter loss.

A comparison of emulsifier effectiveness in lowering interfacial tension between the phase is shown in Table III. Although these measurements would indicate that the emulsifier used in type A emulsions is more effective than the emulsifier used in type B emulsions, the differences between them are such that no definite comparisons can be drawn. However, the emulsifiers used in both type A and B emulsions lowered the interfacial tension to a value sufficiently lower than the interfacial tension existing in type C emulsions such that a higher degree of stability was obtained with these added emulsifiers.

Table III
Effect of Emulsifier and Emulsifier Concentration on
Interfacial Tension

<u>Emulsion Type</u>	<u>Emulsifier Conc. lbs./bbl.</u>	<u>Interfacial Tension Dynes/cm.</u>
C	0*	5.91
A	30	2.77
A	20	1.98
A	10	1.39
B	30	2.77
B	20	2.18
B	10	1.58

*Since type C emulsions utilized natural emulsifiers present in the crude oil, no emulsifier was added externally.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the investigations, the following properties of type A emulsions have been established:

1. Type A emulsions showed a high degree of stability and desirable filtration properties throughout the range of phase volume ratios investigated up to 65/35. Above 65/35, the degree of stability was low.
2. Type A emulsions showed a high degree of stability and desirable filtration properties throughout the range of emulsifier concentrations considered.
3. Over the range of temperatures investigated, type A emulsions showed a high degree of stability and desirable filtration properties.
4. The stability and filtration properties showed no adverse changes over the range of aging and mixing times studied.
5. The apparent viscosities of type A emulsions were higher than apparent viscosities of comparable systems reported by other investigators who used higher gravity oils as the external phase (2,4).

The pertinent properties of type B emulsions were established as follows:

1. Throughout the range of phase volume ratios studied, type B emulsions exhibited desirable filtration properties. Stability comparable to that of type A emulsions existed at a phase volume ratio of 40/60, but the degree of stability shown by type B emulsions decreased with increased phase volume ratio from this point.

2. The filtration properties of type B emulsions were acceptable for field application throughout the range of emulsifier concentrations considered. The highest degree of stability shown by type B emulsions was at an emulsifier concentration of 30 lb./bbl.
3. Stability and filtration properties of type B emulsions did not change greatly with mixing time.
4. Aging has little effect on the stability and filtration properties of type B emulsions.
5. The range of apparent viscosities recorded for type B emulsions was comparable to that recorded for type A emulsions.

As previously stated in the Discussion of Results, type C emulsions were not deemed to be applicable as drilling fluids because of undesirable filtration properties over all ranges of phase volume ratio.

On the basis of the preceding evaluation, type A emulsions prepared with the specific aqueous and oil phases are recommended for general application as drilling fluids where requirements warrant. The type A emulsions are preferable to type B emulsions when conditions demanding dependable stability properties are encountered, such as drilling or completing wells in producing zones which are readily water damaged.

Type B emulsions are sufficiently stable to allow their use as drilling fluids at temperatures up to 140 degrees Fahrenheit and would be best applied when make-up cost of the drilling fluid is the important consideration. Such an application of type B emulsions might be for drilling through shale beds having a tendency toward excessive caving when drilled with water base fluids. Some investigators feel that

asphaltic materials must be present in the oil phase and be adsorbed on the clay particles before they can act as a water-in-oil emulsifier. These investigators believe that if this condition is not fulfilled, the clay will act as an oil in water emulsifier (6). Therefore, type B emulsions as investigated may be limited by the type of oil which can be used in their preparation.

The viscosity ratio method of determining degree of stability, developed for use in this investigation, is recommended for laboratory evaluations of emulsion drilling fluids of all types. This method reflects to some degree the temperature conditions which are encountered in field application of emulsions as drilling fluids. However, the viscosity ratio technique of determining the degree of stability has the disadvantage of producing results which are not readily interpreted by unskilled field personnel. Furthermore, several measurements of apparent viscosity are necessary where a single measurement would be desirable for field checks during drilling.

Subsequent studies are necessary to determine if asphaltic material is needed in the oil phase of type B emulsions. Should the presence of asphaltic material in the oil phase of type B emulsions be necessary, other studies to determine the relative amount of asphaltic material needed will be warranted. The results of the studies recommended will determine if type B emulsions are generally applicable as drilling fluids.

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APPENDIX

Data relating to the oil phase:

Type of Oil: Asphaltic base crude
 API Gravity: 26° at 60 degrees Fahrenheit

Composition:*

.90% Sulfur
 6.38% Wax
 33.3% Asphalt

*Data furnished by the research division of the Continental Oil Company.

Viscosity data:

Pure Oil

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
79	265	107
86	235	92
92	225	87
97	205	77
100	185	67
108	165	57
119	140	45
125	125	38
146	105	28
154	95	23
164	90	21
170	85	19

Type A

Oil plus 20 lb./bbl. emulsifier concentration equivalent to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
83	275	117
89	265	107
99	210	80
108	200	75
121	175	63
128	155	53
138	125	38
141	115	33
149	105	28
154	95	18
162	90	16
170	85	14

Data relating to the oil phase (cont.)

Type A

Oil plus 10 lb./bbl. emulsifier concentration equivalent to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
86	265	107
100	205	77
118	175	62
140	115	32
160	95	22
170	87	18

Oil plus 30 lb./bbl. emulsifier concentration equivalent to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
88	265	107
110	185	67
124	145	47
138	125	37
162	110	30
172	85	18

Values of viscosity obtained from a curve fitted to the entire group of data related to type A emulsification. Used in calculating viscosity ratio.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
120	157	55.5
130	137	44.5
140	120	35.0
150	105	28.0
160	93.7	21.0
170	82.3	15.0
180	75.2	12.5
190	68.1	9.2
200	61.5	7.0

Type B

Oil plus 10 lb./bbl. clay concentration equivalent to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
80	295	122
84	265	107
97	215	82
110	165	57
123	135	42
136	115	32
172	85	17
156	95	22
194	75	12
182	80	15

Data relating to the oil phase (cont.)

Oil plus 20 lb./bbl. clay concentration equivalent to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
80	285	117
86	265	107
92	245	97
104	185	67
111	165	57
118	145	47
133	125	37
140	115	32
158	95	22
172	85	17
179	80	15
192	75	12

Values used from curve fitted to 10 and 20 lb./bbl. clay.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
120	141	55.5
130	123.5	36.8
140	109	29.5
150	99.5	24.8
160	92.0	21.0
170	86.0	18.0
180	80.9	15.4
190	76.2	13.1
200	73.0	11.5

Type B

Oil plus 30 lb./bbl. clay equivalent concentration to that used for phase volume ratio of 50/50.

Temperature, °F	Stormer Viscosity, gm.	App. Viscosity, cp.
92	255	102
116	215	82
120	202	76
130	177	64
138	165	58
140	158	55
150	143	47
156	135	43
160	130.5	40
164	125	38
170	119	35
180	108.4	23
190	100	19

Data related to type A systems:

Phase volume ratio: 40/60
 Emulsifier concentration: 30 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1165 stormer gms., 557 cp. app. at 80°F

Phase volume ratio: 40/60
 Emulsifier concentration: 20 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 940 stormer gms., 445 cp. app. at 80°F
 515 stormer gms., 232 cp. app. at 120°F
 Initial viscosity ratios: 3.31-120°, 3.24-130°, 3.14-150°, 3.09-160°,
 3.18-170°, 3.09-200°.

Data used as example of typical stable system.

Phase volume ratio: 40/60
 Emulsifier concentration: 10 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 915 stormer gms., 432 cp. app. at 80°F;
 465 stormer gms., 207 cp. app. at 120°F
 Initial viscosity ratios: 3.01-120°, 2.91-130°, 2.83-140°, 2.83-150°,
 2.86-160°, 3.04-170°.

Phase volume ratio: 50/50
 Emulsifier concentration: 30 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1665 stormer gms., 807 cp. app. at 80°F

Phase volume ratio: 50/50
 Emulsifier concentration: 20 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1410 stormer gms., 680 cp. app. at 80°F;
 815 stormer gms., 382 cp. app. at 120°F
 Initial viscosity ratios: 5.25-120°, 5.18-130°, 4.95-140°, 5.54-150°,
 5.59-160°, 5.52-170°.

Phase volume ratio: 50/50
 Emulsifier concentration: 10 lb./bbl.
 Initial filter loss at 80°F: 1.5 cc. oil
 Initial viscosity: 1215 stormer gms., 582 cp. app. at 80°F;
 615 stormer gms., 282 cp. app. at 120°F
 Initial viscosity ratios: 4.15-120°, 4.18-130°, 4.24-140°, 4.28-150°,
 4.13-160°, 4.07-170°.

Data related to type A systems: (cont.)

Phase volume ratio: 50/50
 Emulsifier concentration: 15 lb./bbl.
 Initial filter loss at 80°F: 1 cc. oil
 Initial viscosity: 1340 stormer gms., 645 cp. app. at 80°F

Phase volume ratio: 50/50
 Emulsifier concentration: 25 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1520 stormer gms., 735 cp. app. at 80°F

Phase volume ratio: 60/40
 Emulsifier concentration: 30 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1915 stormer gms., 932 cp. app. at 80°F

Phase volume ratio: 65/35
 Emulsifier concentration: 30 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial Viscosity: 2215 stormer gms., 1082 cp. app. at 120°F
 Initial viscosity ratios: 14.26-120°, 14.59-130°, 14.74-140°, 14.66-150°,
 13.87-160°, 13.36-170°, 12.49-180°, 12.26-190°

Phase volume ratio: 65/35
 Emulsifier concentration: 20 lb./bbl.
 Initial filter loss at 80°F: 0 cc. oil
 Initial viscosity: 1540 stormer gms., 745 cp. app. at 150°F
 Initial viscosity ratio: 11.19-150°, 10.83-160°, 10.51-170°, 9.84-180°,
 9.40-190°, 8.78-200°.

Phase volume ratio: 65/35
 Emulsifier concentration: 10 lb./bbl.
 Initial filter loss at 80°F: 0.5 cc. oil
 Initial viscosity: 835 stormer gms., 392 cp. app. at 150°F
 Initial viscosity ratios: 7.75-140°, 7.95-150°, 7.95-160°, 8.28-170°,
 8.57-180°, 8.51-190°, 8.29-200°.

Variable mixing time data.

P.V.R. System	Mixing time min.	App. Viscosity at 80°F cp.	Filter loss at 80°F cc.
40/60			
20 lb./bbl.	5	462	0
	10	595	0
	15	657	0
40/60			
10 lb./bbl.	5	432	0
	10	477	0
	15	632	0

Data related to type A systems: (cont.)

Variable mixing time data.

P.V.R. System	Mixing time min.	App. Viscosity at 80°F cp.	Filter loss at 80°F cc.
50/50			
25 lb./bbl.	5	735	0
	10	957	0
	15	1082	0.5 oil
50/50			
15 lb./bbl.	5	645	1.0 oil
	10	832	0
	15	932	0

Aging characteristics:

P.V.R. System	Aging Time hours	App. Viscosity at 120°F cp.	Filter loss at 80°F cc.
50/50			
30 lb./bbl.	5.25	390	0
	26.83	349	0
	52.50	330	0
	96.30	306	0
40/60			
30 lb./bbl.	9.50	240	0
	27.30	245	0
	52.80	215	0
	95.20	215	0
60/40			
30 lb./bbl.	11.30	665	0
	28.10	485	0
	53.80	460	0
	97.50	510	0
65/35			
30 lb./bbl.	12.50	840	0
	28.70	625	0
	54.80	590	0
	97.10	625	0

Data relating to type B systems:

Phase volume ratio: 50/50

Emulsifier concentration: 10 lb./bbl.

Initial filter loss at 80°F: 0.5 cc. oil

Initial viscosity: 1565 stormer gms., 757 cp. app. at 80°F;

771 stormer gms., 360 cp. app. at 120°F

Initial viscosity ratios: 4.73-200°, 4.70-190°, 4.77-180°, 4.94-170°,
5.16-160°, 5.32-150°, 5.48-140°, 5.44-130°,
5.51-120°.

Phase volume ratio: 50/50

Emulsifier concentration: 20 lb./bbl.

Initial filter loss at 90°F: 2.0 cc. oil

Initial viscosity: 1215 stormer gms., 582 cp. app. at 90°F;

780 stormer gms., 365 cp. app. at 120°F

Initial viscosity ratios: 4.38-200°, 4.59-190°, 4.76-180°, 5.00-170°,
5.21-160°, 5.28-150°, 5.41-140°, 5.46-130°,
5.57-120°.

Phase volume ratio: 50/50

Emulsifier concentration: 30 lb./bbl.

Initial filter loss at 90°F: 0.4 cc. oil

Initial viscosity: 1415 stormer gms., 682 cp. app. at 90°F;

930 stormer gms., 440 cp. app. at 120°F

Initial viscosity ratios: 4.34-200°, 4.30-190°, 4.28-180°, 4.28-170°,
4.37-160°, 4.53-150°, 4.66-140°, 4.69-130°,
4.60-120°.

Phase volume ratio: 40/60

Emulsifier concentration: 10 lb./bbl.

Initial filter loss at 80°F: 2.5 cc. oil

Initial viscosity: 715 stormer gms., 332 cp. app. at 90°F;

420 stormer gms., 185 cp. app. at 120°F

Initial viscosity ratios: 2.42-200°, 2.61-190°, 2.60-180°, 2.65-170°,
2.72-160°, 2.79-150°, 2.89-140°, 2.91-130°,
3.00-120°.

Phase volume ratio: 60/40

Emulsifier concentration: 10 lb./bbl.

Initial filter loss at 80°F: 0.5 cc. oil

Initial viscosity: 1685 stormer gms., 817 cp. app. at 80°F;

952 stormer gms., 451 cp. app. at 120°F

Initial viscosity ratios: 5.64-200°, 5.88-190°, 6.03-180°, 6.27-170°,
6.52-160°, 6.71-150°, 6.86-140°, 6.80-130°,
6.80-120°.

Data relating to type B systems: (cont.)

Phase volume ratio: 60/40

Emulsifier concentration: 39 lb./bbl.

Initial filter loss at 80°F: 0.1 cc. oil

Initial viscosity: 1015 stormer gms., 482 cp. app. at 120°F

Initial viscosity ratios: 4.91-200°, 5.20-190°, 5.42-180°, 5.55-170°,
6.18-160°, 6.16-150°, 5.87-140°, 5.48-130°,
5.02-120°.

Phase volume ratio: 65/35

Emulsifier concentration: 10 lb./bbl.

Initial filter loss at 80°F: 2.0 cc. oil

Initial viscosity: 350 stormer gms., 175 cp. app. at 80°F;

600 stormer gms., 275 cp. app. at 120°F

Initial viscosity ratios: 2.19-200°, 2.76-190°, 3.28-180°, 3.77-170°,
4.02-160°, 4.22-150°, 4.36-140°, 4.29-130°,
4.28-120°.

Data used as example of a typical system.

Variable mixing time data.

P.V.R. System	Mixing time min.	App. Viscosity at 120°F cp.	Filter loss at 80°F cc.
50/50 30 lb./bbl.	5	440	0.4 oil
	10	597	0
	15	670	0
50/50 20 lb./bbl.	5	365	2.0 oil
	10	571	0
	15	590	0
50/50 10 lb./bbl.	5	360	0.5 oil
	10	361	0
	15	422	0

Aging characteristics.

P.V.R. System	Aging Time hours	App. Viscosity at 120°F cp.	Filter loss at 80°F cc.
50/50 10 lb./bbl.	12.0	298	1.2 oil
	45.7	210	1.2 oil
	69.8	315	0.1 oil
	93.8	358	0
60/40 10 lb./bbl.	12.5	450	0.1 oil
	46.5	471	0.6 oil
	70.5	455	1.0 oil
	94.8	454	0

Data relating to type C systems:

Phase volume ratio: 40/60
Initial viscosity: not measured
Initial filter loss at 80°F: 284 cc. emulsion.

Phase volume ratio: 50/50
Initial viscosity: 1515 stormer gm., 732 cp. app. at 80°F
Initial filter loss at 80°F: 460 cc. emulsion.

Phase volume ratio: 60/40
Initial viscosity: 3080 stormer gms., 1515 cp. app. at 80°F
Initial filter loss at 80°F: 280 cc. emulsion.

Phase volume ratio: 70/30
Initial viscosity: not measured
Initial filter loss at 80°F: 246 cc. emulsion.

VITA

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