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Formulation Studies and Grout Development for Fixation of Variable Phosphate/Sulfate Waste, Milestone 195

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Chemical Technology Division

FORMULATION STUDIES AND GROUT DEVELOPMENT FOR FIXATION OF VARIABLE PHOSPHATE/SULFATE WASTE, MILESTONE 195

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1. EXECUTIVE SUMMARY

The objective of this work was to develop a range of cement-based blended dry solids which, when mixed with variable phosphate/sulfate waste (PSW), produce grouts that are processible in the Rockwell Hanford Operations (RHO) Transportable Grout Facility (TGF).[1] The selected formula(s) will also (1) utilize commercially available materials requiring no custom processing and (2) meet all criteria as identified and quantified by RHO, not only for grouts made with the reference formula, but also for those grouts made with reasonable deviations from the reference formula expected during routine TGF operation. This development study was segmented into two phases: (1) preliminary formulation work, performed in FY 1986; and (2) final formulation work, performed in FY 1987.

This report presents experimental data for processibility and solid performance as well as graphical representations of the data. Based upon the results of the preliminary study, several grout formulas were found that produced acceptable grouts. One such formula, composed of Type III Portland cement (50 wt %), class F fly ash (28 wt %), Attapulgite-150 clay (14 wt %), and Indian Red pottery clay (IRPC) (8 wt %), produced acceptable grouts with several of the waste concentrations studied. When mixed with 100% sulfate waste, this blend produced acceptable grouts at mix ratios of 8, 8.5, and 9 lb/gal. This particular blend also produced acceptable grouts at waste concentrations of 25/75 and 75/25 PSW. At a concentration of 50/50 PSW, the amount of cement was lowered to 45 wt %, fly ash was raised to 33 wt %, and the two clay contents remained constant. This blend produced acceptable grouts at mix ratios of 7 and 8 lb/gal for this waste concentration. This blend also produced acceptable grouts using the same mix ratios for a waste concentration of 75/25 PSW.

The results of the preliminary study were analyzed and then incorporated into the final formulation design. The purpose of this final design was to develop a reference formula(s) that would produce an acceptable grout for varying waste compositions even when deviations in the dry-solids blend and/or mix ratio occurred during plant operation.

Two formulas were developed: one for use with 100% sulfate waste and one for use with either 100% sulfate waste or 35/65 PSW. The first formula consists of 47 wt % Type III cement, 30 wt % class F fly ash, 8 wt % IRPC, and 15 wt % Attapulgite-150 clay. The second formula, developed for use with both waste concentrations, contains 42.5 wt % Type III cement, 35.5 wt % class F fly ash, 8 wt % IRPC, 14 wt % Attapulgite-150 clay, and 1 wt % aluminum phosphate ($AlPO_4$). Currently, Rockwell does not have the facilities to add $AlPO_4$, which is a solid, to the waste feed tank. The capability for adding $AlPO_4$ must be acquired if it is to be used. Although the Dry Materials Receiving and Handling Facility (DMRHF) was tested with Type I,II Portland cement, the use of Type III cement should present no problem. Both reference formulas are to be used at a mix ratio of 8.5 lb/gal. Data to support compliance with performance criteria are presented in this report.

Since completion of the original work discussed in this report, the concentrations of the waste stream have changed. It appears that an 80/20 PSW will be grouted initially in the TGF. Based on data obtained in this development work, it appears that a grout formula consisting of 40 wt % Type III cement, 38 wt % class F fly ash, 8 wt % IRPC, and 14 wt % Attapulgite-150 clay may be used. This is based on data from experiments using 25/75 PSW, and no variability in the dry-blend components has been studied. The optimum mix ratio should be 7.5 lb/gal. However, it is recommended that a more detailed experimental design be undertaken before using this formula.

The reference formulas presented in this report produce grouts that are processible and environmentally safe. This study demonstrates the versatility of grout as a means of waste disposal.

2. INTRODUCTION

The initial waste stream to be processed by the Transportable Grout Facility (TGF) is a two-component stream generated by UNC Nuclear Industries in the 100 N area. The stream will be a mixture of 100 N reactor decontamination waste (phosphate) and 100 N fuel basin ion exchange regeneration waste (sulfate and sand filter sludge). Earlier formulation

development was based on a stream that was 50% sulfate waste and 50% phosphate waste (Milestone 140). The uncertainty surrounding the schedule for 100 N reactor decontamination, the amount of waste generated during a decontamination, and the availability of clean double-wall storage tanks necessitated that additional formulation development work be undertaken. This document describes experimental formulation work that bounded all expected waste compositions. The bounds for waste composition are 0% to 75% phosphate. These parameters were determined by analyzing the volume of the waste generated and double-wall tank logistics. These bounds were also used to develop an experimental design such that process variables as well as response variables could be studied.

All development work presented in this report is based on waste stream concentrations anticipated at the time this work was undertaken. Development work focused on the sulfate-rich waste stream, because large volumes of decontamination waste from the 100 N reactor (phosphate) were not anticipated. Since completion of this formulation development work, events have occurred that necessitate initial grouting of an 80/20 PSW stream. As such, recommendation of a grout formula for use with 80/20 PSW is based on a small quantity of data.

3. EXPERIMENTAL METHODOLOGY

This formulation study involved experimentation to clarify if the previously recommended grout formula [(ORNL) Milestone 140] for phosphate/sulfate Hanford Facilities Waste (HFW) would still meet performance criteria when mixed with the variable PSW. Several parameters needed to be varied so that the bounds would encompass all anticipated variations. One parameter of importance is the variation in phosphate concentration. The inverse is that the concentration of sulfate is also varied. The sulfate concentration is addressed, since sulfate is a known set retarder for cement and the waste stream was expected to be sulfate rich. To accommodate waste variations, it is necessary to develop a grout formula(s) that will be processible and meet all other criteria over the expected range of waste variation. The following parameters and their bounds were used for preliminary formulation work:

sulfate waste stream concentration	25–100 vol %
mix ratio	7–9 lb/gal
dry-solids blend components	±5 to = 20%

These ranges are based on evaluation of previous data (Milestone 140) and were derived using an algorithm for extreme vertices design.[2] The preliminary design generated extreme vertices by forming two small groups of points. These points bounded the parameters of interest and generated candidate points of interest.

The results of the scouting study generated variable effects and were used as a guide toward final formulation. The design for final formulation was such that the reference formula was subjected to at least a ±5% variation in variables. Data to support compliance with the criteria are supplied.

4. PERFORMANCE CHARACTERISTICS FOR AN ACCEPTABLE GROUT

A successful grout formulation for variable PSW is defined as one that meets all formulation characteristics as outlined below.

1. Waste loadings will be optimized, with minimum waste disposal volume increases.
2. Commercially available materials will be utilized, requiring little or no custom processing.
3. The grout will achieve turbulent flow at pumping rates ≤60 gpm.
4. Defined criteria will be met, not only by grouts made with the reference formula, but also by those grouts made with reasonable deviations from the recommended reference formula expected during routine TGF operation.

Specific criteria have been developed and revised to reflect changes in both regulatory and processing issues.[3] At the time of this development study, the following criteria were applicable:

- No more than four dry-blend components can be used.
- The reference formula must be able to pass all criteria for a ±5% relative variation for all dry-blend materials.
- Reference formula mix ratio must be ≤8.5 lb/gal.

- Reference formula must be able to pass all criteria for a ±0.5 lb/gal variation in mix ratio.
- No more than three additives can be used in the reference formula.
- Maximum additive flow rate must be ≤0.5 gal/min.
- Frictional pressure drop must be ≤11.2 psi/100 ft of 2-in. schedule 40 pipe.
- The grout must be able to achieve turbulent flow at rates ≤60 gal/min.
- Maximum 10-min gel strength ≤100 $lb_f/100\ ft^2$.
- Compressive strength ≥60 psi using ASTM Test C109-80.
- Drainable liquid volume must be ≤5 vol % after 28 d in a closed laboratory test vessel.
- ANS 16.1 Leachability Index ≥6 for selected radionuclides.

Data to support compliance with these criteria are presented in this report.

4.1 CRITERIA FOR MATERIALS USED IN GROUT DEVELOPMENT

The target objectives of these criteria were waste (solids and liquids) loading ≥50 wt % and volume increases (over the original waste) ≤30 vol %. In order to achieve a waste loading ≥50 wt %, the mix ratio (dry-solids blend to waste ratio) must be maintained at less than the density of the waste (~9 lb/gal). However, this criterion was set to 8.5 lb/gal to accommodate the ±0.5 lb/gal mix ratio variation. It is based on the DMRHF maximum capacity of 30,000 lb/h (500 lb/min), the Transportable Grout Equipment (TGE) maximum design feed capacity of 55-gal liquid waste per minute, and the desire to operate the TGF at the maximum flow rate on a continuous basis.

The dry-solids blend-to-waste mix ratio is a key variable in the formulation studies. Experience has shown that if all criteria are met at mix ratios A and B, then all mix-blend variations between the two will also meet all criteria. Testing of the DMRHF has shown that mix ratios can be controlled to within ±0.5 lb/gal. Consequently, the increment in the mix ratio was 1 lb/gal in the initial formulation studies. Also, the

lower and upper bounds of acceptable mix ratios would need to differ from the recommended value by 0.5 lb/gal. For example, if the lower and upper bounds of acceptable mix ratios were determined to be 7 and 8 lb/gal, respectively, then the recommended mix ratio would be 7.5 lb/gal.

It is realistic to expect that the blended bulk solids will not be prepared at precisely the recommended formula in plant operations. The recommended reference formula will be such that a ±5% relative variation in the dry-solids blend components can be tolerated. This capability has been demonstrated during testing of the DMRHF. With these deviations in dry-blend composition, an acceptable grout formula will continue to meet all other performance criteria.

4.1.1 Dry-Blend Components

Processing criteria state that no more than four dry materials can be used in the dry blend. These components consist of Portland cement, ASTM class F fly ash, Attapulgite-150 drilling clay, and IRPC. A small quantity (1 wt %) of aluminum phosphate is added to the waste to reduce the amount of drainable water on the grout surface after 28 d. The dry-blend components chosen are readily and commercially available.

An acceptable grout must have certain physical properties that meet or exceed performance criteria. These physical properties of the hardened and the wet grout are partially determined by the amount of cement in the blend. The amount of cement used is typically described in the waste-to-cement ratio (w_s/c). In general, a w_s/c of only 0.25 is required for complete hydration of Portland cement, with additional water serving to fluidize the mix and thus making it more readily processible. The cement serves as a binder, solidifying materials during the formation of hydration products within the waste form. This hydration occurs over a period of time and produces a solid matrix of material.

Although several types of Portland cement are available, only Types I,II and III were chosen for use in this study. Type III cement ultimately was chosen for use with PSW because the amount of drainable liquid was reduced when it was used. This cement should present no processing problems in the DMRHF.

The IRPC is added solely as an ion-exchange medium primarily to retain ^{137}Cs. With an exchange capacity of 0.1 meq ^{137}Cs per gram of clay, little clay should be needed.[5,6,7] However, experience at the ORNL facility has shown that the pottery clay content of the dry-solids blend needs to be 8 wt % to ensure intimate contact with the ^{137}Cs. In addition, minor variations (±5%) in the pottery clay content have been shown to have a negligible impact on the grout's rheological properties.

Fly ash is a cement extender, and its use should be maximized due to its low cost. The addition of fly ash also improves the fluid properties of the grout and the adsorption of water. The use of fly ash also decreases the leachability of strontium by incorporating it into the cementitious matrix.

Attapulgite-150 is added primarily to reduce drainable water from the product. However, previous ORNL grout development experience has shown that when present at or above 0.7 lb/gal of water (waste), it also appears to reduce the leachability of the product. Consequently, PSW formulation development studies attempted to maintain the Attapulgite-150 content at or above this value. Attagel, a tradename for Attapulgite-150, was used in this study.

4.1.2 Additives

Tributyl phosphate (TBP) is added to the waste before the addition of the dry-solids blend. The TBP, a defoaming agent which helps reduce the entrainment of air in the grout during mixing, was added at 0.04 vol % of the liquid waste. This is a maximum flow rate of 0.2 gal/min, which is less than the criterion of 0.5 gal/min.

Aluminum phosphate is added to the waste before the addition of the dry-solids blend. Its role is to reduce the amount of drainable water by promoting hydration. This results in the crystalline fibers growing more dense and possibly longer, thus reducing the permeability of the grout. This effect should be beneficial in the retention of hazardous waste constituents and radionuclides. The TGF does not currently have the capability to add the aluminum phosphate to the waste. It is recommended that the capability be acquired if this additive is to be used.

4.2 PROCESSING CRITERIA BASED ON TGE CAPABILITIES

The following criteria are based upon RHO performance criteria with reference to the capabilities of the TGE.[1]

1. The TGF is designed to operate at a nominal capacity of 50 gpm but will be capable of operating at rates <70 gpm.
2. The grout distribution pump will be capable of supplying a continuous output pressure of 350 psi.
3. The grout will be pumpable through 3000 ft of 2-in.-ID distribution pipe.
4. The maximum pressure available to overcome gel strength is limited to 500 psi.

In order to comply with the first three criteria, the grout's rheological properties must be tailored to result in a pressure drop of <335 psi through 3000 ft of 2-in.-ID pipe at a nominal flow rate of 50 gpm. The grout's compliance is determined by applying the following series of equations.[4] The first equation is the power-law model of the relationship between shear stress and shear rate:

$$S_s = K'(S_r)^{n'}, \tag{1}$$

where

S_s = shear stress for non-Newtonian fluids, lb_f/ft^2,

K' = fluid consistency index, $lb_f\ s^{n'}/ft^2$,

S_r = shear rate, s^{-1},

n' = flow behavior index ($0<n'<1.0$), dimensionless.

From Eq. (1), the viscosity in the laminar flow regime can be calculated by

$$\mu = 47880\ K'(S_r)^{n'-1}, \tag{2}$$

where

μ = viscosity in the laminar flow regime, cP.

The Reynolds number is then calculated by

$$N_{Re} = \frac{1.86\ V^{(2-n')}\rho}{K'(96/d_i)^{n'}}, \tag{3}$$

where

N_{Re} = Reynolds number, dimensionless,

V = fluid velocity, ft/s (5.1 ft/s at RHO design conditions nominal pumping rate of 50 gpm),

d_i = inside pipe diam, in. (2.067 in. at RHO design conditions),

ρ = fluid density, lb/gal.

From Eq. (3), frictional pressure drop can then be calculated:

$$\Delta P_f = \frac{0.039\ L\ \rho\ V^2 f}{d_i}, \tag{4}$$

where

ΔP_f = frictional pressure drop through a straight pipe, psi (limited to ≤335 psi at RHO design conditions),

L = pipe length, ft (3000 ft at RHO design conditions),

f = fanning friction factor, dimensionless (f is a function of Reynolds number; 0.008 was used in this study).

In order to demonstrate compliance with the fourth criterion, the pump head pressure necessary to overcome the gel strength of a grout which has been static for 10 min in the distribution pipe is calculated by:

$$P_H = \frac{G \cdot A_W}{(1.44 \times 10^4) A_p}, \tag{5}$$

where

P_H = pump head pressure, psi (limited to ≤500 psi at RHO design conditions),

G = 10-min gel strength, $lb_f/100\ ft^2$,

A_W = pipe inside surface area, $in.^2$,

A_p = inside pipe cross-sectional area, $in.^2$ ($3.35\ in.^2$).

These calculations were performed assuming a pipe diameter of 2.067-in. ID and a length of 3000 ft. Thus, an acceptable grout would be tailored to result in

$$G \leq 100\ lb_f/100\ ft^2. \tag{6}$$

Turbulent flow is necessary to minimize stagnant volumes in the pipe that can eventually lead to excessive pressure buildups. This criterion is intended to minimize this problem, and therefore the grout must obtain a Reynolds number ≥2100 in the TGF distribution pipe at a pump rate ≤60 gpm. Turbulent flow must be achieved by the grout in the TGF so that its performance is not hindered. The critical flow rate of each grout, as calculated, will determine whether or not this criterion is met. The equation for calculating critical flow rate is obtained by rearrangement of Eq. (3) and setting $N_{Re} = 2100$. This value of Reynolds number is generally accepted as the transition point from laminar to turbulent flow.

4.2.1 Determination of Grout Physical Properties

Dry solids are blended in 5-kg lots for 23 h at 30 rpm in a 7.6-L Patterson-Kelly twin shell V-blender prior to grout preparation. Mixing of the dry-solids blend and simulated waste is performed in a Hobart model N-50 mixer with a wire loop whip mixer blade. Mixing is accomplished by adding solids to liquid during an 8- to 15-s interval while stirring at low speed for a total of 30 s. Mixing is then continued at medium speed an additional 30 s for a total mixing time of 60 s. The following measurements and/or calculations are then performed to determine whether process criteria are met.

4.2.1.1 Rheological Measurements

Rheological measurements are made using a standard oil well cement-slurry method with a Model 35A/SR-12 Fann viscometer. Shear stress readings are taken as a function of shear rate, going from high to low shear rates.

Readings in $lb_f/100\ ft^2$ are taken in 12 steps ranging from 600 rpm to 0.9 rpm. The RPMs are converted to reciprocal seconds (the standard shear rate unit) by multiplying by an instrument conversion factor. Shear stress readings from 51 to 100 s^{-1} are used to determine the flow parameters, fluid consistency index (K') and flow behavior index (n'), which, with density, are required for flow calculations. The method of data reduction is described in ORNL Milestone 30 and is based on the Ostwald-de Waele model, more commonly referred to as the power-law model.[4]

Using the same measurement technique, the 10-min gel strength is determined as the maximum deflection of the dial (in $lb_f/100\ ft^2$) at 3 rpm after the grout has been allowed to remain static for 10 min.

4.2.1.2 Flow Consistency Index, K', and Flow Behavior Index, n'

For non-Newtonian grouts, shear stress is dependent on shear rate and is represented by the power-law model,

$$\log S_s = \log K' + n' \log S_r \ , \qquad (7)$$

where

S_s = shear stress, lb_f/ft^2,
K' = fluid consistency index, $lb_f \cdot s^{n'}/ft^2$,
S_r = shear rate, s^{-1},
n' = flow behavior index ($0<n'<1.0$), dimensionless.

Values of n' and K' are determined from the power-law model for a given set of data on viscometer shear stress vs shear rate. The values were then used in the calculation of Reynolds numbers and in the calculation of conditions for turbulent flow of the grouts.

4.2.1.3 Density

The density of each freshly mixed grout was directly measured in lb/gal at room temperature using a Baroid mud balance.

4.2.1.4 Apparent Viscosity

Viscosity in a non-Newtonian grout varies with shear rate. The apparent viscosity in these tests was measured at 511 s^{-1} (300 rpm on the Fann viscometer), which is a common practice.[4] The viscosity of the grout can be calculated using Eq. (2).

4.2.1.5 Gel Strength (10 min)

The 10-min gel strength is a measure of the force required to restart the flow of grout in a pipe after the flow has been stopped for 10 min. The measurement is made in the Fann viscometer with the same grout sample that was used for the other rheological measurements. The grout is allowed to stand in the viscometer for 10 min without stirring, after

which the instrument is turned on with the shear rate set at 3.0 rpm. The 10-min gel strength in $lb_f/100\ ft^2$ is read directly from the viscometer as the maximum deflection on the shear stress scale.

4.3 CRITERIA BASED ON REGULATORY ISSUES

The majority of criteria based on regulatory issues are derived from 10CFR61.56, "Waste Characteristics," and are intended to ensure the stability of the solid waste form. The assumption is made that the waste form will not exhibit any of the criteria listed in 10CFR61.56(a) (i.e., pyrophoric, explosive, reactive with water). This assumption may have to be proven at a later date.

4.3.1 Unconfined Compressive Strength

The compressive strength measurement procedure is representative of the procedures set forth in ASTM C109-80. This procedure uses 2-in. cubes, which is consistent with the methods used in this study. Using ASTM C109-80 meant that the compressive strength criterion had to be raised to >60 psi after 28 d. The use of cylindrical samples, as required in ASTM C39-81, is not only more expensive but consistently gave values that are 20% lower than the values obtained using ASTM C109-80. Therefore, this criterion was adjusted to >60 psi. Compressive strength is measured using a Model 60,000 Super "L" Tinius Olsen Testing Machine.

4.3.2 Drainable Water

Drainable water refers to a separate liquid or water phase that collects at the top of freshly mixed grout. The volume of drainable liquid or water is usually found to increase for a short period of time after the grout is mixed, about 1 d, and then to decrease with further cure time. The increase during the first day is essentially a sedimentation phenomenon caused by the solids settling in the plastic mass. The decrease with further cure time is believed to be due to hydration and/or water adsorption in the grout pore structure.

The standard recommended test for determination of drainable water is the American Nuclear Society (ANS) 55.1 test. This procedure had to be modified for laboratory work, since it required the use of a 55-gal drum, which was obviously not suitable for this experimental study. The

drainable water was thus determined by pouring fresh grout into a 0.5-L calibrated plastic container, sealing the container, and allowing the grout to remain stationary for 28 d. Data were taken at specific time intervals, as reported later in this report. Percent drainable water was determined as 100 × volume of water/original grout volume. Attainment of ≤5% drainable water in 28 d was defined to be necessary for a grout to meet performance criteria.

4.3.3 Leachability Index

The leachability index was determined for the reference formula for 50/50 HFW (Milestone 140). The American Nuclear Society (ANS) 16.1 and the EP-Toxicity tests were performed; the results are presented later in this report. The EP-Toxicity test was also performed on the reference formula and the results presented in Appendix L.

4.3.4 Noncriteria Test

The penetration resistance of the grout sample, which is determined as a function of time, is routinely measured and recorded. The measurement of penetration resistance is a modification of ASTM C403-80 and is done using an Acme Penetrometer, Model CT-426. Fresh grout is poured into 2-in.-ID circular molds and allowed to cure. Measurements are taken at specific time intervals and give an indication of the grout's set time. This test is not a requirement, and, therefore, the ASTM procedure was modified so as to facilitate laboratory measurement and minimize equipment and material costs.

5. DEVELOPMENT STUDIES AND RESULTS

This section describes the methdology used in development of grouts to be used with variable PSW. The rationale for each step, along with the results, is discussed.

5.1 REFERENCE FORMULAS USED IN DEVELOPMENT WORK

Milestone 140 describes a reference blend to be used in the disposal of 50/50 phosphate/sulfate HFW. Since it is optimal to use fewer formulas in the TGF (less unused raw materials, infrequent cleaning of storage

silos, etc.), the use of a previously defined reference formula is naturally the starting point for further development work. The same logic is applied for testing of the reference formula for disposal of neutralized cladding-removal waste (NCRW).[8]

5.1.1 Reference Formula for 50/50 HFW

The reference blend for 50/50 HFW (Blend V1), as well as a variation of it (Blend V3), was tested. Both blends produced grouts with acceptable properties, except for drainable water. The waste used for both blends was 100% sulfate, which represents a worst-case scenario. Sulfate is a known set retarder and can cause expansive damage due to the excessive formation of ettringite.[9] The amount of drainable water was significantly reduced when Type III Portland cement was used. A larger Blaine fineness and higher amounts of ferric oxide could account for the decrease in drainable water. Sources in the literature[8] tend to point to this phenomenon. Since all other grout properties were acceptable within specified limits, the drainable water criterion was the focus of the next experimental series. Table 1 presents the different variations as well as the reference blend used in this initial experimental series.

Table 1. Exploratory studies

	Amount (wt %) by blend No.							
Material	V1	V2	V3	V4	V5	V6	V7	V8
Cement, Type III	41[a]	41	50[a]	50	50	50	41	40
Fly ash, class F	40	40	31	31	28	42	27	52
Attapulgite	11	11	11	11	14	–	14	–
IRPC[b]	8	8	8	8	8	8	8	8

[a]Type I,II cement.
[b]IRPC = Indian Red Pottery clay.

5.1.2 Reference Formula for NCRW

Table 2 presents the various blends used in the next experimental series. As evident from the table, the NCRW blends with the highest cement content were primarily used. As in the previous series, the waste used was 100% sulfate. All of the grouts produced had acceptable properties, with the exception of drainable water.

As with the previous series of experiments, the drainable water appeared to be the most difficult criterion for formulation studies. It is evident that the use of Type III Portland cement significantly reduces the amount of drainable water. There are several possible reasons for this effect, such as Blaine fineness, alumina ratio, and the amount of tricalcium aluminate present in the different types of cement.[10] It is beyond the scope of this report to investigate these areas.

The data for both series of experiments are contained in Appendix A. Plots of the various responses as a function of mix ratio are contained in Appendixes B, C, and D for 50/50 HFW reference formula, Type III Portland cement, and NCRW reference formula, respectively.

Table 2. NCRW reference blends

Material	Amount (wt %) by blend No.			
	40	41	42	43
Cement, Type III	45	47.5	47.5	47.5
Fly ash, class F	35	32.5	32.5	32.5
IRPC[a]	6	10	8	6
Hydrated lime	14	10	12	14

[a]IRPC = Indian Red Pottery clay.

5.2 PRELIMINARY EXPERIMENTAL DESIGN USING TYPE III CEMENT

As discussed in the previous section, the use of Type III cement in grout formulation significantly reduces the amount of drainable water. An experimental design was implemented to study the effects of dry-solids

blend variations, mix ratio, and sulfate concentration. The study, detailed in Table 3, was designed in such a way that credible limits on each of the variables were encompassed. The dry-solids blend components were varied from a minimum of 11% for cement to a maximum of 25% for IRPC (relative %). The waste concentration was varied from 100% sulfate waste to a minimum of 25/75 phosphate/sulfate. Mix ratios studied were 7, 8, and 9 lb/gal.

Table 3. Dry-solids blend variations for variable phosphate/sulfate waste (PSW)[a,b]

Material	Amount (wt %) by blend No.								
	1	2	3	4	5	6	7	8	9
Cement, Type III	40	40	40	45	45	45	50	50	50
Fly ash, class F	38	38	38	33	33	33	28	28	28
Attapulgite	16	14	12	16	14	12	16	14	12
IRPC[c]	6	8	10	6	8	10	6	8	10

[a]Mix ratios studied: 7, 8, 9 lb/gal.
[b]PSW concentrations studied (vol %): 0/100, 25/75, 50/50, and 75/25.
[c]IRPC = Indian Red Pottery clay.

5.3 PREPARATION OF SIMULATED WASTE

The simulated waste used in all experiments was prepared according to the following recipe:[11]

- Prepare separate batches of phosphate and sulfate waste

  - Preparation of simulated phosphate waste (1-L basis)

    280 mL distilled water

    25.5 mL Turco 4521A-17 (without inhibitor)

    0.12 g diethylthiourea

    19 M NaOH solution until pH = 12.0 ±0.1

    Balance is distilled water

- Preparation of simulated sulfate waste (1 L-basis)
  4.5 g Na_2SO_4
  19 M NaOH solution until pH = 12.0 ±0.1
  Balance is distilled water

- Mix them in correct volumes to obtain the required mixture

5.4 TEST RESULTS AND ANALYSIS

This section summarizes the results obtained from the experiment discussed in Sect. 5.2. All data for these experiments are contained in Appendix E. Appendix F contains plots of responses studied as a function of mix ratio for the various blends.

5.4.1 Summary of Acceptable Grouts

An acceptable grout is defined as one that passes all performance criteria as described in Sect. 4. At the time of this work, the drainable water criterion was under evaluation to raise the standard to ≤5 vol % from 0 vol %. The assumption was made that this would be the case and was subsequently applied during this study. During the final formulation work, the drainable water criterion was raised to ≤5 vol %. Attagel, a trade name for Attapulgite-150 clay, was used for this study and is included in the legends for all figures and graphs.

5.4.1.1 Acceptable Grouts Using 100% Sulfate Waste

The use of 100% sulfate waste has previously been described as a worst-case scenario. Naturally, discussion of acceptability should begin with this aspect of the experimental design. As with all grouts, the measure of acceptability is based on adherence to the performance criterion. The compressive strength criterion was passed by all grouts produced during the scouting studies and the experimental design. Since this criterion presented no problem to formulation, further discussion is restricted. The data for this criterion are presented in Appendix A. It should be pointed out that only grouts that pass all criteria are discussed in this section.

Based on the constraints of the TGE, the next criteria of concern would be the fluid properties of the grouts, such as the critical flow rate, 10-min gel strength, and frictional pressure drop. These criteria

will be discussed in relationship to the effect that variations in the dry-solids blend components have on them.

Factors affecting critical flow rate

The first of these criteria, critical flow rate, is the rate at which the grout must be pumped to achieve turbulent flow. Figure 1 illustrates the effect each dry-solids blend component has on the critical flow rate. The amount of each dry-solids blend component is given in pounds of material/gallon of waste. This designation takes into account both the mix ratio and the wt % of each component in the blend. Figure 1 is used primarily as a tool to qualitatively describe the response.

As can be seen from the graph in Fig. 1, each blend component affects the response in varying degrees and direction. Generally, increasing the amount of cement or attapulgite results in an increase in the critical flow rate. The cement appears to have the more pronounced effect. The amount of fly ash has just the opposite effect. The critical flow rate tends to increase as the amount of fly ash decreases. This response is consistent with the fact that fly ash can improve the fluidity of the grout. The addition of IRPC appears to have the least effect on critical flow rate.

Viscosity should also be discussed in this section even though there is no performance criterion pertaining to it. However, the critical flow rate is dependent on this parameter, and, therefore, a brief description of the effects of component variation on viscosity is given. Since critical flow rate is directly proportional to the viscosity, the same general trends should be present. The same effects were seen as a result of component variation. Figure 2 depicts the same general trends as could be seen in Fig. 1.

Factors affecting 10-min gel strength

The 10-min gel strength is a measure of the force necessary to restart grout flow after a stagnant period of time. The majority of grouts produced during this experimental design passed this criterion. As can be seen in Fig. 3, the principal controlling component appears to be the cement. Increasing the amount of cement generally increases the 10-min gel strength. This would be expected, since the cement is

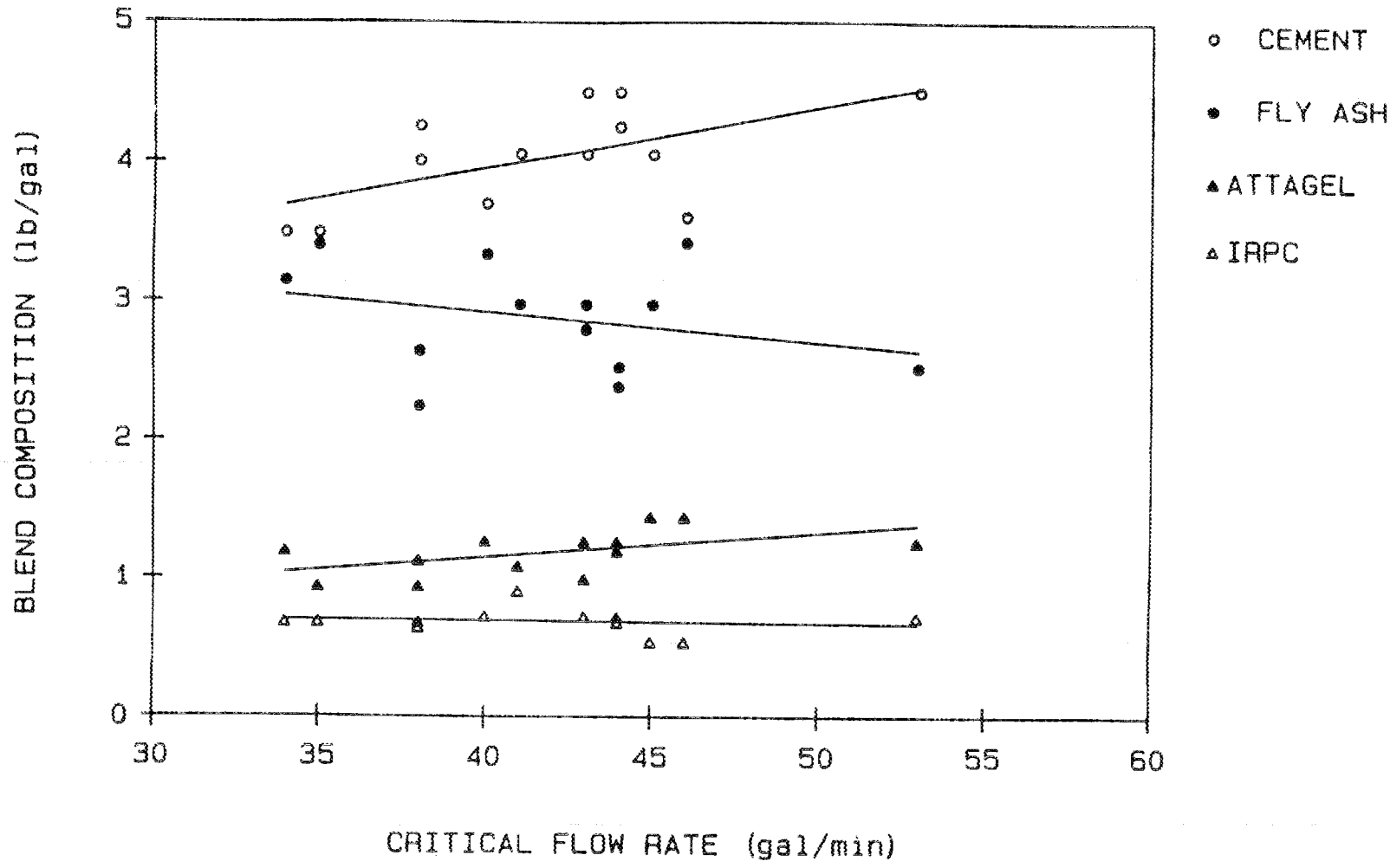

Fig. 1. Effect of blend composition on critical flow rate for 100% sulfate waste.

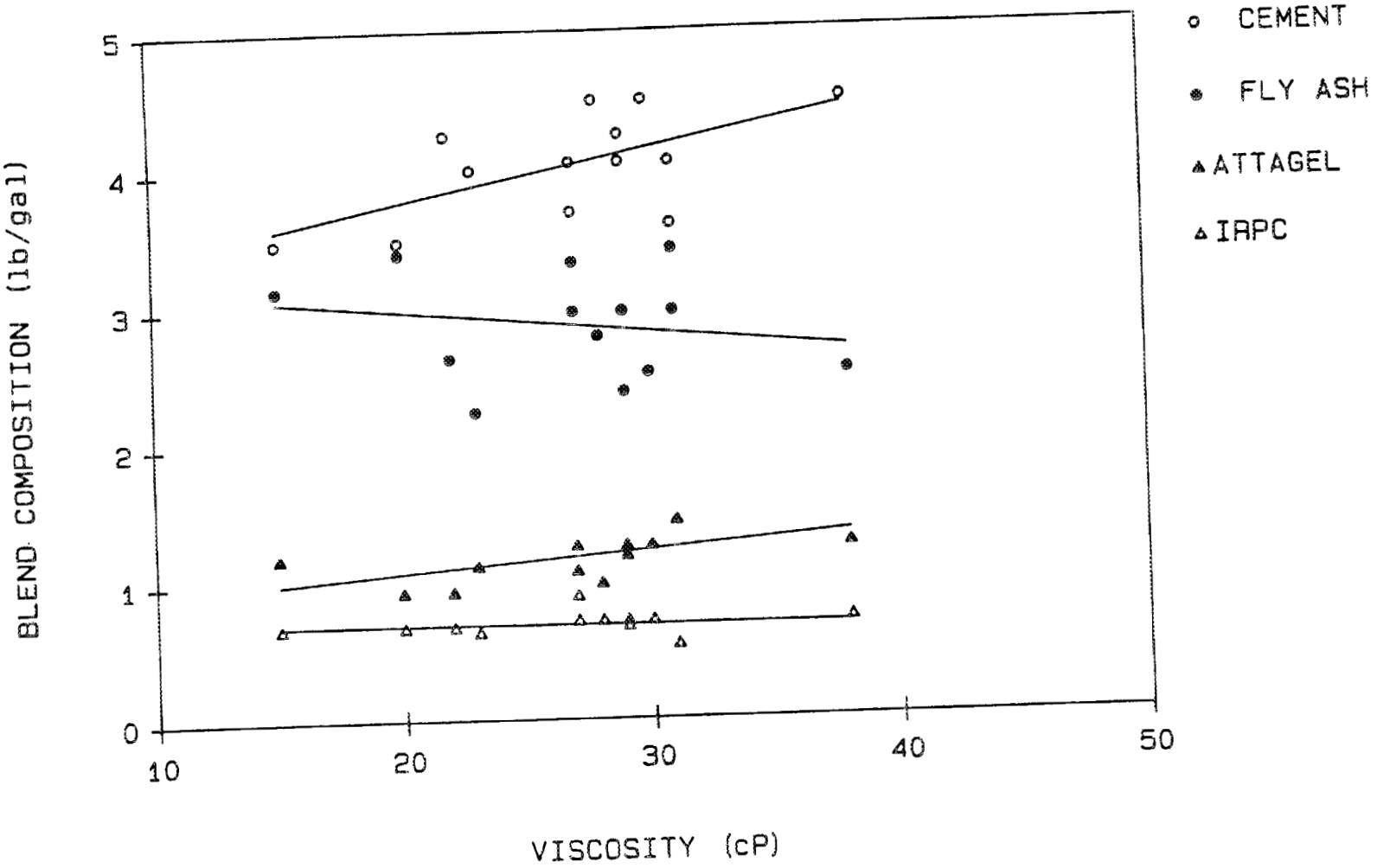

Fig. 2. Effect of blend composition on viscosity for 100% sulfate waste.

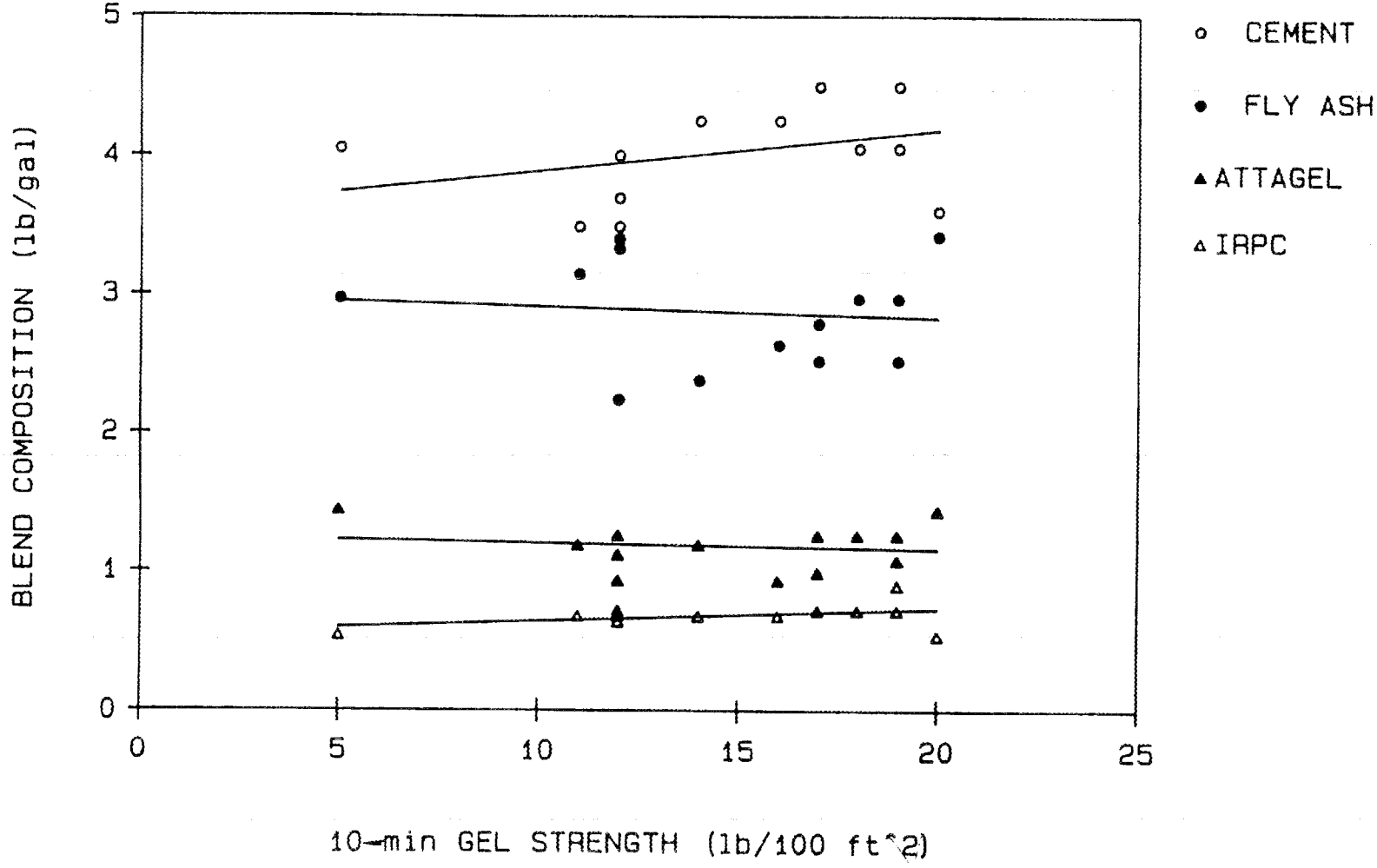

Fig. 3. Effect of blend composition on 10-min gel strength for 100% sulfate waste.

undergoing hydration during this time. The other three components appear to have only a slight effect on this particular response. Both fly ash and Attapulgite content appear to have a slight inverse effect on the 10-min gel strength.

Factors affecting drainable water

The drainable water criterion was the most troublesome standard for this development study. As mentioned earlier, the assumption was made that the criterion will be raised to accommodate some free-standing liquid on the monolith's surface after the curing period. Using this assumption, Fig. 4 presents data from grouts that would pass this criterion. It appears that there are two controlling components for this response, cement and fly ash. However, their effects are in opposing directions. An increase in cement content appears to decrease the amount of drainable water, whereas an increase in fly ash content appears to increase the amount of drainable water. Decreasing the amount of Attapulgite has a slight effect on increasing the amount of drainable water. The IRPC appears to have an insignificant effect on the drainable water. These trends are general in nature and were investigated further in the final development work.

5.4.1.2 Acceptable Grouts Using 25% Phosphate/75% Sulfate Waste

Previous work at ORNL (Milestone 140) has defined parameters for grouting 50/50 sulfate/phosphate HFW. The reference formula for 50/50 sulfate/phosphate HFW was initially tested for use with 100% sulfate waste and found to be unacceptable due to excessive drainable water. Although the experimental design encompassed a wide variation in waste composition (Table 3), this section discusses in detail only grouts made with either 100% sulfate waste or 25% phosphate/75% sulfate waste. These ranges appeared to be the more credible for actual grouting. In the final formulation design, these ranges were subsequently changed, using concentrations that were based on information from RHO.

Factors affecting critical flow rate

Figure 5 depicts acceptable results from this experimental design. As can be readily seen, there are fewer acceptable grouts, and therefore, only very general trends appear. The amounts of cement and fly ash

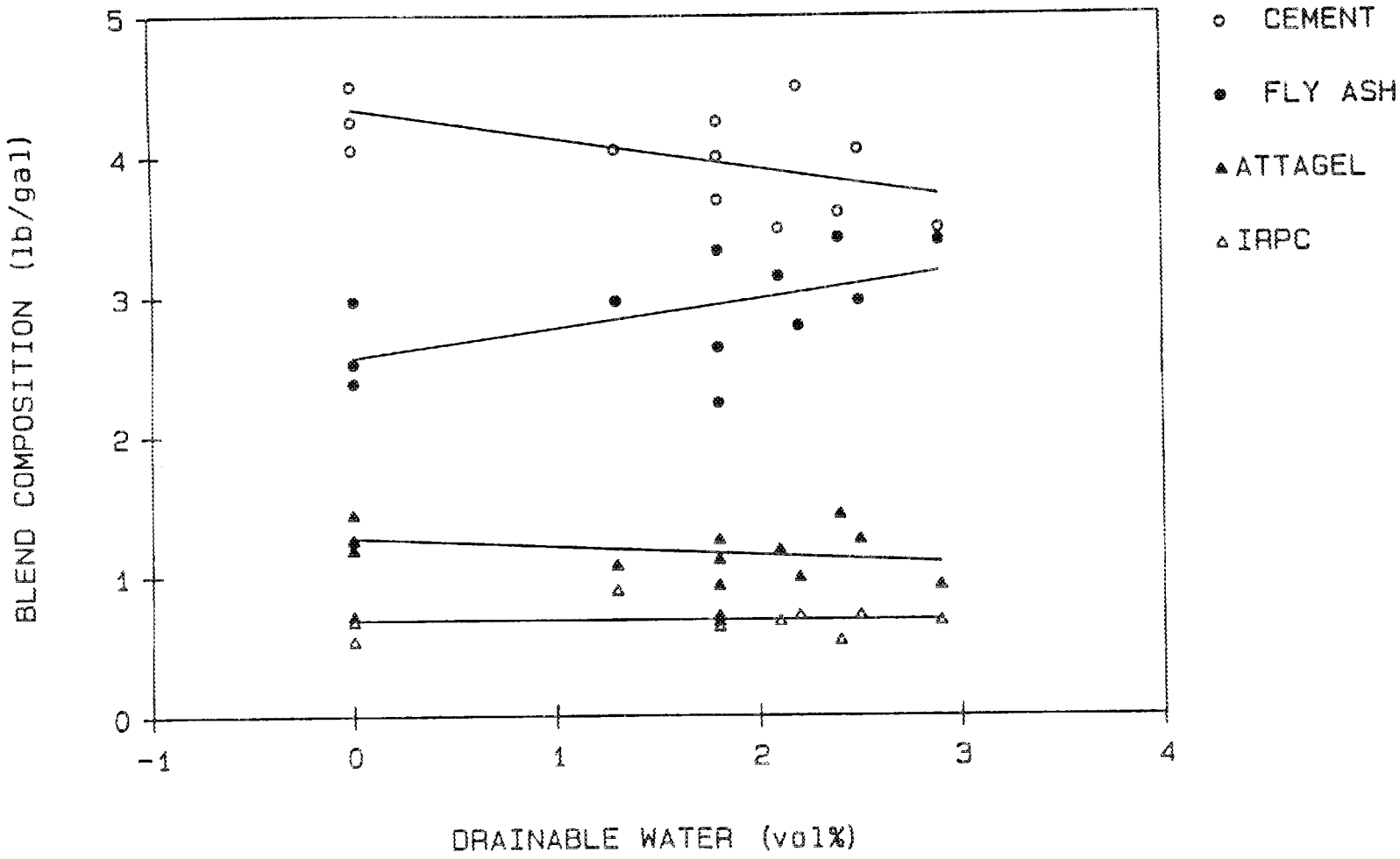

Fig. 4. Effect of blend composition on drainable water for 100% sulfate waste.

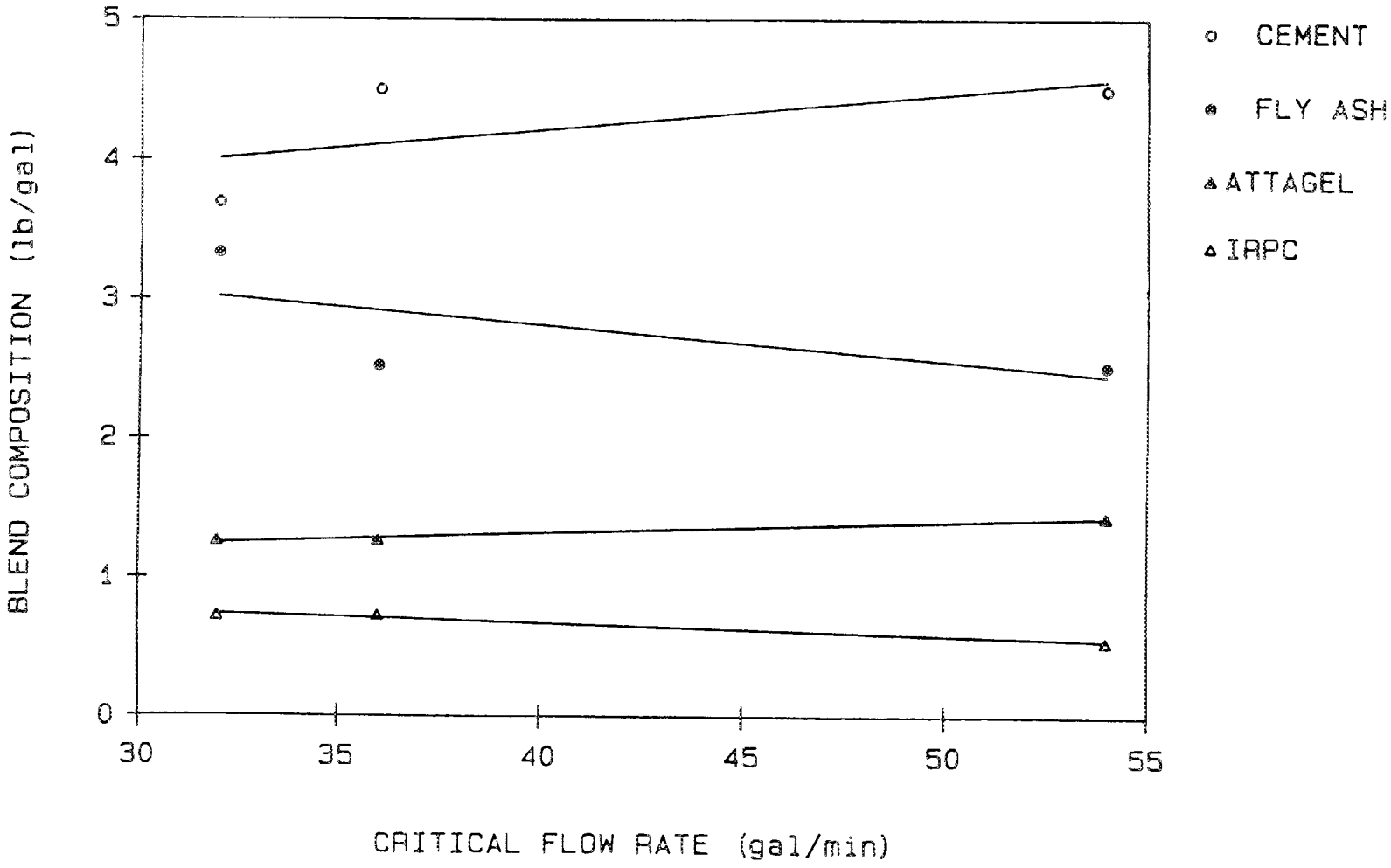

Fig. 5. Effect of blend composition on critical flow rate for 75% sulfate/25% phosphate waste.

appear to have the most significant effects on the critical flow rate. These effects are basically the same as with grouts produced using 100% sulfate waste. An increase in cement content results in an apparent increase in the critical flow rate, while a decrease in fly ash results in an apparent increase in the critical flow rate. The two clays used, Attapulgite and IRPC, appear to impact the critical flow rate to a lesser degree.

The same general trends are evident when viscosity is studied. These trends, illustrated in Fig. 6, are similar to the ones for critical flow rate and follow the same pattern as grouts produced using 100% sulfate waste. Detailed studies of these effects were undertaken in the final formulation work.

Factors affecting 10-min gel strength

The most pronounced factors affecting the 10-min gel strength are the cement and fly ash contents. As was seen with grouts produced using 100% sulfate waste, an increase in cement content and a decrease in fly ash content results in an increase in the 10-min gel strength, as illustrated in Fig. 7. These effects appear to be more significant than the ones seen with the 100% sulfate grouts. The Attapulgite and IRPC content appear to have very minimal effects on the 10-min gel strength. It should be noted that very few grouts produced during the entire experimental design failed this criterion.

Factors affecting drainable water

For this block of experiments, few grouts passed the drainable water criterion. However, the data were plotted and are shown in Fig. 8. Since so few data points are used, any trends are very general. The same basic trends are evident: decreasing the cement content and increasing the fly ash content result in an increase in the amount of drainable water. Lesser effects are seen for varying the amount of IRPC and Attapulgite. No acceptable grouts were produced using 75% sulfate/25% phosphate waste that had 0 vol % drainable water. This problem area was investigated in detail during final formulation work.

5.4.2 Effect of Sulfate Concentration

The sulfate concentration in the waste stream has a measurable effect on all the responses. Blend No. 7 from the experimental design was chosen

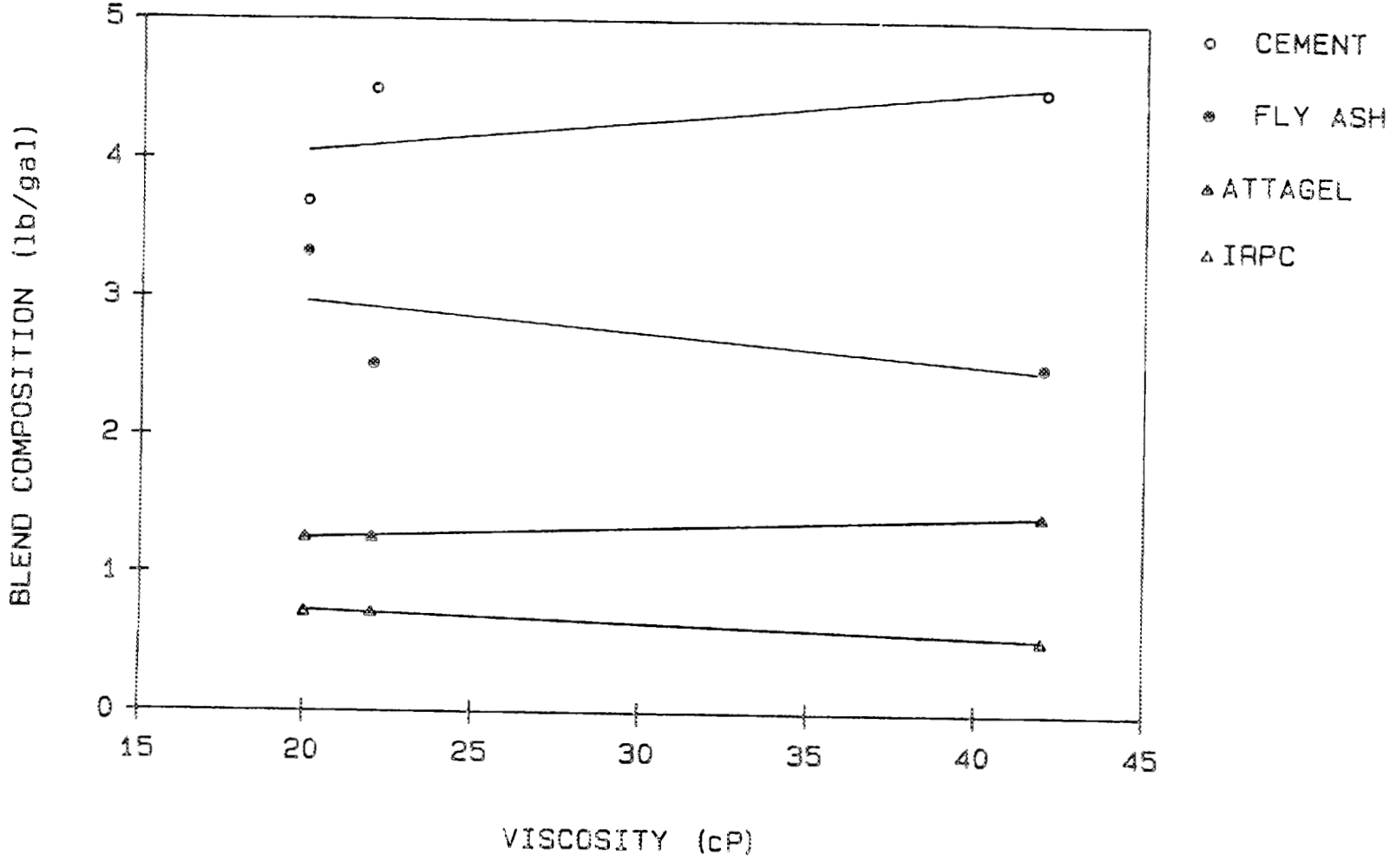

Fig. 6. Effect of blend composition on viscosity for 75% sulfate/25% phosphate waste.

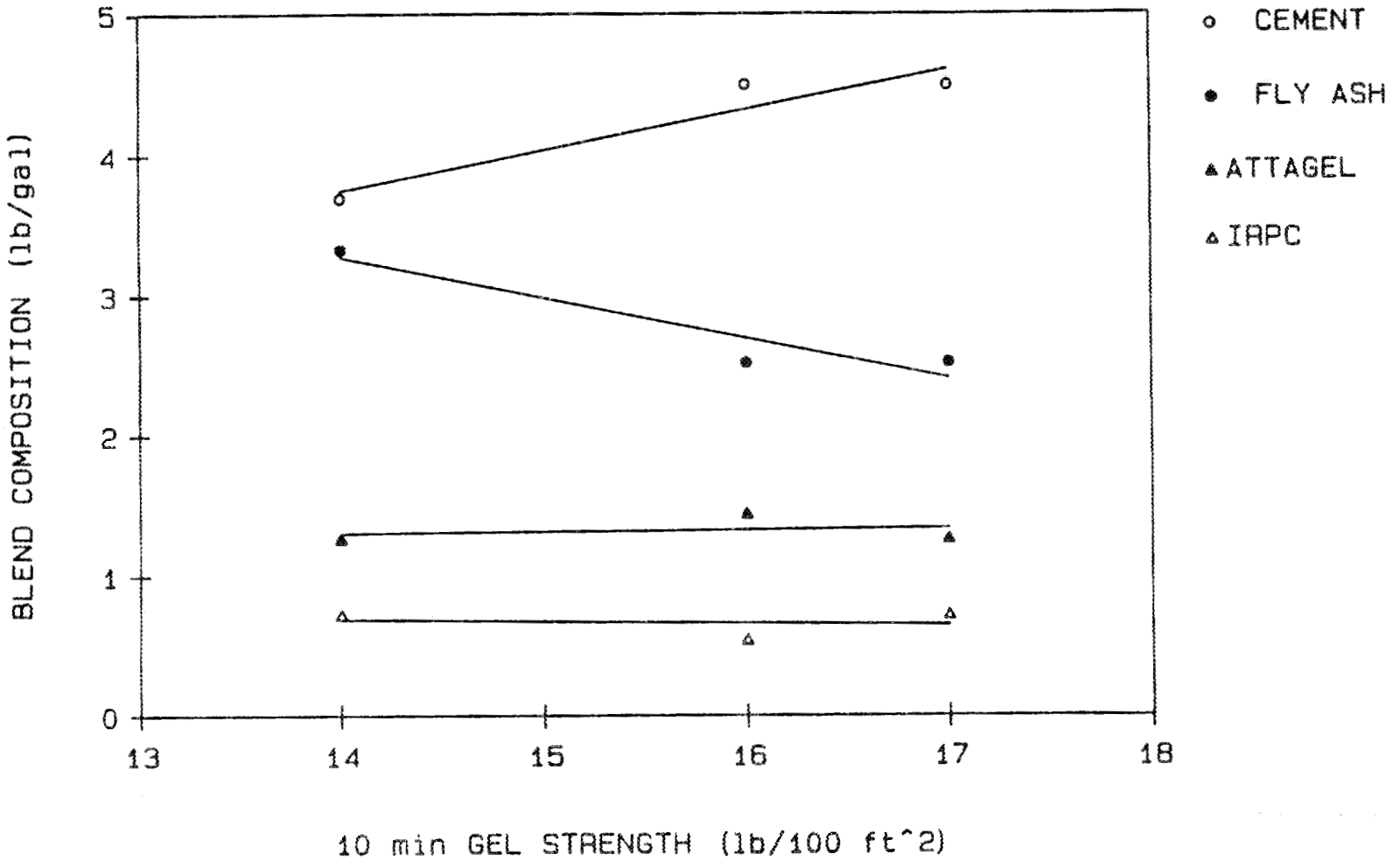

Fig. 7. Effect of blend composition on 10-min gel strength for 75% sulfate/25% phosphate waste.

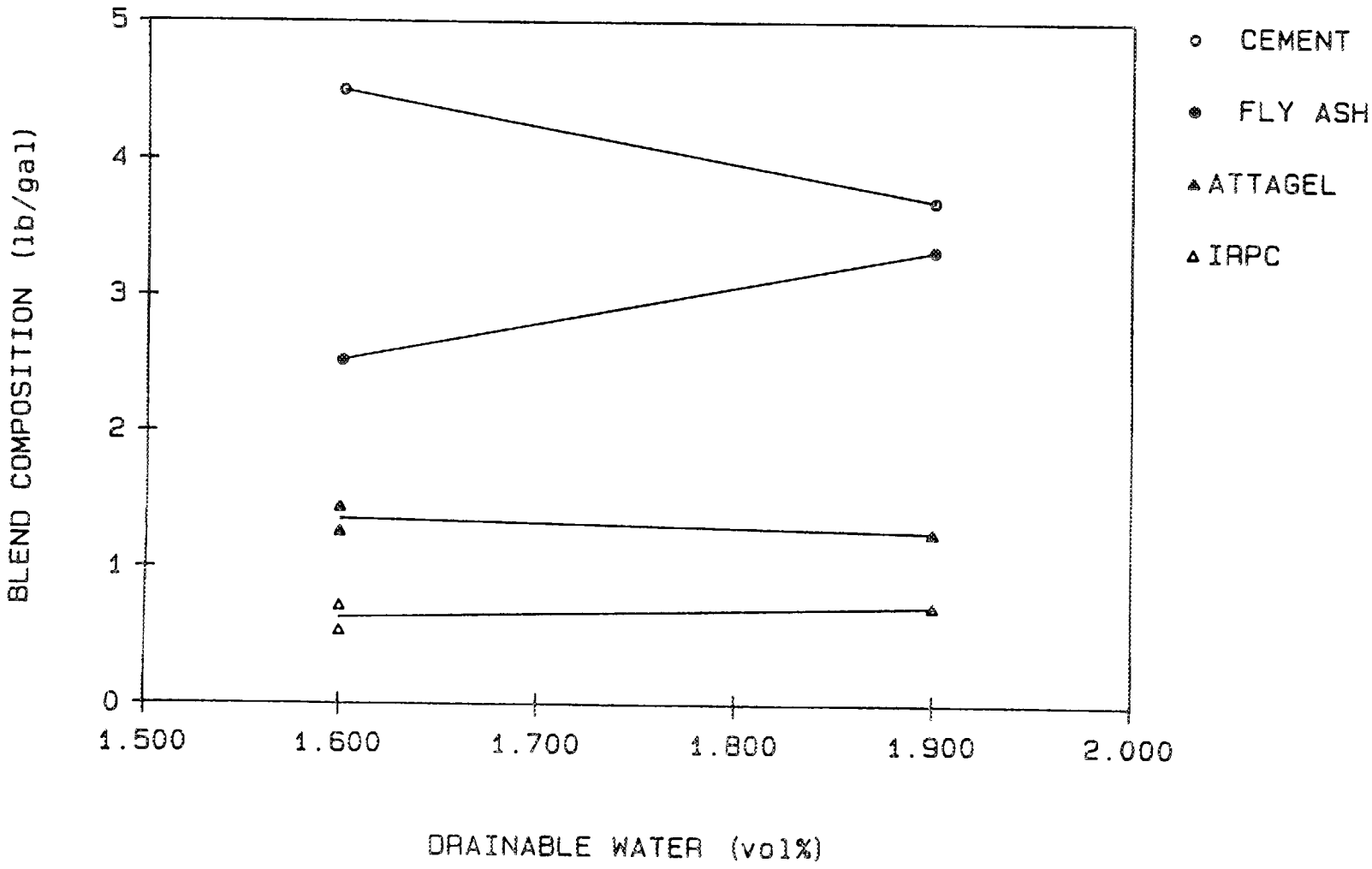

Fig. 8. Effect of blend composition on drainable water for 75% sulfate/25% phosphate waste.

to illustrate the effects of sulfate concentration. Figures 9 and 10 show that as the sulfate concentration decreases, the corresponding parameters, critical flow rate and compressive strength, respectively, increase. This effect was the same for all mix ratios studied. The two other responses, 10-min gel strength and drainable water (Figs. 11 and 12, respectively), were affected by the sulfate concentration but with no discernible pattern. The causes of these anomalies were investigated during later work. These anomalies are more prevalent at the 75% sulfate/25% phosphate range. This particular waste concentration has consistently been troublesome during this initial formulation study. As discussed earlier, the most difficult criterion has been the drainable water. The largest volume of drainable water has been seen when using the 75% sulfate/25% phosphate waste.

5.5 LEACHABILITY OF GROUTS PREPARED USING 50/50 PHOSPHATE/SULFATE HFW

Grouts were prepared using a 50/50 phosphate/sulfate HFW. This waste was prepared according to the previously described procedure, except that all trace elements[11] were added at concentrations of 100 times those specified. After the grouts were cured for 28 d, they were taken to a CERCLA-approved laboratory where an EP-Toxicity leach test was performed. The test was performed in triplicate, and the results are presented in Table 4. The grout formula used for these samples is the one identified in Milestone 140. The concentrations of trace elements used are given in Table 5. The results show that the grout samples pass the EP-Toxicity leach test.

5.6 SUMMARY OF ACCEPTABLE GROUTS

An acceptable grout is one that passes all performance criteria. For the development studies reported, the assumption was made that the drainable water criterion would be relaxed to ≤5 vol %. Based on this assumption, several different grout formulas are deemed acceptable. The first of these preliminary formulas, which was developed for use with 100% sulfate waste, is as follows: Type III Portland cement (50 wt %), class F fly ash (28 wt %), Attapulgite clay (14 wt %), and IRPC (8 wt %). This

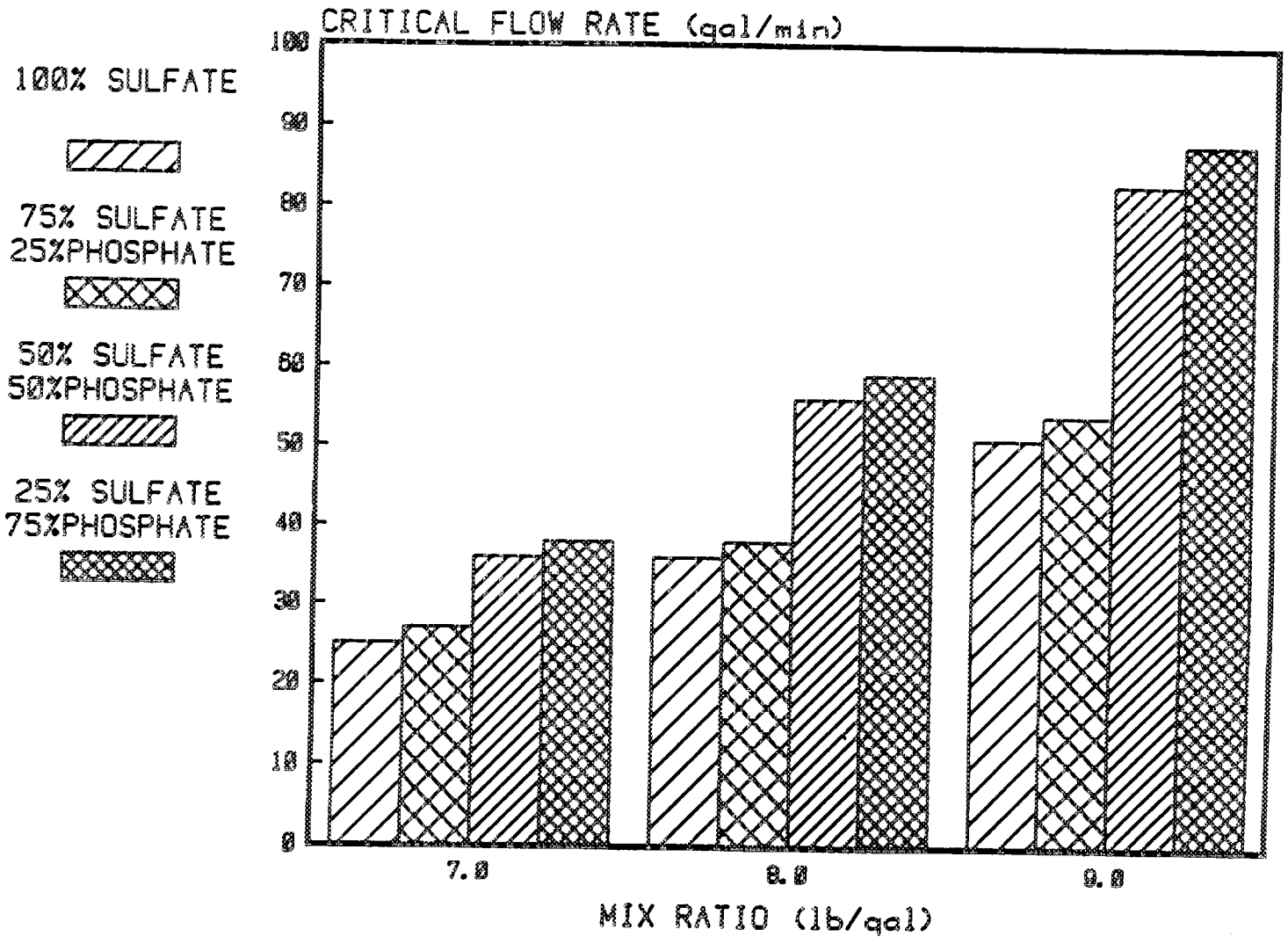

Fig. 9. Effect of sulfate concentration on critical flow rate for blend 7.

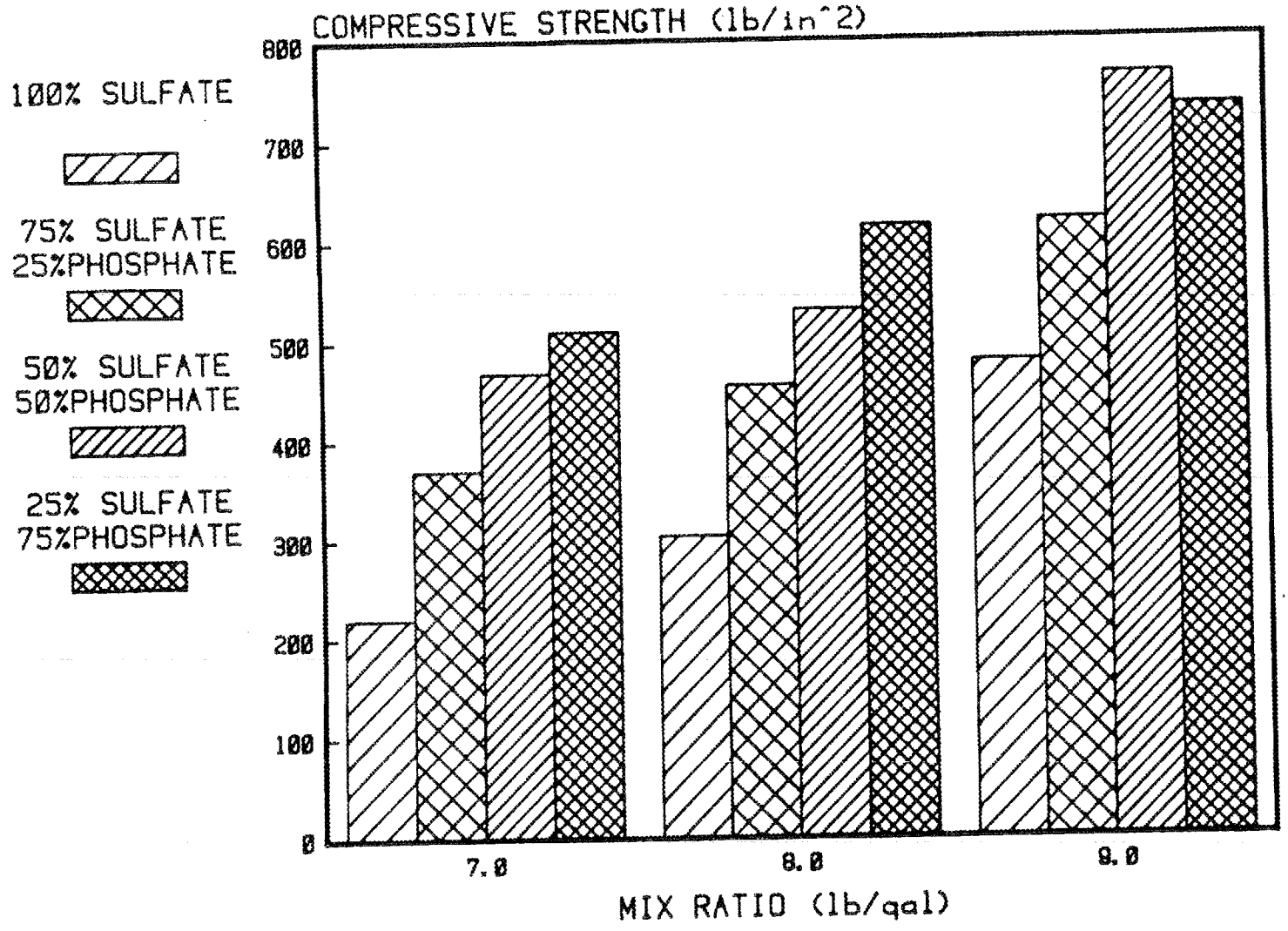

Fig. 10. Effect of sulfate concentration on compressive strength for blend 7.

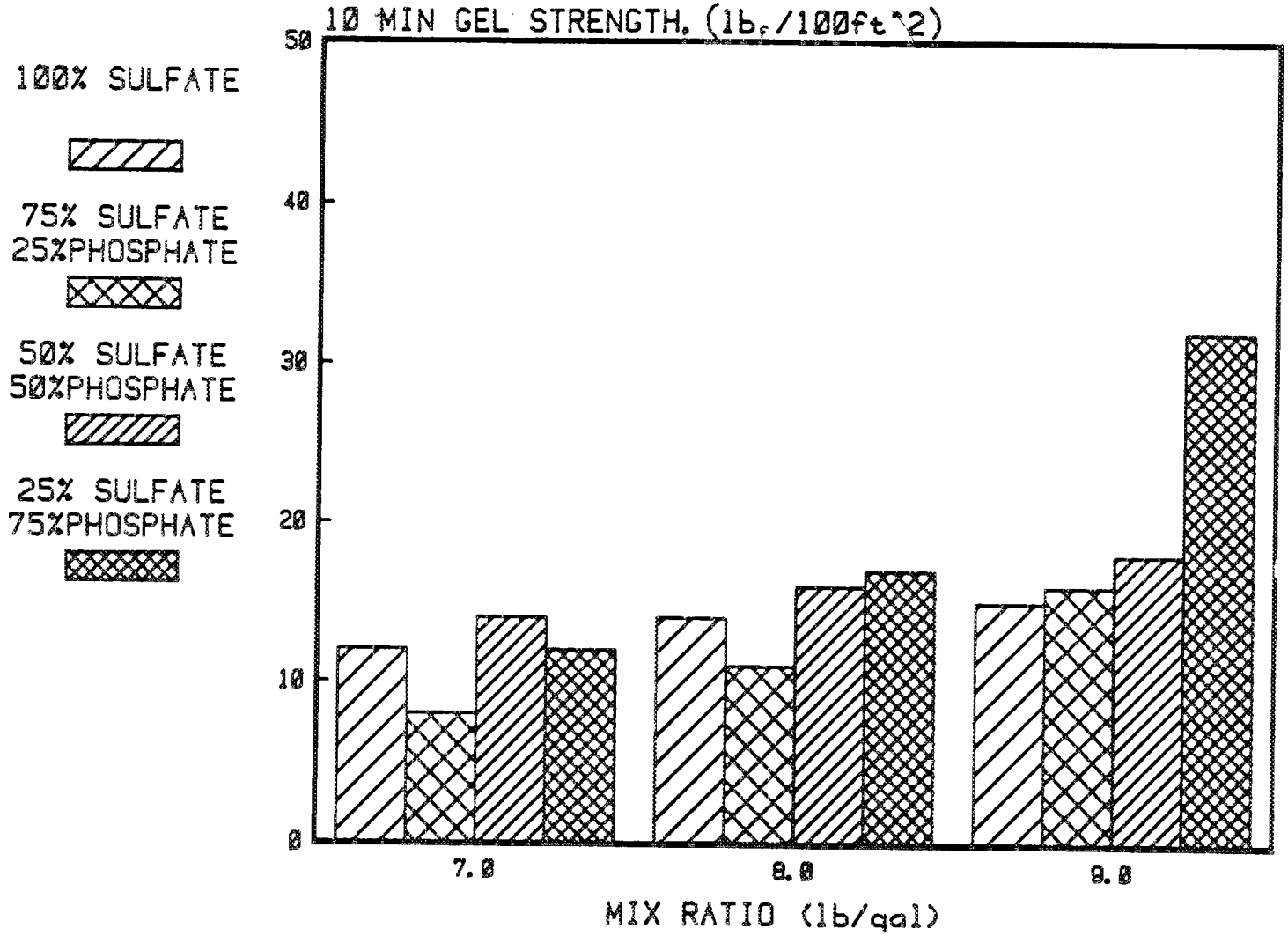

Fig. 11. Effect of sulfate concentration on 10-min gel strength for blend 7.

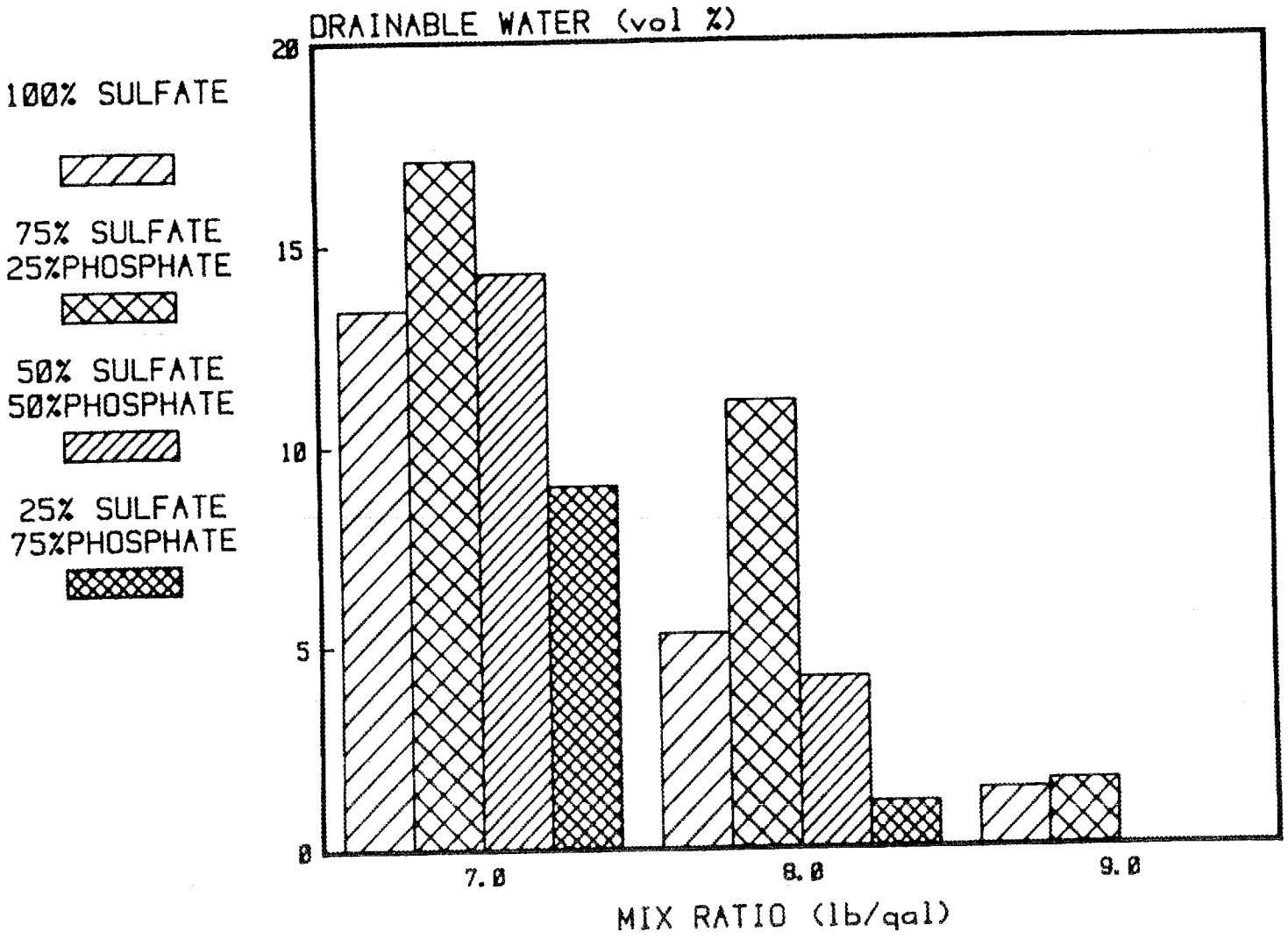

Fig. 12. Effect of sulfate concentration on drainable water for blend 7.

Table 4. Results of EP-Toxicity leach test performed on 50/50 HFW reference formula[a,b]

Element	Results (mg/L)	EP-Toxicity threshold limits (mg/L)	National drinking water standards (mg/L)
Barium	0.20 0.19 0.16	100	1.00
Cadmium	0.0030 0.0030 0.0030	1	0.01
Chromium	0.010 0.010 0.010	5	0.05
Silver	0.0060 0.0060 0.0060	5	0.05
Arsenic	0.012 0.014 0.016	5	0.05
Lead	0.025 0.033 0.010	5	0.05
Selenium	0.006 0.006 0.008	1	0.01
Mercury	0.0018 0.0019 0.0023	0.2	0.002

[a]Type I,II cement - 41 wt %; class F fly ash - 40 wt %; Attapulgite-150 - 11 wt %; Indian Red Pottery clay - 8 wt %; mix ratio - 7.5 lb/gal.

[b]50/50 phosphate/sulfate waste.

Table 5. Simulated waste concentration for leach study

Form	Reference waste ($g/L \times 10^2$)		Simulated waste used for leach studies (g/L)	
	Sulfate	Phosphate	Sulfate	Phosphate
As_2O_3	5.3×10^{-6}	4.0×10^{-6}	None	0.39993
$BaCO_3$	5.4×10^{-4}	7.4×10^{-5}	0.05431	0.07422
$Cd(NO_3)_2 \cdot 4H_2O$	1.5×10^{-4}	6.6×10^{-6}	0.01445	0.06635
$Cr(NO_3)_2 \cdot 9H_2O$	7.3×10^{-2}	1.1×10^{-2}	0.07675	0.01107
$Pb(NO_3)_2$	1.3×10^{-3}	7.1×10^{-5}	0.01293	0.07159
$Hg(NO_3)_2 \cdot H_2O$	2.7×10^{-5}	9.8×10^{-6}	0.02712	0.09884
SeO_2	5.5×10^{-2}	4.216×10^{-2}	0.05624	0.04222
$AgNO_3$	1.3×10^{-4}	1.9×10^{-5}	0.01315	0.01880
$CuSO_4 \cdot 4H_2O$	1.2×10^{-3}	2.7×10^{-4}	0.01265	0.02738
$Fe(NO_3)_3 \cdot 6H_2O$	9.7×10^{-2}	1.0	0.10056	1.0010
$Fe_2(SO_4)_3$	1.6	1.3×10^{-1}	1.60800	0.13516
$MnSO_4 \cdot 4H_2O$	1.0×10^{-2}	8.7×10^{-2}	0.01000	0.08720
$ZnSO_4 \cdot 7H_2O$	1.7×10^{-1}	3.1×10^{-3}	0.17004	0.03268
$Ni(NO_3)_2 \cdot 6H_2O$	1.5×10^{-1}	9.2×10^{-3}	0.01764	0.09315
$Al(NO_3)_3 \cdot 9H_2O$	2.4×10^{-2}	None	0.24217	None
KNO_3	2.0×10^{-2}	None	0.0209	None
$CaSO_4$	6.8×10^{-2}	None	0.06811	None
NaF	8.8×10^{-2}	2.6×10^{-2}	0.08826	0.02622
NaCl	6.6×10^{-2}	3.6×10^{-2}	0.06615	0.03675
$Ca(NO_3)_2 \cdot 4H_2O$	None	1.3×10^{-2}	None	0.01536

blend was run at mix ratios of 8, 8.5, and 9 lb/gal, with all criteria, including drainable water (<1.8 vol %), having been met.

The same formula was acceptable for 25% phosphate/75% sulfate waste. However, a mix ratio of 9 lb/gal was necessary to bring drainable water levels to <5 vol %. For this waste concentration, the only acceptable grouts produced were at 9 lb/gal, whereas, with the 100% sulfate waste, mix ratios of 8, 8.5, and 9 lb/gal were acceptable with this preliminary formula. Other grout formulas were acceptable for use with 100% sulfate waste but only at mix ratios of 8.5 and 9 lb/gal. The data for all runs are included in Appendix A.

The next waste concentration studied, 50/50 phosphate/sulfate, was previously studied and a reference formula developed and reported in Milestone 140. The preliminary formula presented here uses Type III cement instead of the Type I,II cement used in Milestone 140. At mix ratios of 7 and 8 lb/gal, the following preliminary formula produced acceptable grouts having <2.5 vol % drainable water: Type III Portland cement (45 wt %), class F fly ash (33 wt %), Attapulgite clay (14 wt %), and IRPC (8 wt %). Again, only a total of three acceptable grouts were produced with this concentration.

The last waste concentration studied was 75/25 phosphate/sulfate. This particular concentration had more acceptable grouts than any of the others. Two blends produced acceptable grouts at mix ratios of 7, 8, and 9 lb/gal. All of these acceptable grouts had 0 vol % drainable water. Blend No. 3 contained Type III Portland cement (40 wt %), class F fly ash (38 wt %), Attapulgite clay (12 wt %), and IRPC (10 wt %). Blend No. 9, the other acceptable blend, contained Type III Portland cement (50 wt %), class F fly ash (28 wt %), Attapulgite clay (12 wt %), and IRPC (10%). Several other blends passed all criteria but at fewer mix ratios. All of the data are found in Appendix A, while Table 6 summarizes some of the acceptable blends.

6. FINAL FORMULATION EXPERIMENTAL DESIGN

The results of the scouting studies were utilized in developing the next series of experiments. The final formulation design was set up to

Table 6. Summary of acceptable grouts for preliminary work

Parameter	Blend No.					
	V5	V7	V5	5	3	9
Cement, Type III (wt %)	50	41	50	45	40	50
Fly ash, class F (wt %)	28	37	38	33	38	28
Attapulgite (wt %)	14	14	14	14	12	12
IRPC (wt %)	8	8	8	8	10	10
Mix ratio (lb/gal)	8,8.5,9	8.5,9	9	7,8	7,8,9	7,8,9
Waste concentration (phosphate/sulfate)	0/100	0/100	25/75	50/50	75/25	75/25

develop a grout formula(s) that could be used for all anticipated waste concentrations expected to be processed in the TGF. Such a formula was developed along with separate formulas specific to certain waste stream concentrations.

6.1 INVESTIGATION OF ALL WASTE CONCENTRATIONS

The first step was to investigate the effects of various waste concentrations on grout performance. A series of experiments (Table 7) was set up to study concentration effects over a range of dry-solids blend compositions. The results of these experiments are contained in Appendix I.

Waste concentrations of 100% sulfate and 75/25 phosphate/sulfate produced the largest number of acceptable grouts over the range of blend compositions. The drainable water criterion proved to be the most troublesome to pass. Since the reference formula for 50/50 phosphate/sulfate waste should work on a waste concentration of 75/25 phosphate/sulfate, the decision was made to formulate for 100% sulfate waste.

Table 7. Initial experimental design for PSW[a] formulation[b,c]

Material	Amount (wt %) by blend No.								
	1	2	3	4	5	6	7	8	9
Cement, Type III	40	40	40	45	45	45	50	50	50
Fly ash, class F	38	38	38	33	33	33	28	28	28
Attapulgite-150	16	14	12	16	14	12	16	14	12
IRPC[d]	6	8	10	6	8	10	6	8	10

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 7, 8, 9 lb/gal.
[c]Phosphate/sulfate concentration = 0/100, 25/75, 50/50, and 75/25.
[d]IRPC = Indian Red Pottery clay.

6.2 FORMULATION RESULTS FOR 100% SULFATE WASTE

The results of the previously discussed experimental matrix indicated that an acceptable grout could be produced at cement contents of 45 to 50 wt %.

A matrix of experiments was then set up to develop a reference formula for 100% sulfate waste. This matrix (Table 8) was performed in

Table 8. Experimental matrix for 100% sulfate waste formulation[a,b]

Material	Amount (wt %) by blend No.		
	10	11	12
Cement, Type III	44.5	47.0	49.5
Fly ash, Class F	34.5	30	25.5
Attapulgite-150	14	15	16
IRPC[c]	7	8	9

[a]Mix ratios = 8, 8.5, 9 lb/gal.
[b]Phosphate/sulfate concentration = 30/70 and 0/100.
[c]IRPC = Indian Red Pottery clay.

triplicate and used waste concentrations of 100% sulfate and 30/70 phosphate/sulfate. The latter concentration was chosen based on predicted availability of waste streams. The results of these tests are included in Appendix I.

Drainable water was a problem area just as it was in the previous matrix. However, the grouts produced using 100% sulfate waste were acceptable throughout the matrix. As such, the data were analyzed and a reference formula developed as follows:

Portland cement, Type III	(47 ± 2.5) wt %
Class F fly ash, Centralia, Washington	(30 ± 2.5) wt %
Attapulgite -150 clay	(15 ± 4.5) wt %
IRPC	(8 ± 1) wt %
Mix ratio	(8.5 ± 0.5) lb/gal
Waste concentration	100% sulfate

The mix ratio from the three blends (10, 11, and 12) was treated as a single independent variable, with the variations in blend components treated as unknown. For example, at a mix ratio of 8 lb/gal, for blends 10, 11, and 12, the nine mixes (each mix performed in triplicate) were combined and the mean was determined. The mean for the 8 lb/gal mixes was then plotted, along with the 95% confidence interval. This method assumes that if the reference formula is being used, then uncontrollable variations in the blend composition are taken into consideration for production of an acceptable grout. Figures 13 to 17 depict the results of this matrix of experiments.

The results of this series of experiments were somewhat promising for production of an acceptable grout using 30/70 PSW. But just as in the previous sets of experiments, the drainable water presented a problem. Figure 18 depicts the results of this series of experiments, using the same treatment already discussed, for the drainable water criterion. Acceptable grouts were produced using a high-cement content (≥47 wt %) and high mix ratios (≥8.5 lb/gal). Efforts were then turned toward solving the drainable water problem.

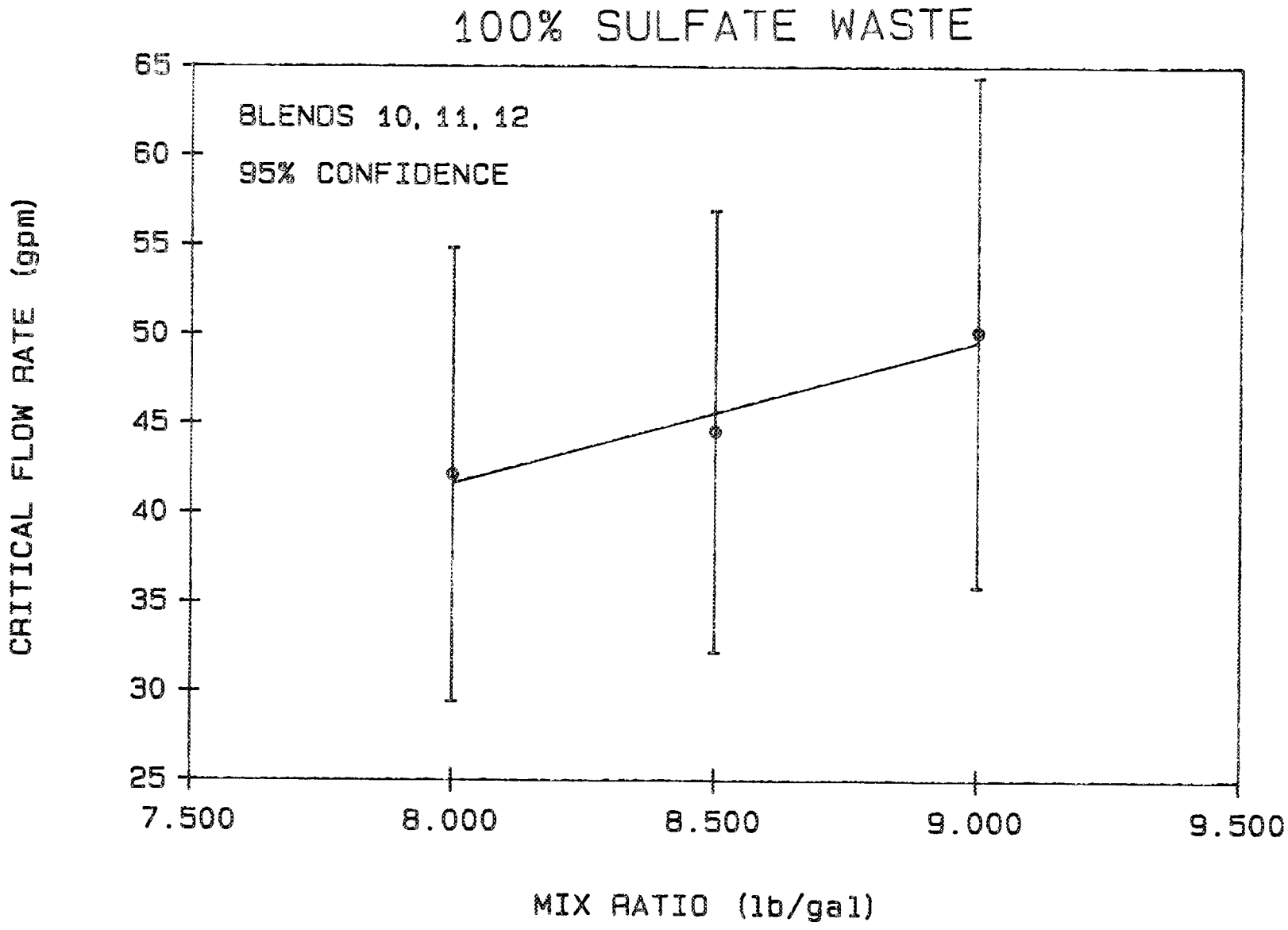

Fig. 13. Critical flow rate vs mix ratio for blends 10, 11, 12.

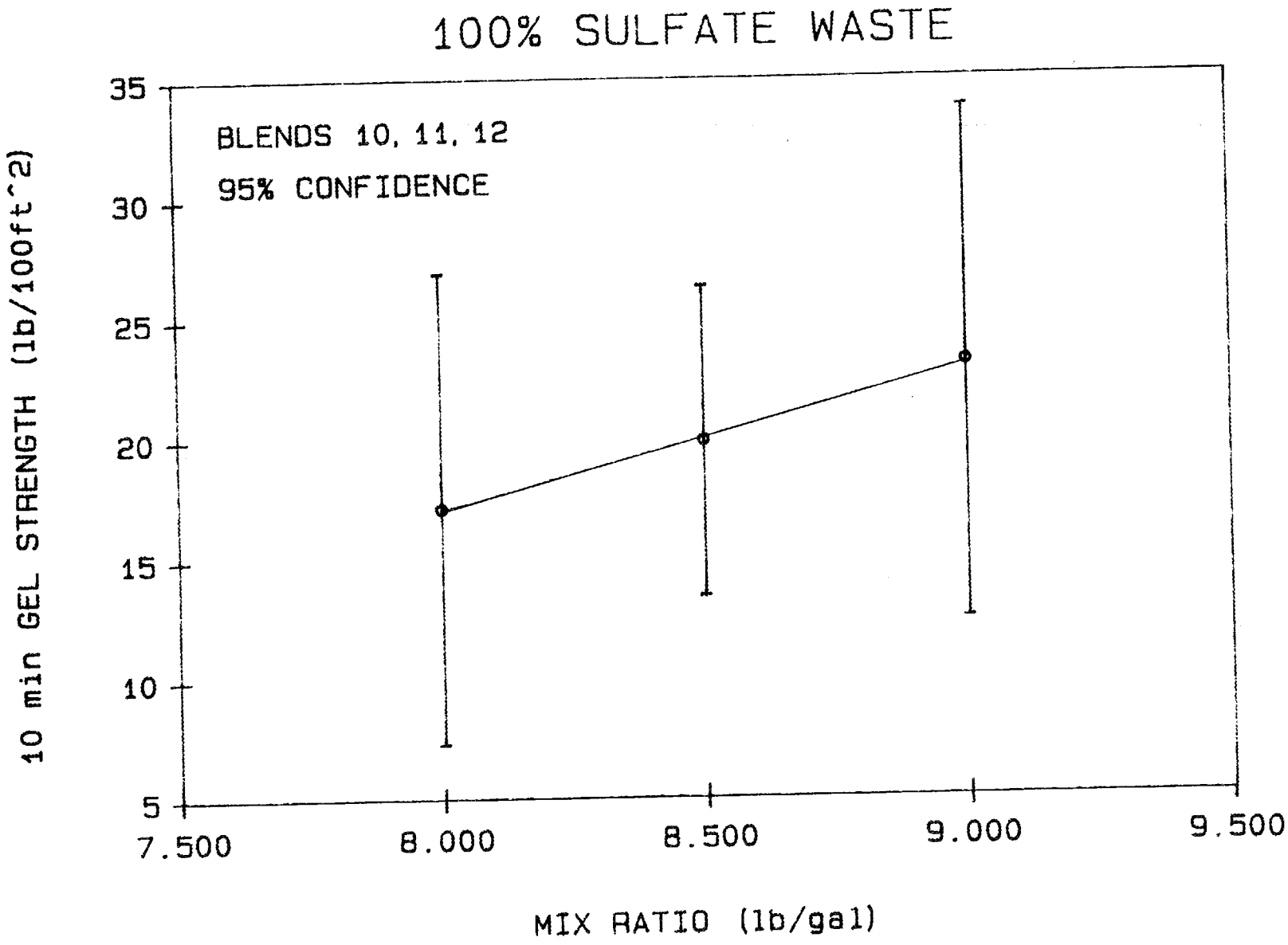

Fig. 14. Gel strength vs mix ratio for blends 10, 11, 12.

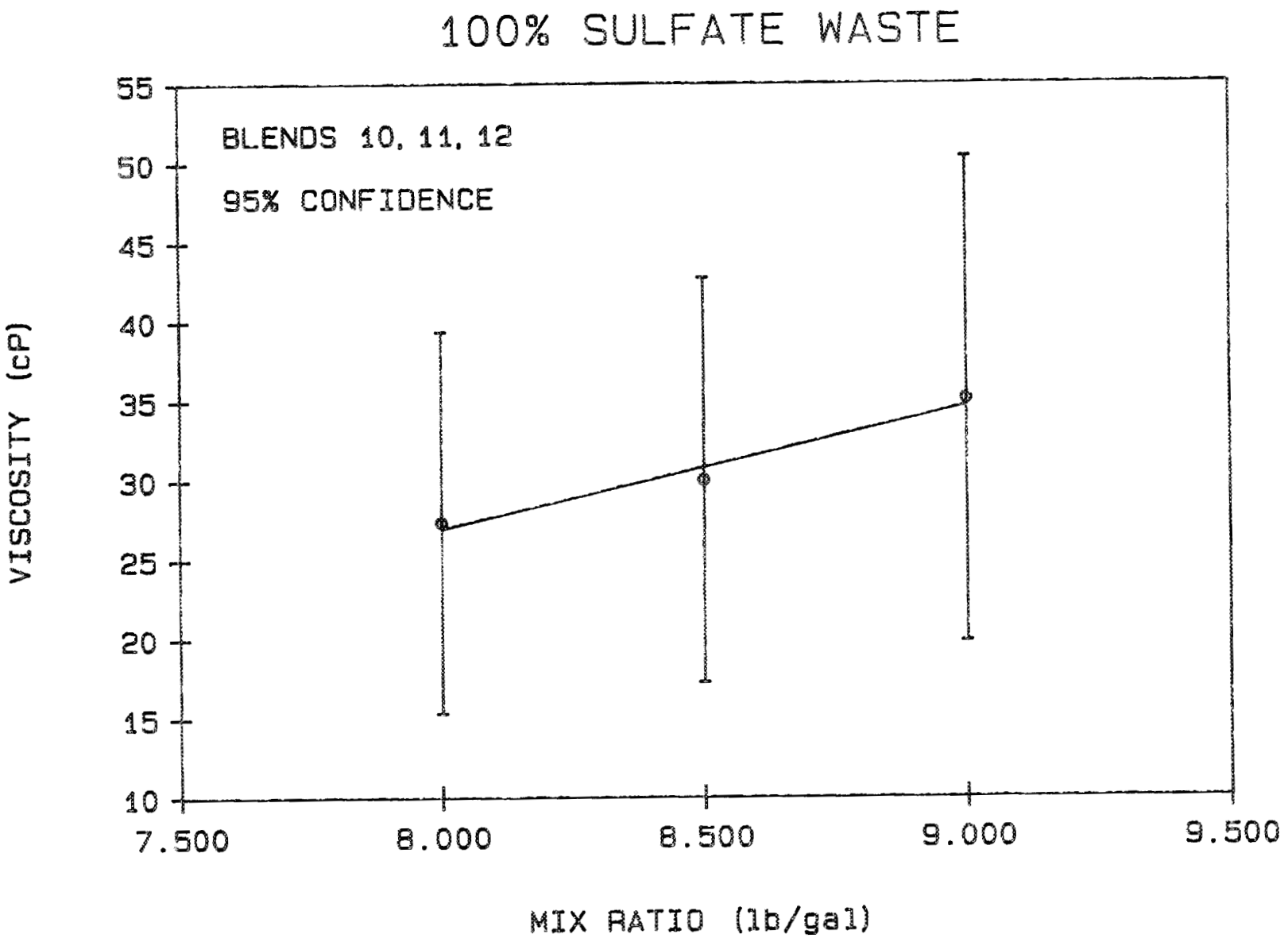

Fig. 15. Viscosity vs mix ratio for blends 10, 11, 12.

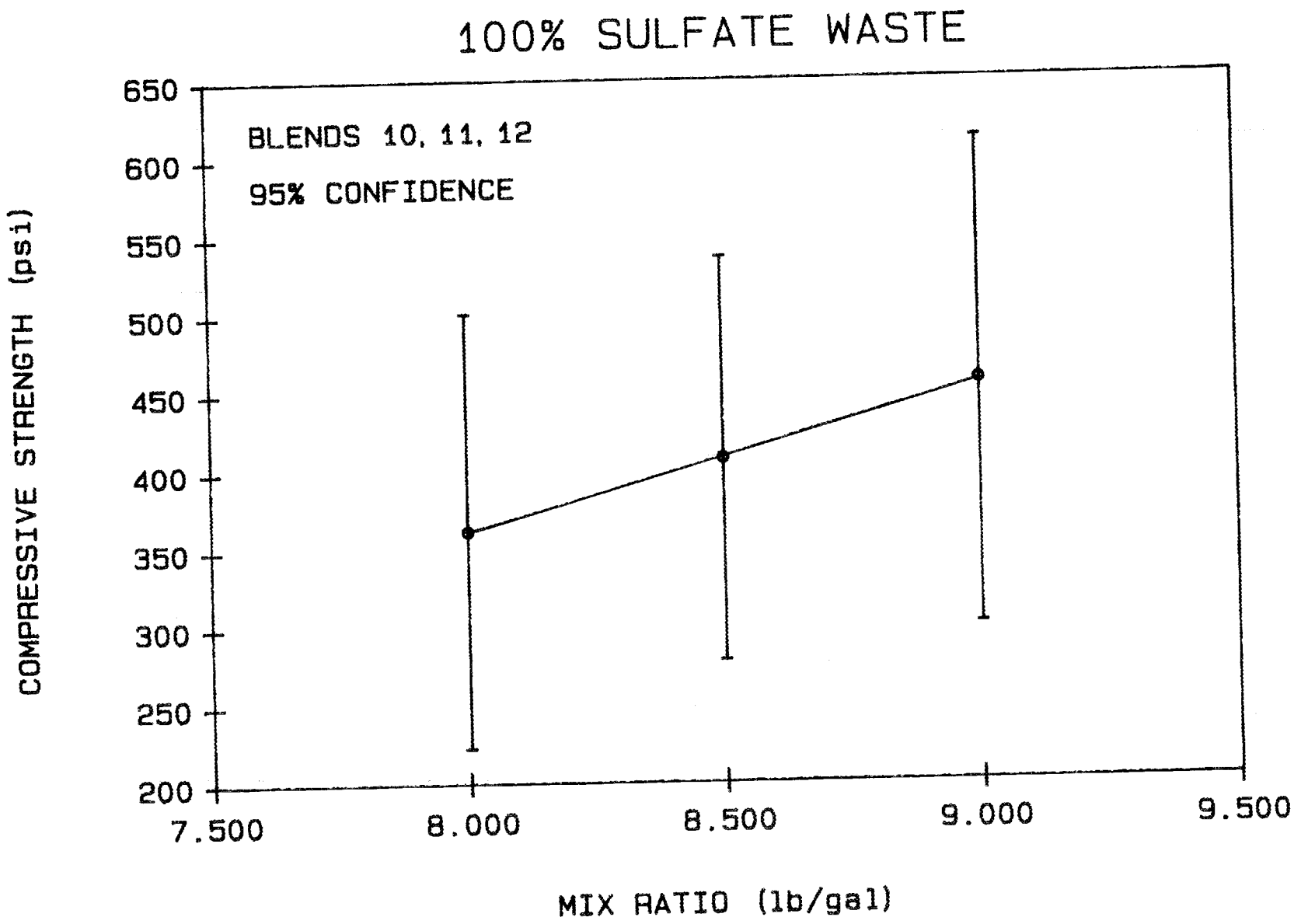

Fig. 16. Compressive strength vs mix ratio for blends 10, 11, 12.

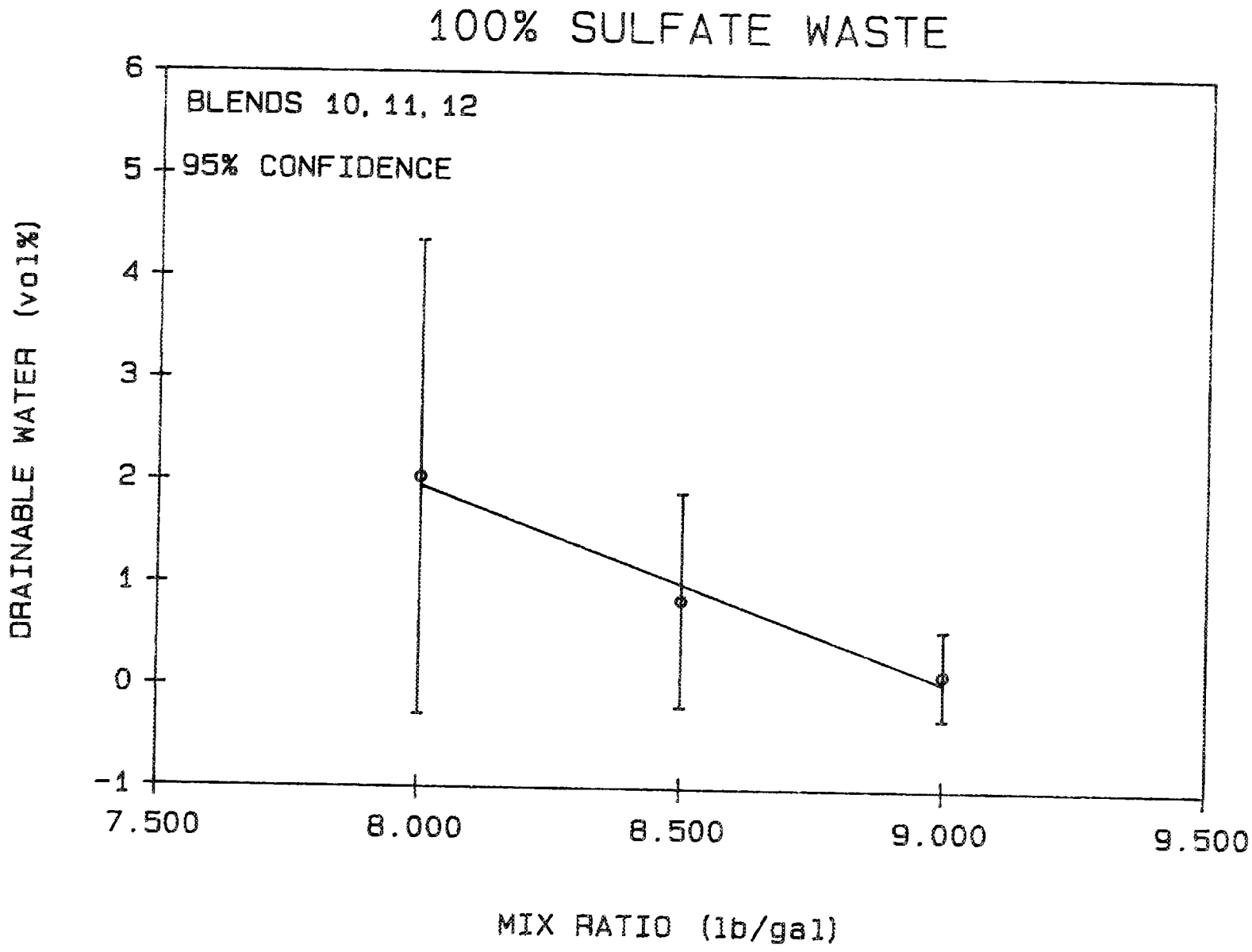

Fig. 17. Drainable water vs mix ratio for blends 10, 11, 12.

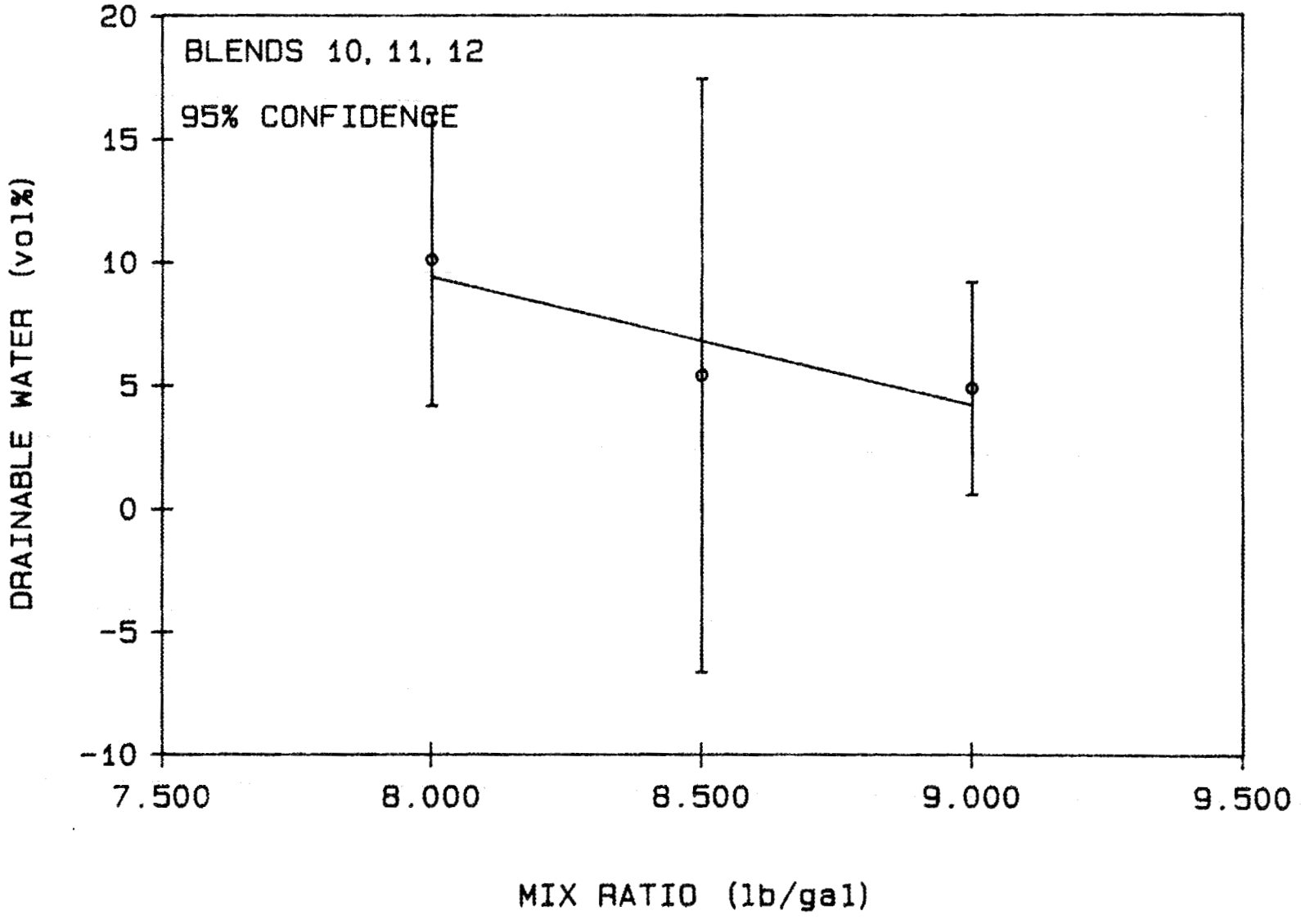

Fig. 18. Drainable water vs mix ratio for blends 10, 11, 12 (30/70 PSW).

6.3 EXPERIMENTAL RESULTS FOR 30/70 AND 25/75 PSW

As previously discussed, a grout formula was developed for use with 100% sulfate waste. Since the drainable water criterion presented the most problems, efforts were focused on solving this area during final formulation for 30/70 PSW. The 25/75 PSW concentration was used in one series of experiments to see what effects a change in waste would have on the grout performance.

6.3.1 Formulation Results for 30/70 PSW

The results of the previous series of tests indicated that a lower cement content might have beneficial effects on reduction of drainable water. The series of experiments shown in Tables 9 and 10 were performed. These experiments were set up to study the effects of lower cement, higher Attapulgite-150, and IRPC contents. Two of the blends, 13 and 16, produced acceptable grouts at mix ratios >8.5 lb/gal. Although 25/75 PSW was used for Blend No. 16, the results were similar to Blend No. 13. This confirmed the need for higher cement content. Regression analysis demonstrated that IRPC has little effect on the rheological properties of the grout (Figs. 5 to 7). Higher attapulgite content tended to decrease the volume of drainable liquid; however, a higher cement content was also needed. Because of the delivery capacity of the DMRHF and the economics involved with using higher quantities of these two components, attention was then turned to solving the drainable water problem by the use of other materials.

The series of experiments shown in Table 11 was set up to evaluate the use of Type I, II Portland cement. The original intent was to use a Type I, II cement that had been ground to a Blaine fineness comparable to a Type III. However, the material was not readily available, so the experiments were done using a regular grind of Type I, II. The blends were used at mix ratios of 7, 8, and 9 lb/gal with both the 30/70 PSW and 100% sulfate waste. The results were similar to previous ones using Type I,II cement except there was an increase in drainable water. This reaffirmed the use of a Type III cement if an acceptable grout formula was to be developed.

Table 9. Experimental design for 30/70 PSW[a] formulation[b,c]

Material	Amount (wt %) by blend No. 13	14	15
Cement, Type III	47	44	41
Fly ash, Class F	31	34	37
Attapulgite-150	14	15	16
IRPC[d]	8	7	6

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 8, 8.5, 9 lb/gal.
[c]Phosphate/sulfate concentration = 30/70.
[d]IRPC = Indian Red Pottery clay.

Table 10. Experimental design for 25/75 PSW[a] formulation[b,c]

Material	Amount (wt %) by blend No. 16	17	18
Cement, Type III	46	43	41
Fly ash, Class F	30	32	32
Attapulgite-150	16	17	19
IRPC[d]	8	8	8

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 8, 8.5, 9 lb/gal.
[c]Phosphate/sulfate concentration = 25/75.
[d]IRPC = Indian Red Pottery clay.

Table 11. Experimental design for 30/70 and 0/100 PSW[a] formulation using Type I, II cement[b,c]

Material	Amount (wt %) blend No. 19	20	21	22
Cement, Type I,II	45	50	45	50
Fly ash, Class F	33	28	31	26
Attapulgite-150	14	14	16	16
IRPC[d]	8	8	8	8

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 7, 8, 9 lb/gal.
[c]Phosphate/sulfate concentration = 30/70 and 0/100.
[d]IRPC = Indian Red Pottery clay.

Development studies were directed toward utilization of hydrated lime [$Ca(OH)_2$], instead of IRPC clay, as a dry-blend component. Table 12 shows the series of experiments set up to determine if this was a viable option. The drainable water criterion was again the one that posed problems: none of the grouts produced in this series passed this criterion. All other criteria were passed by these grouts.

6.4 UTILIZATION OF ALUMINUM PHOSPHATE FOR REDUCTION OF DRAINABLE WATER

All prior development work indicated the need for an additive for reduction of drainable water. A reference formula had already been developed for use with 100% sulfate waste (Sect. 6.2), but one needed to be developed for use with all expected waste concentrations. At this point in the work, the decision was made to use 35/65 PSW as well as 100% sulfate waste. Based on available data, these concentrations appeared to be the most credible for use in actual grouting operation.

Previous work at ORNL[12] (Milestone 173) had shown that the use of aluminum compounds could reduce the amount of drainable water. The decision was made to use aluminum phosphate instead of aluminum nitrate because the waste already contains phosphate. The possible leaching of nitrate from the grout was also a consideration. The aluminum phosphate

Table 12. Experimental design for 30/70 PSW[a] formulation using hydrated lime[b,c]

Material	Amount (wt %) by blend No. 23	24	25
Cement, Type III	40	40	40
Fly ash, Class F	40	40	40
Attapulgite-150	8	10	12
Hydrated lime	12	10	8

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 8, 8.5, 9 lb/gal.
[c]Phosphate/sulfate concentration = 30/70.

admixture appears to decrease the amount of drainable water by increasing the growth rate of the hydration products. This increased growth of hydration product decreases the settling velocity, thus decreasing the volume of drainable water. The increased growth also increases the uptake of free water and thus reduces the drainable water. These ideas have not been proven, but work has shown the benefits from using aluminum compound admixtures.[12]

Data from all previous work performed using PSW were analyzed to determine the starting matrix of experiments. Table 13 was developed, and work was initiated using 1 wt % of aluminum phosphate added to the waste prior to mixing with the dry-solids blend. The amount of aluminum phosphate admixture is based on the amount of dry-solids blend used in the grout. Appendix J contains graphical representations of the effects of mix ratio and cement content on the various grout properties.

Inspection of the data and response analysis indicated that decreasing the cement content would be beneficial, particularly in reducing the volume of drainable water. The amount of attapulgite needed to be adjusted to ensure acceptability of the grout. These concepts formed the basis for Table 13. The blends shown were developed to study the effects of component variation of the grout properties. An acceptable grout formula must be able to tolerate blend variations as well as mix

Table 13. Experimental design for 35/65 and 0/100 PSW[a] formulation[b,c]

Material	Amount (wt %) by blend No.															
	27	28	29	30	5	31	32	33	34	35	36	37	38	39	40	41
Cement, Type III	42.5	42.5	42.5	45	45	45	47.5	47.5	47.5	40	40	40	42.5	42.5	45	45
Fly ash, Class F	38.5	35.5	32.5	36	33	30	33.5	30.5	27.5	40	38	36	37.5	33.5	35	31
Attapulgite	12	14	16	12	14	16	12	14	16	13	14	15	13	15	13	15
IRPC[d]	7	8	9	7	8	9	7	8	9	7	8	9	7	9	7	9

[a]PSW = phosphate/sulfate waste.
[b]Mix ratios = 8, 8.5, 9 lb/gal.
[c]1 wt % $AlPO_4$ added to waste.
[d]IRPC = Indian Red Pottery clay.

ratio variations. Blends 28 and 5 were also used in this final formulation design since the matrix bounded these particular blends.

After all the experiments had been performed, the results were analyzed. The reference formula was developed based on data from the following blends: 5, 27, 28, 35, 36, 38, 40, 41, and 30. These blends encompass variations of at least ±5% for each of the dry-blend components. The data from these blends are represented in Figs. 19 to 24.

The same data treatment was used for this analysis as was used in development of the 100% sulfate waste reference formula (Sect. 6.2). The data from all nine blends, at a particular mix ratio (i.e., 8 lb/gal), were used to generate a mean value and a standard deviation. These values formed the basis for the following reference formula:

Type III, Portland cement	(43 ± 2.5) wt %
Class F fly ash, Centralia, WA	(36 ± 2.5) wt %
Attapulgite-150 clay	(13 ± 1.0) wt %
IRPC	(8 ± 1.0) wt %
Mix ratio	(8.5 ± 0.5) lb/gal
Aluminum phosphate	1.0 wt %
Waste concentration	35/65 and/or 0/100 PSW

As can be seen in Figs. 19 to 24, this reference formula produced grouts with acceptable properties even when variations in the dry-blend components were factored in. The reference formula can be used for both 100% sulfate waste and 35/65 PSW. The standard deviations shown in the graphs represent expected ranges for each of the responses depicted.

6.4.1 Effect of Waste Concentration

The effects of various waste concentrations were studied using Blend 28 at 9 lb/gal. This blend was chosen because of the similarity between it and the reference formula, while the high mix ratio was chosen because it represents the worst case for rheological properties. The plots (Figs. 25 to 27) illustrate the effect of increasing sulfate concentration and decreasing phosphate concentration. Regression analysis yields the following responses as a function of increasing the sulfate concentration:

(1) decreased critical flow rate,

(2) increased gel strength, and

(3) decreased drainable water.

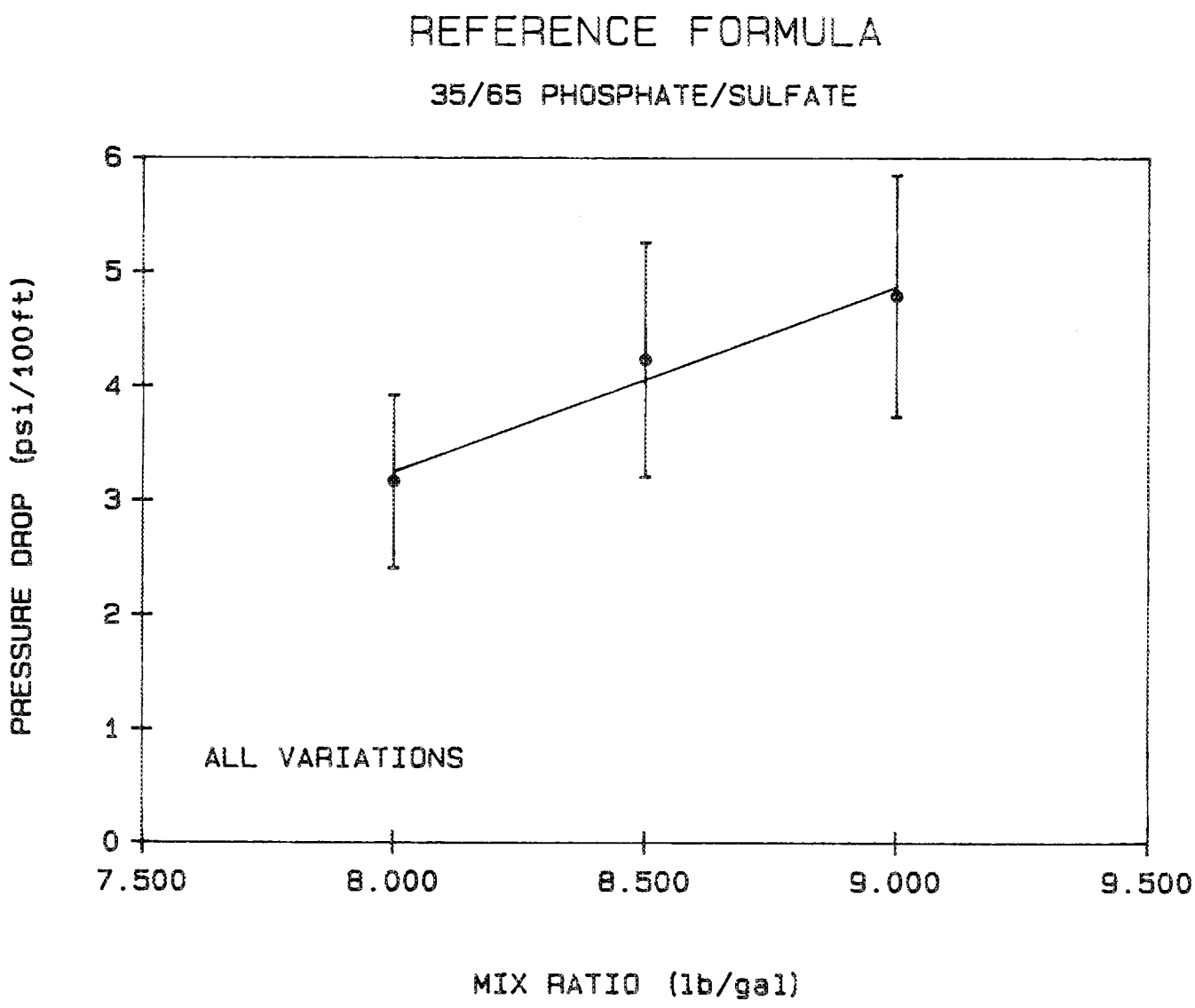

Fig. 19. Frictional pressure drop vs mix ratio for reference formula.

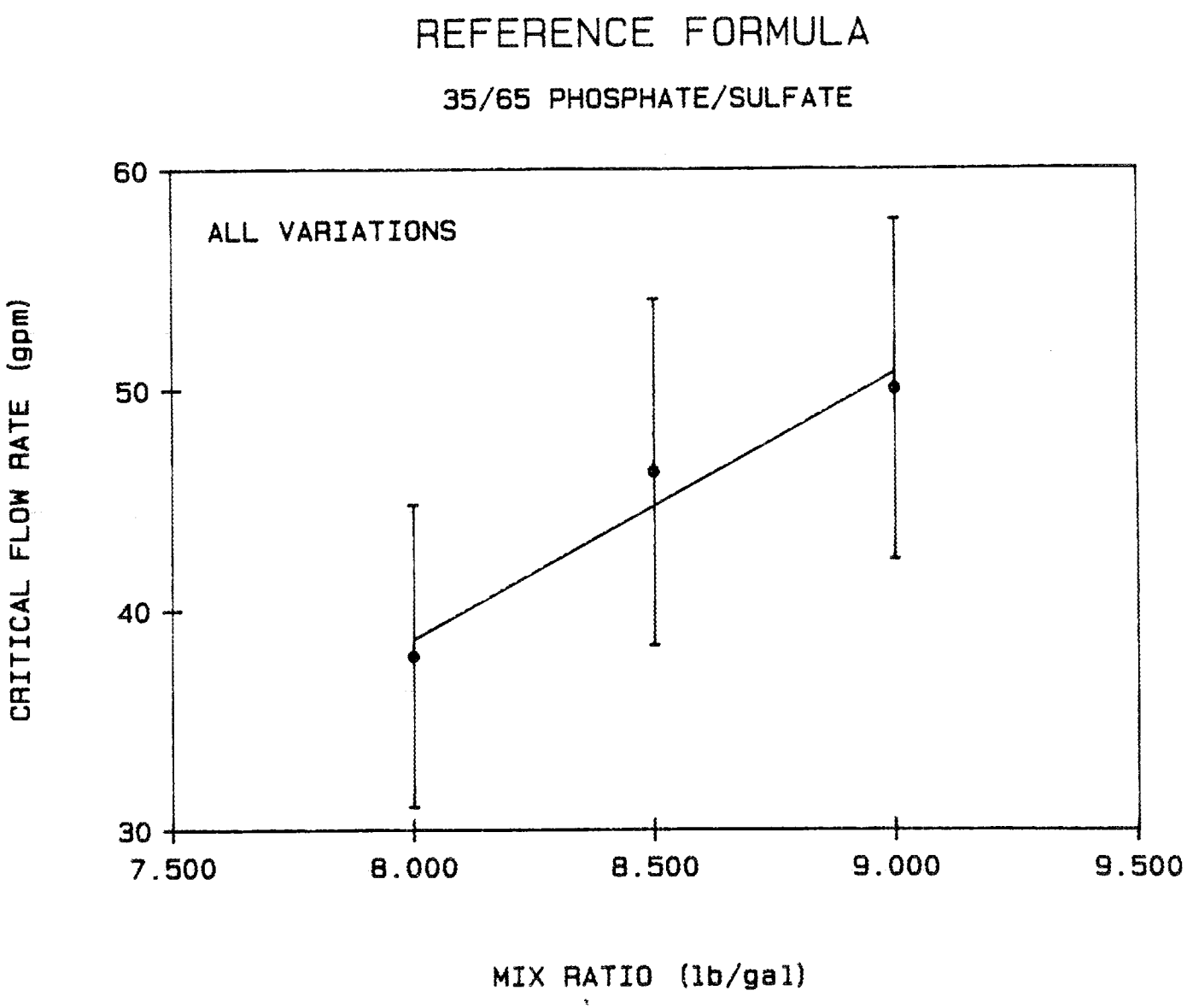

Fig. 20. Critical flow rate vs mix ratio for reference formula.

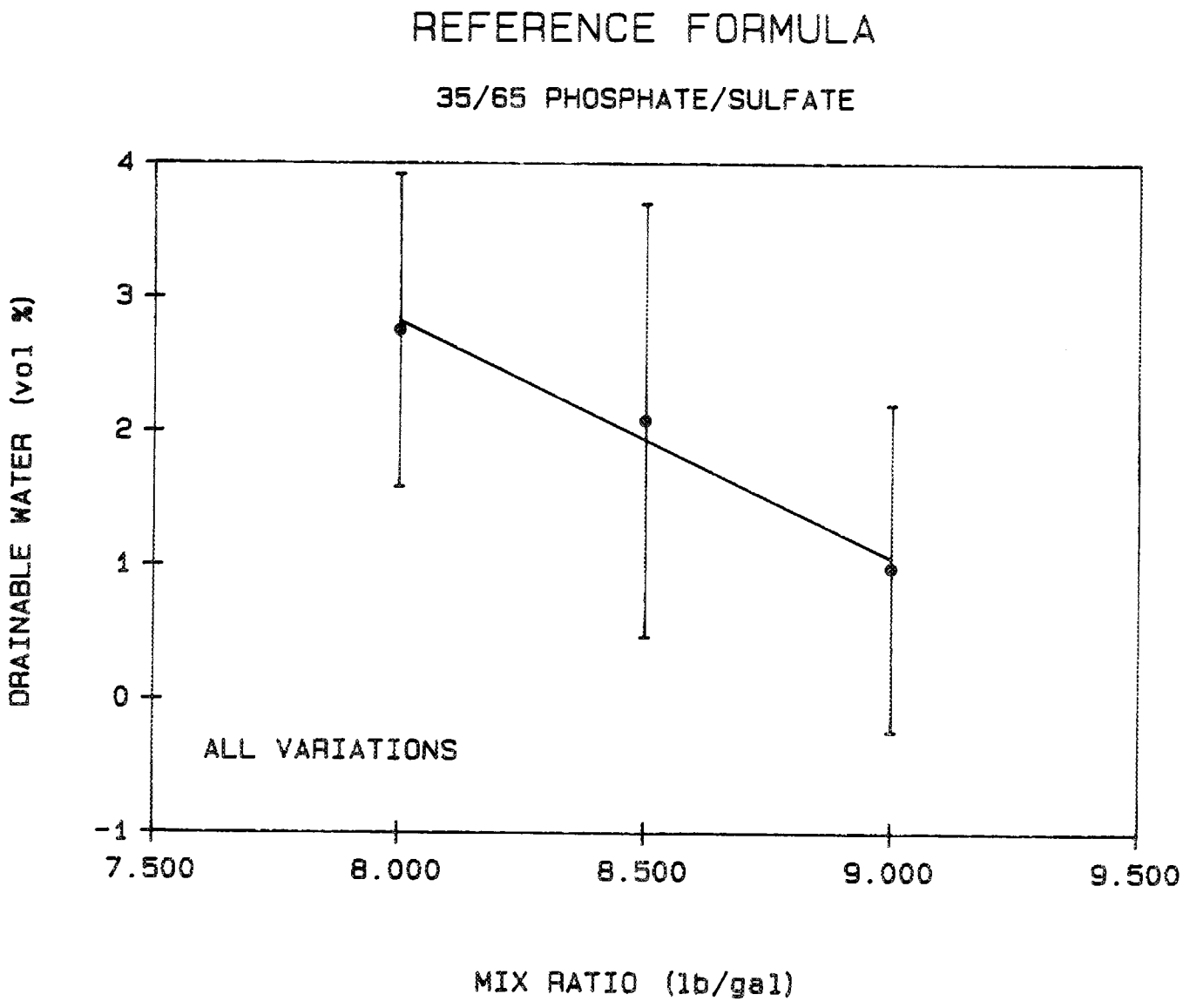

Fig. 21. Drainable water vs mix ratio for reference formula.

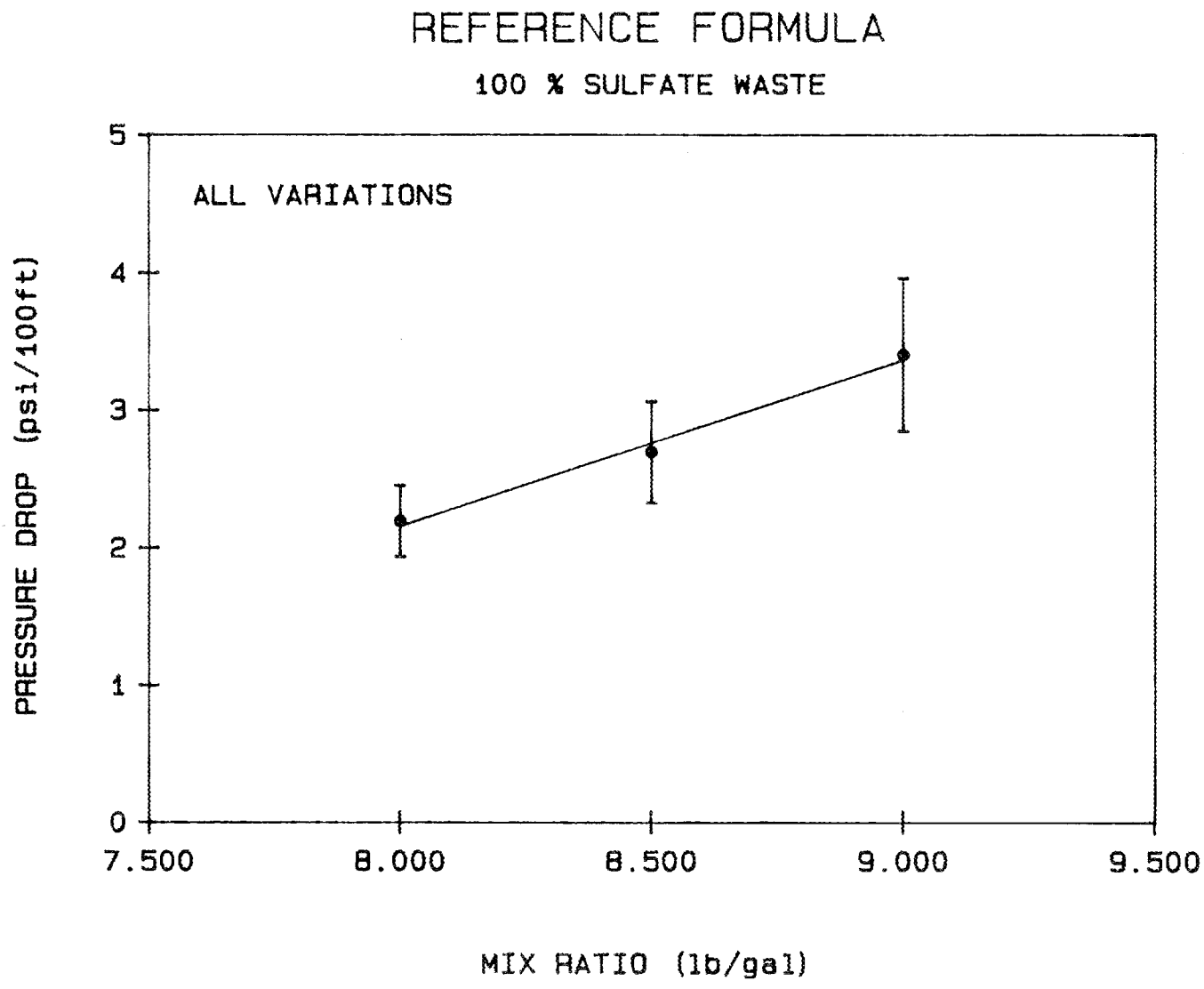

Fig. 22. Frictional pressure drop vs mix ratio for reference formula.

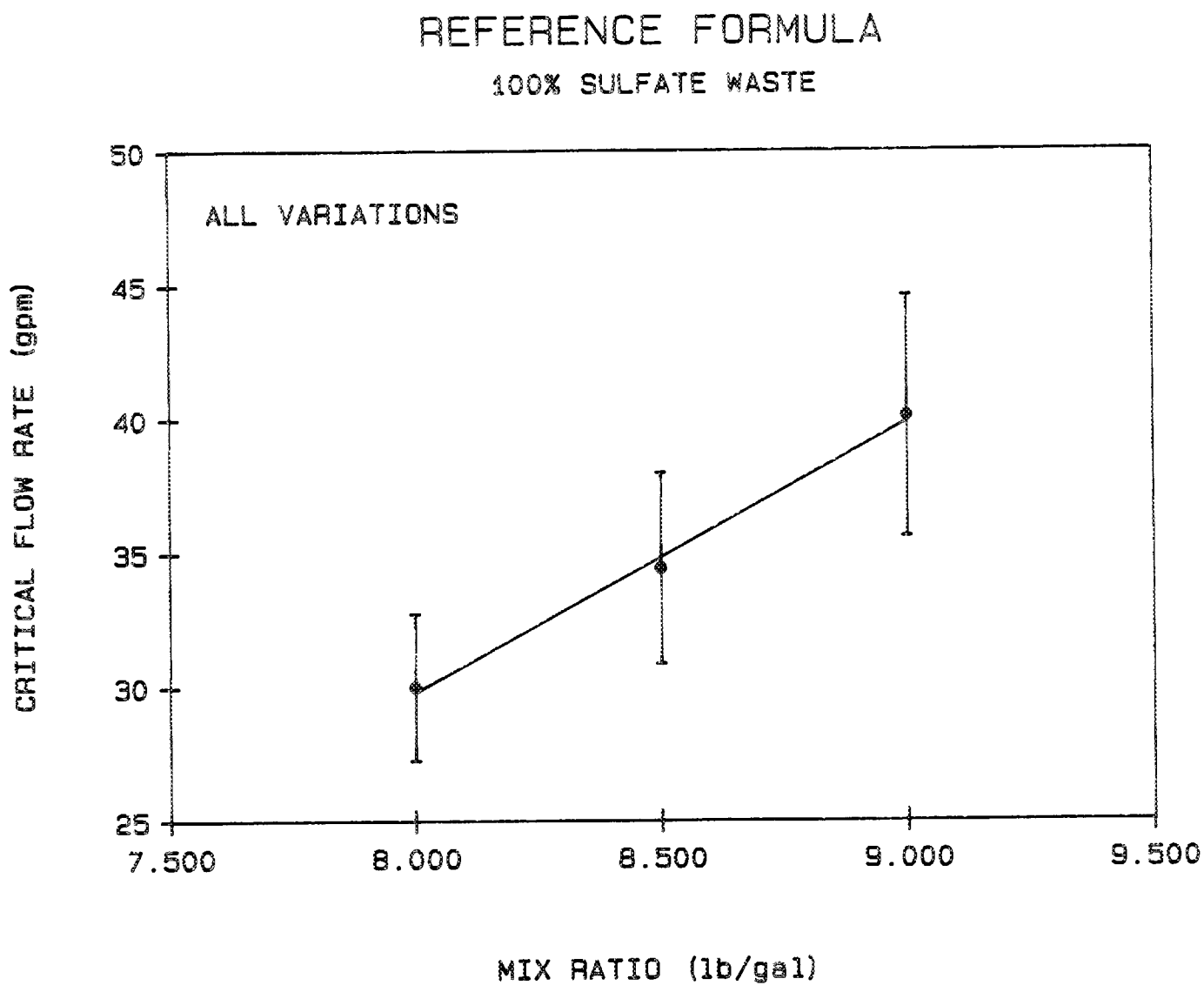

Fig. 23. Critical flow rate vs mix ratio for reference formula.

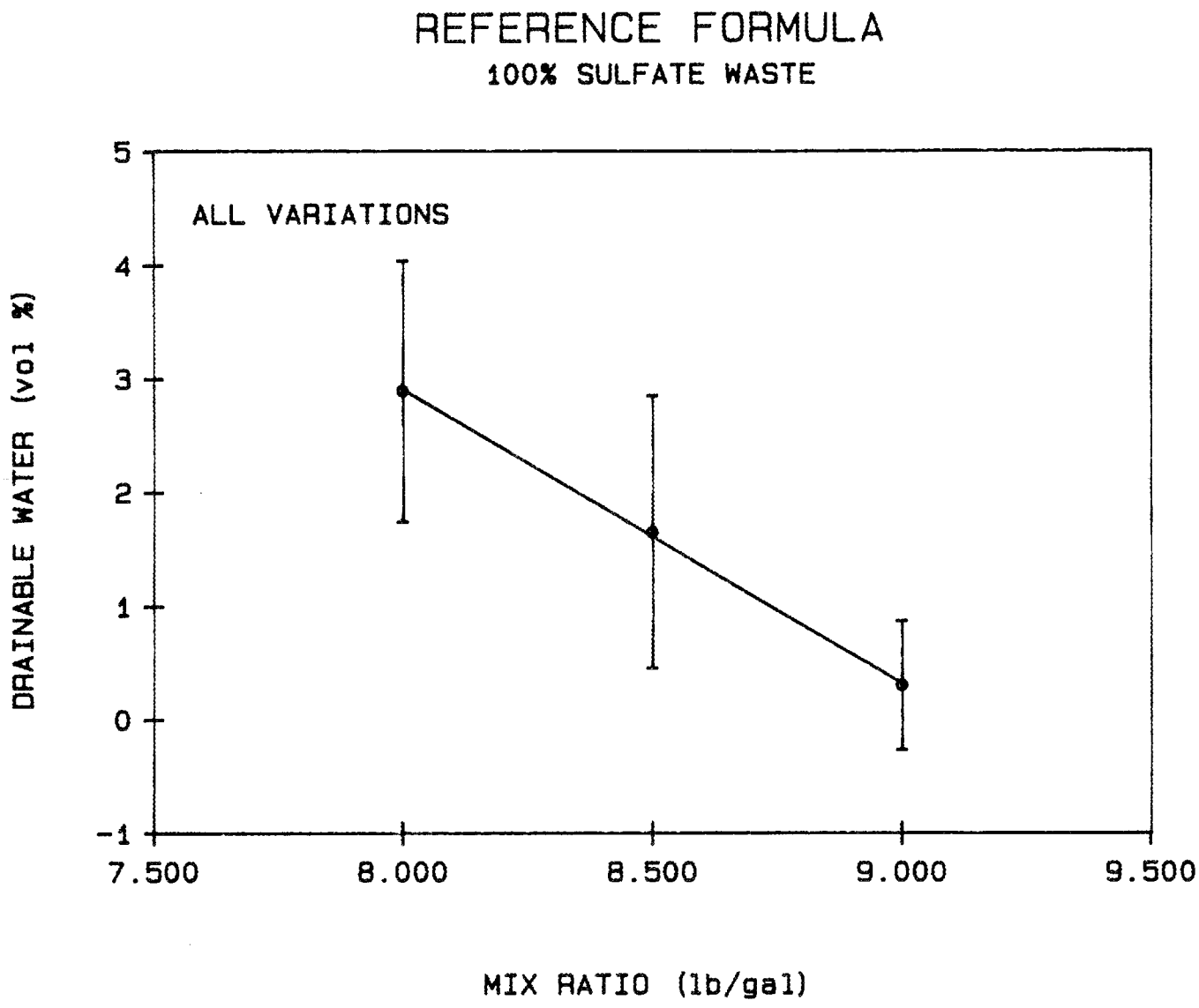

Fig. 24. Drainable water vs mix ratio for reference formula.

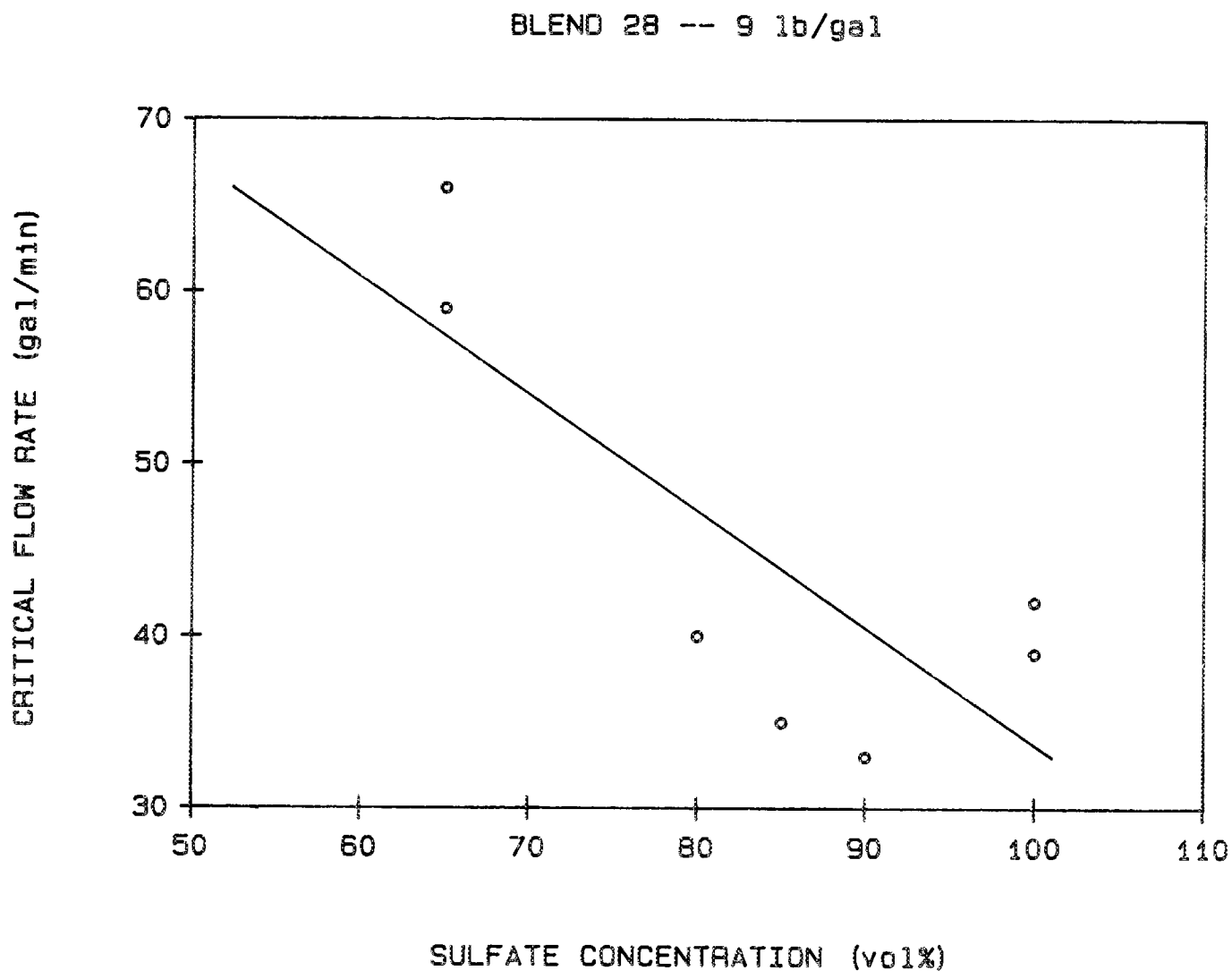

Fig. 25. Effect of waste concentration on critical flow rate.

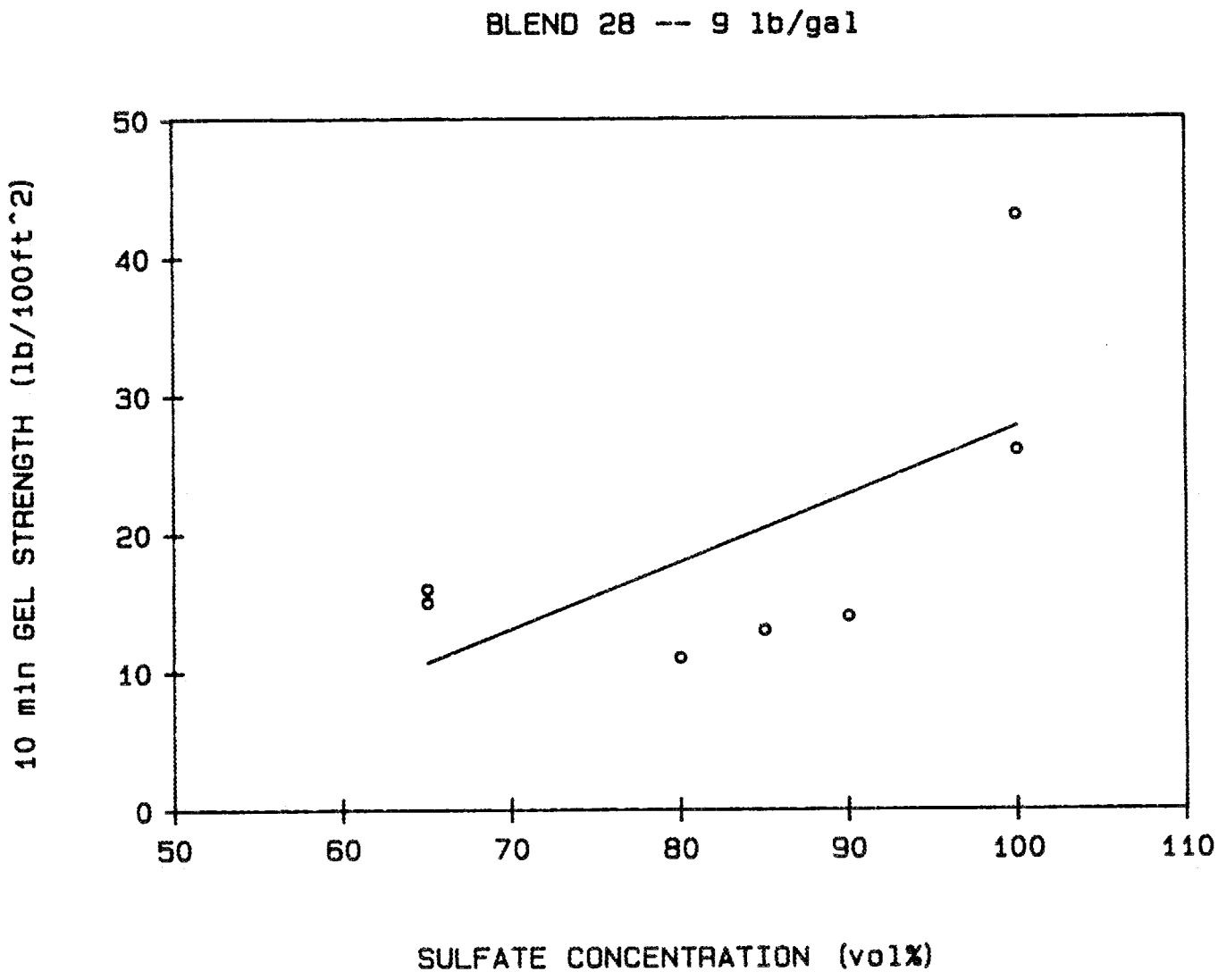

Fig. 26. Effect of waste concentration on gel strength.

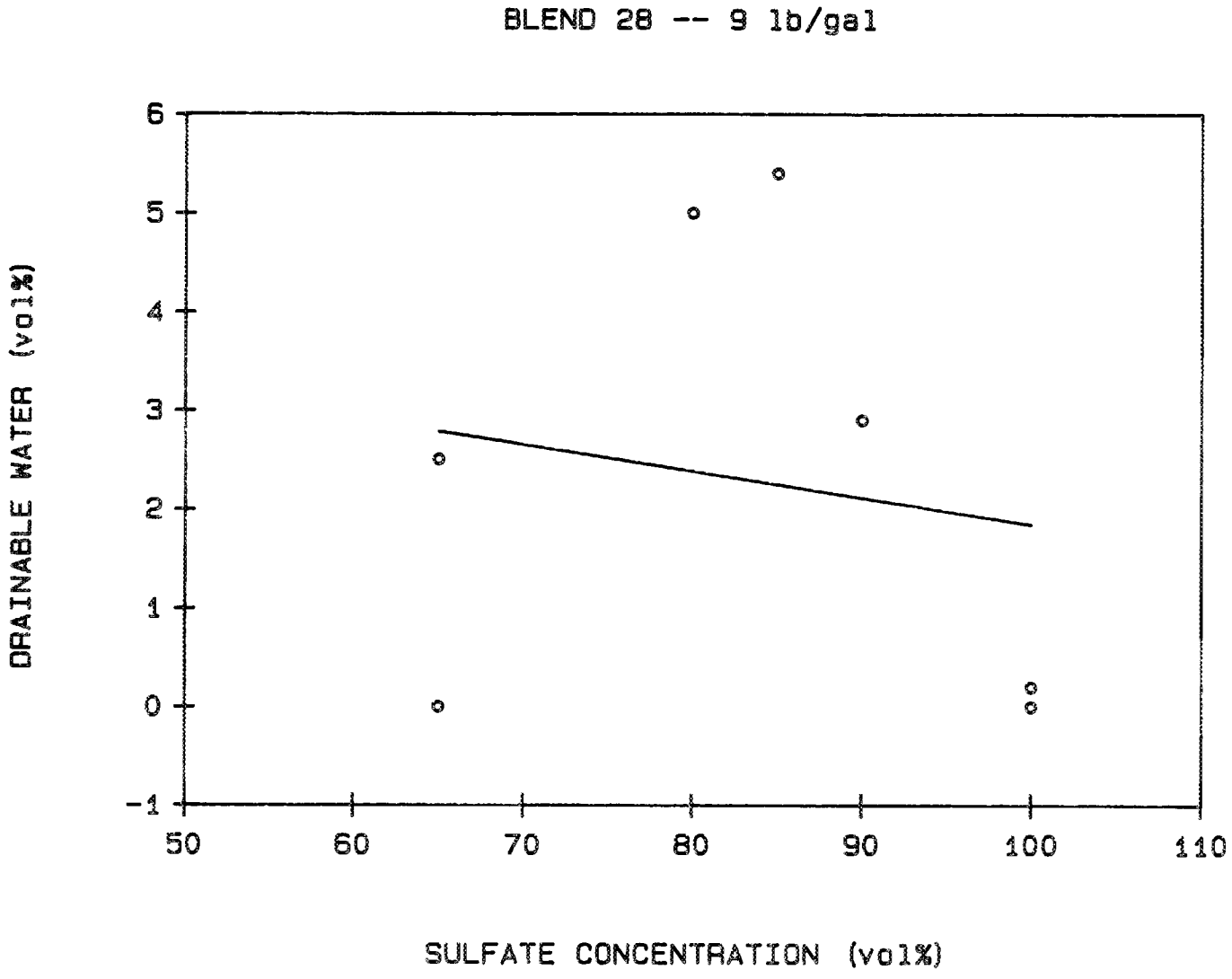

Fig. 27. Effect of waste concentration on drainable water.

These expected responses are within experimental error and the range of acceptability for the grout properties.

7. CONCLUSIONS

This report presents all data that were accumulated during both the preliminary and the final formulation development work for the immobilization of variable PSW. Several problem areas were encountered during this study, but solutions were found. The use of aluminum phosphate as an additive proved to be a viable solution to the drainable water problem. Acceptable grouts were produced at previously expected waste concentrations of 100% sulfate and 35/65 PSW. A reference formula was developed for use with these concentrations, and a separate formula was developed for 100% sulfate waste. These formulas are as follows:

Waste	35/65 PSW and/or 100% sulfate
Type III Portland cement	(43 ± 2.5) wt %
Class F fly ash, Centralia, WA	(36 ± 2.5) wt %
Attapulgite-150 clay	(13 ± 1.0) wt %
IRPC	(8 ± 1.0) wt %
Mix ratio	(8.5 ± 0.5) lb/gal
Aluminum phosphate (additive)	1.0 wt %

Waste	100% Sulfate
Type III Portland cement	(47.0 ± 2.5) wt %
Class F fly ash, Centralia, WA	(30 ± 4.5) wt %
Attapulgite-150 clay	(15 ± 1.0) wt %
IRPC	(8 ± 1.0) wt %
Mix ratio	(8.5 ± 0.5) lb/gal

If a large degree of confidence can be placed on the control of the dry-blend component mixing, then the data indicate that the following variation in the above reference formula for 100% sulfate will work for 30/70 PSW. The tolerances are very narrow for this particular blend: cement (47.5-49.5 wt %), fly ash (25.5-31 wt %), Attapulgite-150 (14-16 wt %), IRPC (8-9 wt %), and mix ratio (8.5-9 lb/gal). As can be seen, there is not a ±5% variation in all the components, nor is there a ±0.5 lb/gal variation in the mix ratio. However, the data indicate that this blend will work if the close variations are maintained.

The work described in this report was based on waste stream concentrations that were expected to occur before startup of the TGF. However, it appears that an 80/20 PSW will be the initial stream grouted. During the preliminary phase of this work, a 25/75 PSW was investigated. Based on this preliminary work, a grout formula consisting of 40 wt % Type III cement, 38 wt % class F fly ash, 8 wt % IRPC, and 14 wt % Attapulgite-150 clay may be a viable option. The optimum mix ratio appears to be 7.5 lb/gal. However, it is recommended that further work be undertaken before a final decision to use this formula is made. A detailed experimental design should be developed in order to ensure that this formula is acceptable. The data for the 25/75 PSW stream are contained in Appendix A.

This formulation development work encompassed a variety of possible waste concentrations. The results of this study produced reference formulas for use in the immobilization of PSW. All expected waste concentrations were studied as well as a brief study on various other concentrations. The reference formulas, as presented, will produce acceptable grouts that are processible, durable, and environmentally safe. The reference formulas are such that variations in the dry-solids blend components will not adversely affect the grout properties. The data were treated in such a manner as to verify this statement. Grouts were subjected to the EP-Toxicity test and were found to be nontoxic as defined by the test. This development study for the immobilization of variable PSW demonstrates the versatility of cement-based grouts.

8. REFERENCES

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APPENDIXES

APPENDIX A

RESULTS OF PRELIMINARY FORMULATION DEVELOPMENT WORK

This appendix contains all the data generated during this development study. The data are segmented into several areas. The data are divided into acceptable and unacceptable grouts, with each of these segments divided in terms of waste dilution. All applicable variables and responses are presented. Nomenclature used in this appendix is given below.

BLEND# = blend number

CEMENT = amount of Type III Portland cement, wt %

FLYASH = amount of class F fly ash, wt %

IRPC = amount of Indian Red pottery clay, wt %

ATTAG = amount of Attapulgite clay, wt %

LIME = amount of hydrated lime, wt %

SULF = amount of sulfate waste, vol %

PHOSP = amount of phosphate waste, vol %

MIXRAT = mix ratio, lb/gal

VISC = viscosity, cP

GELST = 10-min gel strength, $lb_f/100$ ft

DENSITY = density, lb/gal

KINDEX = fluid consistency index, $lb \cdot s^{n'}/ft^2$

NPRIME = flow behavior index

PHASE = amount of drainable water, vol %

COMST = compressive strength, $lb_f/in.^2$

REYNUM = Reynolds number

FPRES = frictional pressure drop per 100 ft, $lb_f/in.^2$

CRTFW = critical flow rate, gal/min

PHPRES = pump head pressure, $lb_f/in.^2$

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
3	25/75	40.0	38.0	10.0	12.0	7.0	18	11
2	25/75	40.0	38.0	8.0	14.0	7.0	19	23
3	25/75	40.0	38.0	10.0	12.0	9.0	50	40
2	25/75	40.0	38.0	8.0	14.0	8.0	37	36
3	25/75	40.0	38.0	10.0	12.0	8.0	27	23
6	25/75	45.0	33.0	10.0	12.0	7.0	15	23
4	25/75	45.0	33.0	6.0	16.0	8.0	41	32
5	25/75	45.0	33.0	8.0	14.0	8.0	42	32
6	25/75	45.0	33.0	10.0	12.0	8.0	28	24
9	25/75	50.0	28.0	10.0	12.0	7.0	18	11
9	25/75	50.0	28.0	10.0	12.0	8.0	29	24
5	25/75	45.0	33.0	8.0	14.0	7.0	21	23
7	25/75	50.0	28.0	6.0	16.0	8.0	45	17
1	25/75	40.0	38.0	6.0	16.0	7.0	23	31
8	25/75	50.0	28.0	8.0	14.0	8.0	40	19
V5	25/75	50.0	28.0	8.0	14.0	9.0	28	12
V5	25/75	50.0	28.0	8.0	14.0	8.5	22	12
V7	25/75	41.0	37.0	8.0	14.0	9.0	27	10
V4	25/75	50.0	31.0	8.0	11.0	9.0	20	14
V2	25/75	41.0	40.0	8.0	11.0	9.0	18	11
8	25/75	50.0	28.0	8.0	16.0	7.0	20	12
V2	25/75	41.0	40.0	8.0	11.0	8.5	15	9

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
26	65/35	43.0	38.0	8.0	11.0	7.0	13	7
26	65/35	43.0	38.0	8.0	11.0	8.0	19	8
26	65/35	43.0	38.0	8.0	11.0	9.0	29	13
5	65/35	45.0	33.0	8.0	14.0	8.0	23	9
5	65/35	45.0	33.0	8.0	14.0	9.0	39	12
27	65/35	42.5	38.5	7.0	12.0	8.0	22	8
27	65/35	42.5	38.5	7.0	12.0	8.5	25	11
27	65/35	42.5	38.5	7.0	12.0	9.0	34	13
28	65/35	42.5	35.5	8.0	14.0	8.0	26	11
28	65/35	42.5	35.5	8.0	14.0	8.5	32	12
28	65/35	42.5	35.5	8.0	14.0	9.0	47	15
29	65/35	42.5	32.5	9.0	16.0	8.0	32	13
29	65/35	42.5	32.5	9.0	16.0	8.5	46	16
30	65/35	45.0	36.0	7.0	12.0	8.0	20	9
30	65/35	45.0	36.0	7.0	12.0	8.5	25	10
30	65/35	45.0	36.0	7.0	12.0	9.0	29	12
5	65/35	45.0	33.0	8.0	14.0	8.0	25	10
5	65/35	45.0	33.0	8.0	14.0	8.5	32	12
5	65/35	45.0	33.0	8.0	14.0	9.0	45	14
31	65/35	45.0	30.0	9.0	16.0	8.0	36	9
33	65/35	47.5	30.5	8.0	14.0	9.0	47	11
34	65/35	47.5	27.5	9.0	16.0	8.5	43	11
35	65/35	40.0	40.0	7.0	13.0	8.0	23	7
35	65/35	40.0	40.0	7.0	13.0	8.5	29	10
35	65/35	40.0	40.0	7.0	13.0	9.0	38	12
36	65/35	40.0	38.0	8.0	14.0	8.0	28	11
36	65/35	40.0	38.0	8.0	14.0	8.5	37	12
37	65/35	40.0	36.0	9.0	15.0	8.0	31	13
37	65/35	40.0	36.0	9.0	15.0	8.5	40	12
40	65/35	45.0	35.0	7.0	13.0	9.0	39	11
41	65/35	45.0	31.0	9.0	15.0	8.0	31	10
41	65/35	45.0	31.0	9.0	15.0	8.5	42	12
38	65/35	42.5	37.5	7.0	13.0	8.5	33	13
38	65/35	42.5	37.5	7.0	13.0	9.0	49	14
39	65/35	42.5	33.5	9.0	15.0	8.0	32	13
39	65/35	42.5	33.5	9.0	15.0	8.5	43	14

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
5	50/50	45.0	33.0	8.0	14.0	7.0	20	13
5	50/50	45.0	33.0	8.0	14.0	8.0	40	17
1	50/50	40.0	38.0	6.0	16.0	7.0	21	14
2	50/50	40.0	38.0	8.0	14.0	8.0	34	9
7	50/50	50.0	28.0	6.0	16.0	8.0	43	16
3	50/50	40.0	38.0	10.0	12.0	8.0	29	13

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
11	70/30	47.0	30.0	8.0	15.0	8.5	44	24
11	70/30	47.0	30.0	8.0	15.0	9.0	40	10
12	70/30	49.5	25.5	9.0	16.0	8.5	38	10
12	70/30	49.5	25.5	9.0	16.0	9.0	47	11
13	70/30	47.0	31.0	8.0	14.0	8.5	35	12
13	70/30	47.0	31.0	8.0	14.0	9.0	47	11

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
7	75/25	50.0	28.0	6.0	16.0	9.0	42	16
V5	75/25	50.0	28.0	8.0	14.0	9.0	22	17
V7	75/25	41.0	37.0	8.0	14.0	9.0	20	14
V4	75/25	50.0	31.0	8.0	11.0	9.0	21	13
V5	75/25	50.0	28.0	8.0	14.0	8.5	19	14
V7	75/25	41.0	37.0	8.0	14.0	8.5	16	11
8	75/25	50.0	28.0	8.0	14.0	9.0	42	10
16	75/25	46.0	30.0	8.0	16.0	8.5	41	11

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
28	80/20	42.5	35.5	8.0	14.0	9.0	28	11

Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
28	90/10	42.5	35.5	8.0	14.0	9.0	22	14

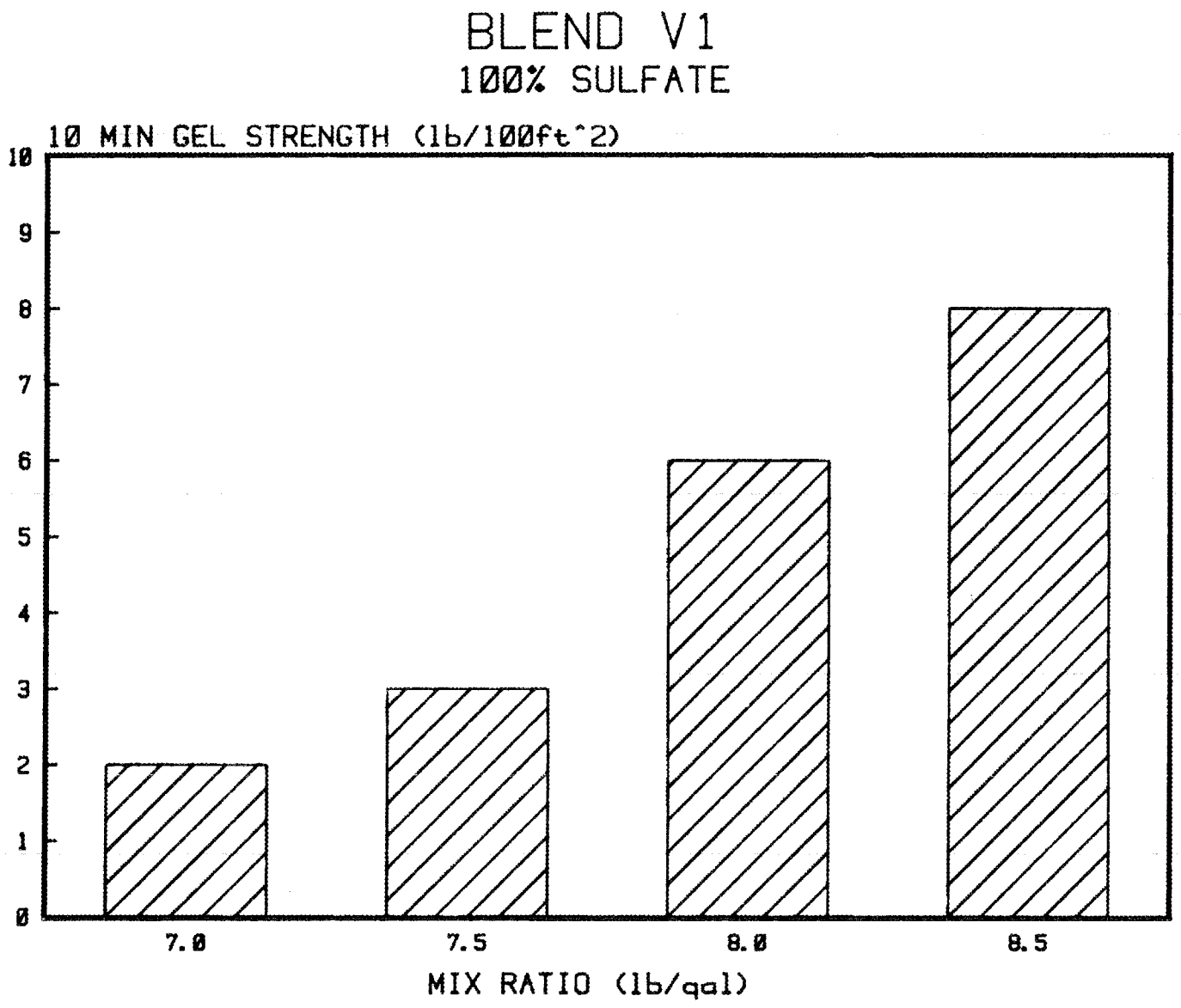
Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
4	100/0	45.0	33.0	6.0	16.0	9.0	31	5
V5	100/0	50.0	28.0	8.0	14.0	9.0	38	17
V5	100/0	50.0	28.0	8.0	14.0	8.5	29	14
8	100/0	50.0	28.0	8.0	14.0	9.0	30	19
6	100/0	45.0	33.0	10.0	12.0	9.0	27	19
V7	100/0	41.0	37.0	8.0	14.0	9.0	27	12
V5	100/0	50.0	28.0	8.0	14.0	8.0	23	12
V4	100/0	50.0	31.0	8.0	11.0	8.5	22	16
V7	100/0	41.0	37.0	8.0	14.0	8.5	15	11
V4	100/0	50.0	31.0	8.0	11.0	9.0	28	17
1	100/0	40.0	38.0	6.0	16.0	9.0	31	20
5	100/0	45.0	33.0	8.0	14.0	9.0	29	18
V2	100/0	41.0	40.0	8.0	11.0	8.5	20	12
7	100/0	50.0	28.0	6.0	16.0	9.0	35	15
40	100/0	45.0	35.0	6.0	0.0	9.0	17	21
9	100/0	50.0	28.0	10.0	12.0	9.0	27	20
6	100/0	45.0	33.0	10.0	10.0	8.0	19	17
3	100/0	40.0	38.0	10.0	12.0	9.0	25	16
V4	100/0	50.0	31.0	8.0	11.0	8.0	19	12
V5	100/0	50.0	28.0	8.0	14.0	7.0	15	9
40	100/0	45.0	35.0	6.0	0.0	9.0	18	20
41	100/0	47.5	32.5	10.0	0.0	9.0	16	19
43	100/0	47.5	32.5	8.0	0.0	9.0	18	23
10	100/0	44.5	34.5	7.0	14.0	8.0	20	17
10	100/0	44.5	34.5	7.0	14.0	8.5	24	16
10	100/0	44.5	34.5	7.0	14.0	9.0	31	15
11	100/0	47.0	30.0	8.0	15.0	8.0	23	14
11	100/0	47.0	30.0	8.0	15.0	8.5	28	18
11	100/0	47.0	30.0	8.0	15.0	9.0	35	20
12	100/0	49.5	25.5	9.0	16.0	8.0	24	17
12	100/0	49.5	25.5	9.0	16.0	8.5	30	20
12	100/0	49.5	25.5	9.0	16.0	9.0	40	21
10	100/0	44.5	34.5	7.0	14.0	8.0	19	16
10	100/0	44.5	34.5	7.0	14.0	8.5	23	20
10	100/0	44.5	34.5	7.0	14.0	9.0	29	22
11	100/0	47.0	30.0	8.0	15.0	8.0	21	16
11	100/0	47.0	30.0	8.0	15.0	8.5	26	20
11	100/0	47.0	30.0	8.0	15.0	9.0	29	23
12	100/0	49.5	25.5	9.0	16.0	8.0	25	20
12	100/0	49.5	25.5	9.0	16.0	8.5	32	22
12	100/0	49.5	25.5	9.0	16.0	9.0	42	28
10	100/0	44.5	34.5	7.0	14.0	8.0	30	9
10	100/0	44.5	34.5	7.0	14.0	8.5	33	13
10	100/0	44.5	34.5	7.0	14.0	9.0	37	26
11	100/0	47.0	30.0	8.0	15.0	8.0	32	23
11	100/0	47.0	30.0	8.0	15.0	8.5	34	23
11	100/0	47.0	30.0	8.0	15.0	9.0	42	22
12	100/0	49.5	25.5	9.0	16.0	8.0	36	18
12	100/0	49.5	25.5	9.0	16.0	8.5	41	31

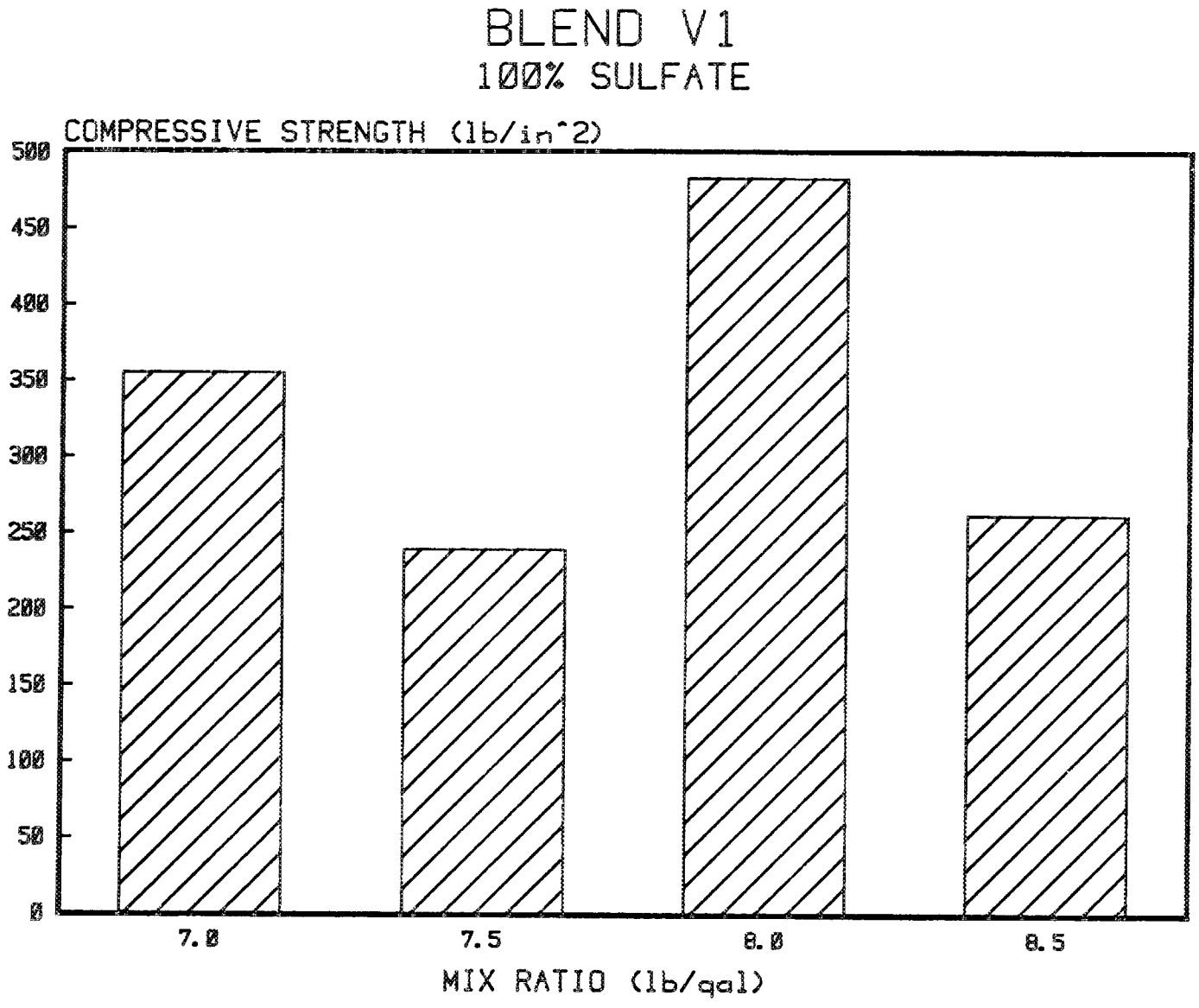
Blend No.	SULF/PHOSP	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
12	100/0	49.5	25.5	9.0	16.0	9.0	46	31
26	100/0	43.0	38.0	8.0	11.0	8.0	15	20
26	100/0	43.0	38.0	8.0	11.0	9.0	21	27
5	100/0	45.0	33.0	8.0	14.0	8.0	18	24
5	100/0	45.0	33.0	8.0	14.0	9.0	28	33
27	100/0	42.5	38.5	7.0	12.0	8.0	14	20
27	100/0	42.5	38.5	7.0	12.0	8.5	18	25
27	100/0	42.5	38.5	7.0	12.0	9.0	22	31
28	100/0	42.5	35.5	8.0	14.0	8.0	17	20
28	100/0	42.5	35.5	8.0	14.0	8.5	21	25
28	100/0	42.5	35.5	8.0	14.0	9.0	26	26
29	100/0	42.5	32.5	9.0	16.0	8.0	20	25
29	100/0	42.5	32.5	9.0	16.0	8.5	25	27
29	100/0	42.5	32.5	9.0	16.0	9.0	33	32
30	100/0	45.0	36.0	7.0	12.0	8.5	16	24
30	100/0	45.0	36.0	7.0	12.0	9.0	20	32
5	100/0	45.0	33.0	8.0	14.0	8.5	22	26
5	100/0	45.0	33.0	8.0	14.0	9.0	27	29
31	100/0	45.0	30.0	9.0	16.0	8.0	20	17
31	100/0	45.0	30.0	9.0	16.0	8.5	26	18
31	100/0	45.0	30.0	9.0	16.0	9.0	33	22
32	100/0	47.5	33.5	7.0	12.0	8.5	19	15
32	100/0	47.5	33.5	7.0	12.0	9.0	22	18
33	100/0	47.5	30.5	8.0	14.0	8.0	18	17
33	100/0	47.5	30.5	8.0	14.0	8.5	22	19
33	100/0	47.5	30.5	8.0	14.0	9.0	28	22
34	100/0	47.5	27.5	9.0	16.0	8.0	20	18
34	100/0	47.5	27.5	9.0	16.0	8.5	25	20
34	100/0	47.5	27.5	9.0	16.0	9.0	32	33
35	100/0	40.0	40.0	7.0	13.0	8.0	15	16
35	100/0	40.0	40.0	7.0	13.0	8.5	19	19
35	100/0	40.0	40.0	7.0	13.0	9.0	23	23
36	100/0	40.0	38.0	8.0	14.0	8.0	19	11
36	100/0	40.0	38.0	8.0	14.0	8.5	22	21
36	100/0	40.0	38.0	8.0	14.0	9.0	27	25
37	100/0	40.0	36.0	9.0	15.0	19	16	
37	100/0	40.0	36.0	9.0	15.0	8.5	24	18
37	100/0	40.0	36.0	9.0	15.0	9.0	31	23
40	100/0	45.0	35.0	7.0	13.0	8.0	16	15
40	100/0	45.0	35.0	7.0	13.0	8.5	19	18
40	100/0	45.0	35.0	7.0	13.0	9.0	24	23
41	100/0	45.0	31.0	9.0	15.0	8.0	20	15
41	100/0	45.0	31.0	9.0	15.0	8.5	24	22
41	100/0	45.00	31.0	9.0	15.0	9.0	30	27
38	100/0	42.5	37.5	7.0	13.0	8.0	17	16
38	100/0	42.5	37.5	7.0	13.0	8.5	21	20
38	100/0	42.5	37.5	7.0	13.0	9.0	26	22
28	100/0	42.5	35.5	8.0	14.0	8.0	18	24
28	100/0	42.5	35.5	8.0	14.0	8.5	23	32
28	100/0	42.5	35.5	8.0	14.0	9.0	29	43
39	100/0	42.5	33.5	9.0	15.0	8.0	19	21
39	100/0	42.5	33.5	9.0	15.0	8.5	24	26
39	100/0	42.5	33.5	9.0	15.0	9.0	31	33

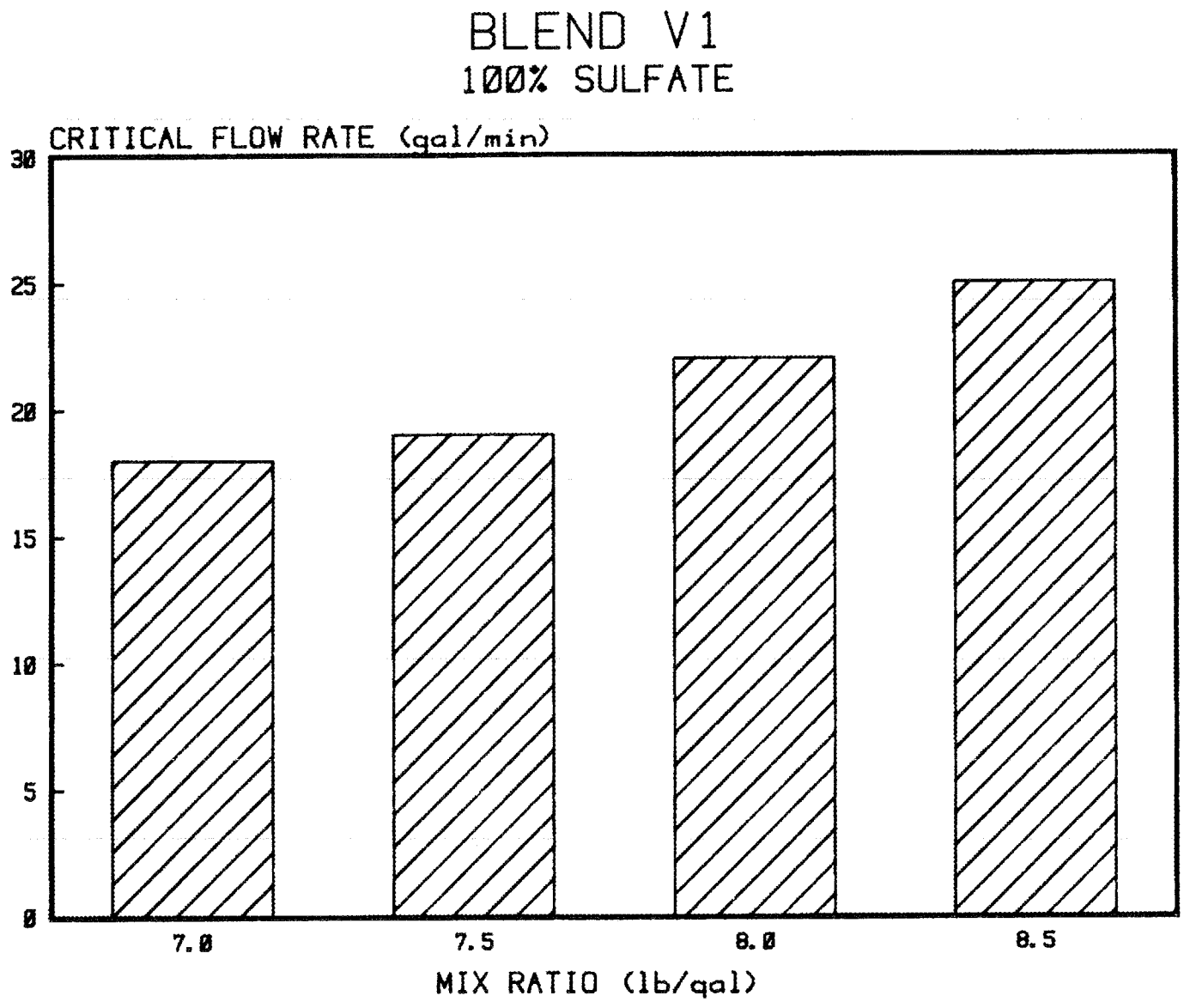
APPENDIX B

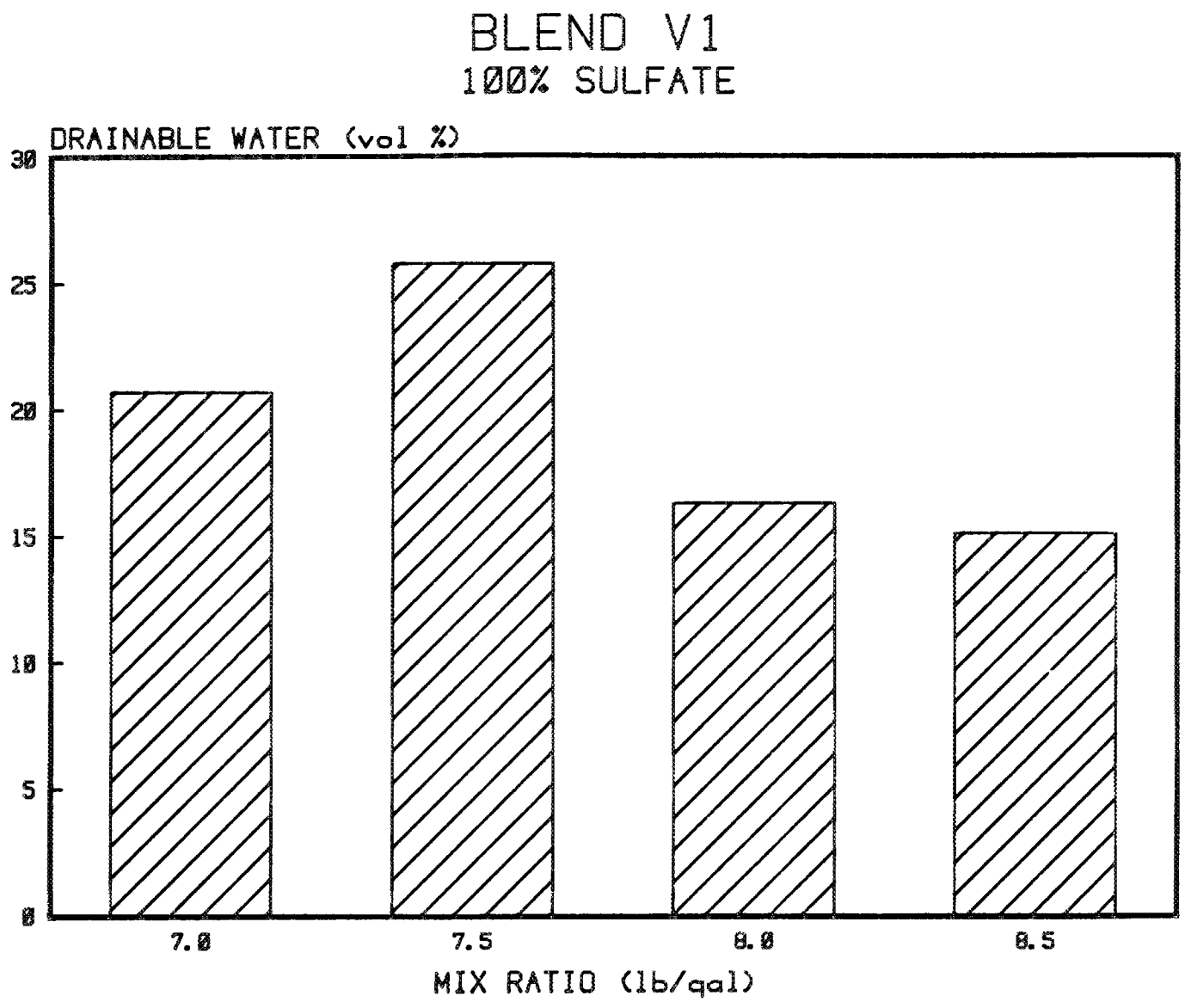
EFFECTS OF MIX RATIO ON GROUT PROPERTIES USING TYPE I,II CEMENT

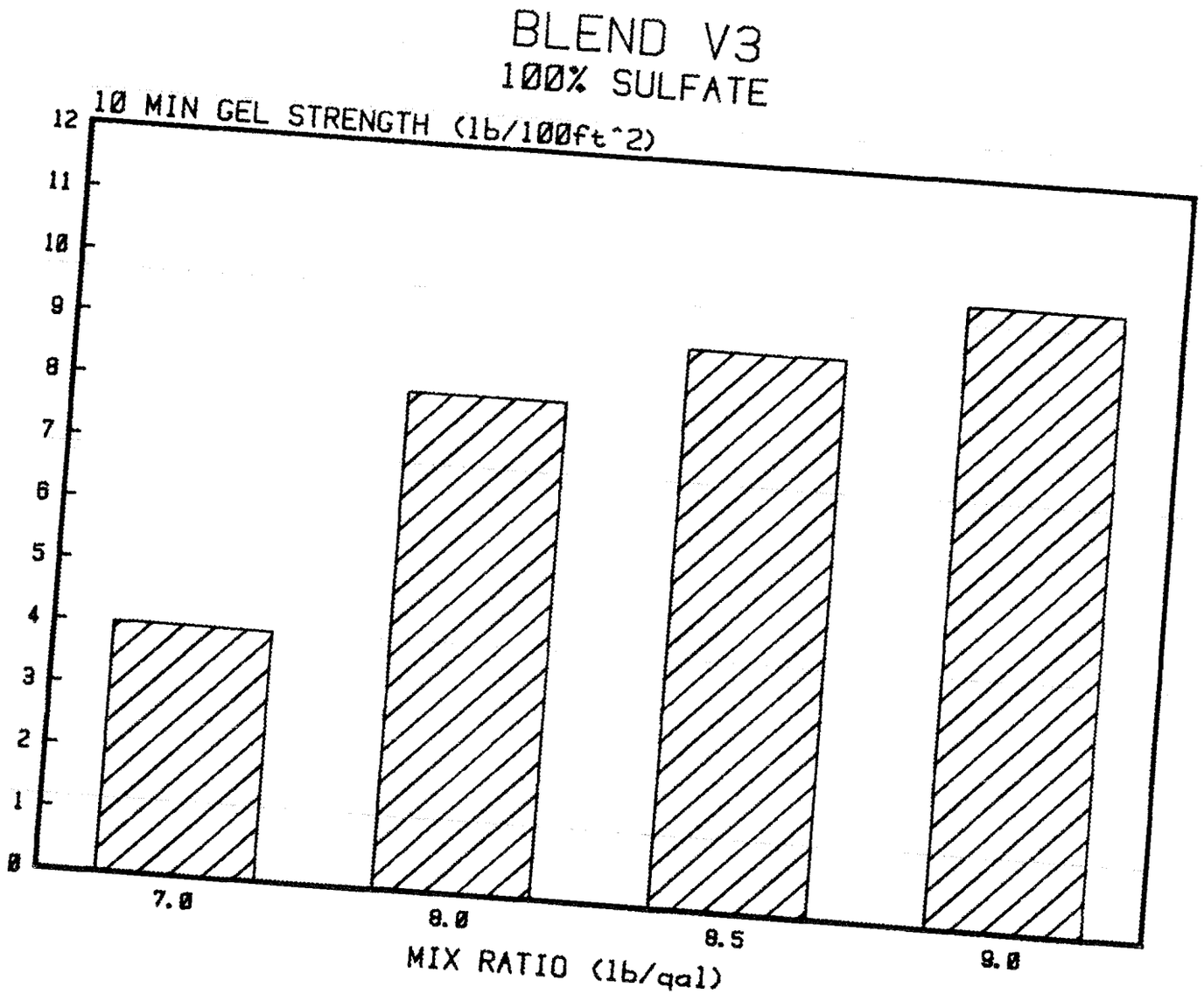
This appendix contains plots of various responses vs mix ratio using Type I,II cement and the reference formula for 50/50 sulfate/phosphate HFW. The tendency is that an increase in mix ratio results in an increase in critical flow rate and 10-min gel strength. There is no discernible pattern as to the effects of mix ratio on compressive strength or drainable water.

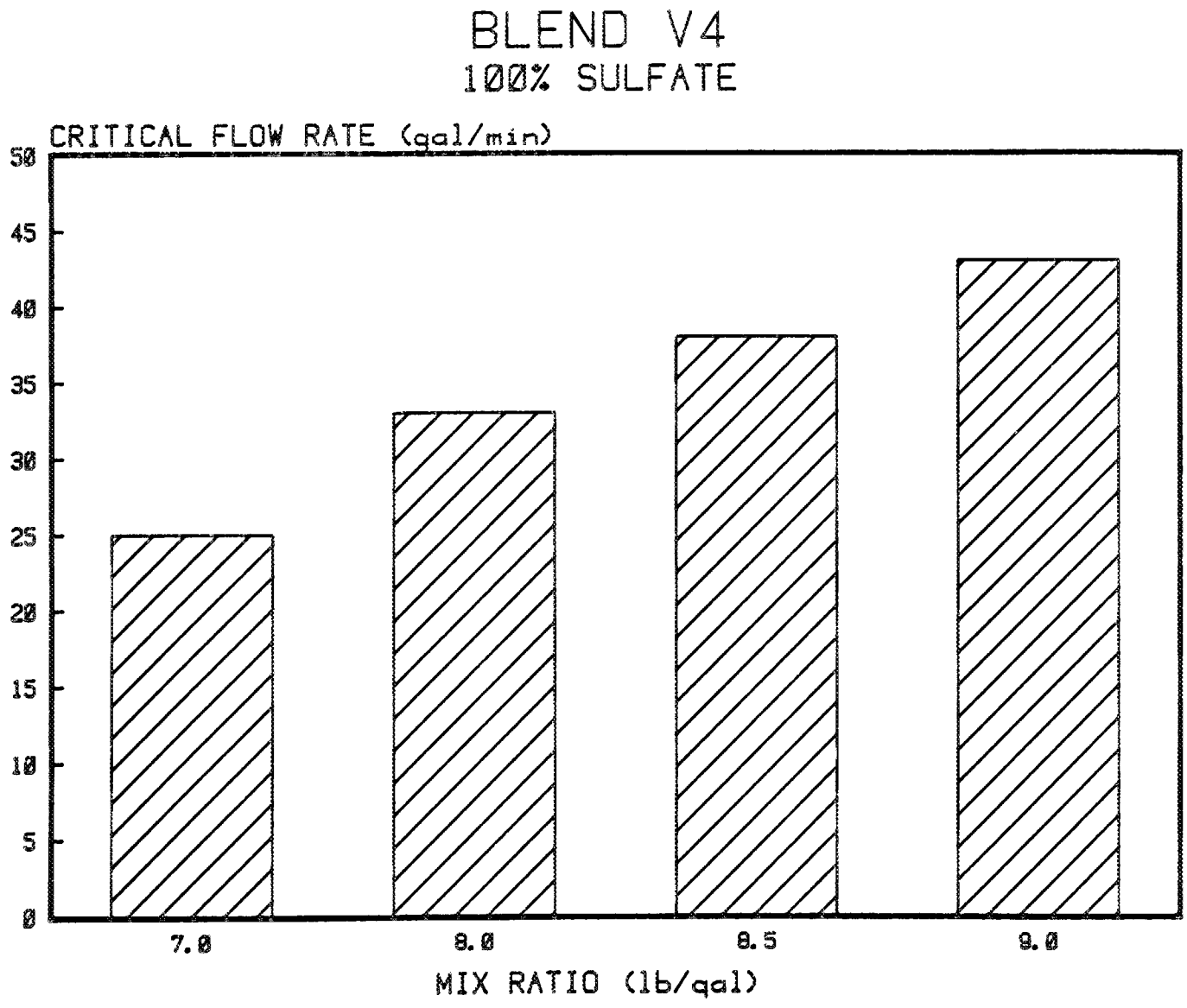

BLEND V1
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
10
9
8
7
6
5
4
3
2
1
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

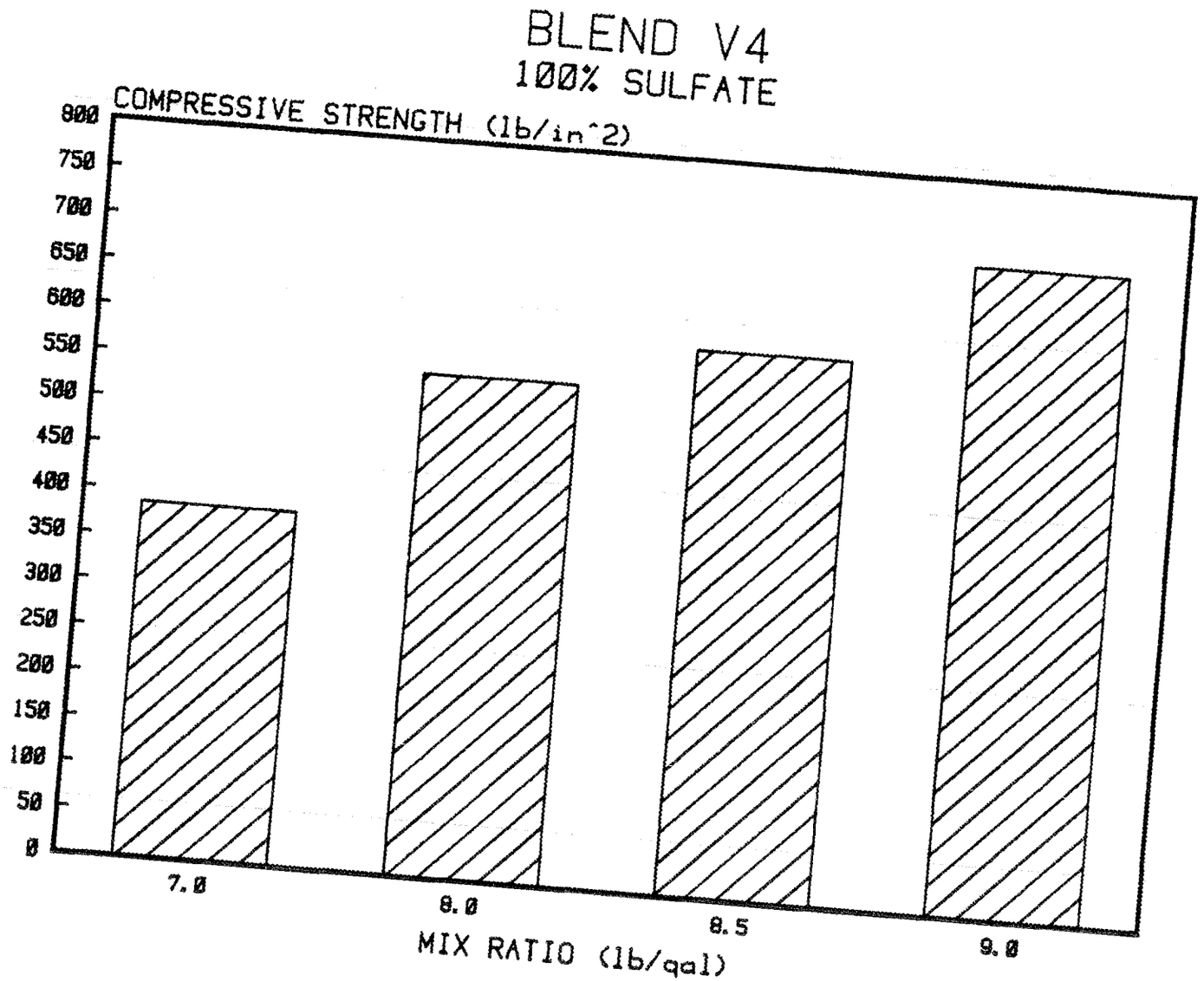

BLEND V1
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
500
450
400
350
300
250
200
150
100
50
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

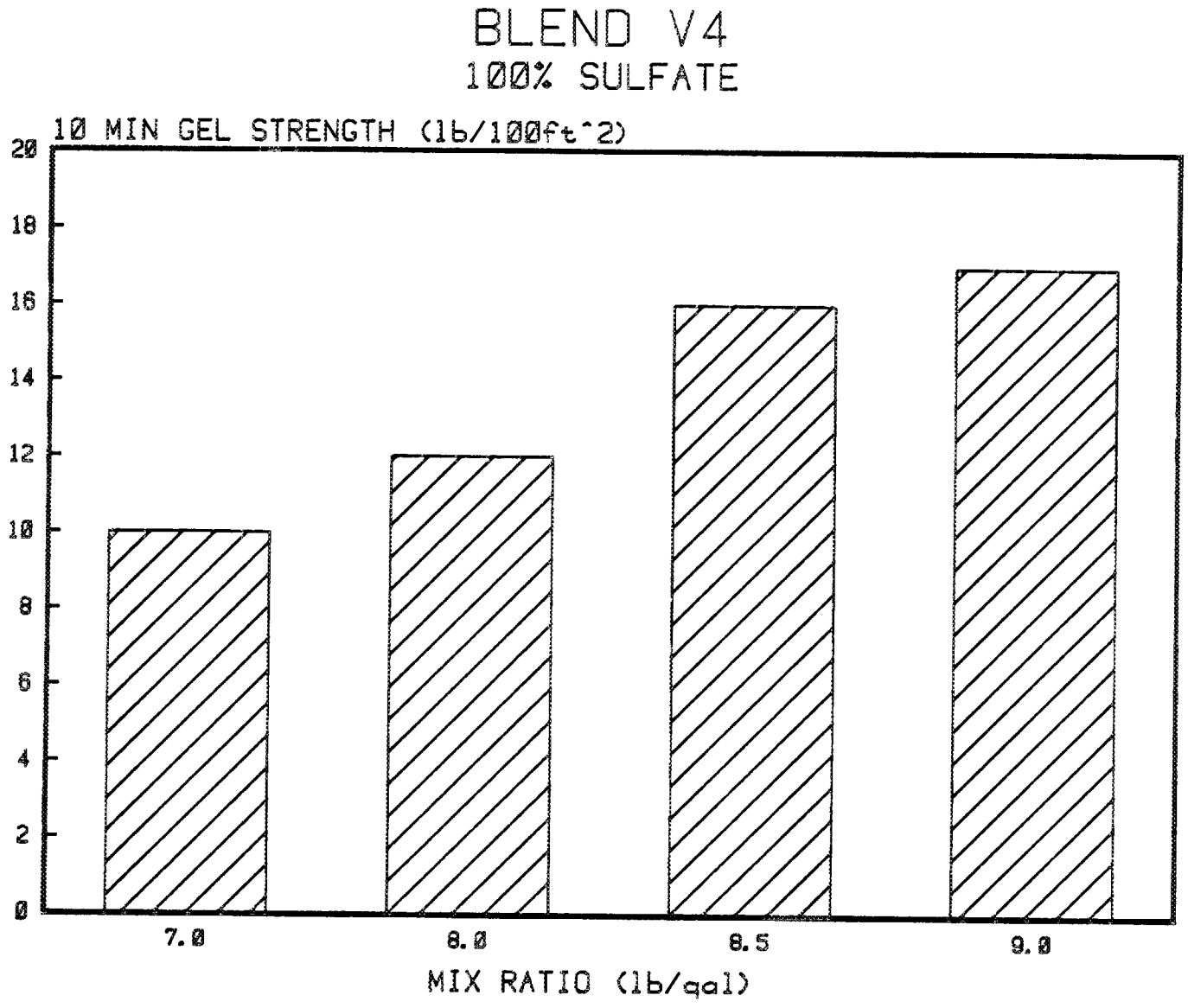

BLEND V1
100% SULFATE
CRITICAL FLOW RATE (gal/min)
30
25
20
15
10
5
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

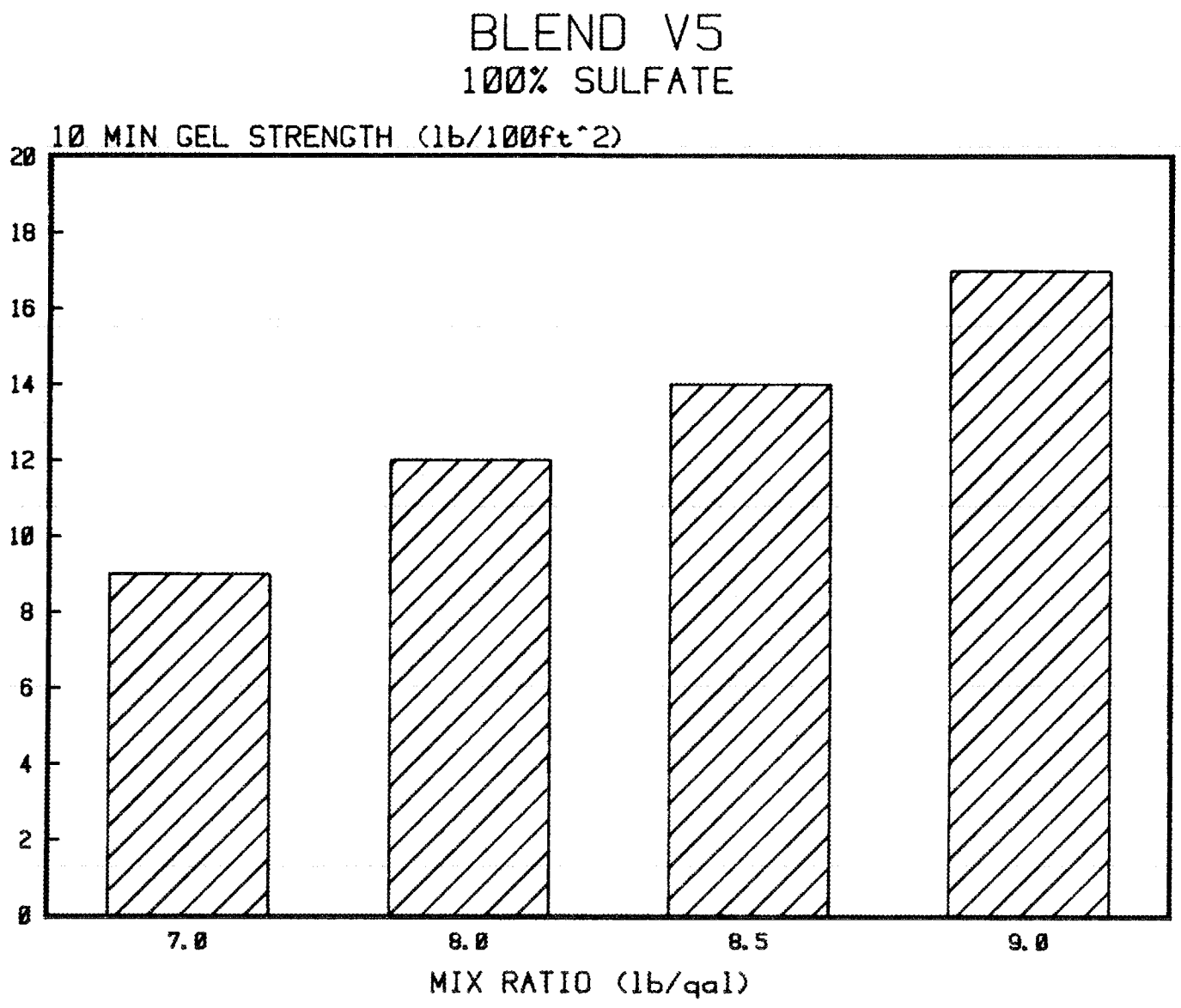

BLEND V1
100% SULFATE
DRAINABLE WATER (vol %)
30
25
20
15
10
5
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

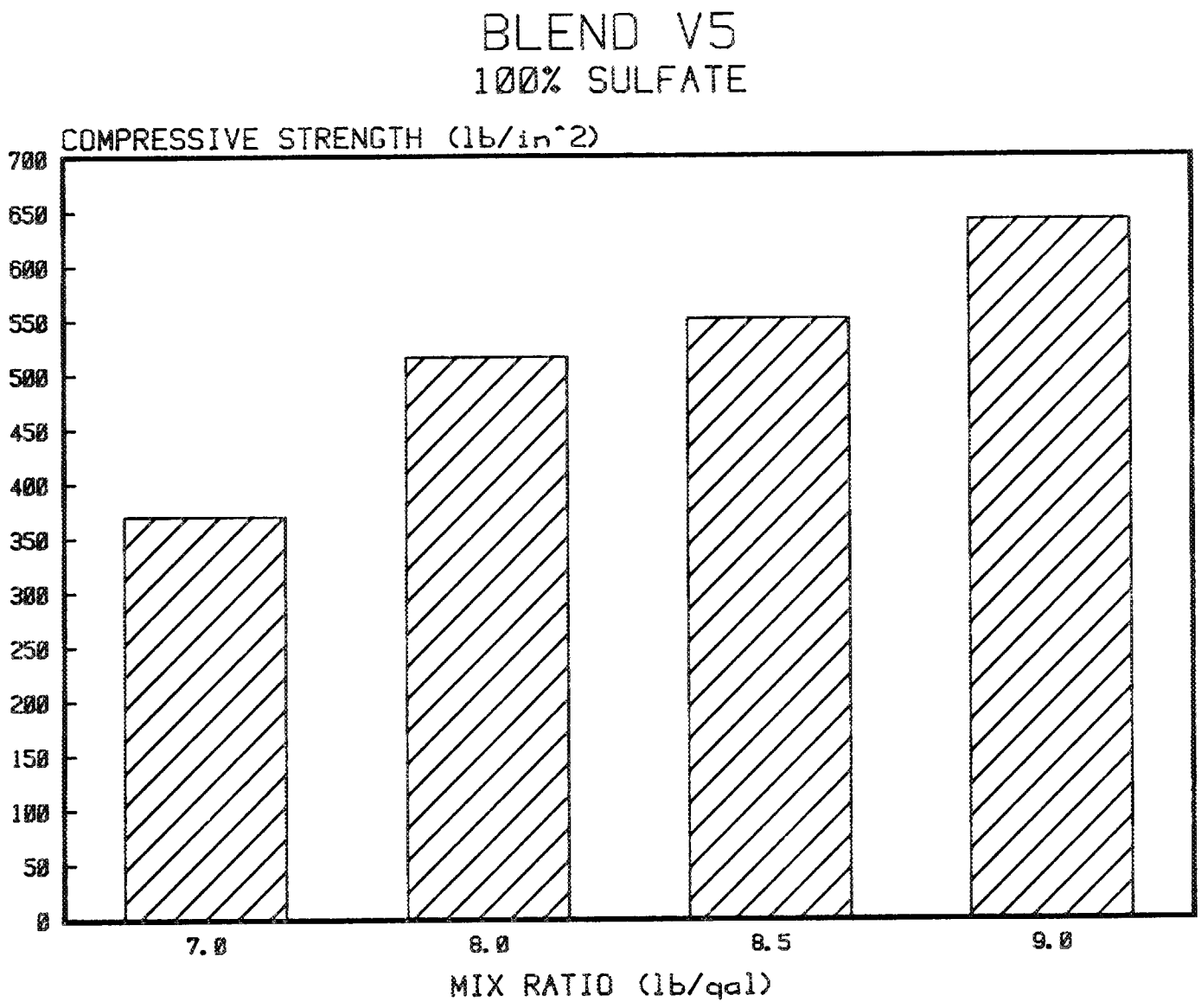

BLEND V3
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
12
11
10
9
8
7
6
5
4
3
2
1
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

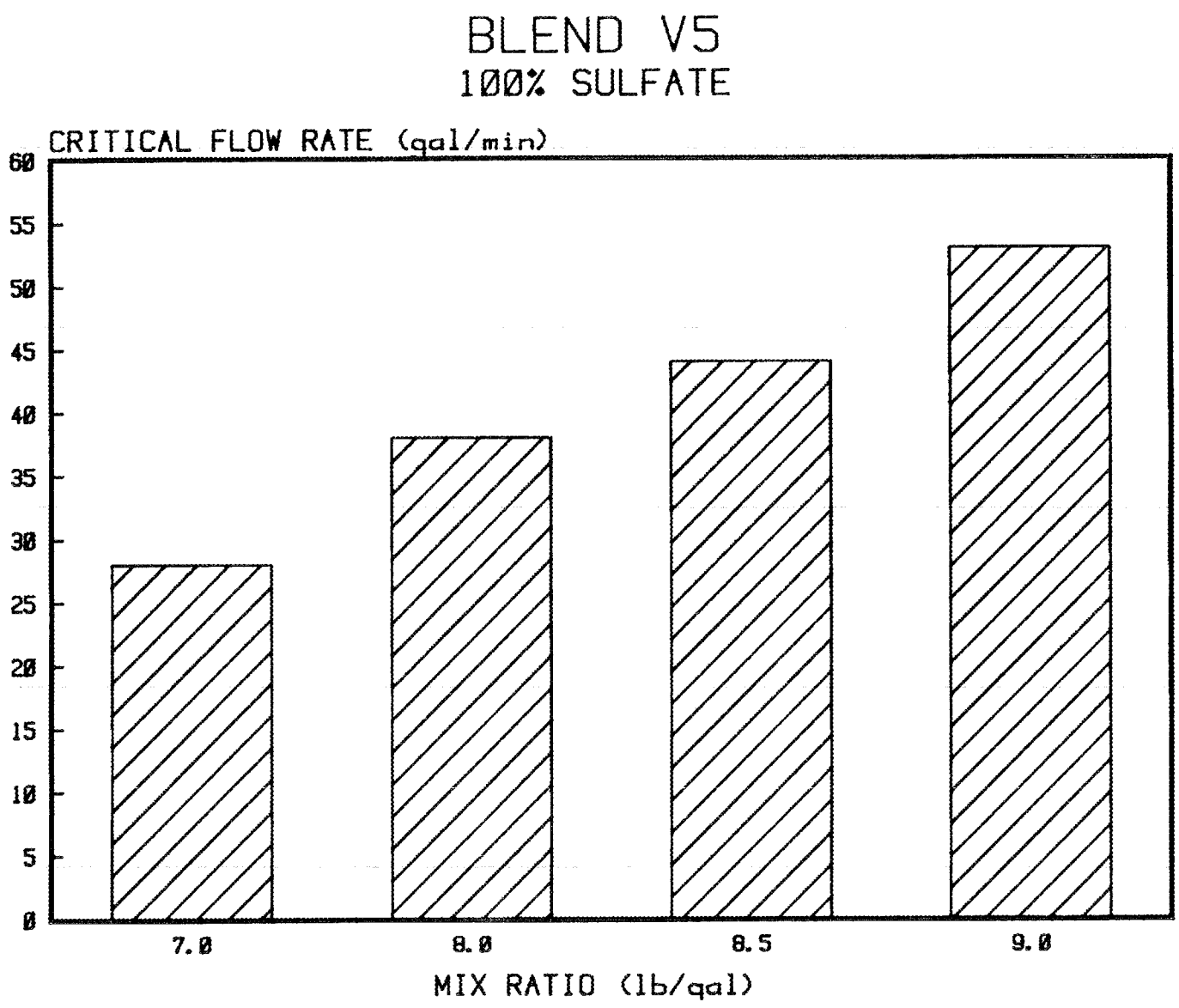

BLEND V4
100% SULFATE
CRITICAL FLOW RATE (gal/min)
50
45
40
35
30
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

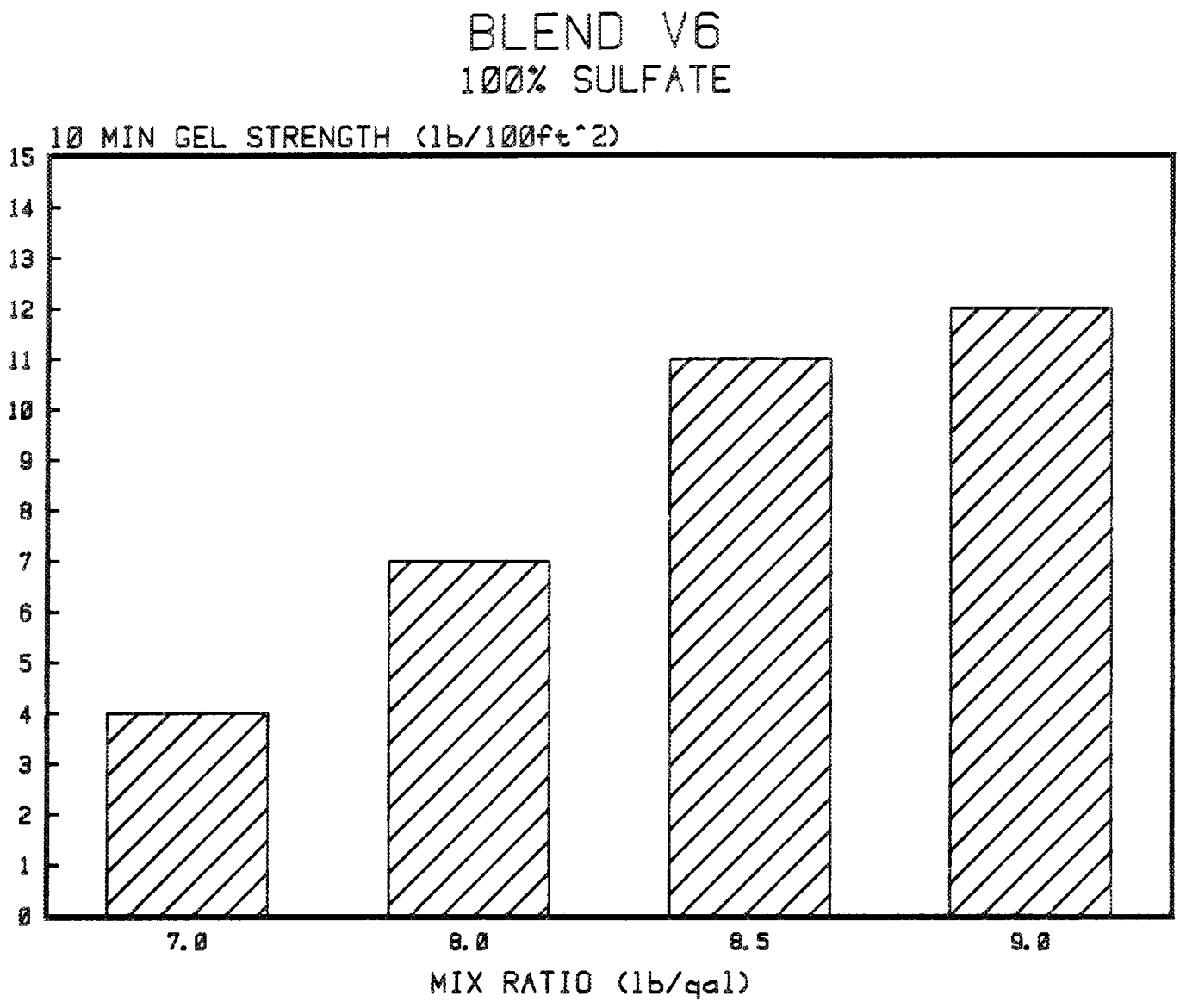

BLEND V4
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

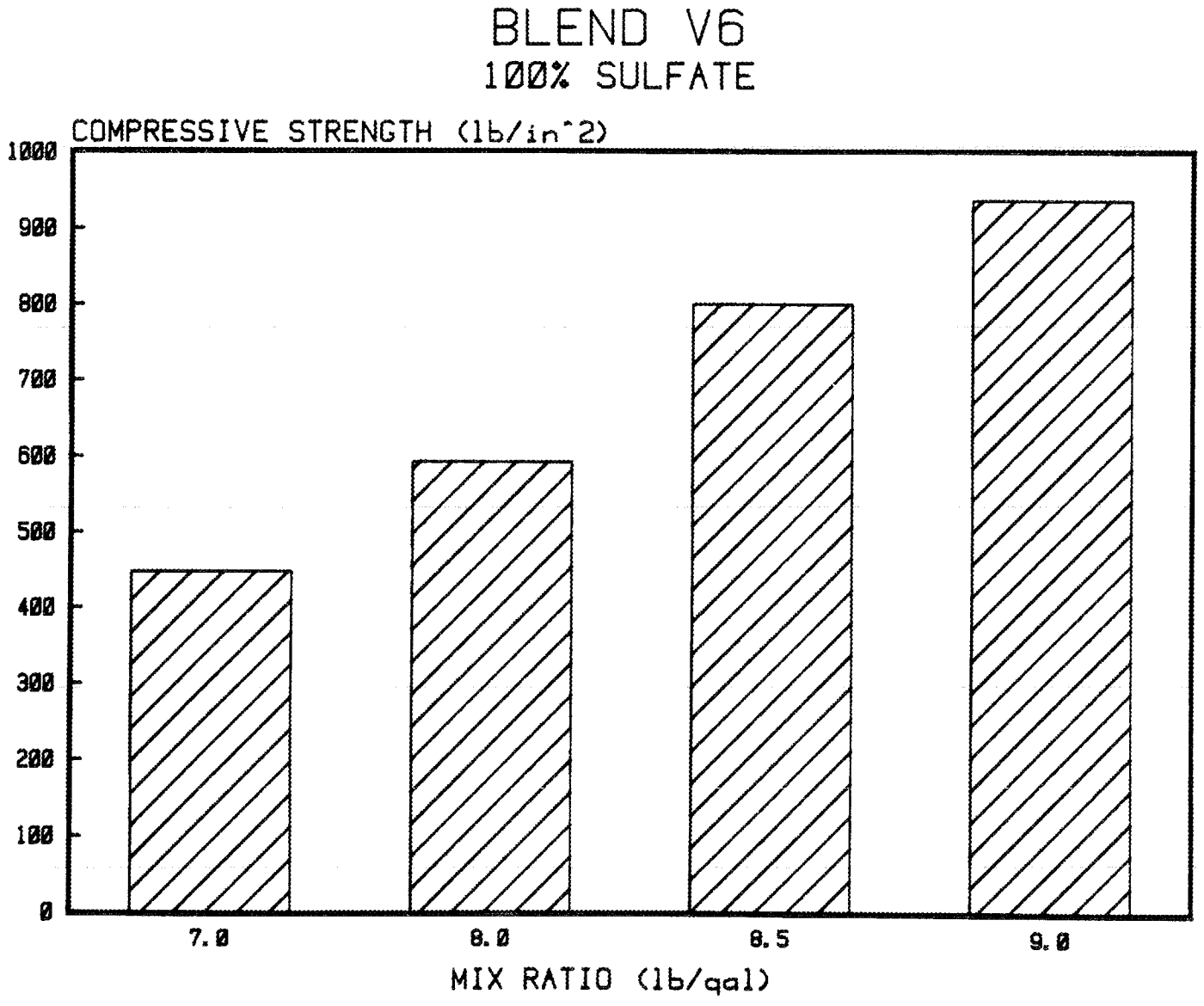

BLEND V4
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
20
18
16
14
12
10
8
6
4
2
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

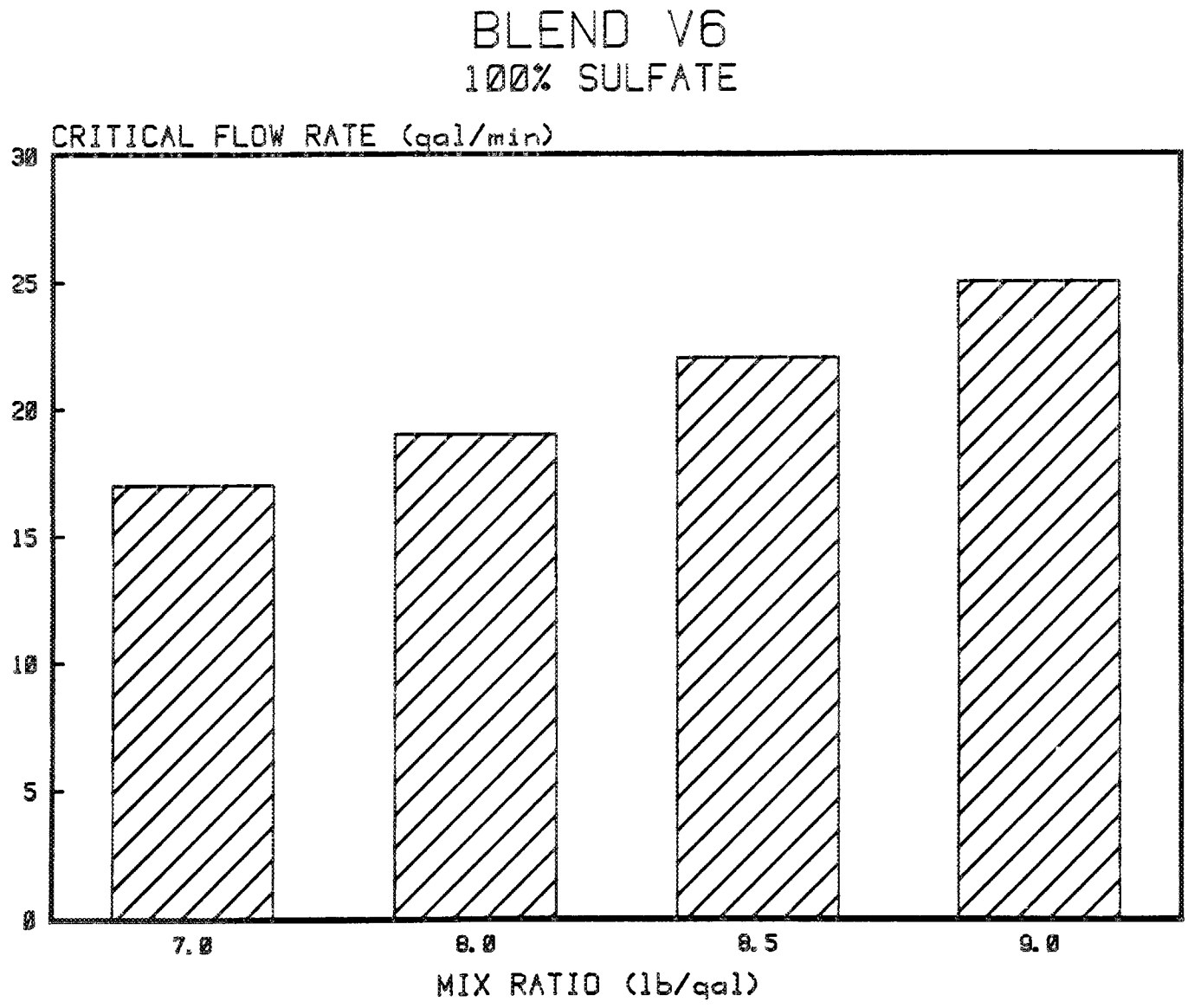

BLEND V5
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
20
18
16
14
12
10
8
6
4
2
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

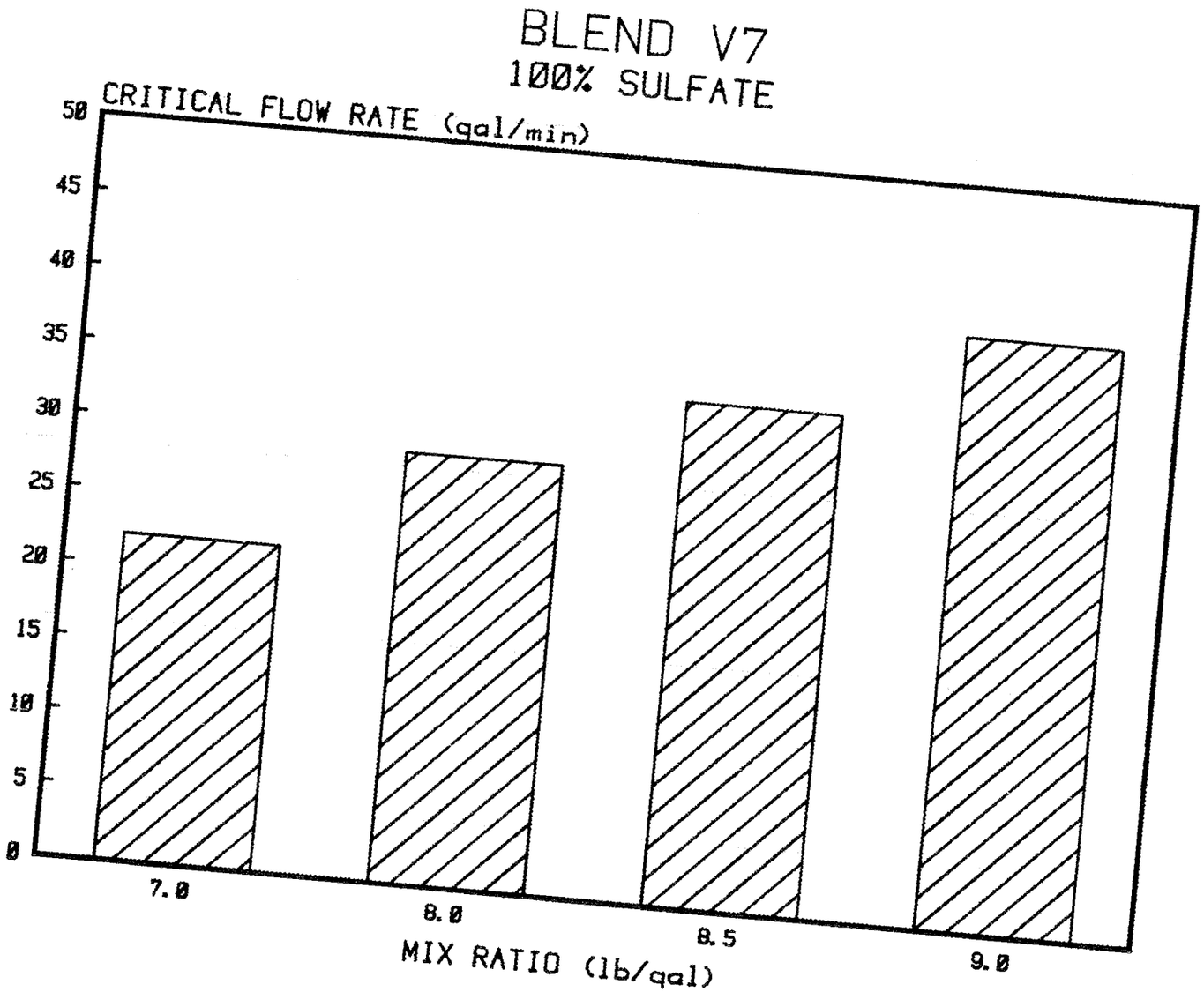

BLEND V5
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

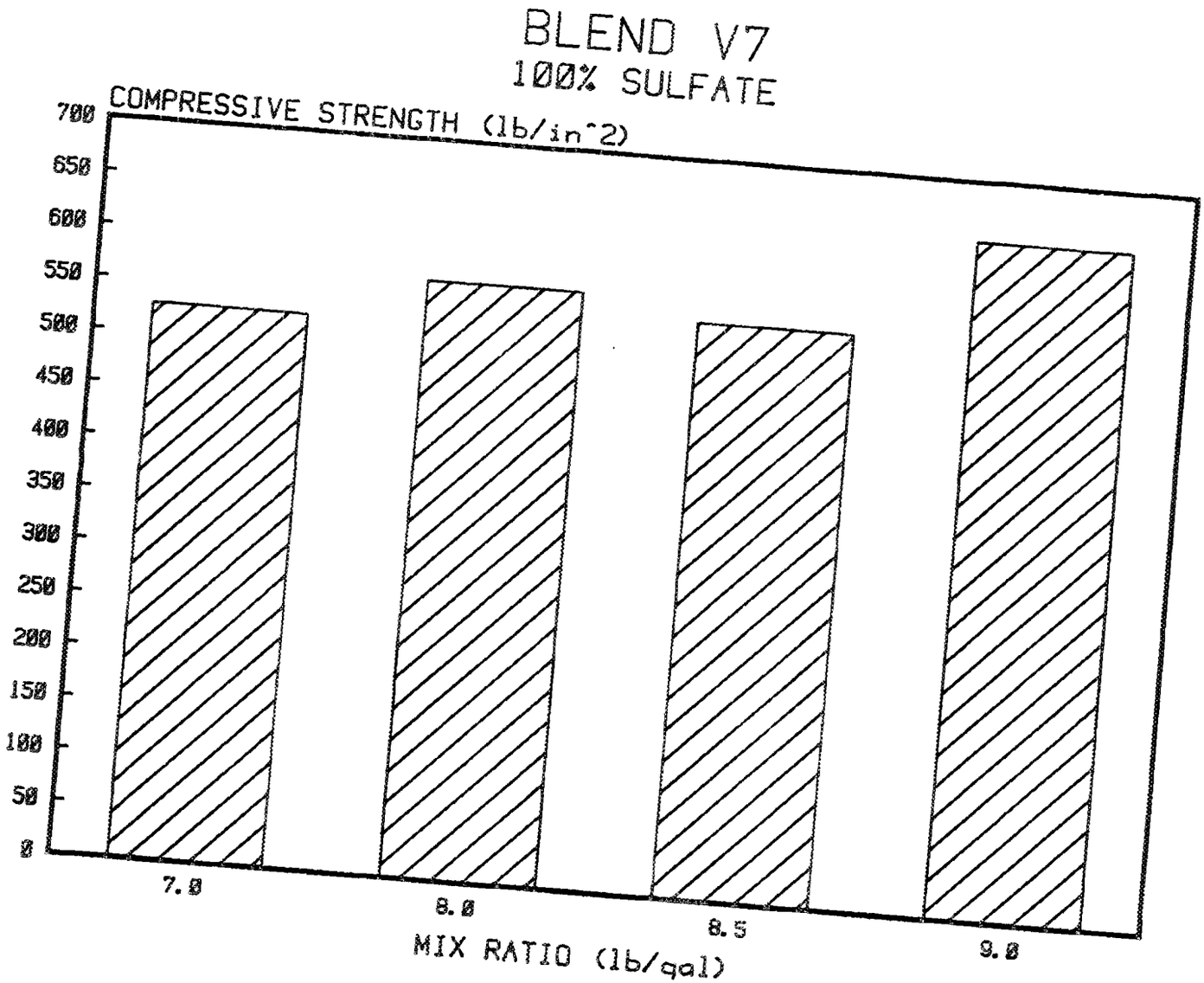

BLEND V5
100% SULFATE
CRITICAL FLOW RATE (gal/min)
60
55
50
45
40
35
30
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

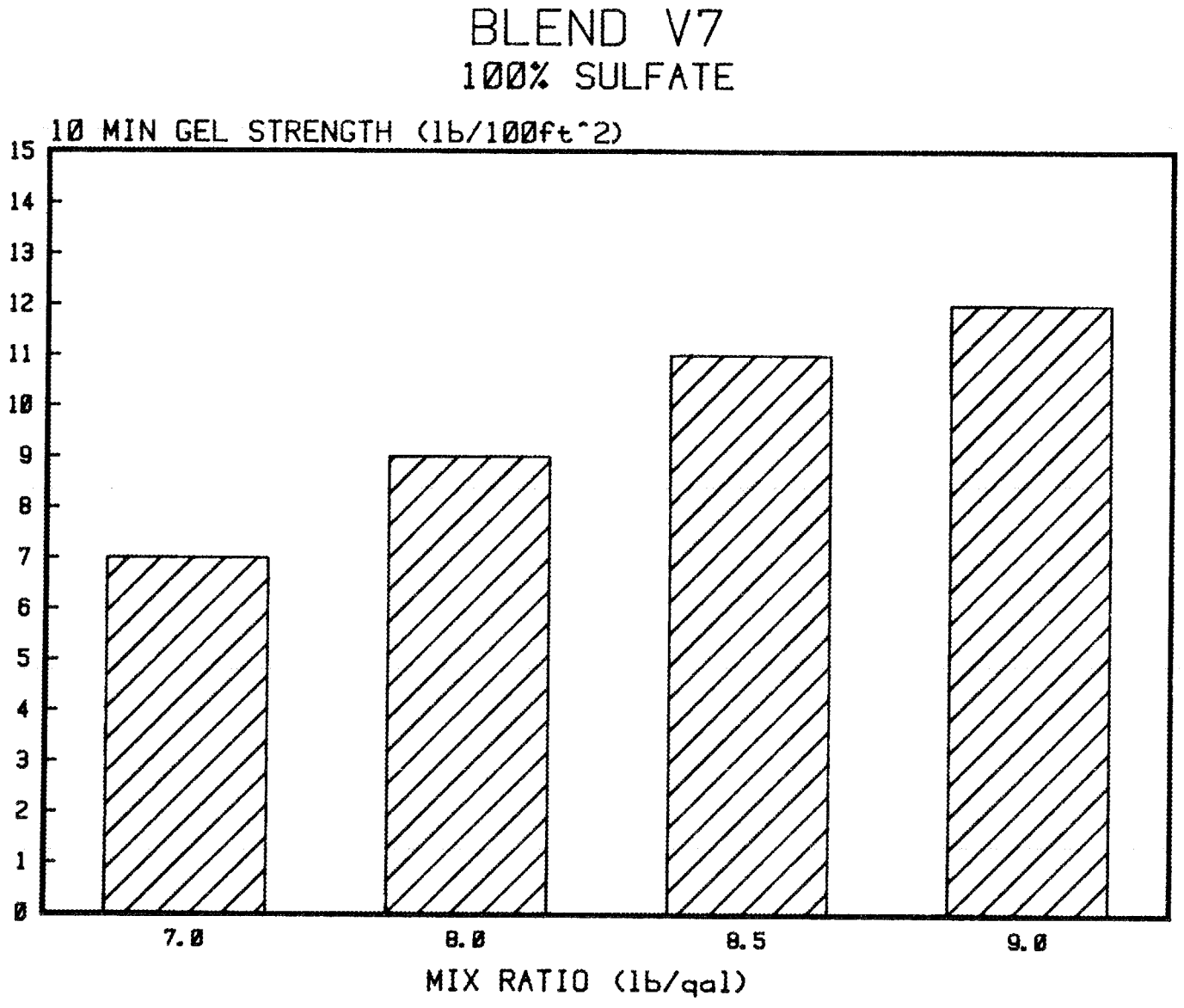

BLEND V6
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

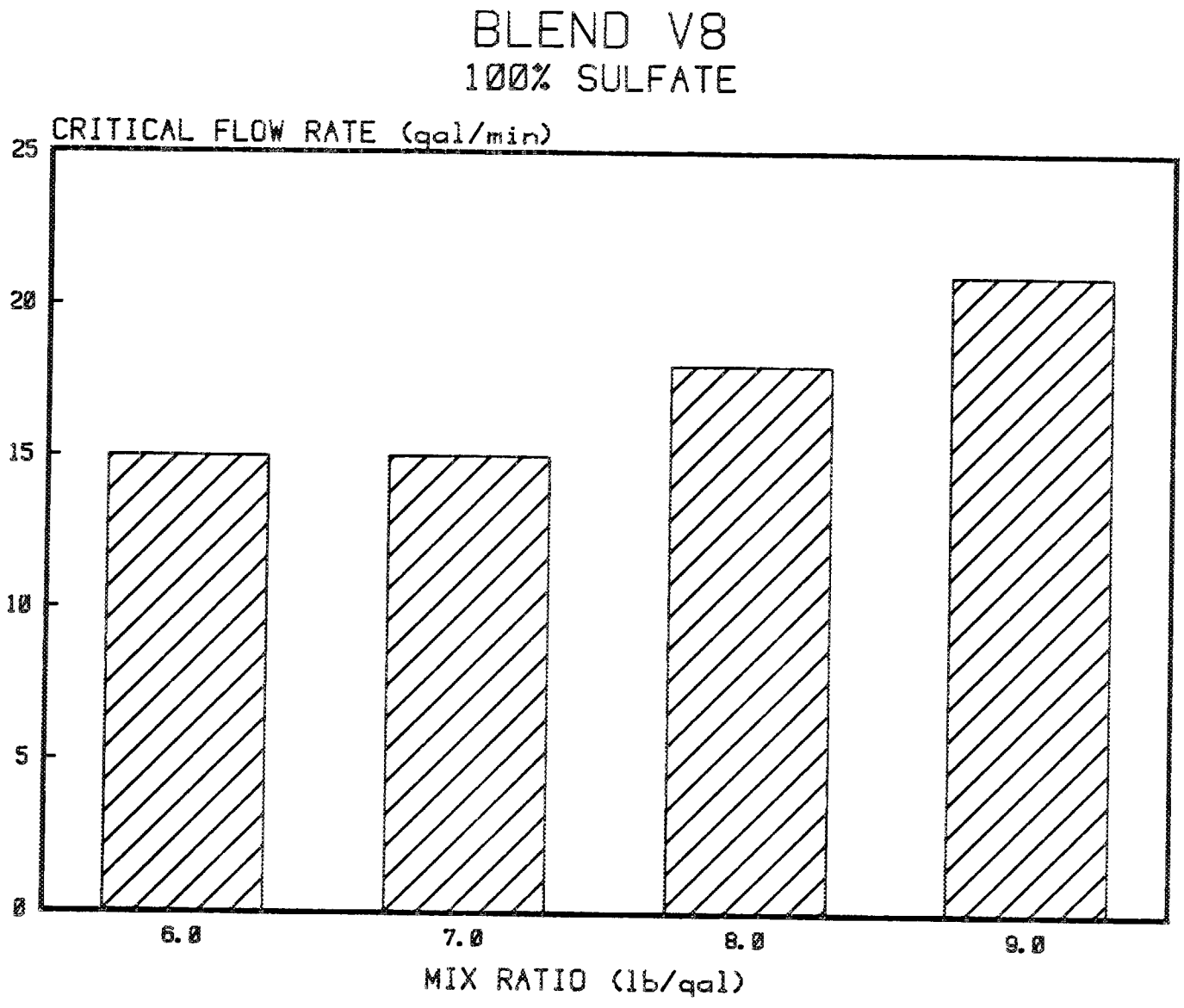

BLEND V6
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
1000
900
800
700
600
500
400
300
200
100
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

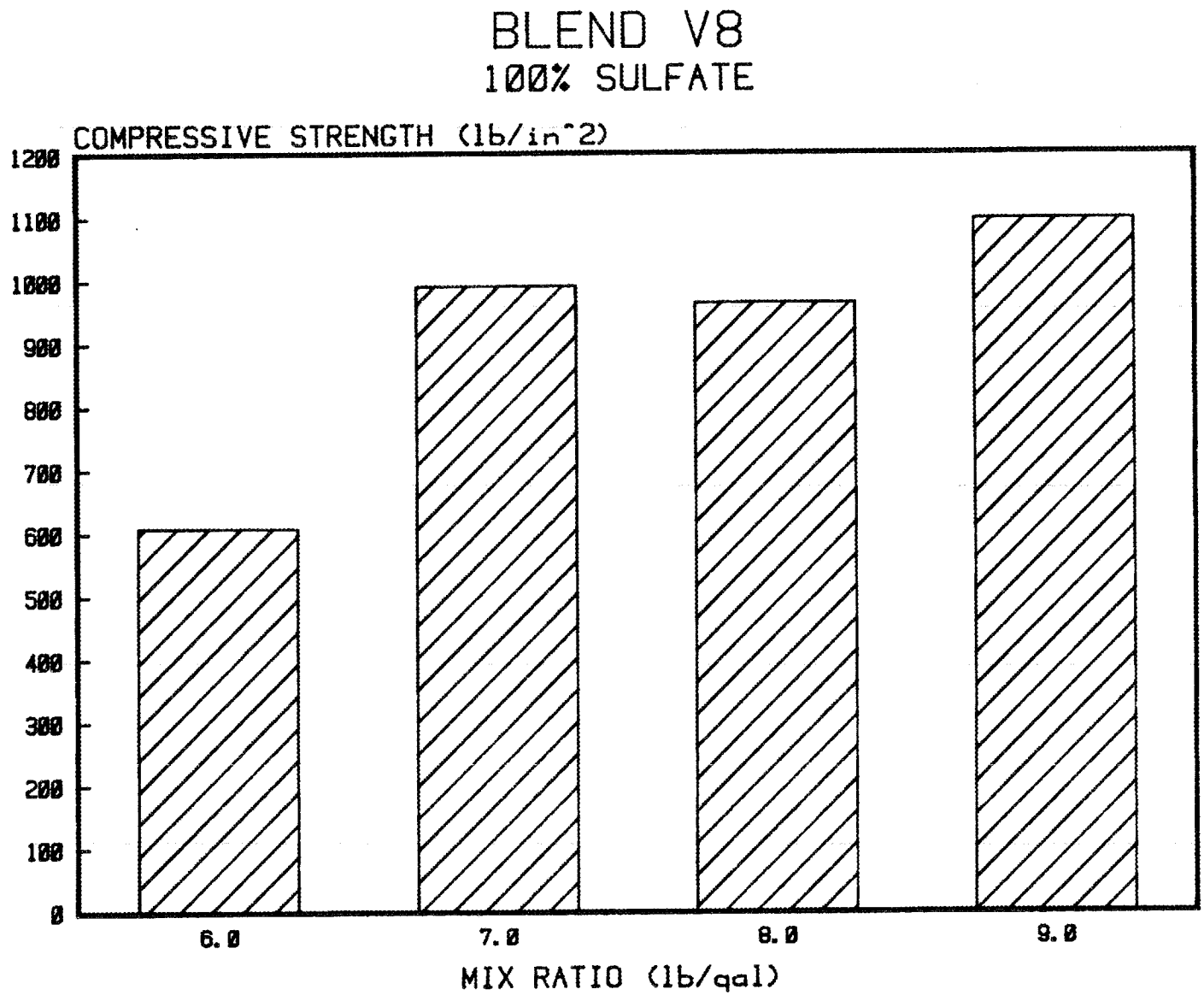

BLEND V6
100% SULFATE
CRITICAL FLOW RATE (gal/min)
30
25
20
15
10
5
0
7.0
8.0
9.5
9.0
MIX RATIO (lb/gal)

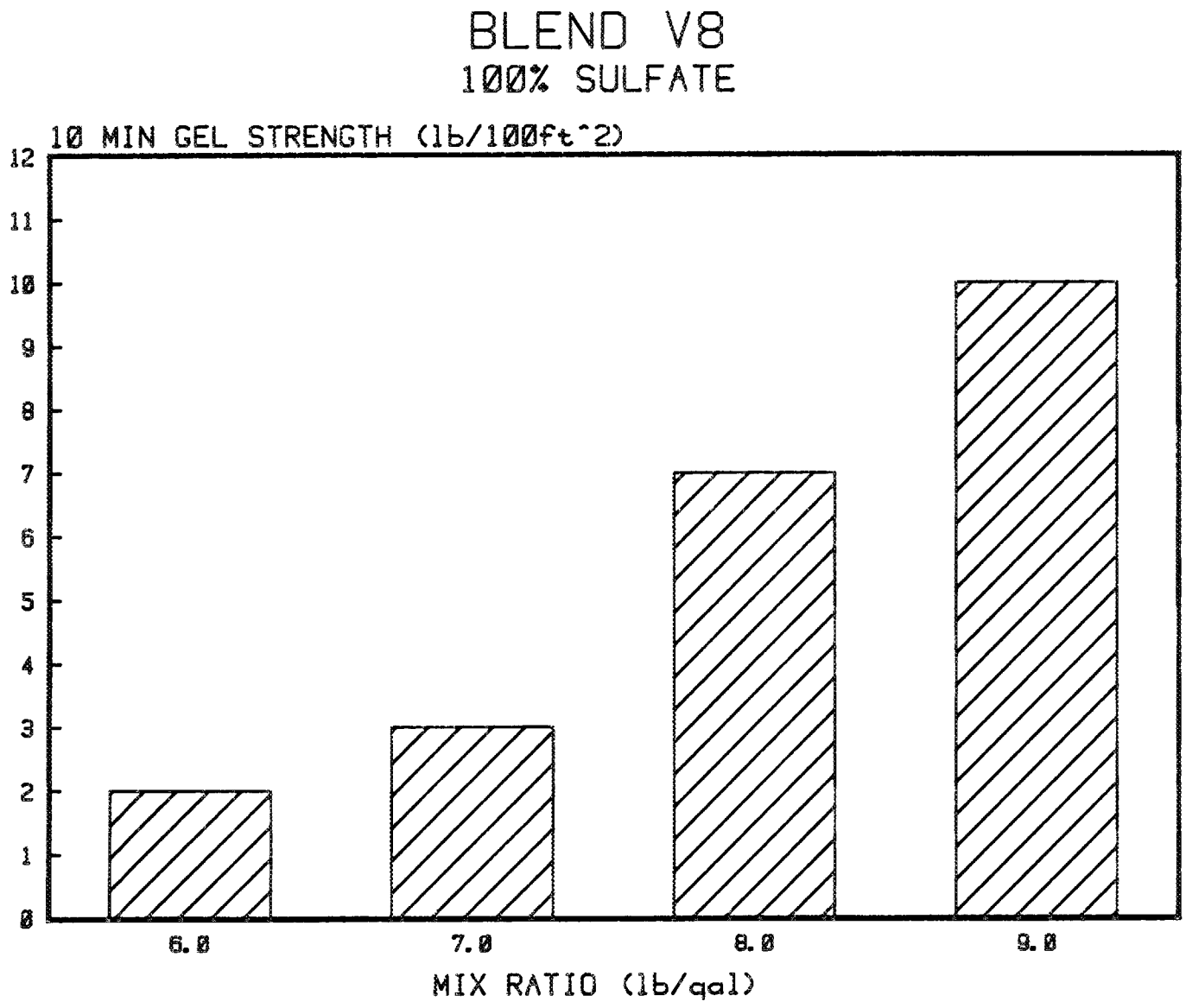

BLEND V7
100% SULFATE
CRITICAL FLOW RATE (gal/min)
50
45
40
35
30
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V7
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V7
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V8
100% SULFATE
CRITICAL FLOW RATE (gal/min)
25
20
15
10
5
0
6.0
7.0
8.0
9.0
MIX RATIO (lb/gal)


BLEND V8
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
6.0
7.0
8.0
9.0
MIX RATIO (lb/gal)


BLEND V8
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
12
11
10
9
8
7
6
5
4
3
2
1
0
6.0
7.0
8.0
9.0
MIX RATIO (lb/gal)

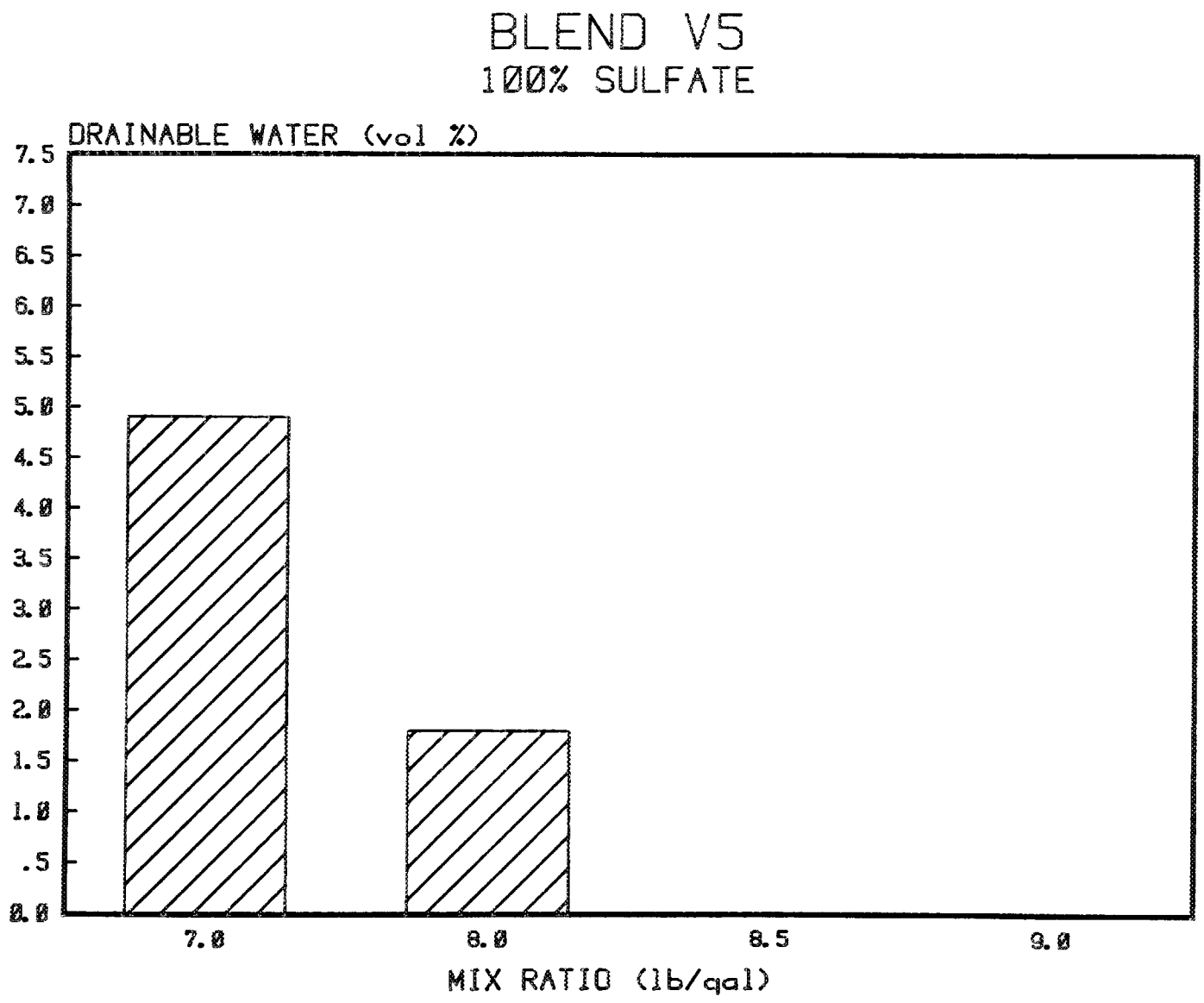
APPENDIX C

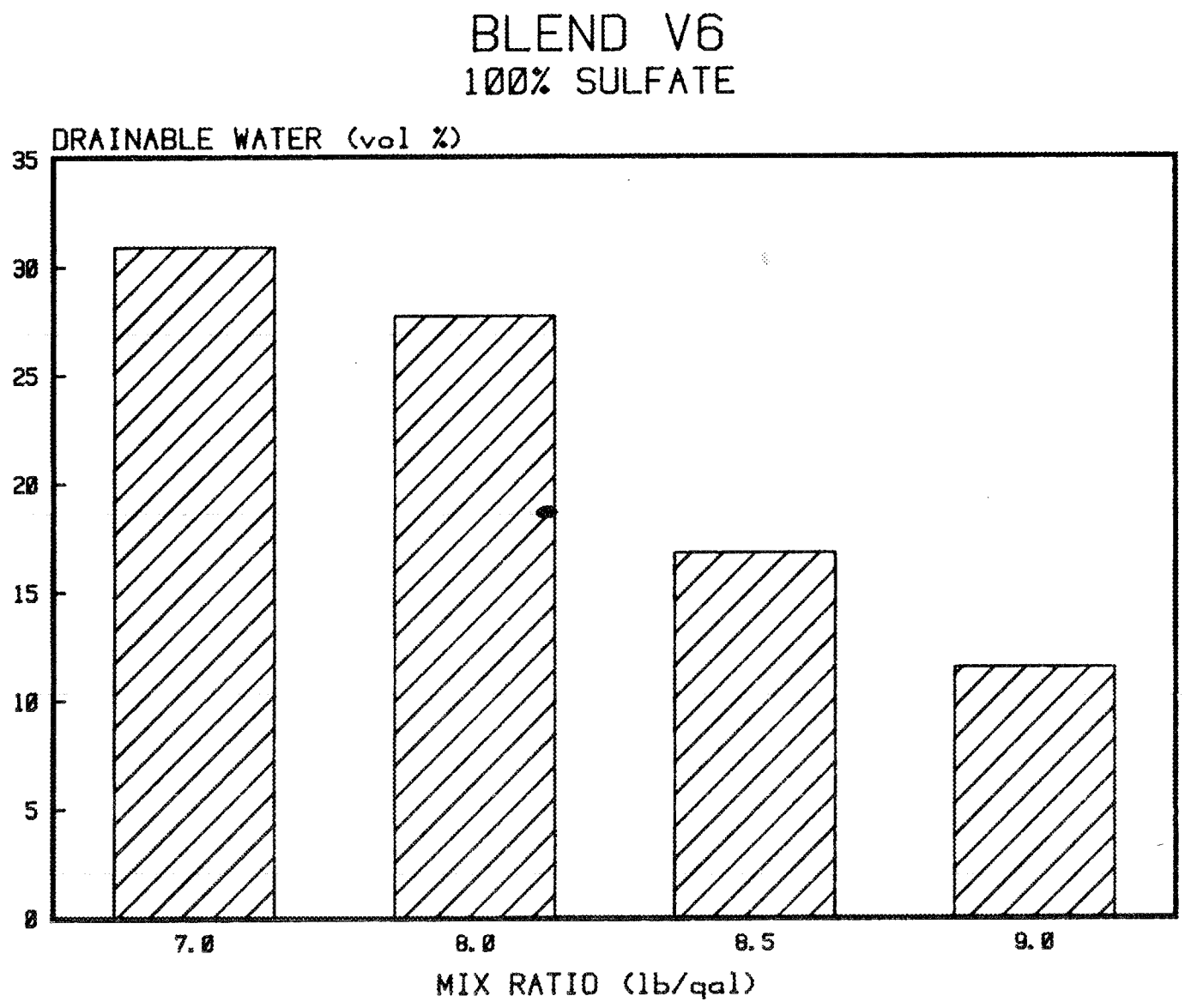
EFFECTS OF MIX RATIO ON GROUT PROPERTIES FOR 100% SULFATE WASTE USING TYPE III CEMENT

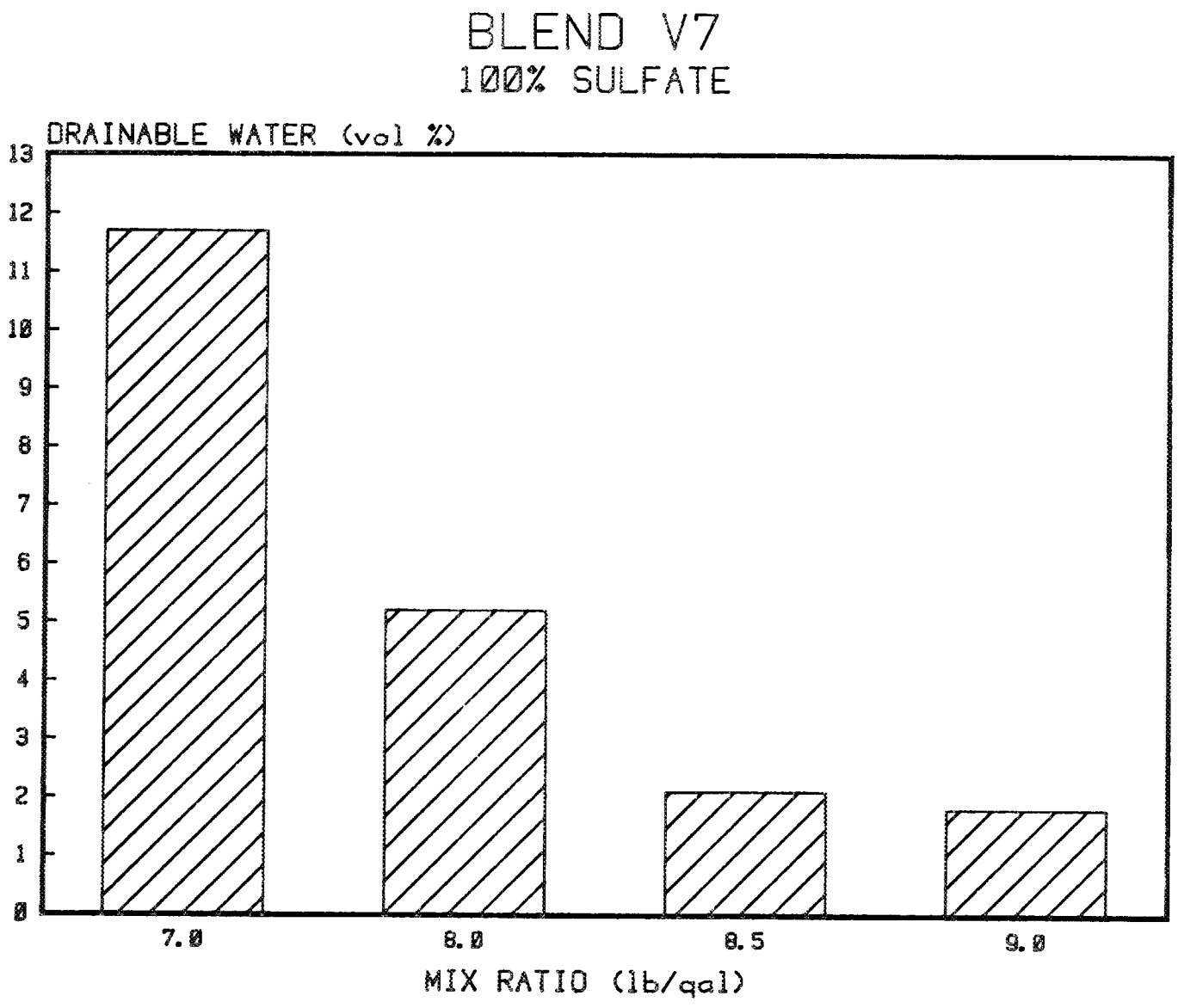
This appendix contains plots of various responses as a function of mix ratio for various blends used during the initial exploratory study. The following general trends were noticed as a result of increasing the mix ratio:

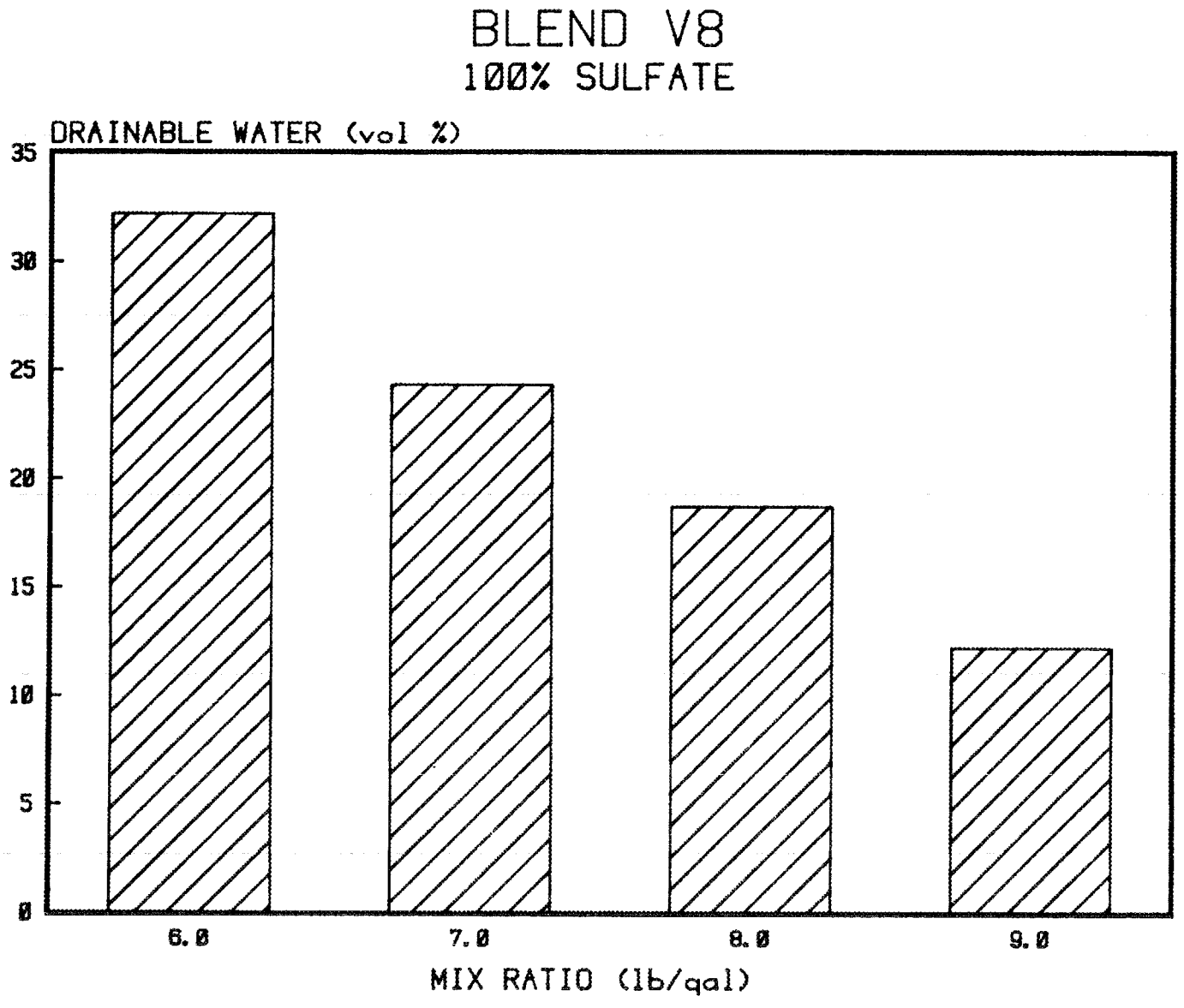
1. drainable water - decreases
2. critical flow rate - increases
3. compressive strength - increases
4. 10-min gel strength - increases

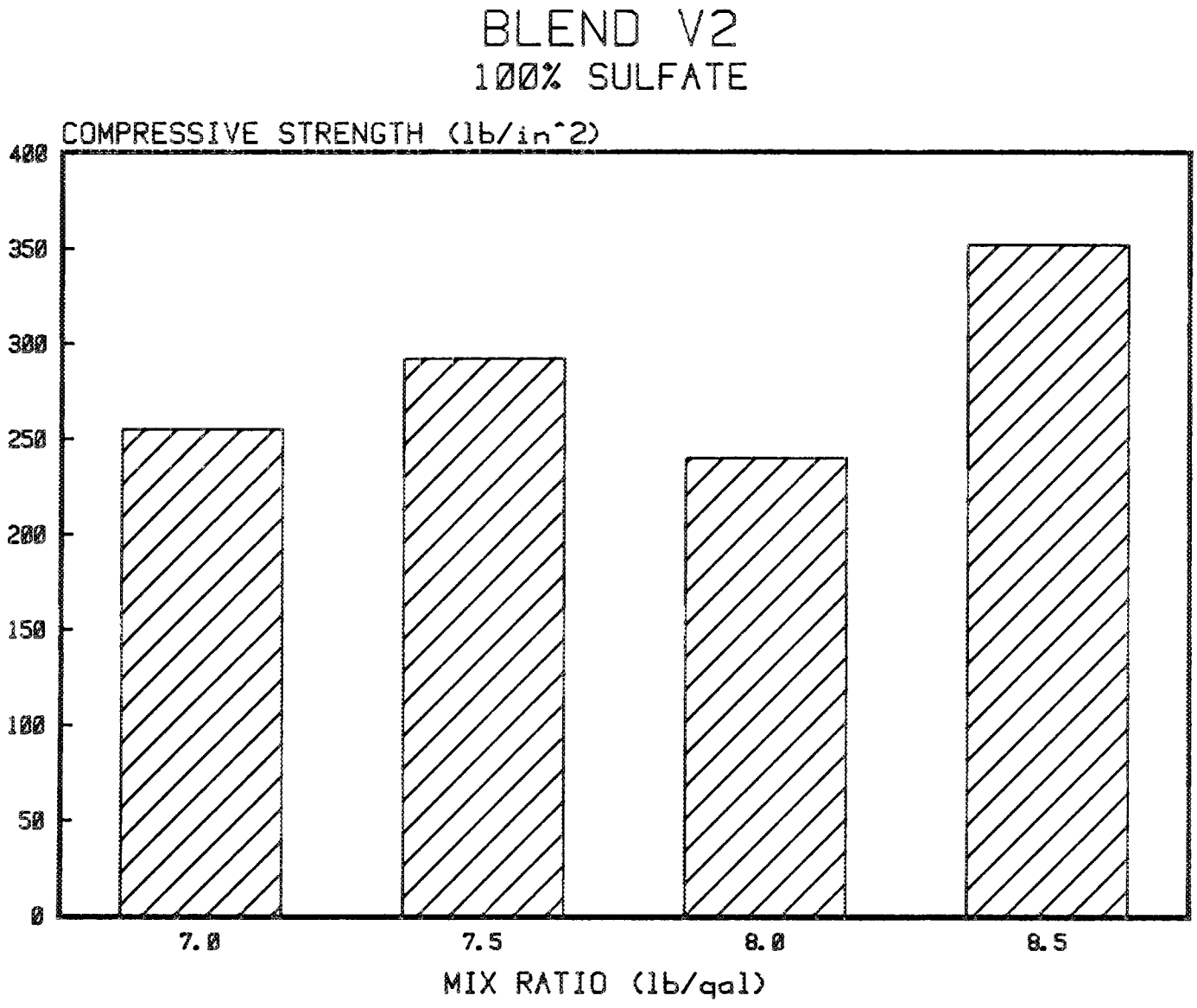
All of the blends represented in this appendix were prepared using type III Portland cement.

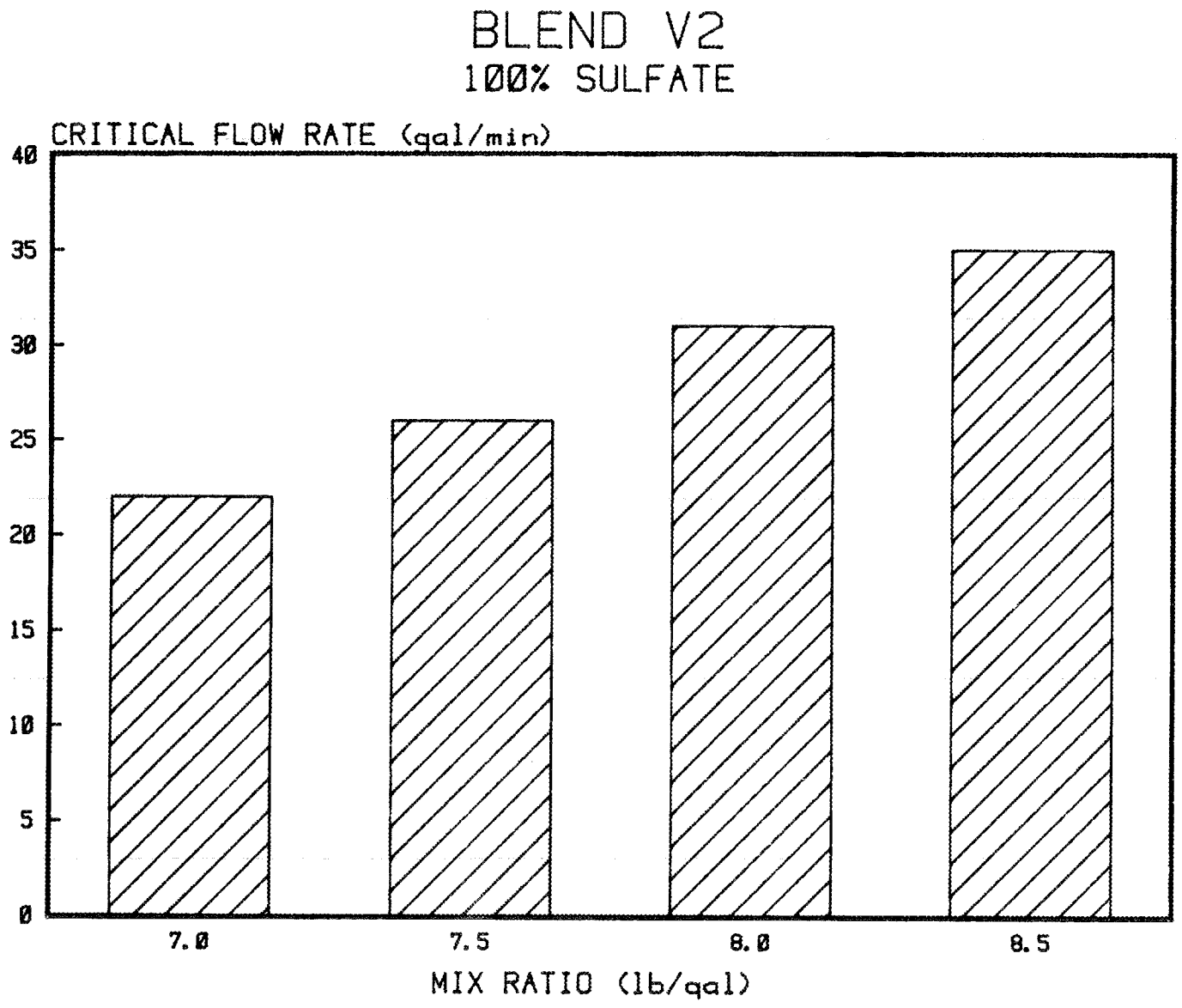

BLEND V5
100% SULFATE
DRAINABLE WATER (vol %)
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0.0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

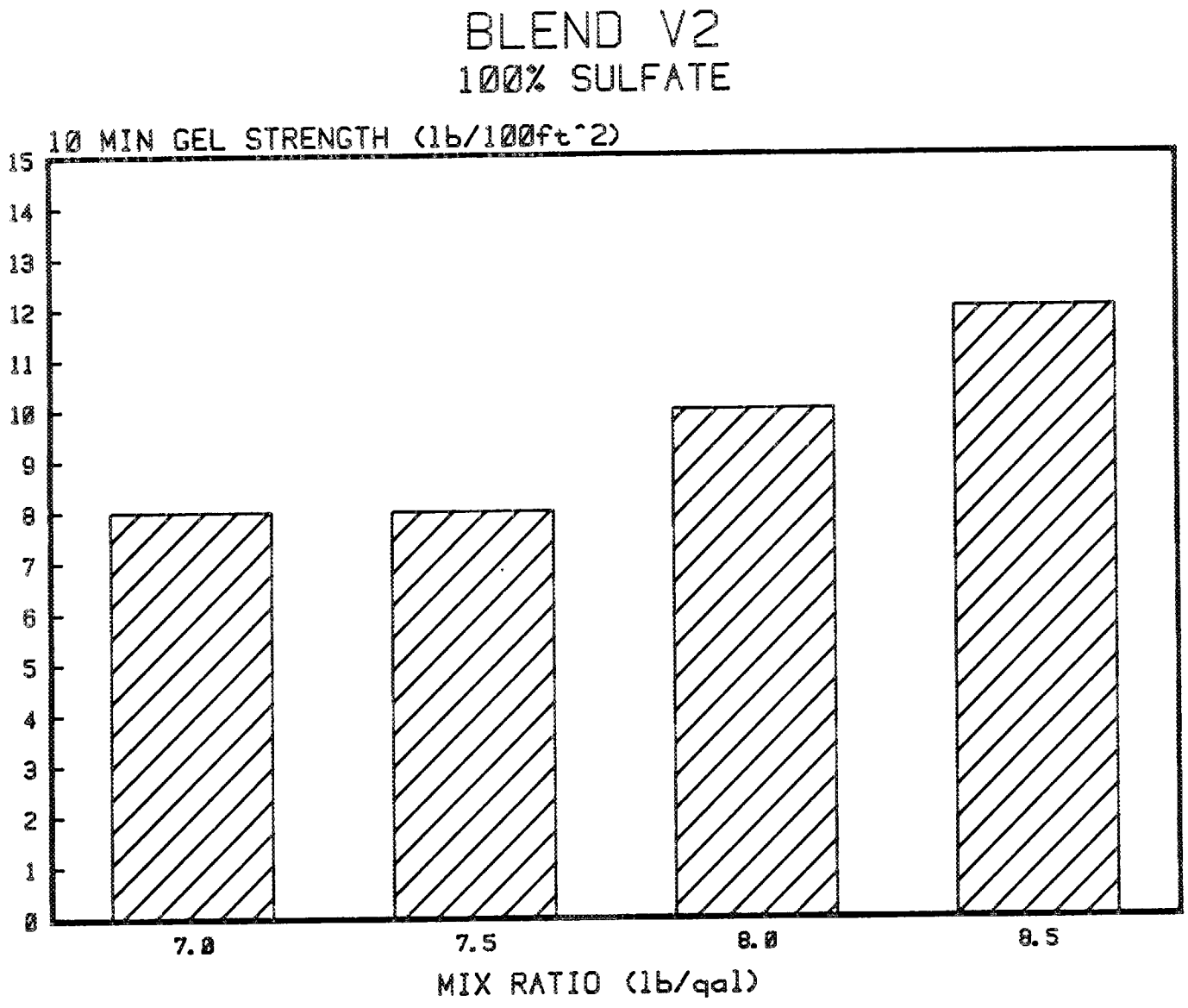

BLEND V6
100% SULFATE
DRAINABLE WATER (vol %)
35
30
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V7
100% SULFATE
DRAINABLE WATER (vol %)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V8
100% SULFATE
DRAINABLE WATER (vol %)
35
30
25
20
15
10
5
0
6.0
7.0
8.0
9.0
MIX RATIO (lb/gal)


BLEND V2
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
400
350
300
250
200
150
100
50
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

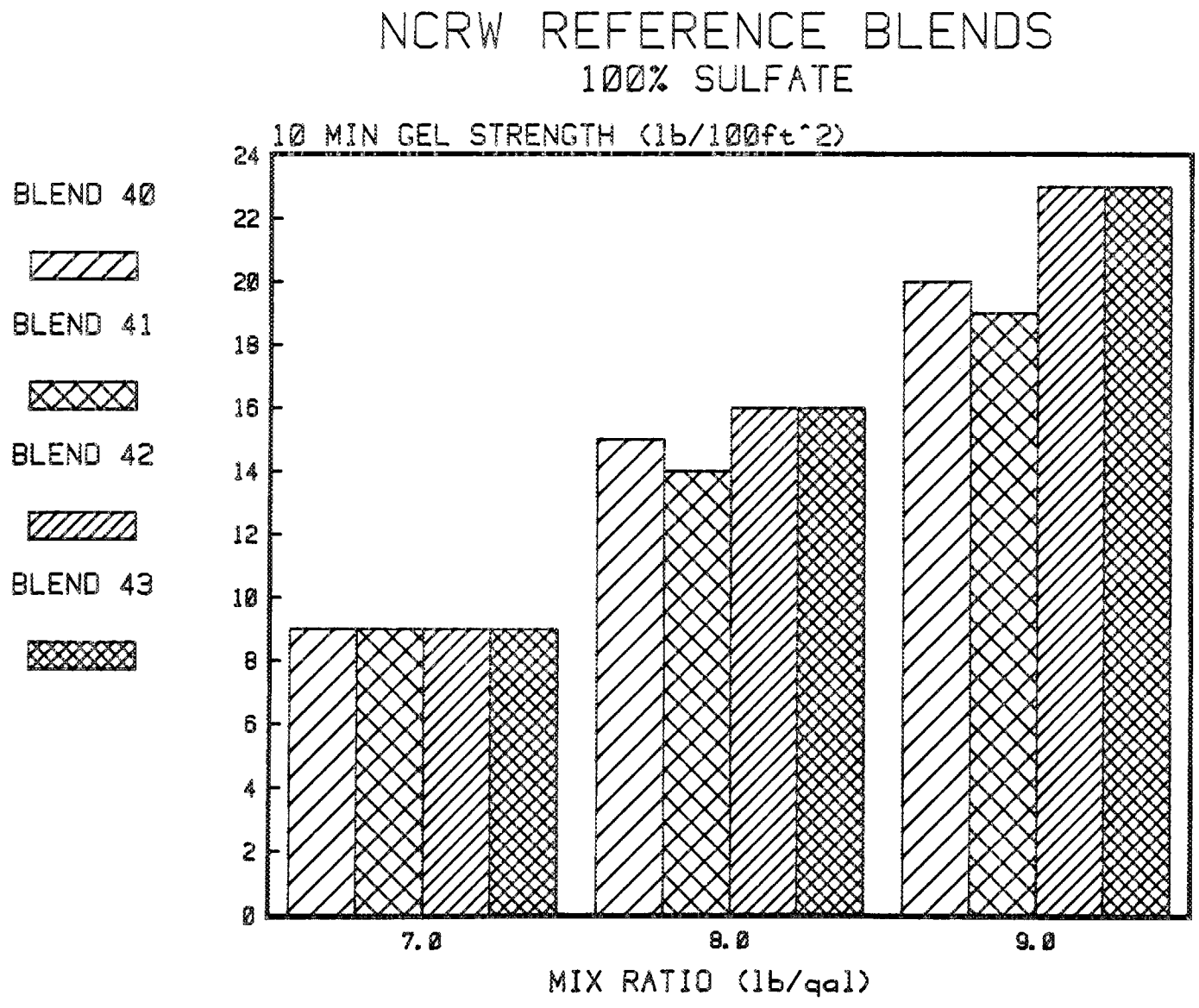

BLEND V2
100% SULFATE
CRITICAL FLOW RATE (gal/min)
40
35
30
25
20
15
10
5
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

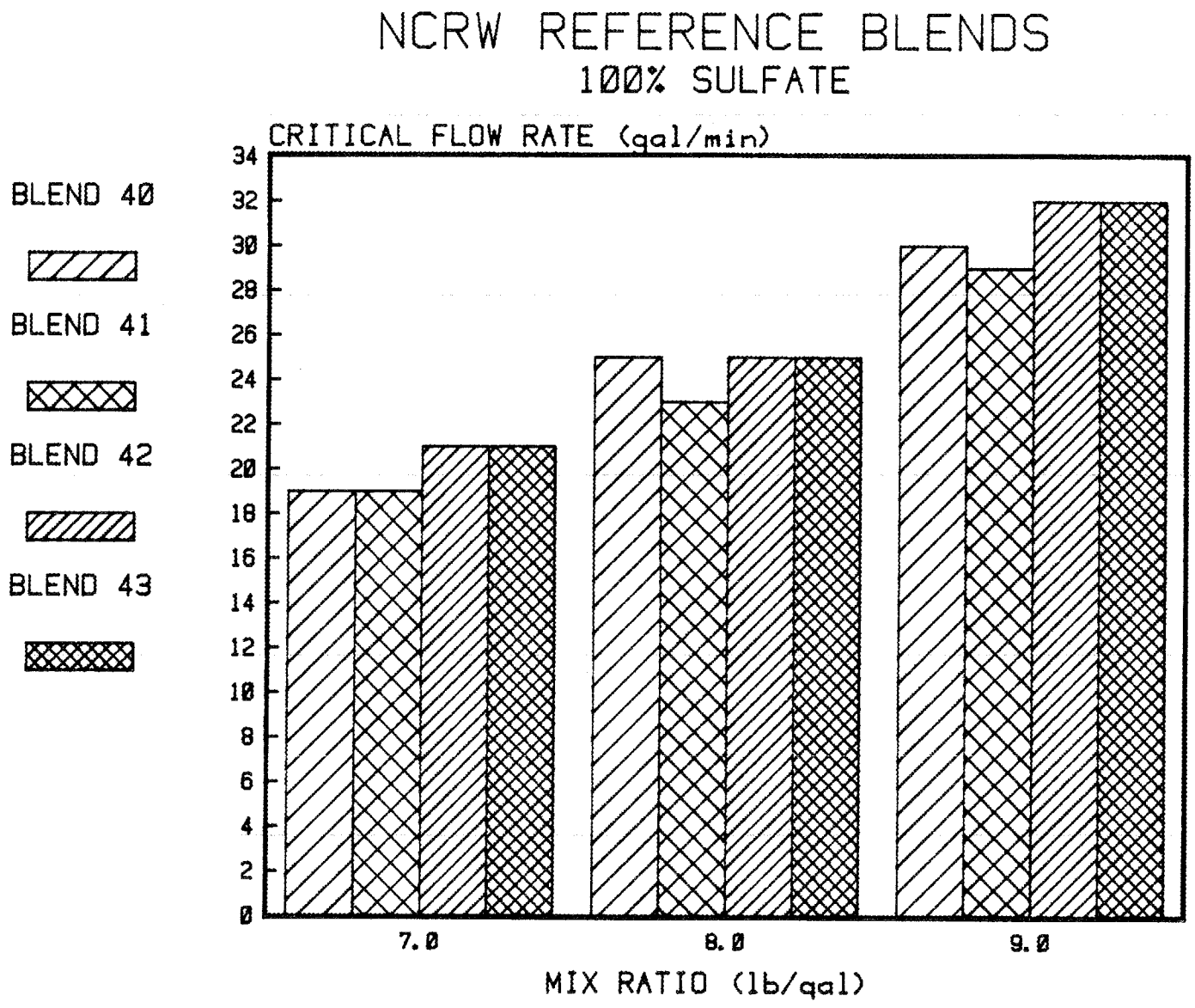

BLEND V2
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
7.0
7.5
8.0
8.5
MIX RATIO (lb/gal)

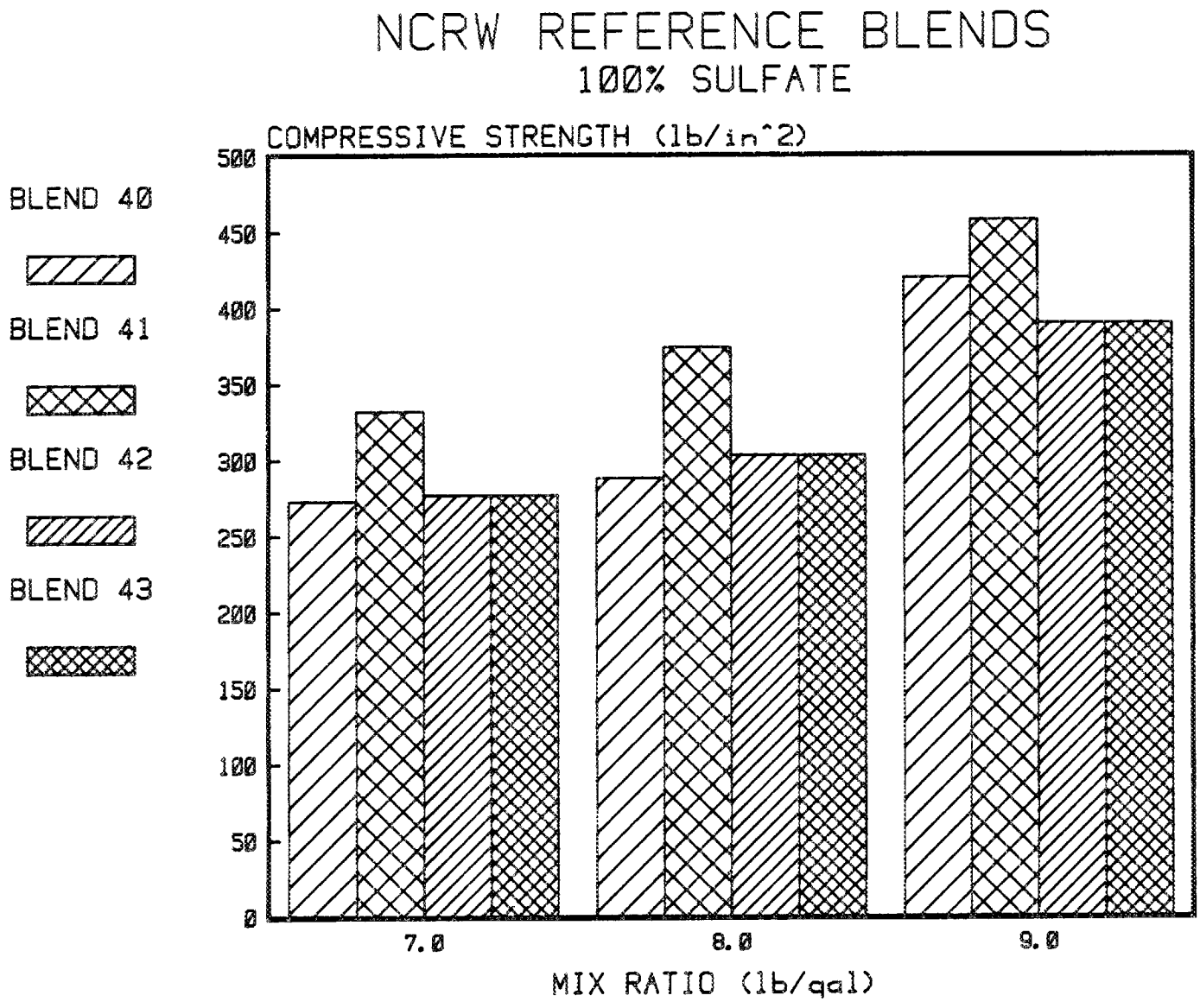
APPENDIX D

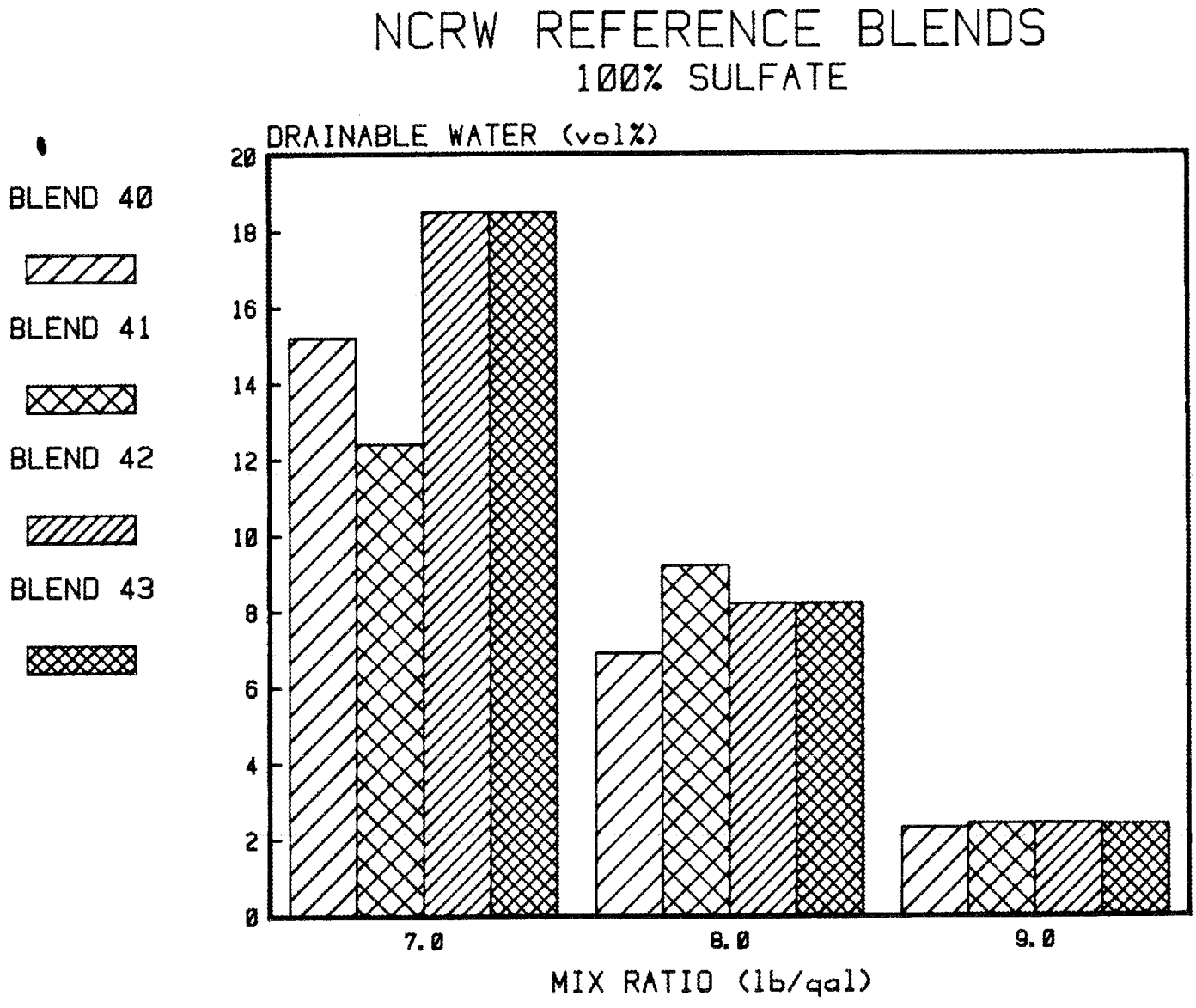
EFFECTS OF MIX RATIO ON GROUT PROPERTIES FOR NCRW REFERENCE BLEND

This appendix contains plots of various responses as a function of mix ratio for grouts prepared with variations of the NCRW reference blend. Only those grouts prepared at a mix ratio of 9 lb/gal passed performance criteria. Even at this mix ratio, the drainable water was consistently in the range of 2.5 vol %. These experiments were performed to determine the feasibility of utilizing the NCRW reference blend for disposal of 100% sulfate waste. As with the 50/50 sulfate/phosphate HFW reference blend, several modifications in the formula are needed in order to make acceptable grouts.


NCRW REFERENCE BLENDS
100% SULFATE
10 MIN GEL STRENGTH (lb/100ft^2)
BLEND 40
BLEND 41
BLEND 42
BLEND 43
24
22
20
18
16
14
12
10
8
6
4
2
0
7.0
8.0
9.0
MIX RATIO (lb/gal)


NCRW REFERENCE BLENDS
100% SULFATE
CRITICAL FLOW RATE (gal/min)
BLEND 40
BLEND 41
BLEND 42
BLEND 43
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7.0
8.0
9.0
MIX RATIO (lb/gal)

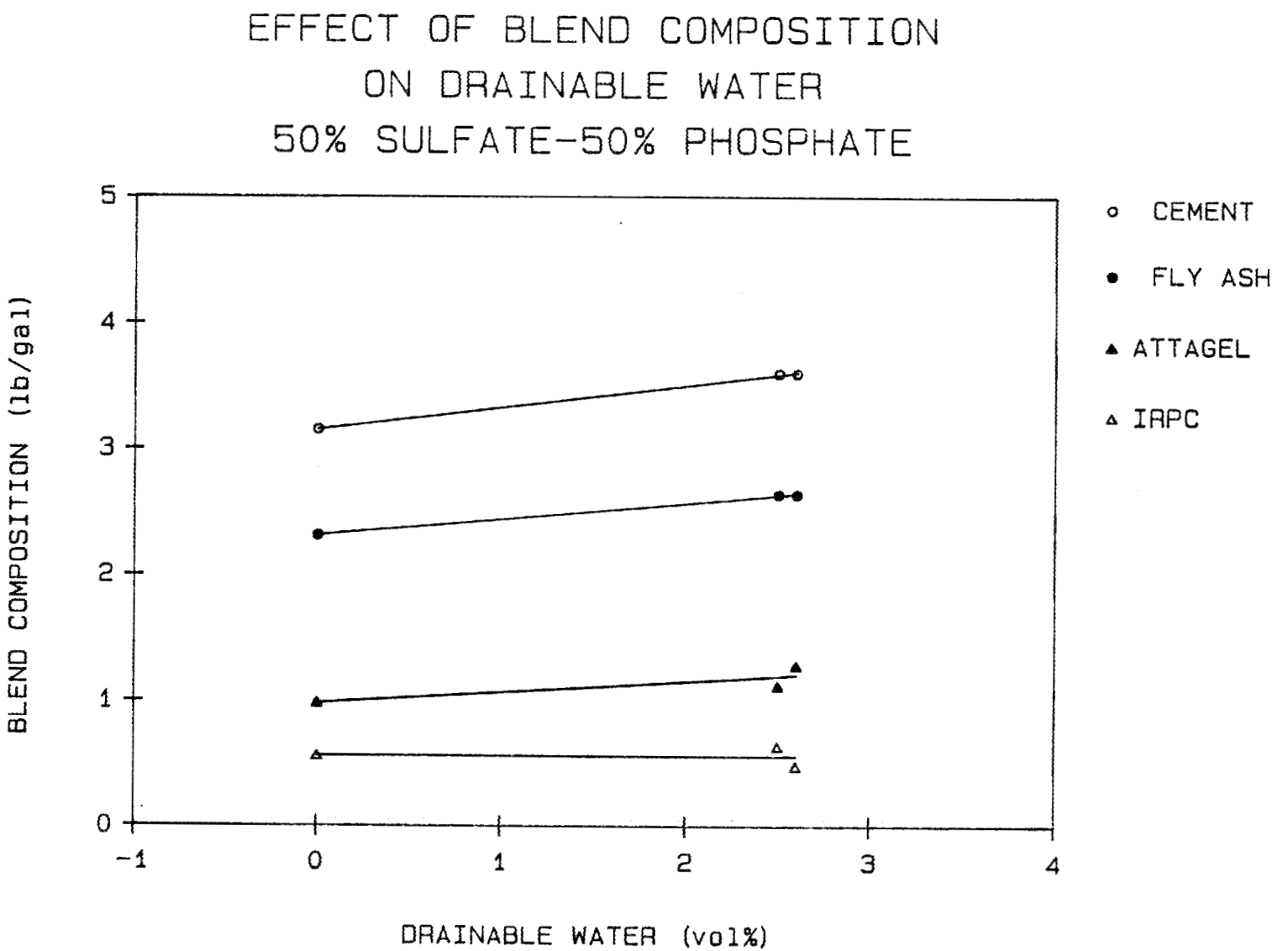

NCRW REFERENCE BLENDS
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
500
450
400
350
300
250
200
150
100
50
0
BLEND 40
BLEND 41
BLEND 42
BLEND 43
7.0
8.0
9.0
MIX RATIO (lb/gal)

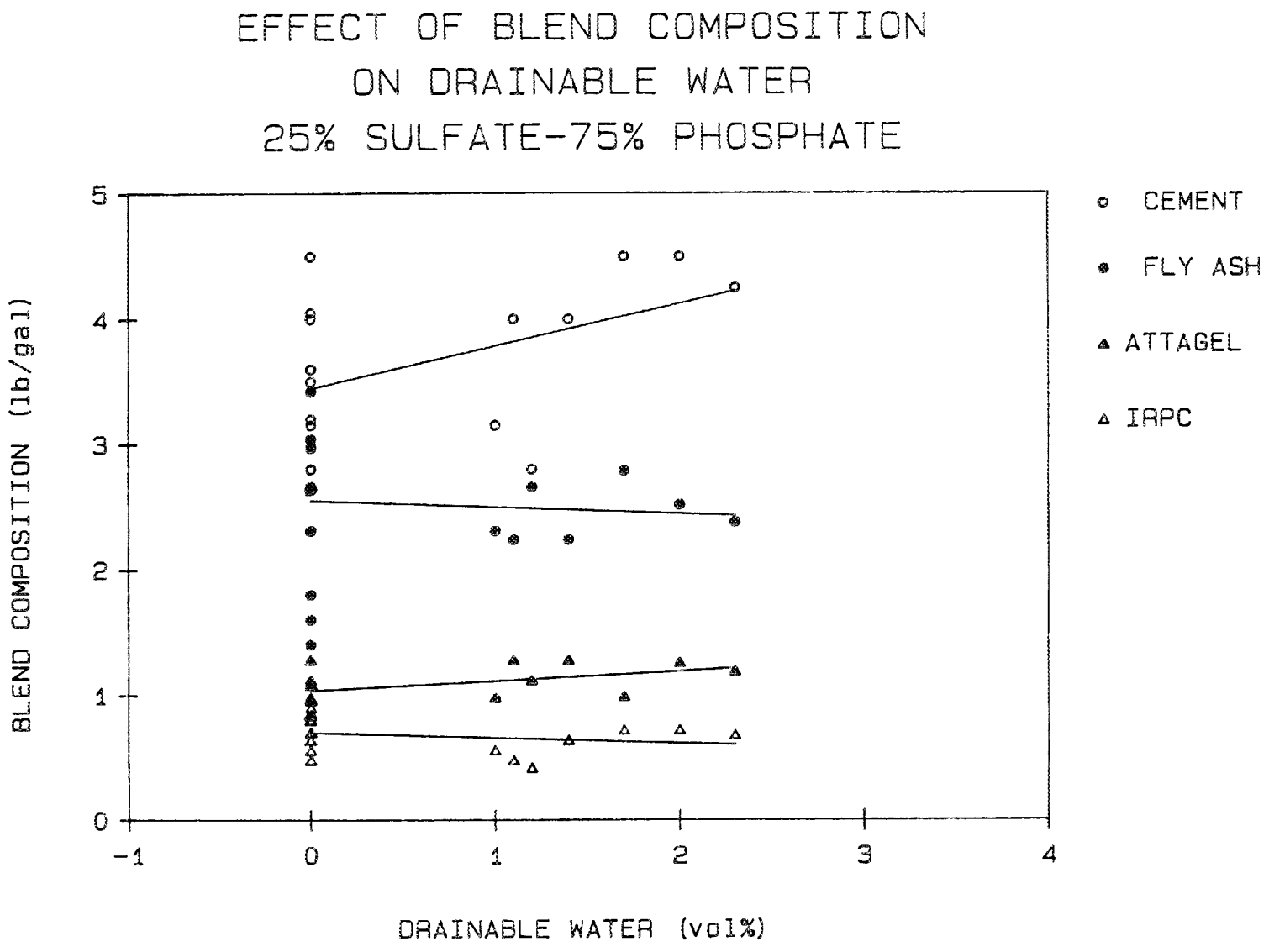

NCRW REFERENCE BLENDS
100% SULFATE
DRAINABLE WATER (vol%)
20
18
16
14
12
10
8
6
4
2
0
BLEND 40
BLEND 41
BLEND 42
BLEND 43
7.0
8.0
9.0
MIX RATIO (lb/gal)

APPENDIX E

EFFECT OF BLEND COMPOSITION ON GROUT PROPERTIES FOR 50/50 AND 25/75 SULFATE/PHOSPHATE WASTE

This appendix contains plots of the effects of blend composition on various responses. Only acceptable grouts for 50/50 and 25/75 sulfate/phosphate waste concentrations are presented.

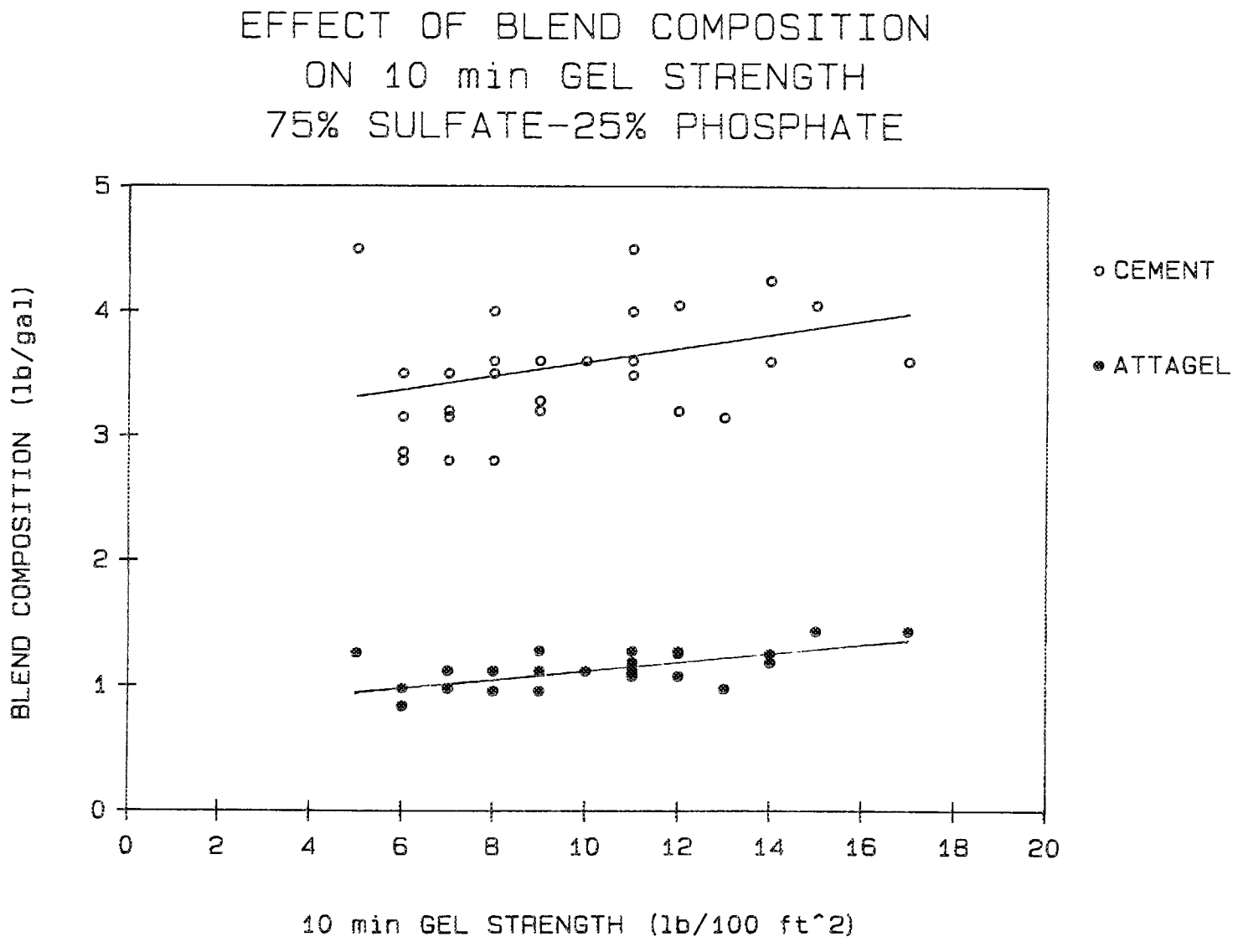

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
50% SULFATE-50% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
-1
0
1
2
3
4
CEMENT
FLY ASH
ATTAGEL
IRPC

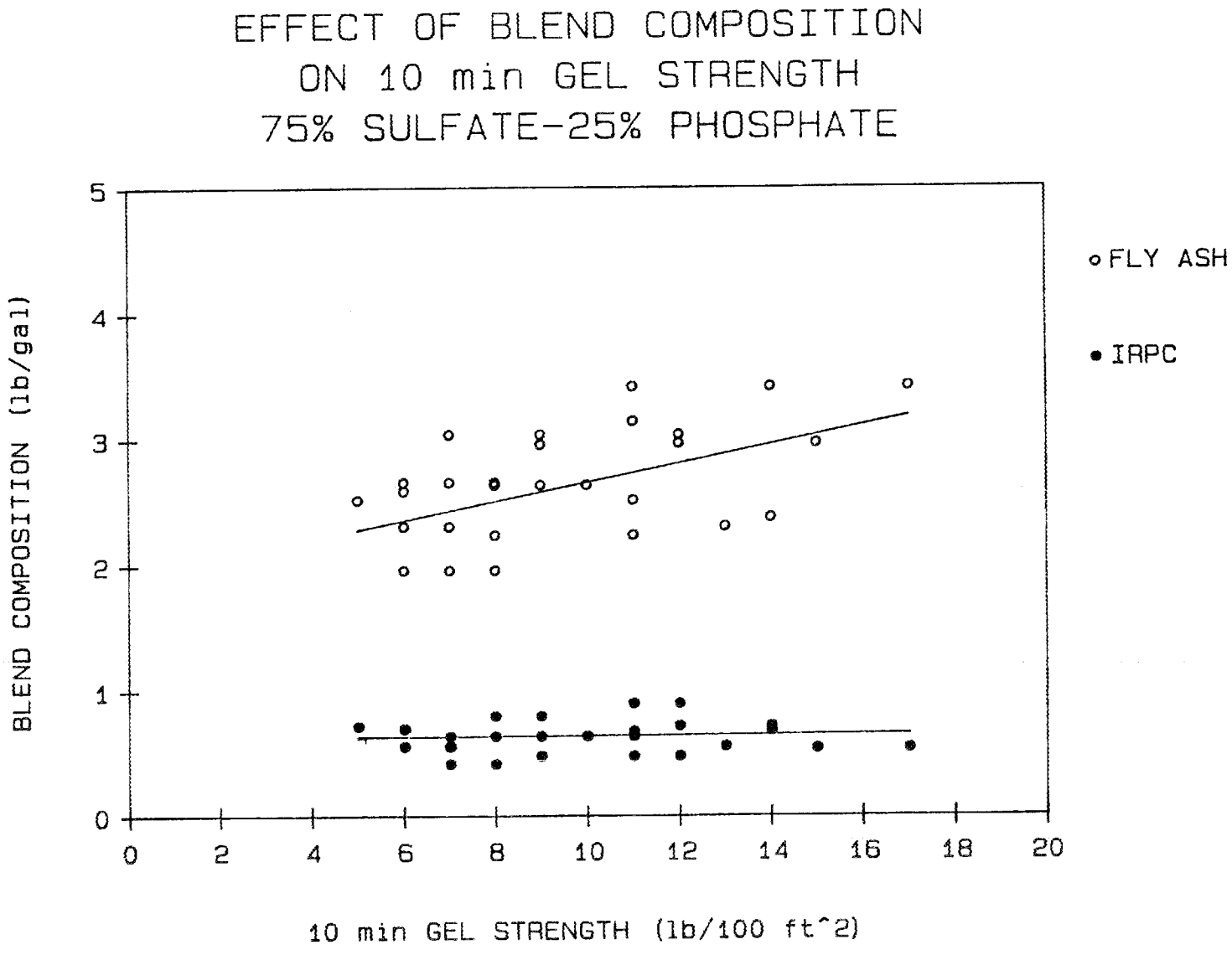

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
25% SULFATE-75% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
CEMENT
FLY ASH
ATTAGEL
IRPC
5
4
3
2
1
0
-1
0
1
2
3
4

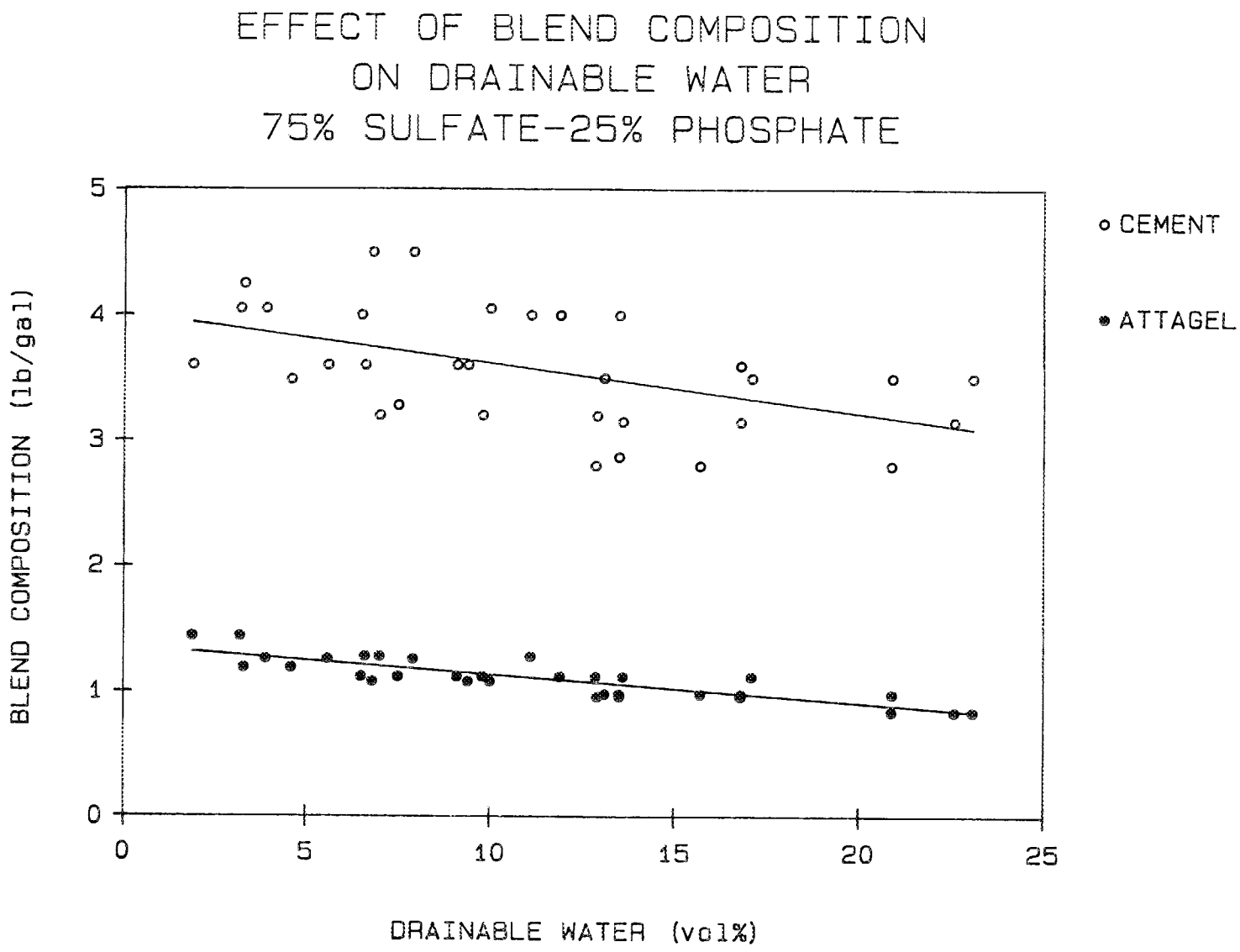
APPENDIX F

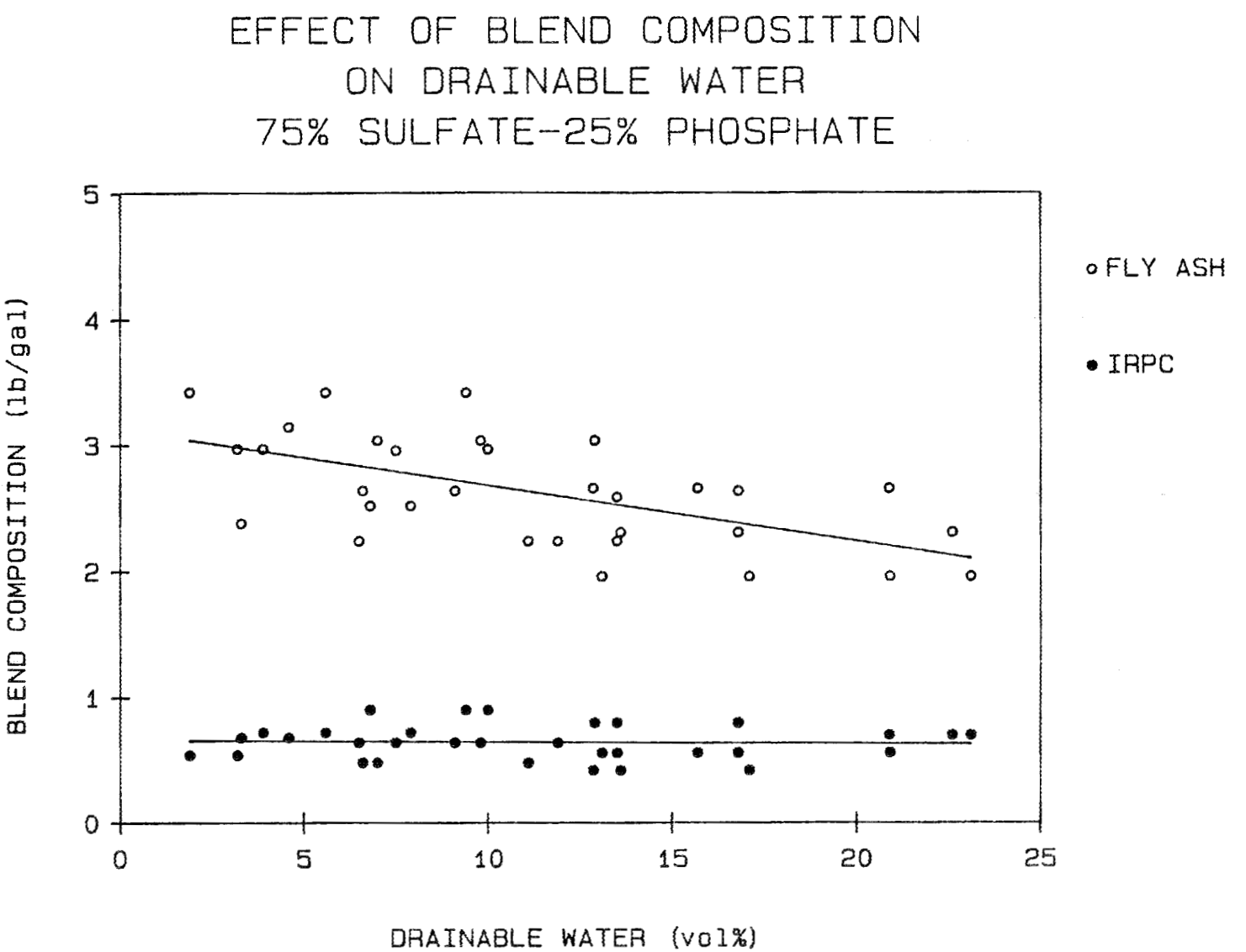
EFFECT OF BLEND COMPOSITION ON GROUT PROPERTIES FOR 100 AND 75/25 SULFATE/PHOSPHATE WASTE

This appendix contains plots of the effects of blend composition on various responses for grouts produced using 100% sulfate and 75/25 sulfate/phosphate HFW. Only unacceptable grouts are presented because acceptable grouts were discussed in the main body of this report. However, it should be noted that the same general trends are evident as discussed in the main report body.


EFFECT OF BLEND COMPOSITION
ON 10 min GEL STRENGTH
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
10 min GEL STRENGTH (lb/100 ft^2)
CEMENT
ATTAGEL
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
20


EFFECT OF BLEND COMPOSITION
ON 10 min GEL STRENGTH
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
10 min GEL STRENGTH (lb/100 ft^2)
FLY ASH
IRPC
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
20


EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
0
5
10
15
20
25
CEMENT
ATTAGEL

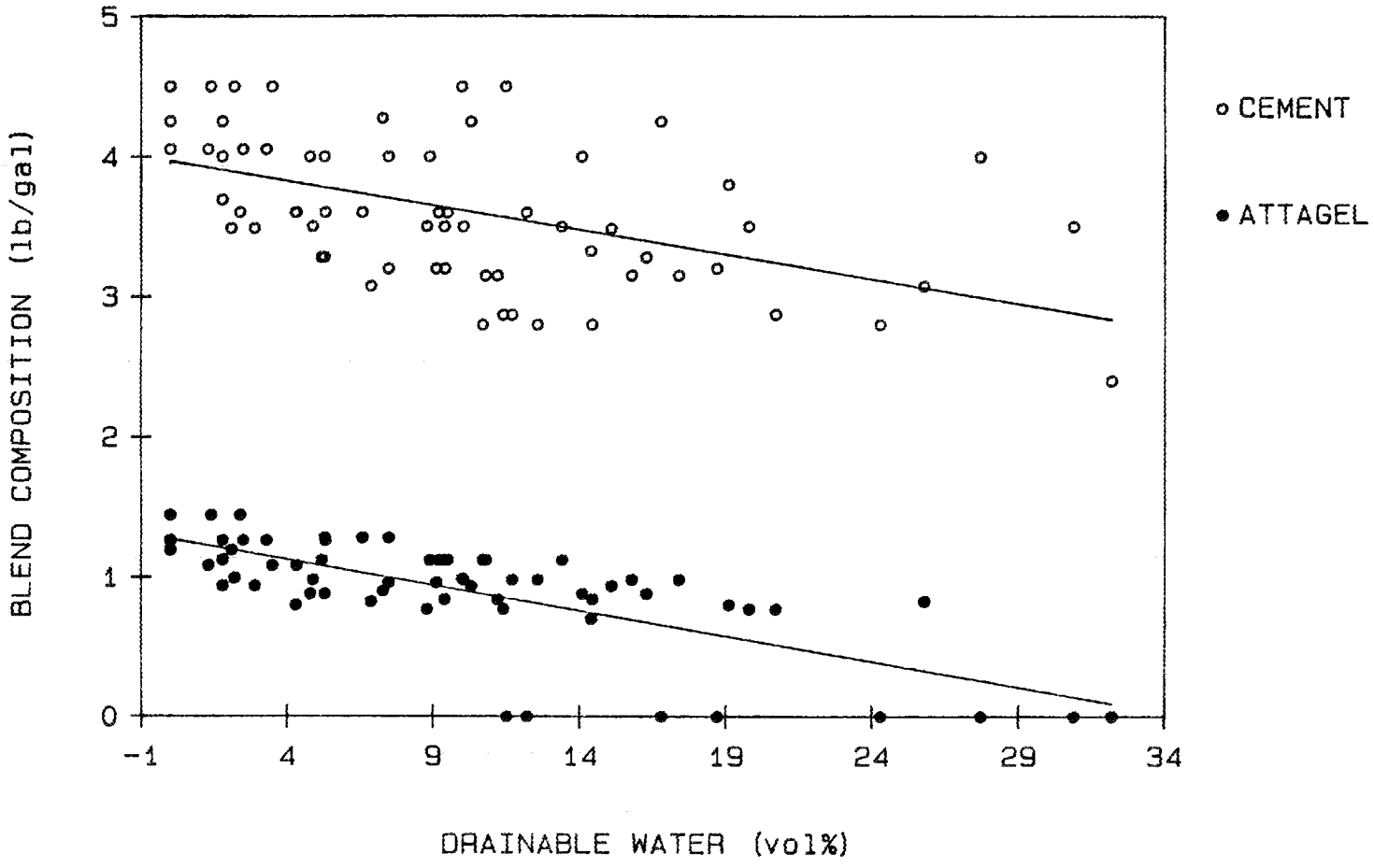

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
0
5
10
15
20
25
FLY ASH
IRPC

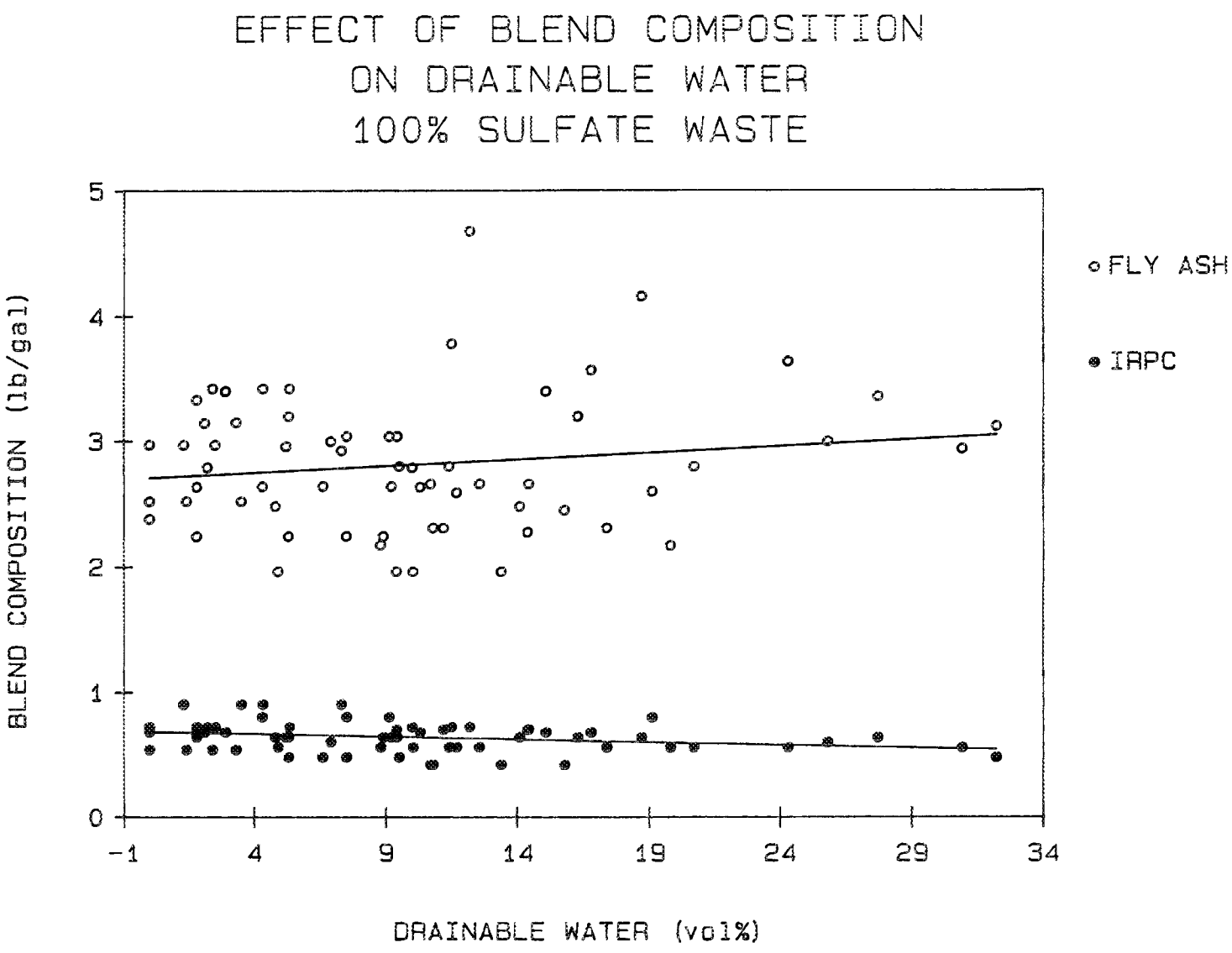
APPENDIX G

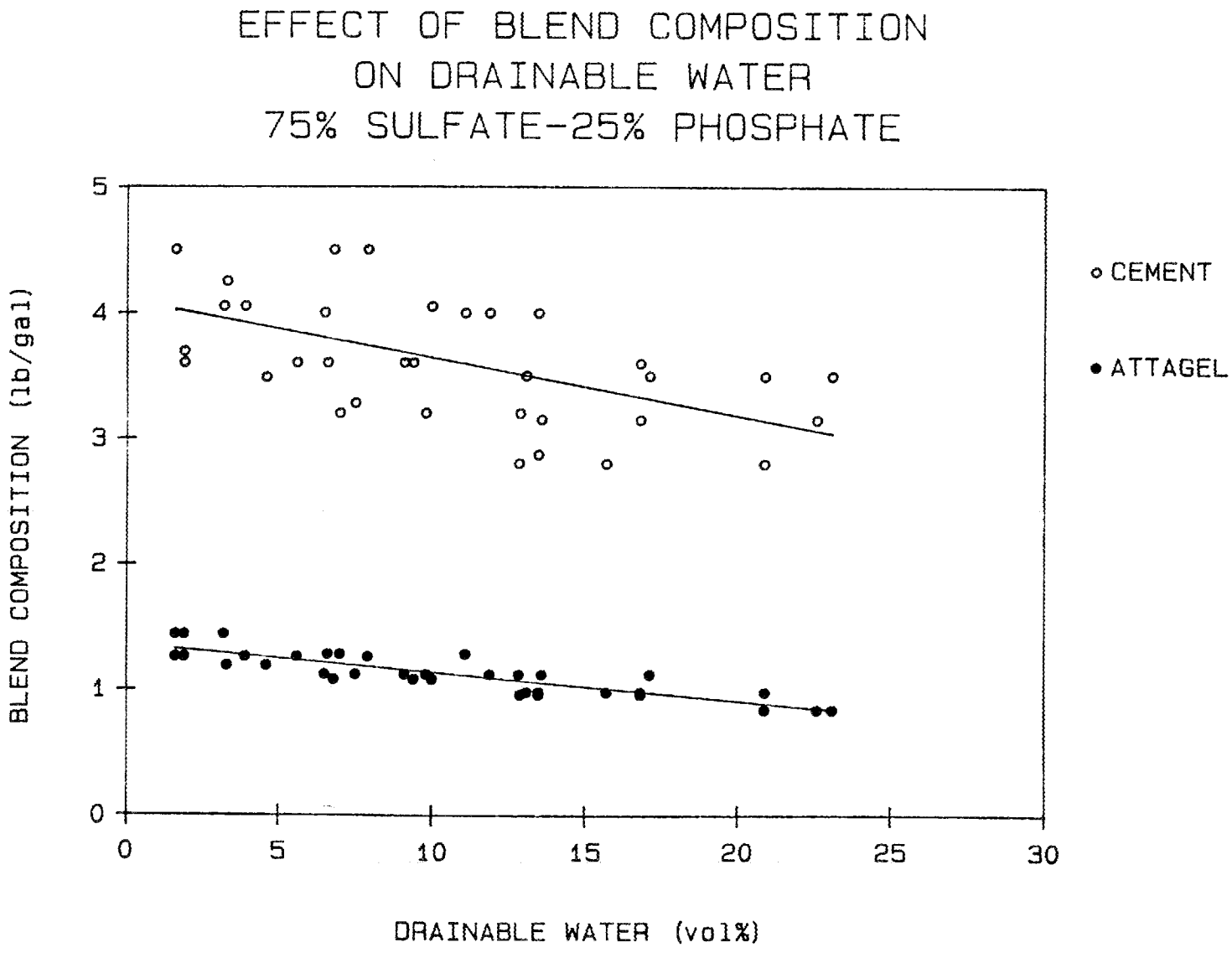
EFFECTS OF BLEND COMPOSITION ON DRAINABLE WATER

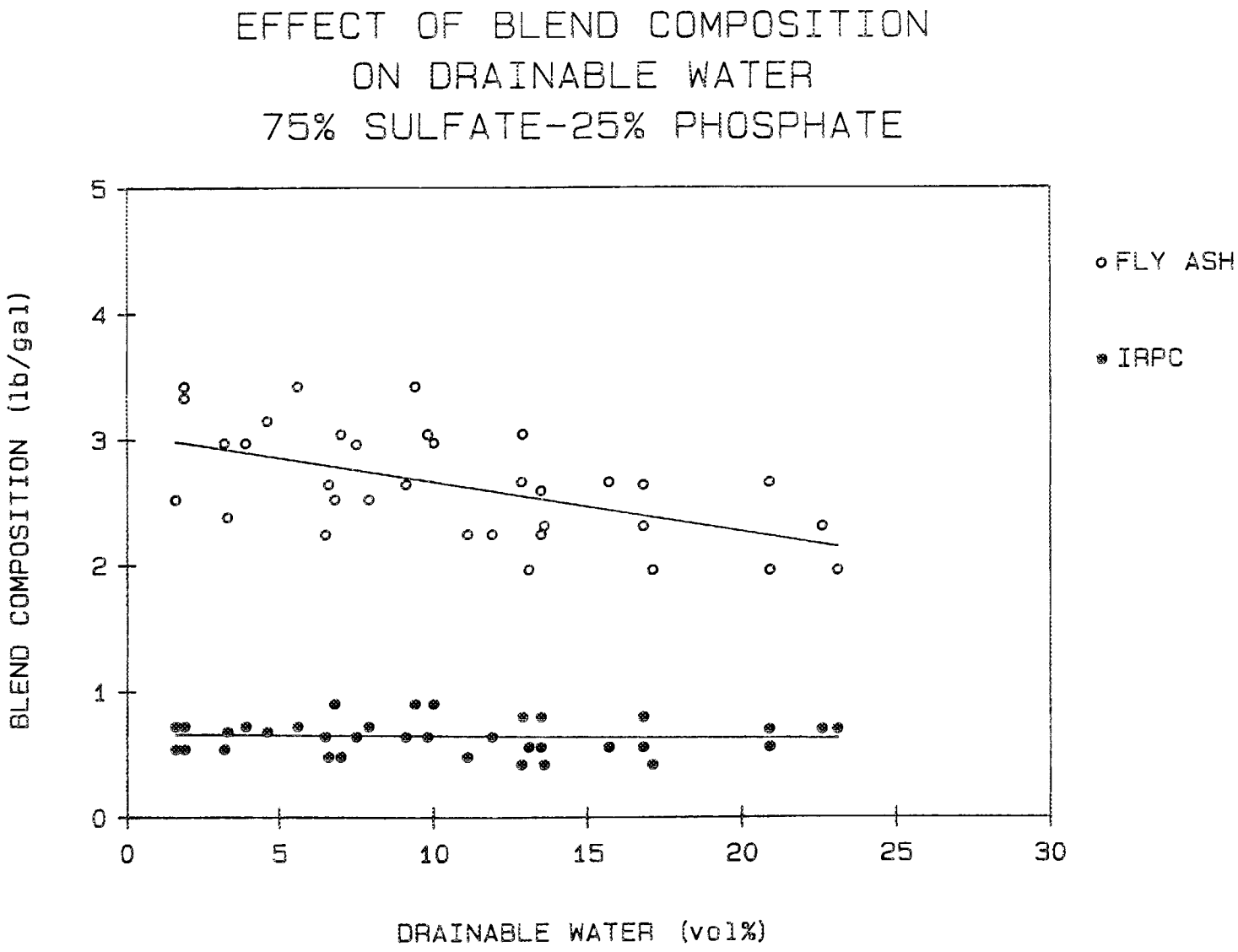
This appendix contains plots of the effects of blend composition on drainable water. The plots represent all grouts prepared using each of the four waste concentrations studied. Since the most difficult criteria was the drainable water, it is important to study the effect of each blend component on the amount of drainable water. The drainable water response is difficult to handle because some of the components have various effects at different waste concentrations. These effects are currently under investigation and will be included in a later report.

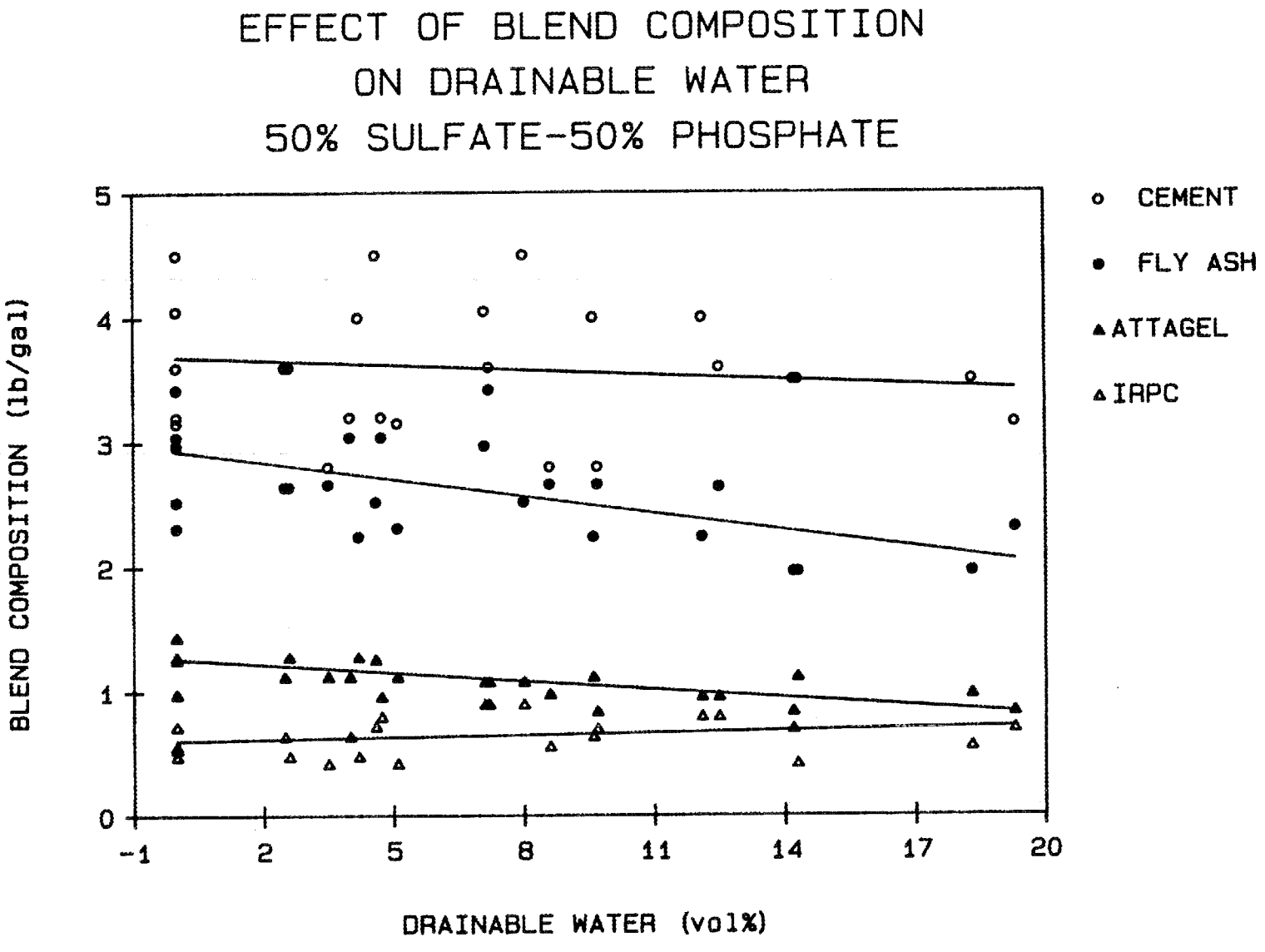
EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
100% SULFATE WASTE



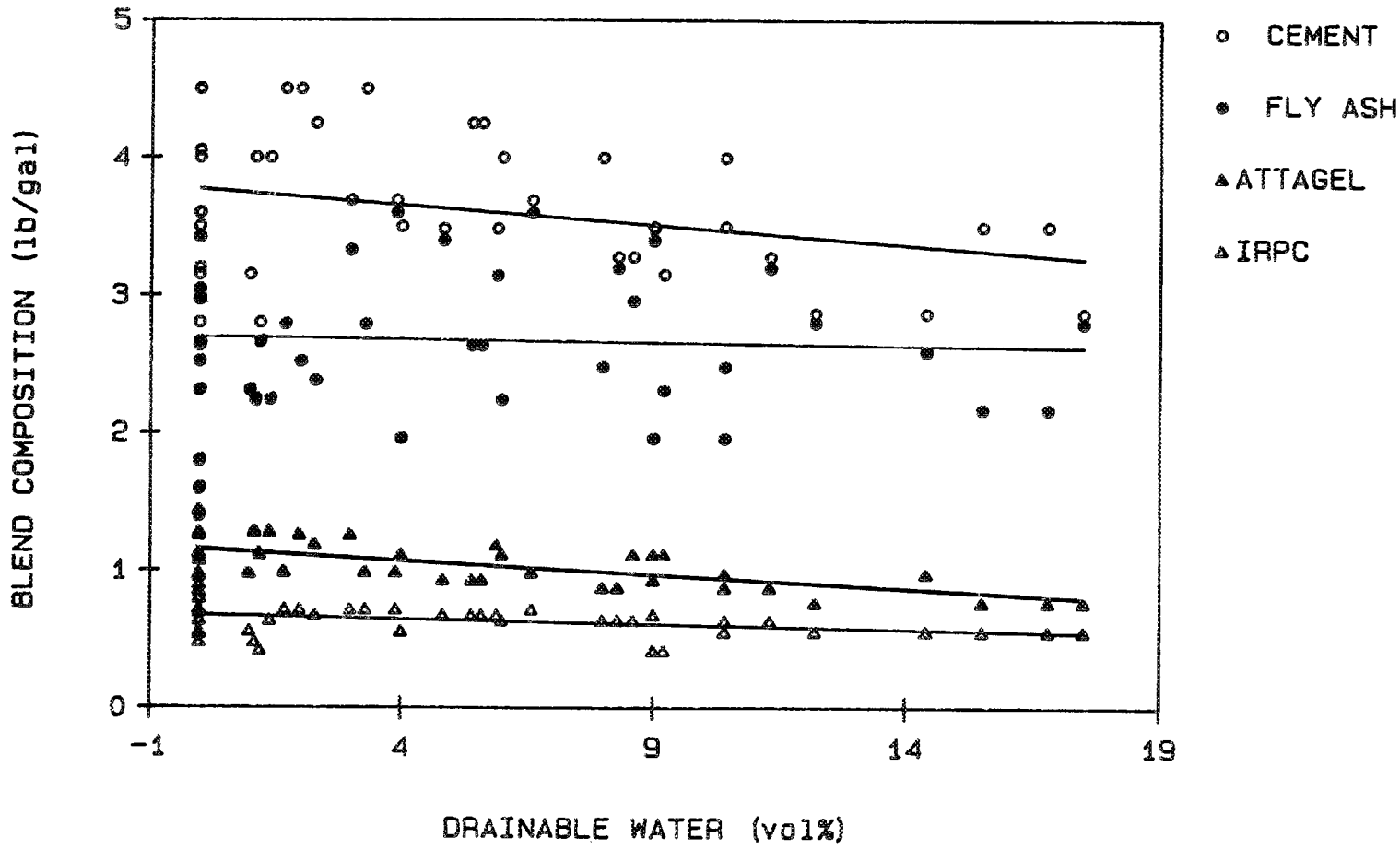

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
FLY ASH
IRPC
0
1
2
3
4
5
-1
4
9
14
19
24
29
34

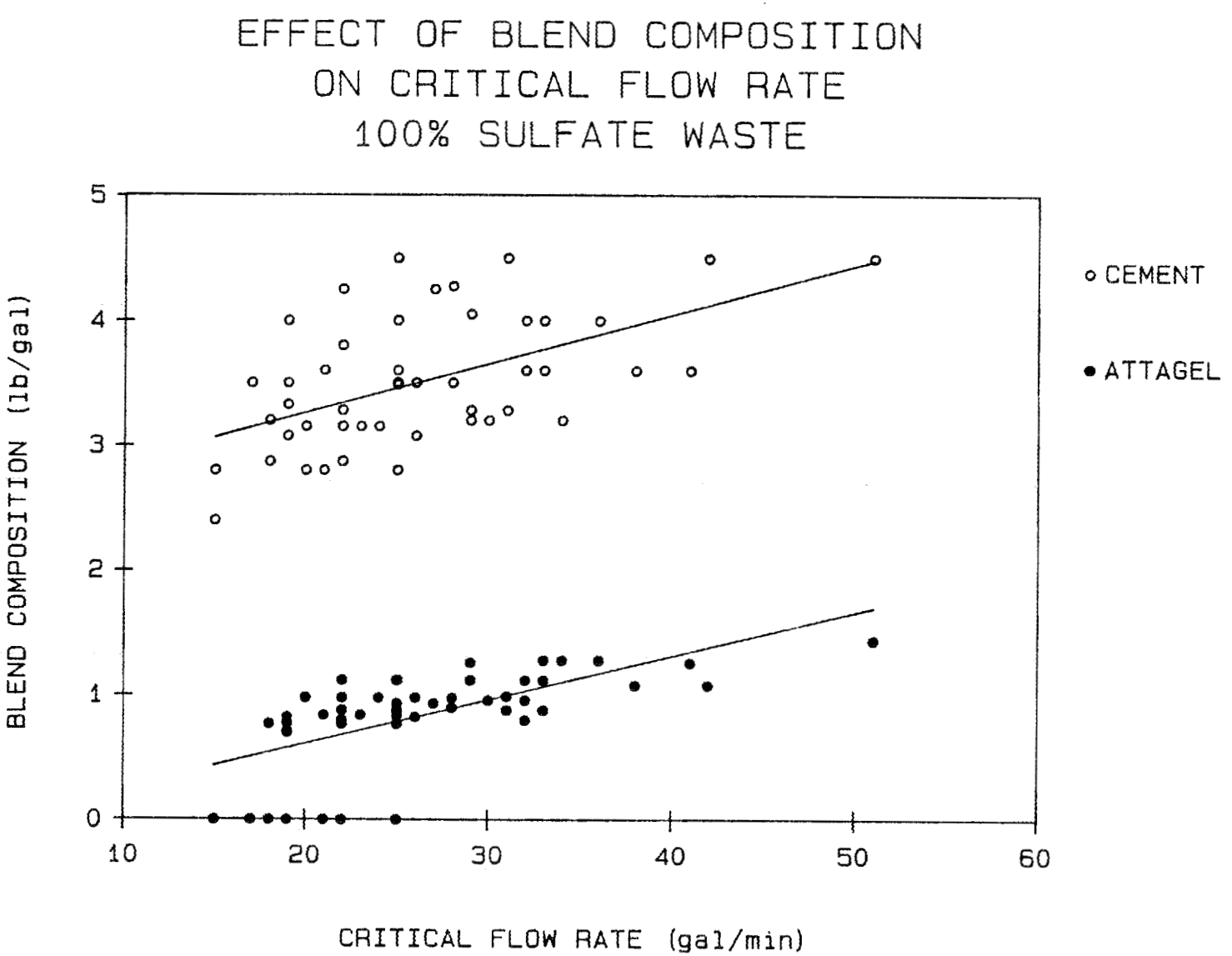

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
0
5
10
15
20
25
30
CEMENT
ATTAGEL


EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
FLY ASH
IRPC
0
1
2
3
4
5
0
5
10
15
20
25
30

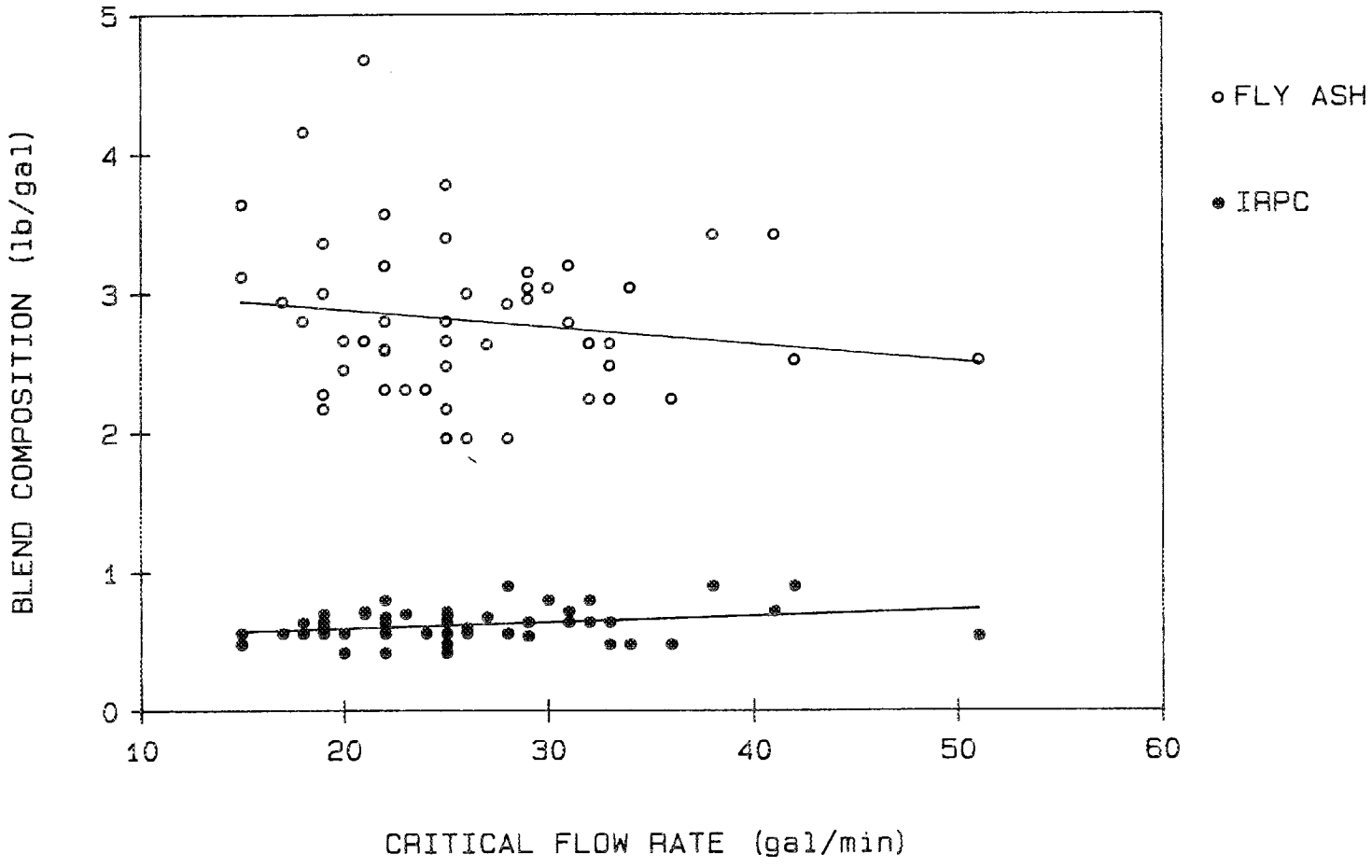

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
50% SULFATE-50% PHOSPHATE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
-1
2
5
8
11
14
17
20
CEMENT
FLY ASH
ATTAGEL
IRPC

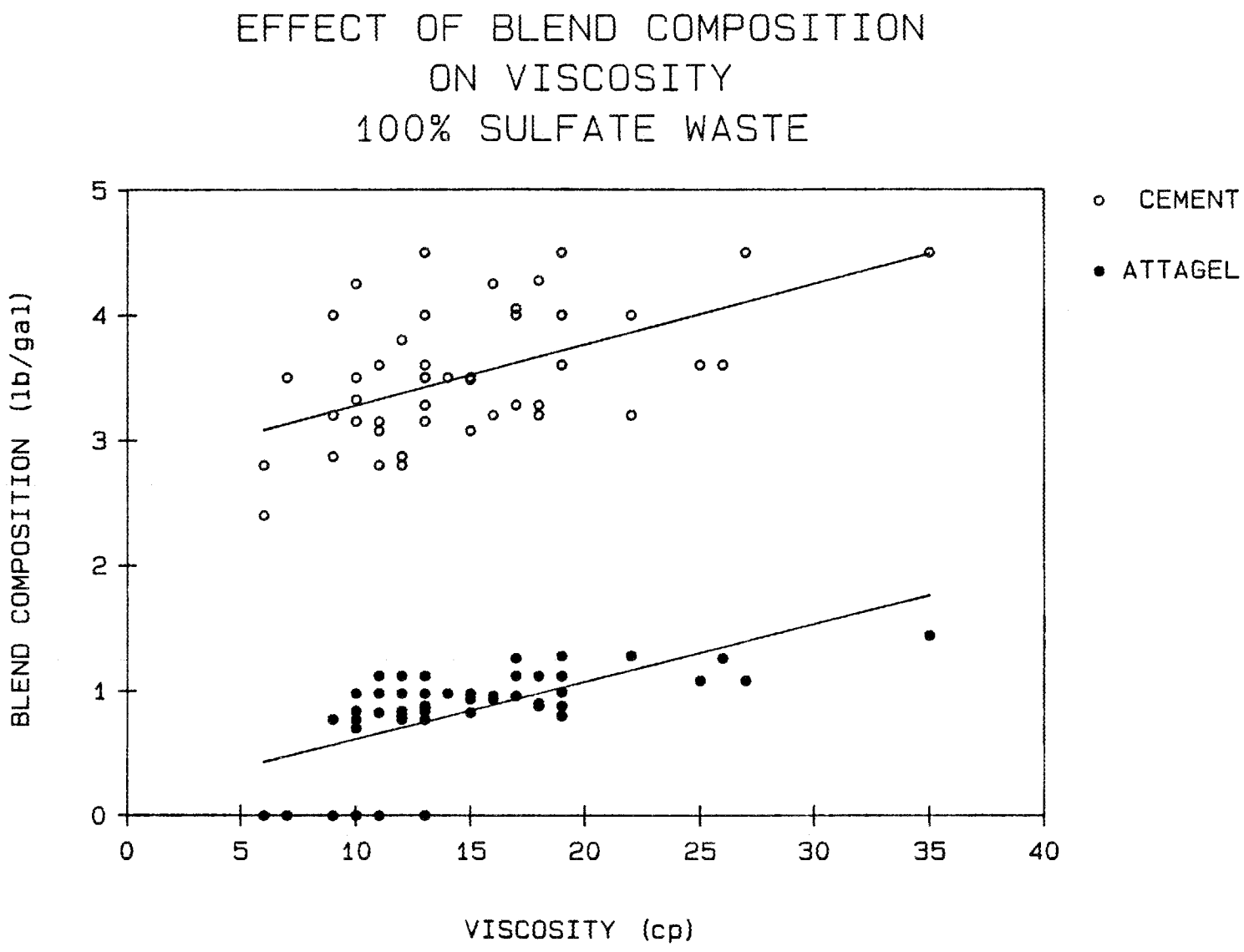
EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
25% SULFATE-75% PHOSPHATE



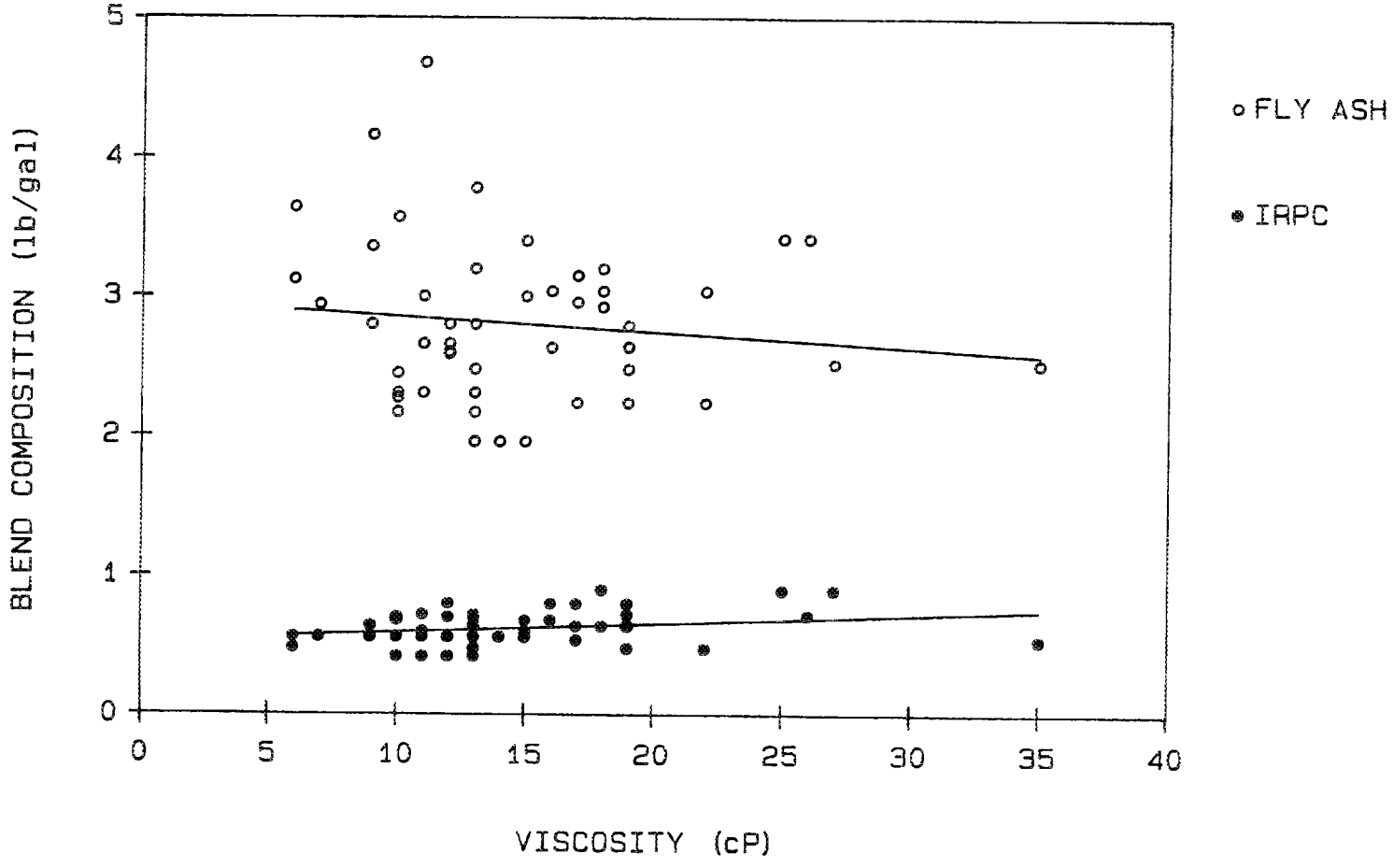

EFFECT OF BLEND COMPOSITION
ON CRITICAL FLOW RATE
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
0
1
2
3
4
5
10
20
30
40
50
60
CRITICAL FLOW RATE (gal/min)
CEMENT
ATTAGEL

EFFECT OF BLEND COMPOSITION
ON CRITICAL FLOW RATE
100% SULFATE WASTE

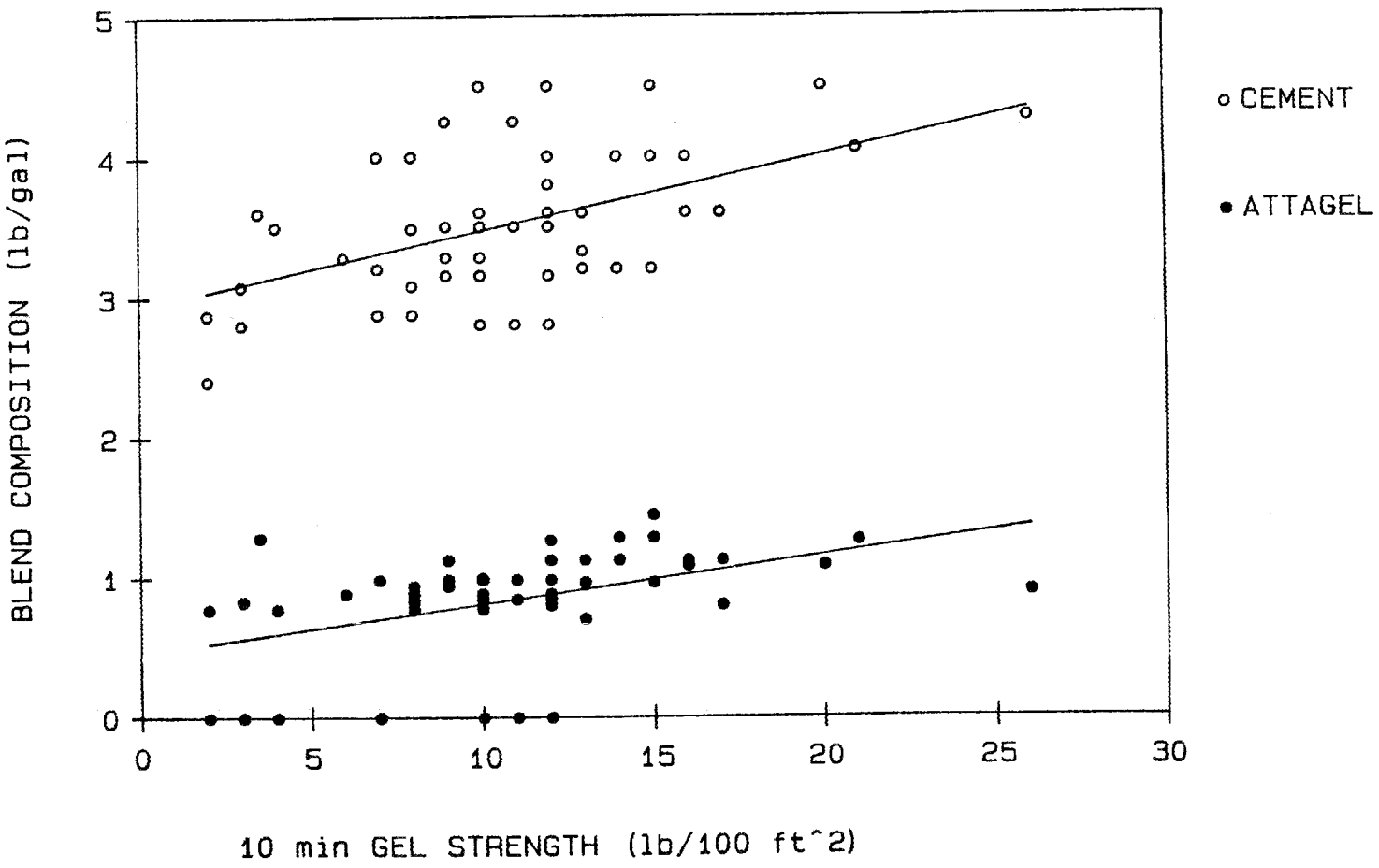


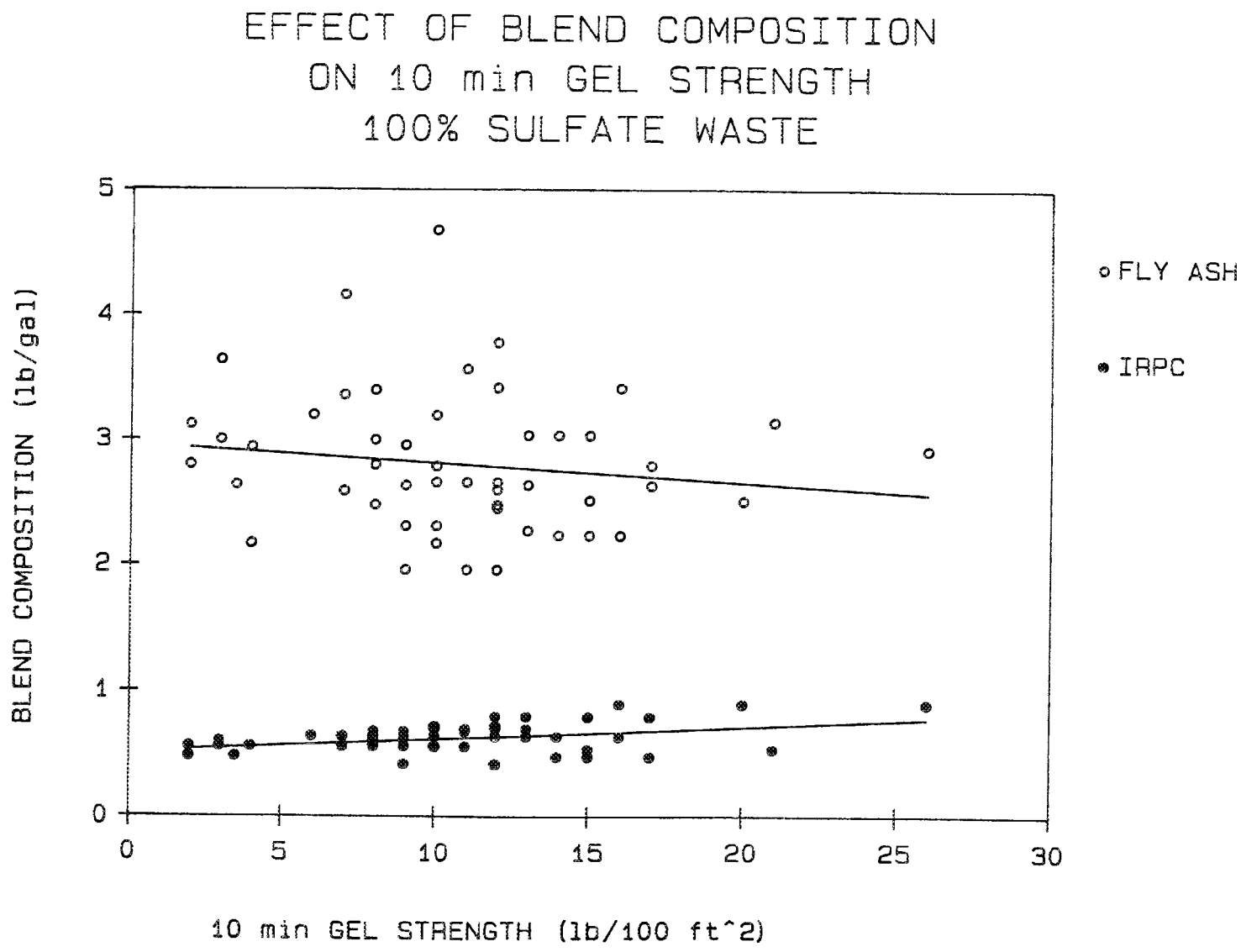

EFFECT OF BLEND COMPOSITION
ON VISCOSITY
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
VISCOSITY (cp)
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40
CEMENT
ATTAGEL

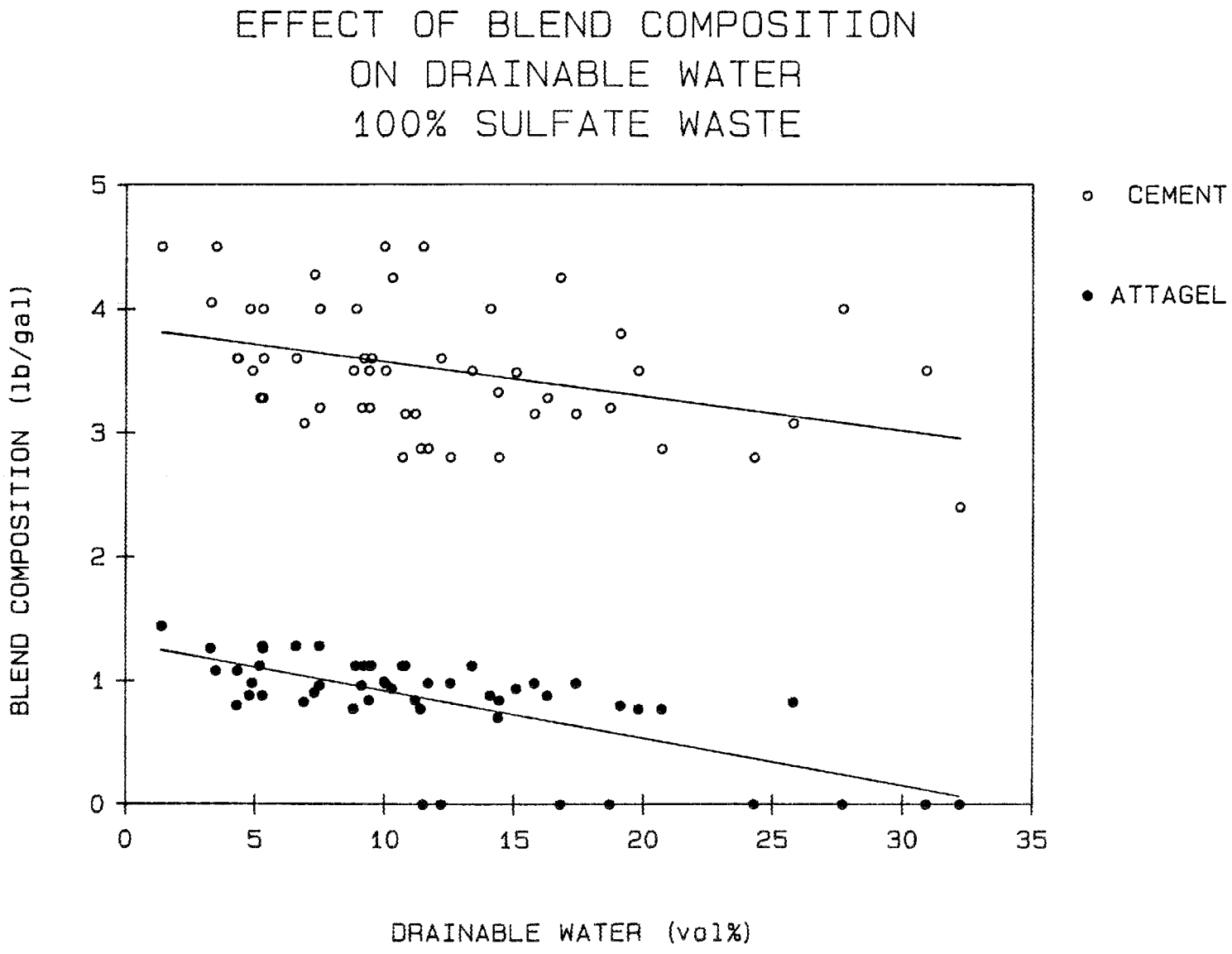
EFFECT OF BLEND COMPOSITION
ON VISCOSITY
100% SULFATE WASTE

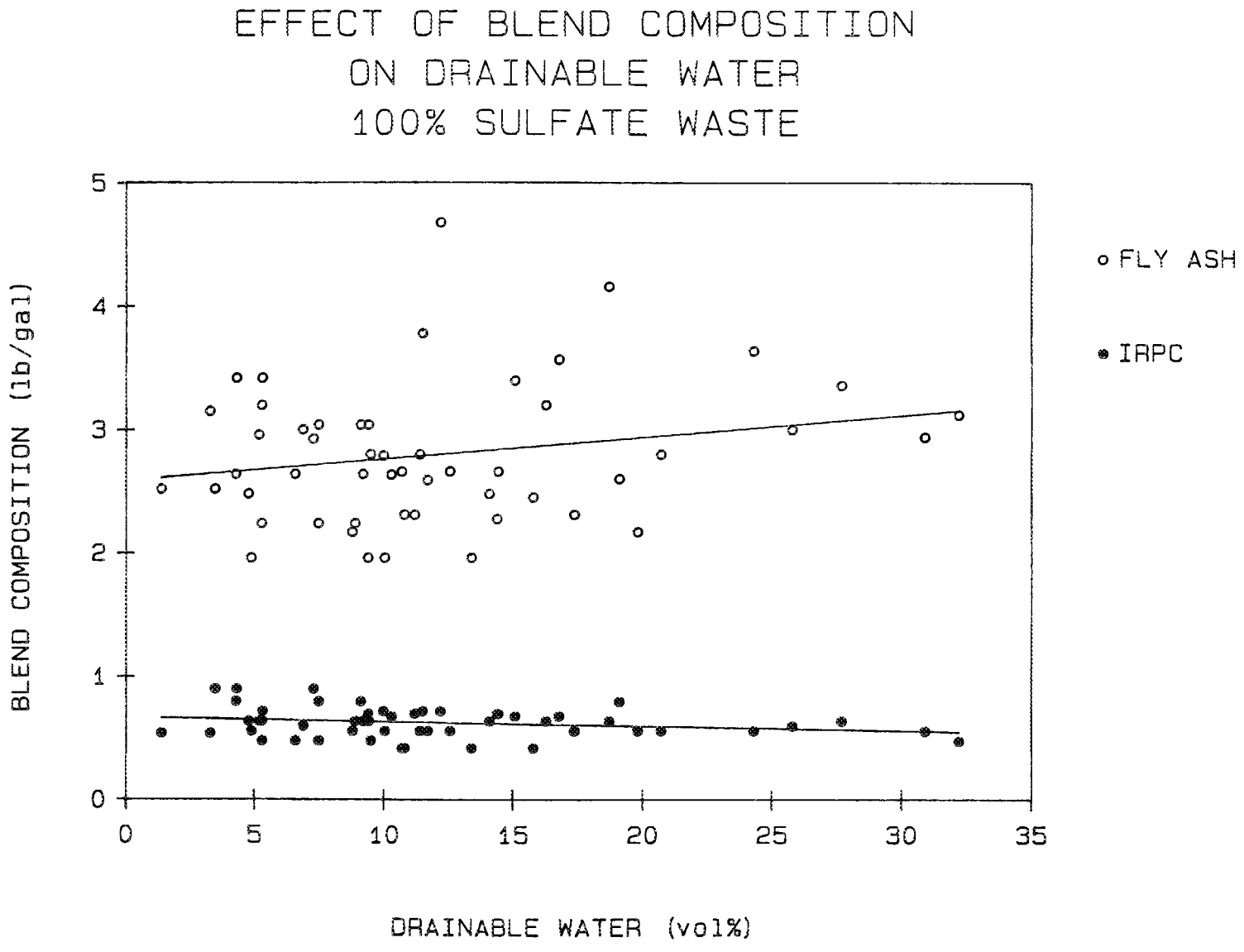


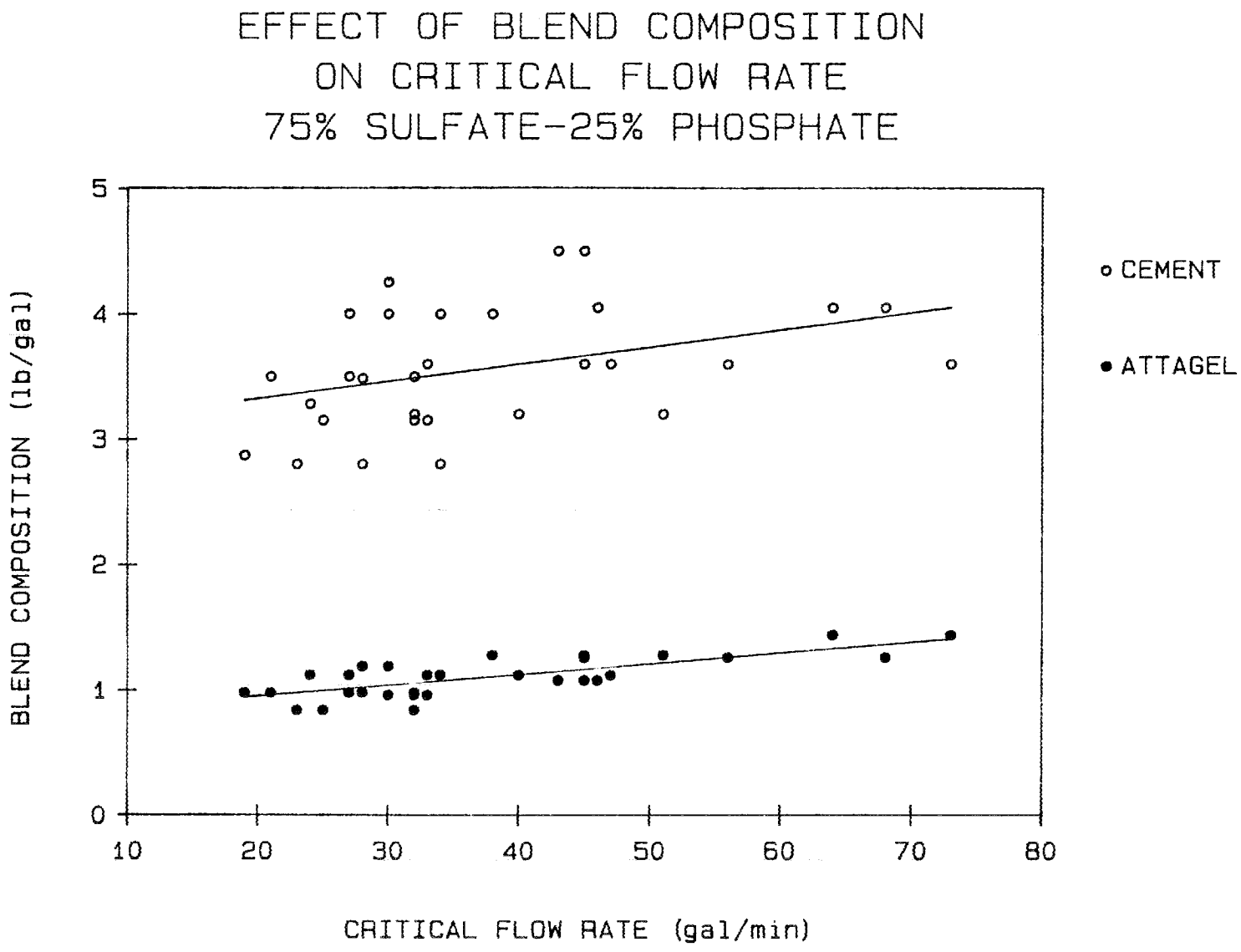
EFFECT OF BLEND COMPOSITION
ON 10 min GEL STRENGTH
100% SULFATE WASTE

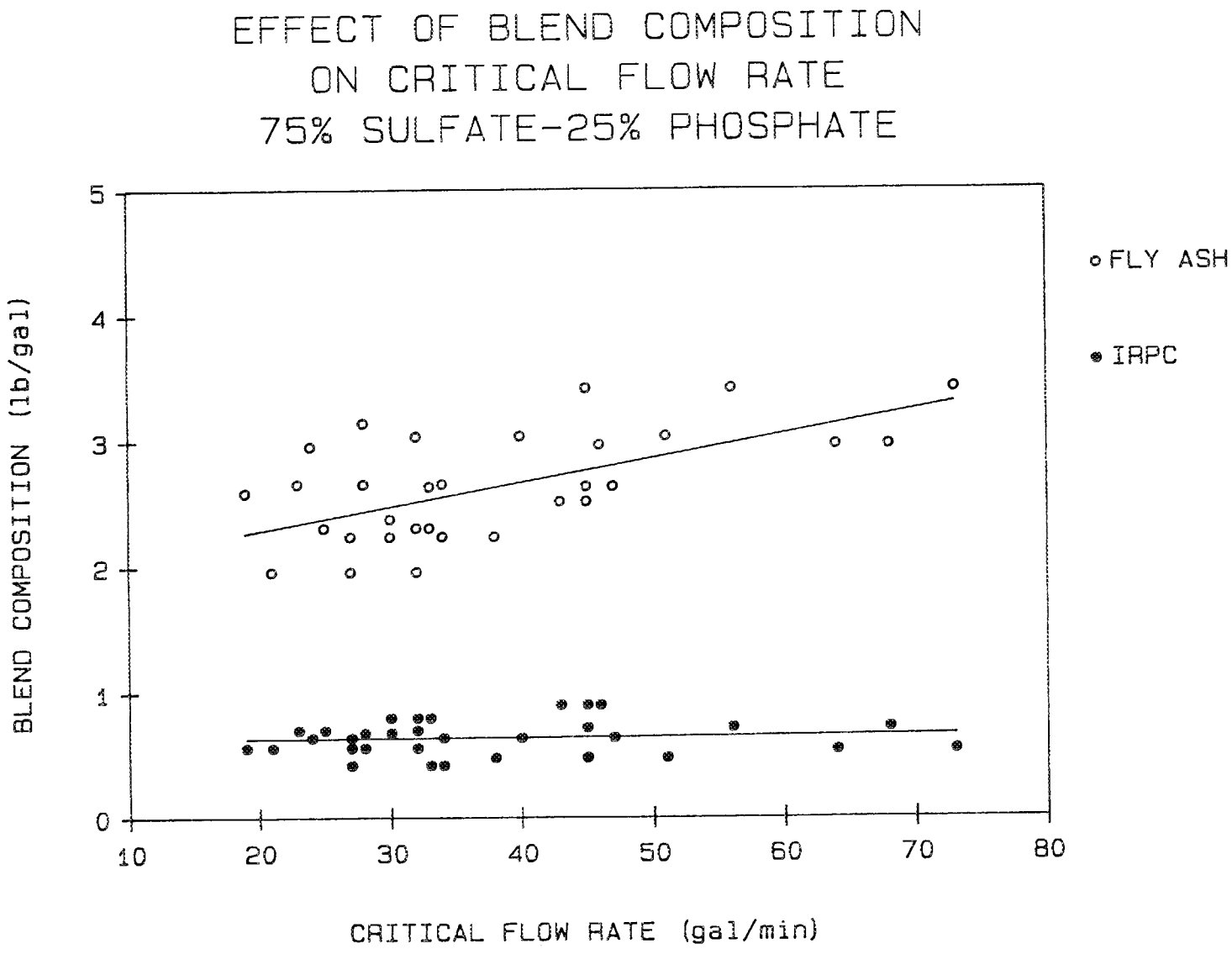


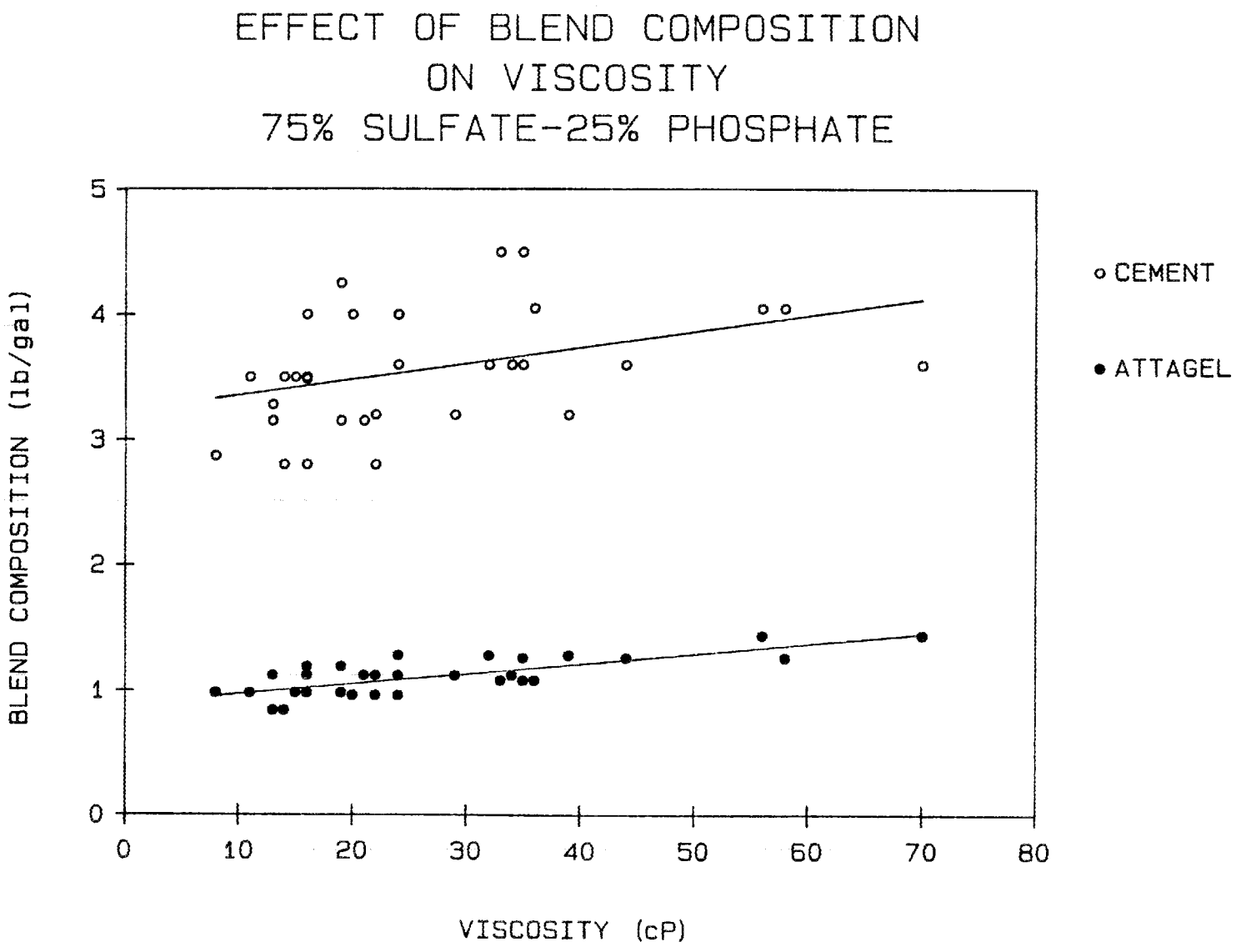

EFFECT OF BLEND COMPOSITION
ON 10 min GEL STRENGTH
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
10 min GEL STRENGTH (lb/100 ft^2)
0
1
2
3
4
5
0
5
10
15
20
25
30
FLY ASH
IRPC

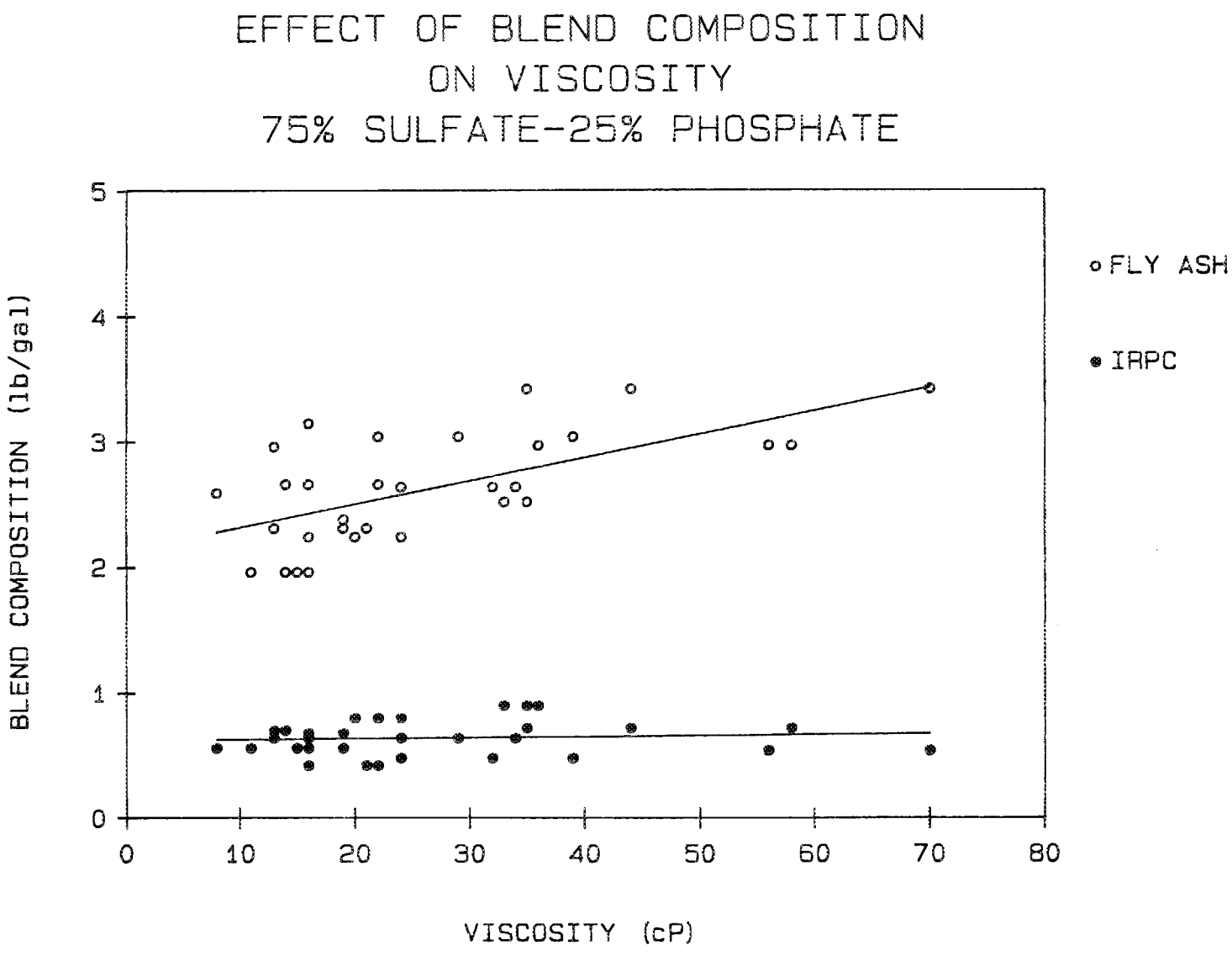

EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
CEMENT
ATTAGEL
0
1
2
3
4
5
0
5
10
15
20
25
30
35


EFFECT OF BLEND COMPOSITION
ON DRAINABLE WATER
100% SULFATE WASTE
BLEND COMPOSITION (lb/gal)
DRAINABLE WATER (vol%)
0
1
2
3
4
5
0
5
10
15
20
25
30
35
FLY ASH
IRPC


EFFECT OF BLEND COMPOSITION
ON CRITICAL FLOW RATE
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
0
1
2
3
4
5
10
20
30
40
50
60
70
80
CRITICAL FLOW RATE (gal/min)
CEMENT
ATTAGEL


EFFECT OF BLEND COMPOSITION
ON CRITICAL FLOW RATE
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
0
1
2
3
4
5
10
20
30
40
50
60
70
80
CRITICAL FLOW RATE (gal/min)
FLY ASH
IRPC

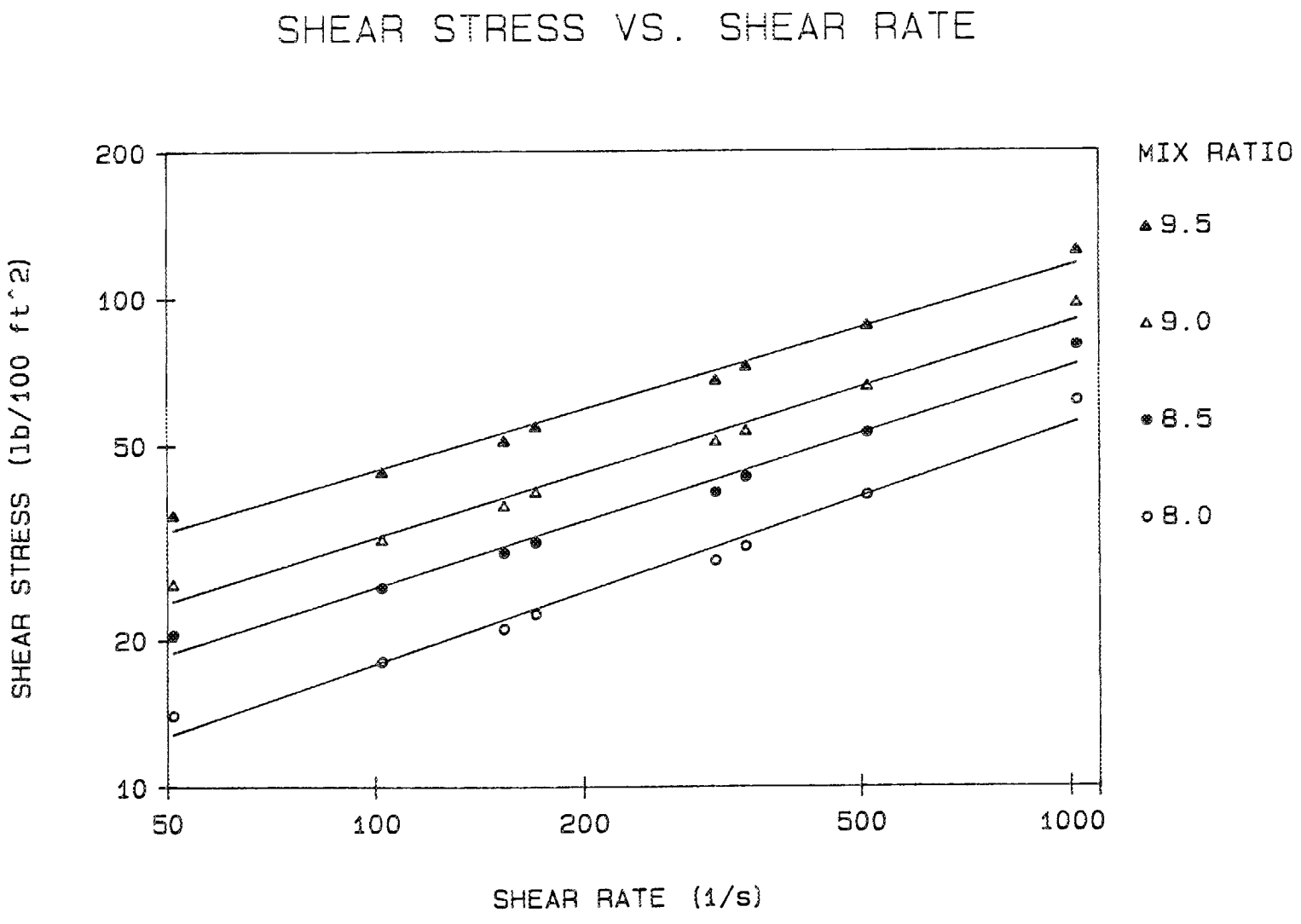

EFFECT OF BLEND COMPOSITION
ON VISCOSITY
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
VISCOSITY (cP)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
CEMENT
ATTAGEL


EFFECT OF BLEND COMPOSITION
ON VISCOSITY
75% SULFATE-25% PHOSPHATE
BLEND COMPOSITION (lb/gal)
VISCOSITY (cP)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
FLY ASH
IRPC

APPENDIX H

RESULTS OF T-TEST

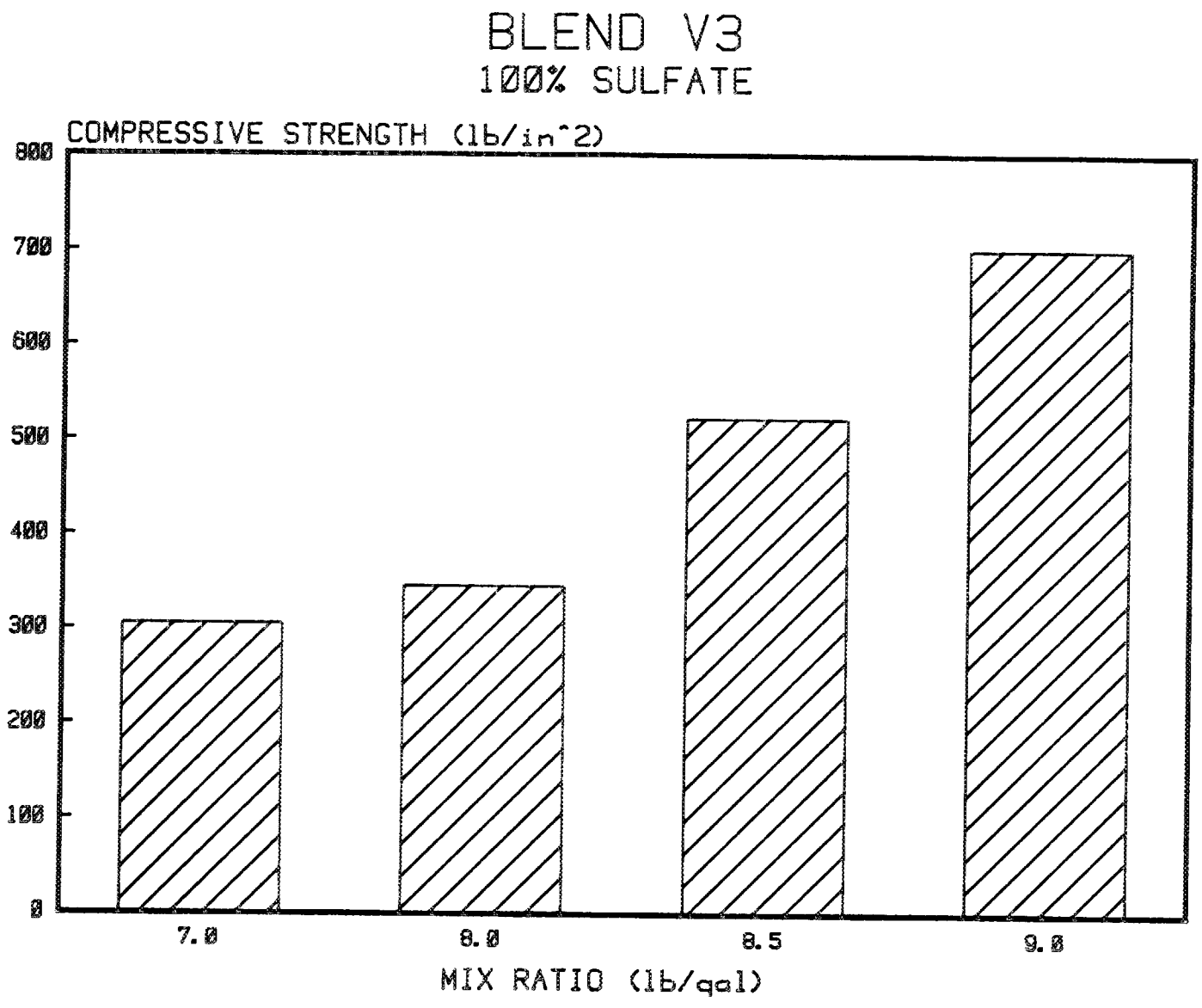
This appendix contains several items. A plot of shear stress vs shear rate shows the effect of increasing mix ratio. Also included is a table of the results of the t-test performed on data for acceptable grouts. This information will be useful when planning future formulation work and is included for information purposes only.

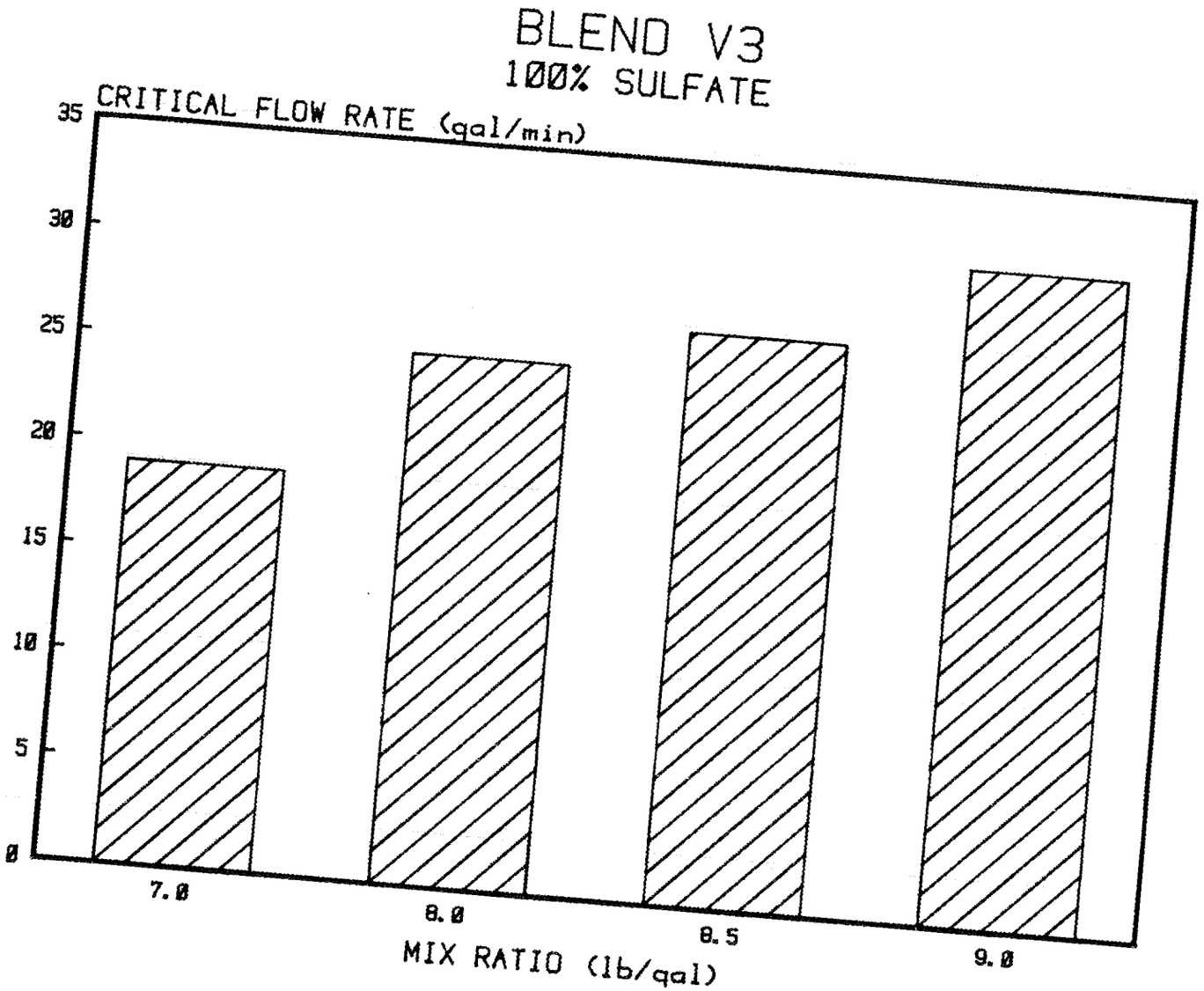

SHEAR STRESS VS. SHEAR RATE
SHEAR STRESS (lb/100 ft^2)
200
100
50
20
10
50
100
200
500
1000
SHEAR RATE (1/s)
MIX RATIO
9.5
9.0
8.5
8.0

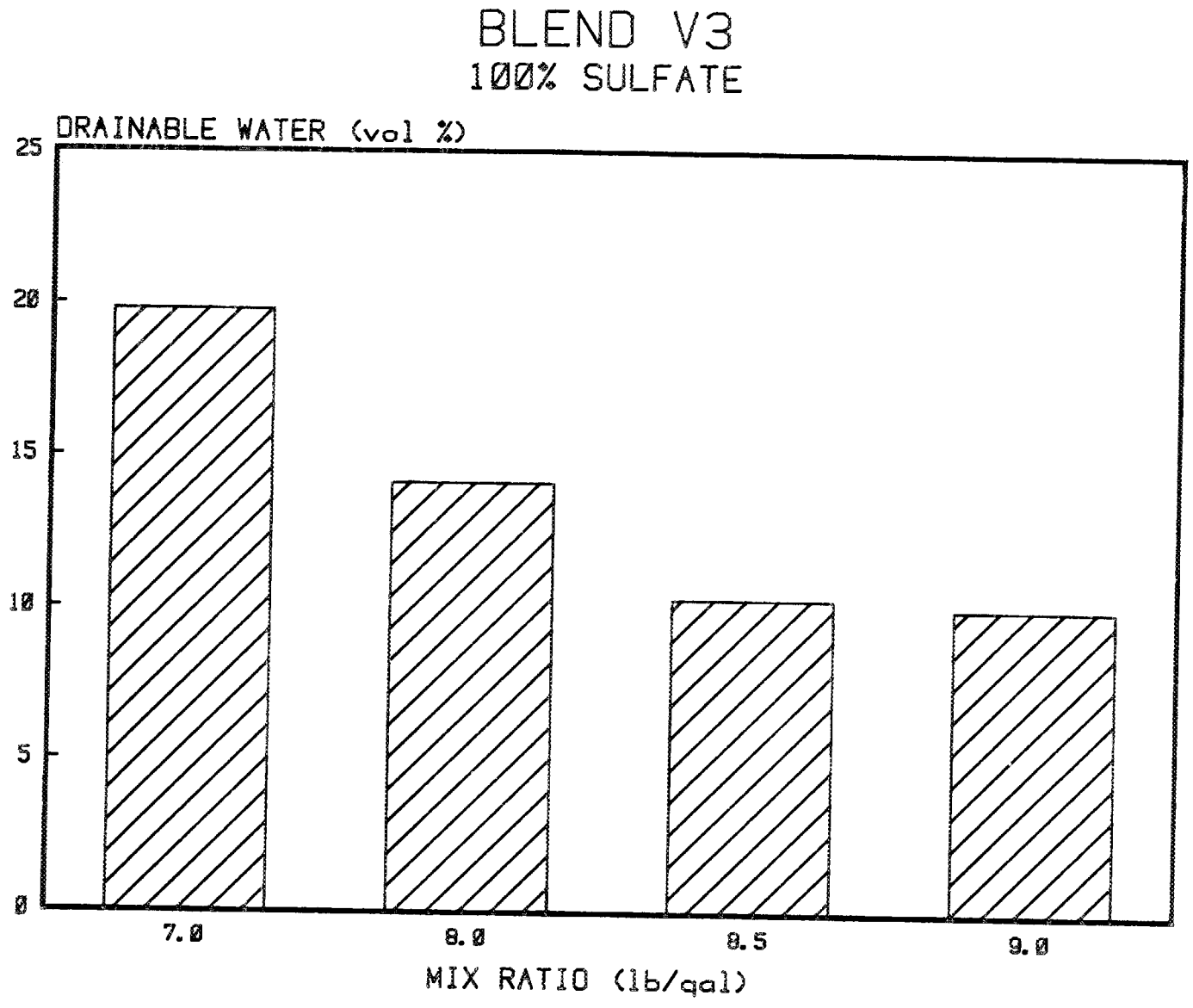
RESULTS OF T-TEST* FOR ACCEPTABLE GROUTS

	SULFATE/PHOSPHATE CONCENTRATION			
	100	75/25	50/50	25/75
CEMENT	46.0+-3.4	47.0+-24.3	45.0+-0.0	45.2+-2.6
FLY ASH	32.7+-3.4	31.0+-24.3	33.0+-0.0	31.8+-3.7
ATTAPULGITE	13.5+-1.4	14.7+-5.4	14.7+-5.4	13.5+-1.0
IRPC	7.9+-0.8	7.3+-5.4	7.3+-5.4	8.5+-0.9
MIX RATIO	8.8+-0.3	9.0+-0.0	7.7+-2.7	8.0+-0.5
GEL STRENGTH	14.8+-3.5	15.7+-7.2	18.3+-28.6	24.6+-6.7
DRAINABLE WATER	1.5+-0.9	1.7+-0.8	1.7+-6.9	0.5+-0.5
COMPRESSIVE STRENGTH	513+-123	565+-1236	530+-320	599+-109
CRITICAL FLOW RATE	42+-4	41+-55	50+-64	44+-8
FRICTIONAL PRES. DROP	3.6+-0.6	3.5+-7.3	4.8+-9.1	4.1+-1.1

* 99% CONFIDENCE INTERVAL


BLEND V3
100% SULFATE
COMPRESSIVE STRENGTH (lb/in^2)
800
700
600
500
400
300
200
100
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V3
100% SULFATE
CRITICAL FLOW RATE (gal/min)
35
30
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)


BLEND V3
100% SULFATE
DRAINABLE WATER (vol %)
25
20
15
10
5
0
7.0
8.0
8.5
9.0
MIX RATIO (lb/gal)

APPENDIX I

RESULTS FROM EXPERIMENTS PERFORMED TO STUDY THE EFFECTS OF WASTE CONCENTRATION ON GROUT PERFORMANCE

This appendix contains the results from experiments performed to study the effects of waste concentration on grout performance. This series of blends was set up to encompass a wide variety of blend compositions. All data from the formulation study are included in this appendix.

BLEND#	SULF/PHOS	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
4	100/0	45.0	33.0	6.0	16.0	9.0	31	5
V5	100/0	50.0	28.0	8.0	14.0	9.0	38	17
V5	100/0	50.0	28.0	8.0	14.0	8.5	29	14
8	100/0	50.0	28.0	8.0	14.0	9.0	30	19
6	100/0	45.0	33.0	10.0	12.0	9.0	27	19
V7	100/0	41.0	37.0	8.0	14.0	9.0	27	12
V5	100/0	50.0	28.0	8.0	14.0	8.0	23	12
V4	100/0	50.0	31.0	8.0	11.0	8.5	22	16
V7	100/0	41.0	37.0	8.0	14.0	8.5	15	11
V4	100/0	50.0	31.0	8.0	11.0	9.0	28	17
1	100/0	40.0	38.0	6.0	16.0	9.0	31	20
5	100/0	45.0	33.0	8.0	14.0	9.0	29	18
V2	100/0	41.0	40.0	8.0	11.0	8.5	20	12
7	75/25	50.0	28.0	6.0	16.0	9.0	42	16
V5	75/25	50.0	28.0	8.0	14.0	9.0	22	17
V7	75/25	41.0	37.0	8.0	14.0	9.0	20	14
5	50/50	45.0	33.0	8.0	14.0	7.0	20	13
5	50/50	45.0	33.0	8.0	14.0	8.0	40	17
4	50/50	45.0	33.0	6.0	16.0	8.0	49	25
3	25/75	40.0	38.0	10.0	12.0	7.0	18	11
2	25/75	40.0	38.0	8.0	14.0	7.0	19	23
1	25/75	40.0	38.0	6.0	16.0	8.0	51	52
3	25/75	40.0	38.0	10.0	12.0	9.0	50	40
2	25/75	40.0	38.0	8.0	14.0	8.0	37	36
3	25/75	40.0	38.0	10.0	12.0	8.0	27	23
6	25/75	45.0	33.0	10.0	12.0	7.0	15	23
4	25/75	45.0	33.0	6.0	16.0	8.0	41	32
5	25/75	45.0	33.0	8.0	14.0	8.0	42	32
6	25/75	45.0	33.0	10.0	12.0	9.0	53	20
6	25/75	45.0	33.0	10.0	12.0	8.0	28	24
9	25/75	50.0	28.0	10.0	12.0	9.0	52	39
9	25/75	50.0	28.0	10.0	12.0	7.0	18	11
9	25/75	50.0	28.0	10.0	12.0	8.0	29	24
5	25/75	45.0	33.0	8.0	14.0	7.0	21	23
7	25/75	50.0	28.0	6.0	16.0	8.0	45	17
1	25/75	40.0	38.0	6.0	16.0	7.0	23	31
8	25/75	50.0	28.0	8.0	14.0	8.0	40	19
V4	75/25	50.0	31.0	8.0	11.0	9.0	21	13
V5	25/75	50.0	28.0	8.0	14.0	9.0	28	12
V5	25/75	50.0	28.0	8.0	14.0	8.5	22	12
7	100/0	50.0	28.0	6.0	16.0	9.0	35	15
40	100/0	45.0	35.0	6.0	0.0	9.0	17	21
9	100/0	50.0	28.0	10.0	12.0	9.0	27	20
6	100/0	45.0	33.0	10.0	10.0	8.0	19	17
3	100/0	40.0	38.0	10.0	12.0	9.0	25	16
V4	100/0	50.0	31.0	8.0	11.0	8.0	19	12
V5	100/0	50.0	28.0	8.0	14.0	7.0	15	9
V7	100/0	41.0	37.0	8.0	14.0	8.0	17	9
V2	100/0	41.0	40.0	8.0	11.0	8.0	18	10
7	100/0	50.0	28.0	6.0	16.0	8.0	22	14
2	100/0	40.0	38.0	8.0	14.0	9.0	26	12
4	100/0	45.0	33.0	6.0	16.0	8.0	19	4
V2	100/0	41.0	40.0	8.0	11.0	7.5	15	8

41	100/0	47.5	32.5	10.0	0.0	9.0	18	26
1	100/0	40.0	38.0	6.0	16.0	8.0	22	15
9	100/0	50.0	28.0	10.0	12.0	8.0	17	15
V4	100/0	50.0	31.0	8.0	11.0	7.0	13	10
8	100/0	50.0	28.0	8.0	14.0	8.0	19	16
3	100/0	40.0	38.0	10.0	12.0	8.0	16	13
5	100/0	45.0	33.0	8.0	14.0	8.0	19	13
9	100/0	50.0	28.0	10.0	12.0	7.0	13	12
2	100/0	40.0	38.0	8.0	14.0	8.0	18	14
40	100/0	45.0	35.0	6.0	0.0	8.0	13	17
V3	100/0	50.0	31.0	8.0	11.0	9.0	19	10
8	100/0	50.0	28.0	8.0	14.0	7.0	14	11
V3	100/0	50.0	31.0	8.0	11.0	8.5	16	9
1	100/0	40.0	38.0	6.0	16.0	7.0	12	12
4	100/0	45.0	33.0	6.0	16.0	7.0	11	9
6	100/0	45.0	33.0	10.0	12.0	7.0	10	10
V2	100/0	41.0	40.0	8.0	11.0	7.0	12	8
V6	100/0	50.0	42.0	8.0	0.0	9.0	13	12
V7	100/0	41.0	37.0	8.0	14.0	7.0	12	7
V8	100/0	40.0	52.0	8.0	0.0	9.0	11	10
2	100/0	40.0	38.0	8.0	14.0	7.0	11	10
7	100/0	50.0	28.0	6.0	16.0	7.0	13	12
V3	100/0	50.0	31.0	8.0	11.0	8.0	13	8
41	100/0	47.5	32.5	10.0	0.0	7.0	10	13
3	100/0	40.0	38.0	10.0	12.0	7.0	12	11
V1	100/0	41.0	40.0	8.0	11.0	8.5	15	8
40	100/0	45.0	35.0	6.0	0.0	7.0	10	12
V1	100/0	41.0	40.0	8.0	11.0	8.0	13	6
V6	100/0	50.0	42.0	8.0	0.0	8.0	10	11
5	100/0	45.0	33.0	8.0	14.0	7.0	13	10
V8	100/0	40.0	52.0	8.0	0.0	8.0	9	7
41	100/0	47.5	32.5	10.0	0.0	8.0	12	12
V3	100/0	50.0	31.0	8.0	11.0	7.0	10	4
V1	100/0	41.0	40.0	8.0	11.0	7.0	9	2
V8	100/0	40.0	52.0	8.0	0.0	7.0	6	3
V1	100/0	41.0	40.0	8.0	11.0	7.5	11	3
V6	100/0	50.0	42.0	8.0	0.0	7.0	9	7
V6	100/0	50.0	42.0	8.0	0.0	6.0	7	4
V8	100/0	40.0	52.0	8.0	0.0	6.0	6	2
1	75/25	40.0	38.0	6.0	16.0	9.0	70	17
4	75/25	45.0	33.0	6.0	16.0	9.0	56	15
V5	75/25	50.0	28.0	8.0	14.0	8.5	19	14
5	75/25	45.0	33.0	8.0	14.0	9.0	58	12
V7	75/25	41.0	37.0	8.0	14.0	8.5	16	11
2	75/25	40.0	38.0	8.0	14.0	9.0	44	14
V5	75/25	50.0	28.0	8.0	14.0	8.0	16	11
4	75/25	45.0	33.0	6.0	16.0	8.0	32	9
9	75/25	50.0	28.0	10.0	12.0	9.0	33	11
1	75/25	40.0	38.0	6.0	16.0	8.0	39	12
V7	75/25	41.0	37.0	8.0	14.0	8.0	13	9
8	75/25	50.0	28.0	8.0	14.0	9.0	35	5
5	75/25	45.0	33.0	8.0	14.0	8.0	34	10
3	75/25	40.0	38.0	10.0	12.0	9.0	35	11
2	75/25	40.0	38.0	8.0	14.0	8.0	29	7
6	75/25	45.0	33.0	10.0	12.0	9.0	36	12
7	75/25	50.0	28.0	6.0	16.0	8.0	24	11
8	75/25	50.0	28.0	8.0	14.0	8.0	24	8
1	75/25	40.0	38.0	6.0	16.0	7.0	22	8

3	75/25	40.0	38.0	10.0	12.0	8.0	22	9
V5	75/25	50.0	28.0	8.0	14.0	7.0	11	7
V7	75/25	41.0	37.0	8.0	14.0	7.0	8	6
9	75/25	50.0	28.0	10.0	12.0	8.0	20	8
4	75/25	45.0	33.0	6.0	16.0	7.0	21	7
2	75/25	40.0	38.0	8.0	14.0	7.0	16	7
5	75/25	45.0	33.0	8.0	14.0	7.0	19	13
6	75/25	45.0	33.0	10.0	12.0	8.0	24	8
7	75/25	50.0	28.0	6.0	16.0	7.0	16	8
3	75/25	40.0	38.0	10.0	12.0	7.0	14	6
8	75/25	50.0	28.0	8.0	14.0	7.0	15	7
6	75/25	45.0	33.0	10.0	12.0	7.0	13	6
9	75/25	50.0	28.0	10.0	12.0	7.0	14	6
1	50/50	40.0	38.0	6.0	16.0	8.0	55	32
1	50/50	40.0	38.0	6.0	16.0	9.0	120	50
2	50/50	40.0	38.0	8.0	14.0	9.0	65	33
5	50/50	45.0	33.0	8.0	14.0	9.0	87	29
4	50/50	45.0	33.0	6.0	16.0	9.0	90	39
7	50/50	50.0	28.0	6.0	16.0	9.0	81	18
1	50/50	40.0	38.0	6.0	16.0	7.0	21	14
2	50/50	40.0	38.0	8.0	14.0	8.0	34	9
7	50/50	50.0	28.0	6.0	16.0	8.0	43	16
8	50/50	50.0	28.0	8.0	14.0	9.0	74	20
3	50/50	40.0	38.0	10.0	12.0	8.0	29	13
4	50/50	45.0	33.0	6.0	16.0	7.0	25	13
6	50/50	45.0	33.0	10.0	12.0	9.0	52	22
3	50/50	40.0	38.0	10.0	12.0	9.0	49	15
9	50/50	50.0	28.0	10.0	12.0	9.0	47	23
2	50/50	40.0	38.0	8.0	14.0	7.0	18	10
8	50/50	50.0	28.0	8.0	14.0	8.0	34	13
3	50/50	40.0	38.0	10.0	12.0	7.0	17	7
9	50/50	50.0	28.0	10.0	12.0	8.0	28	11
6	50/50	45.0	33.0	10.0	12.0	8.0	30	10
9	50/50	50.0	28.0	10.0	12.0	7.0	15	8
7	50/50	50.0	28.0	6.0	16.0	7.0	22	14
8	50/50	50.0	28.0	8.0	14.0	7.0	20	11
6	50/50	45.0	33.0	10.0	12.0	7.0	17	10
1	25/75	40.0	38.0	6.0	16.0	9.0	119	56
2	25/75	40.0	38.0	8.0	14.0	9.0	73	43
4	25/75	45.0	33.0	6.0	16.0	9.0	84	68
5	25/75	45.0	33.0	8.0	14.0	9.0	89	73
8	25/75	50.0	28.0	8.0	16.0	9.0	73	29
7	25/75	50.0	28.0	6.0	16.0	9.0	89	32
V7	25/75	41.0	37.0	8.0	14.0	9.0	27	10
V4	25/75	50.0	31.0	8.0	11.0	9.0	20	14
V2	25/75	41.0	40.0	8.0	11.0	9.0	18	11
8	25/75	50.0	28.0	8.0	16.0	7.0	20	12
V2	25/75	41.0	40.0	8.0	11.0	8.5	15	9
V4	75/25	50.0	31.0	8.0	11.0	8.5	17	11
V4	25/75	50.0	31.0	8.0	11.0	8.5	16	11
V7	25/75	41.0	37.0	8.0	14.0	8.5	23	10
V5	25/75	50.0	28.0	8.0	14.0	8.0	19	10
V2	75/25	41.0	40.0	8.0	11.0	9.0	22	11
V4	25/75	50.0	31.0	8.0	11.0	8.0	15	8
V2	25/75	41.0	40.0	8.0	11.0	8.0	14	8
V7	25/75	41.0	37.0	8.0	14.0	8.0	17	9
V2	75/25	41.0	40.0	8.0	11.0	8.5	16	9
7	25/75	50.0	28.0	6.0	16.0	7.0	25	12

4	25/75	45.0	33.0	6.0	16.0	7.0	23	20
V5	25/75	50.0	28.0	8.0	14.0	7.0	14	6
V4	75/25	50.0	31.0	8.0	11.0	8.0	13	9
V2	75/25	41.0	40.0	8.0	11.0	8.0	14	8
V2	25/75	41.0	40.0	8.0	11.0	7.0	10	7
V7	25/75	41.0	37.0	8.0	14.0	7.0	13	6
V4	75/25	50.0	31.0	8.0	11.0	7.0	9	7
V4	25/75	50.0	31.0	8.0	11.0	7.0	13	6
V2	75/25	41.0	40.0	8.0	11.0	7.0	13	5
40	100/0	45.0	35.0	6.0	0.0	9.0	18	20
41	100/0	47.5	32.5	10.0	0.0	9.0	16	19
43	100/0	47.5	32.5	8.0	0.0	9.0	18	23
40	100/0	45.0	35.0	6.0	0.0	8.0	12	15
43	100/0	47.5	32.5	8.0	0.0	8.0	14	16
41	100/0	47.5	32.5	10.0	0.0	8.0	14	14
41	100/0	47.5	32.5	10.0	0.0	7.0	9	9
40	100/0	45.0	35.0	6.0	0.0	7.0	9	9
43	100/0	47.5	32.5	8.0	0.0	7.0	10	9
10	100/0	44.5	34.5	7.0	14.0	8.0	20	17
10	100/0	44.5	34.5	7.0	14.0	8.5	24	16
10	100/0	44.5	34.5	7.0	14.0	9.0	31	15
10	70/30	44.5	34.5	7.0	14.0	8.0	24	9
10	70/30	44.5	34.5	7.0	14.0	8.5	32	10
10	70/30	44.5	34.5	7.0	14.0	9.0	38	10
11	100/0	47.0	30.0	8.0	15.0	8.0	23	14
11	100/0	47.0	30.0	8.0	15.0	8.5	28	18
11	100/0	47.0	30.0	8.0	15.0	9.0	35	20
11	70/30	47.0	30.0	8.0	15.0	8.0	26	10
11	70/30	47.0	30.0	8.0	15.0	8.5	44	24
11	70/30	47.0	30.0	8.0	15.0	9.0	40	10
12	100/0	49.5	25.5	9.0	16.0	8.0	24	17
12	100/0	49.5	25.5	9.0	16.0	8.5	30	20
12	100/0	49.5	25.5	9.0	16.0	9.0	40	21
12	70/30	49.5	25.5	9.0	16.0	8.0	29	9
12	70/30	49.5	25.5	9.0	16.0	8.5	38	10
12	70/30	49.5	25.5	9.0	16.0	9.0	47	11
10	100/0	44.5	34.5	7.0	14.0	8.0	19	16
10	100/0	44.5	34.5	7.0	14.0	8.5	23	20
10	100/0	44.5	34.5	7.0	14.0	9.0	29	22
11	100/0	47.0	30.0	8.0	15.0	8.0	21	16
11	100/0	47.0	30.0	8.0	15.0	8.5	26	20
11	100/0	47.0	30.0	8.0	15.0	9.0	29	23
12	100/0	49.5	25.5	9.0	16.0	8.0	25	20
12	100/0	49.5	25.5	9.0	16.0	8.5	32	22
12	100/0	49.5	25.5	9.0	16.0	9.0	42	28
10	100/0	44.5	34.5	7.0	14.0	8.0	30	9
10	100/0	44.5	34.5	7.0	14.0	8.5	33	13
10	100/0	44.5	34.5	7.0	14.0	9.0	37	26
11	100/0	47.0	30.0	8.0	15.0	8.0	32	23
11	100/0	47.0	30.0	8.0	15.0	8.5	34	23
11	100/0	47.0	30.0	8.0	15.0	9.0	42	22
12	100/0	49.5	25.5	9.0	16.0	8.0	36	18
12	100/0	49.5	25.5	9.0	16.0	8.5	41	31
12	100/0	49.5	25.5	9.0	16.0	9.0	46	31
13	70/30	47.0	31.0	8.0	14.0	8.0	27	9
13	70/30	47.0	31.0	8.0	14.0	8.5	35	12
13	70/30	47.0	31.0	8.0	14.0	9.0	47	11
13	70/30	47.0	31.0	8.0	14.0	9.5	60	14

14	70/30	44.0	34.0	7.0	15.0	8.0	32	10
14	70/30	44.0	34.0	7.0	15.0	8.5	41	11
14	70/30	44.0	34.0	7.0	15.0	9.0	56	13
14	70/30	44.0	34.0	7.0	15.0	9.5	77	16
15	70/30	41.0	37.0	6.0	16.0	8.0	37	11
15	70/30	41.0	37.0	6.0	16.0	8.5	50	13
15	70/30	41.0	37.0	6.0	16.0	9.0	62	14
15	70/30	41.0	37.0	6.0	16.0	9.5	82	20
8	75/25	50.0	28.0	8.0	14.0	8.0	26	9
8	75/25	50.0	28.0	8.0	14.0	8.5	33	10
8	75/25	50.0	28.0	8.0	14.0	9.0	42	10
16	75/25	46.0	30.0	8.0	16.0	8.0	31	11
16	75/25	46.0	30.0	8.0	16.0	8.5	41	11
16	75/25	46.0	30.0	8.0	16.0	9.0	51	11
17	75/25	43.0	32.0	8.0	17.0	8.0	40	10
17	75/25	43.0	32.0	8.0	17.0	8.5	51	14
17	75/25	43.0	32.0	8.0	17.0	9.0	70	15
18	75/25	41.0	32.0	8.0	19.0	8.0	50	12
18	75/25	41.0	32.0	8.0	19.0	8.5	66	14
18	75/25	41.0	32.0	8.0	19.0	9.0	95	21
19	100/0	45.0	33.0	8.0	14.0	7.0	10	3
19	100/0	45.0	33.0	8.0	14.0	8.0	14	6
19	100/0	45.0	33.0	8.0	14.0	9.0	21	8
19	70/30	45.0	33.0	8.0	14.0	7.0	14	6
19	70/30	45.0	33.0	8.0	14.0	8.0	22	9
19	70/30	45.0	33.0	8.0	14.0	9.0	36	13
20	70/30	50.0	28.0	8.0	14.0	7.0	14	7
20	70/30	50.0	28.0	8.0	14.0	8.0	22	9
20	70/30	50.0	28.0	8.0	14.0	9.0	37	14
20	100/0	50.0	28.0	8.0	14.0	7.0	10	3
20	100/0	50.0	28.0	8.0	14.0	8.0	14	6
20	100/0	50.0	28.0	8.0	14.0	9.0	20	8
21	100/0	45.0	31.0	8.0	16.0	7.0	11	4
21	100/0	45.0	31.0	8.0	16.0	8.0	16	6
21	100/0	45.0	31.0	8.0	16.0	9.0	25	9
21	70/30	45.0	31.0	8.0	16.0	7.0	17	10
21	70/30	45.0	31.0	8.0	16.0	8.0	31	12
21	70/30	45.0	31.0	8.0	16.0	9.0	60	20
22	100/0	50.0	26.0	8.0	16.0	7.0	11	4
22	100/0	50.0	26.0	8.0	16.0	8.0	15	6
22	100/0	50.0	26.0	8.0	16.0	9.0	24	8
22	70/30	50.0	26.0	8.0	16.0	7.0	16	9
22	70/30	50.0	26.0	8.0	16.0	8.0	28	11
22	70/30	50.0	26.0	8.0	16.0	9.0	54	15
23	70/30	40.0	40.0	0.0	8.0	7.0	10	7
23	70/30	40.0	40.0	0.0	8.0	8.0	13	11
23	70/30	40.0	40.0	0.0	8.0	9.0	17	11
24	70/30	40.0	40.0	0.0	10.0	7.0	10	7
24	70/30	40.0	40.0	0.0	10.0	8.0	13	9
24	70/30	40.0	40.0	0.0	10.0	9.0	18	14
25	70/30	40.0	40.0	0.0	12.0	7.0	10	7
25	70/30	40.0	40.0	0.0	12.0	8.0	14	9
25	70/30	40.0	40.0	0.0	12.0	9.0	19	11
26	70/30	43.0	38.0	8.0	11.0	7.0	10	6
26	70/30	43.0	38.0	8.0	11.0	8.0	12	8
26	70/30	43.0	38.0	8.0	11.0	9.0	16	11
26	65/35	43.0	38.0	8.0	11.0	7.0	13	7
26	65/35	43.0	38.0	8.0	11.0	8.0	19	8

26	65/35	43.0	38.0	8.0	11.0	9.0	29	13
26	100/0	43.0	38.0	8.0	11.0	7.0	10	14
26	100/0	43.0	38.0	8.0	11.0	8.0	15	20
26	100/0	43.0	38.0	8.0	11.0	9.0	21	27
5	65/35	45.0	33.0	8.0	14.0	7.0	15	7
5	65/35	45.0	33.0	8.0	14.0	8.0	23	9
5	65/35	45.0	33.0	8.0	14.0	9.0	39	12
5	100/0	45.0	33.0	8.0	14.0	7.0	12	16
5	100/0	45.0	33.0	8.0	14.0	8.0	18	24
5	100/0	45.0	33.0	8.0	14.0	9.0	28	33
26	65/35	43.0	38.0	8.0	11.0	7.0	10	3
26	65/35	43.0	38.0	8.0	11.0	8.0	15	3
26	65/35	43.0	38.0	8.0	11.0	9.0	22	6
26	100/0	43.0	38.0	8.0	11.0	7.0	7	11
26	100/0	43.0	38.0	8.0	11.0	8.0	10	14
26	100/0	43.0	38.0	8.0	11.0	9.0	14	18
5	65/35	45.0	33.0	8.0	14.0	7.0	9	6
5	65/35	45.0	33.0	8.0	14.0	8.0	12	5
5	65/35	45.0	33.0	8.0	14.0	9.0	16	7
5	100/0	45.0	33.0	8.0	14.0	7.0	13	13
5	100/0	45.0	33.0	8.0	14.0	8.0	19	17
5	100/0	45.0	33.0	8.0	14.0	9.0	31	29
27	65/35	42.5	38.5	7.0	12.0	8.0	22	8
27	65/35	42.5	38.5	7.0	12.0	8.5	25	11
27	65/35	42.5	38.5	7.0	12.0	9.0	34	13
27	100/0	42.5	38.5	7.0	12.0	8.0	14	20
27	100/0	42.5	38.5	7.0	12.0	8.5	18	25
27	100/0	42.5	38.5	7.0	12.0	9.0	22	31
28	65/35	42.5	35.5	8.0	14.0	8.0	26	11
28	65/35	42.5	35.5	8.0	14.0	8.5	32	12
28	65/35	42.5	35.5	8.0	14.0	9.0	47	15
28	100/0	42.5	35.5	8.0	14.0	8.0	17	20
28	100/0	42.5	35.5	8.0	14.0	8.5	21	25
28	100/0	42.5	35.5	8.0	14.0	9.0	26	26
29	65/35	42.5	32.5	9.0	16.0	8.0	32	13
29	65/35	42.5	32.5	9.0	16.0	8.5	46	16
29	65/35	42.5	32.5	9.0	16.0	9.0	67	14
29	100/0	42.5	32.5	9.0	16.0	8.0	20	25
29	100/0	42.5	32.5	9.0	16.0	8.5	25	27
29	100/0	42.5	32.5	9.0	16.0	9.0	33	32
30	65/35	45.0	36.0	7.0	12.0	8.0	20	9
30	65/35	45.0	36.0	7.0	12.0	8.5	25	10
30	65/35	45.0	36.0	7.0	12.0	9.0	29	12
30	100/0	45.0	36.0	7.0	12.0	8.0	14	19
30	100/0	45.0	36.0	7.0	12.0	8.5	16	24
30	100/0	45.0	36.0	7.0	12.0	9.0	20	32
5	65/35	45.0	33.0	8.0	14.0	8.0	25	10
5	65/35	45.0	33.0	8.0	14.0	8.5	32	12
5	65/35	45.0	33.0	8.0	14.0	9.0	45	14
5	100/0	45.0	33.0	8.0	14.0	8.0	18	24
5	100/0	45.0	33.0	8.0	14.0	8.5	22	26
5	100/0	45.0	33.0	8.0	14.0	9.0	27	29
31	65/35	45.0	30.0	9.0	16.0	8.0	36	9
31	65/35	45.0	30.0	9.0	16.0	8.5	56	12
31	65/35	45.0	30.0	9.0	16.0	9.0	75	14
31	100/0	45.0	30.0	9.0	16.0	8.0	20	17
31	100/0	45.0	30.0	9.0	16.0	8.5	26	18
31	100/0	45.0	30.0	9.0	16.0	9.0	33	22

32	65/35	47.5	33.5	7.0	12.0	8.0	19	8
32	65/35	47.5	33.5	7.0	12.0	8.5	25	9
32	65/35	47.5	33.5	7.0	12.0	9.0	30	9
32	100/0	47.5	33.5	7.0	12.0	8.0	16	14
32	100/0	47.5	33.5	7.0	12.0	8.5	19	15
32	100/0	47.5	33.5	7.0	12.0	9.0	22	18
33	65/35	47.5	30.5	8.0	14.0	8.0	24	9
33	65/35	47.5	30.5	8.0	14.0	8.5	34	10
33	65/35	47.5	30.5	8.0	14.0	9.0	47	11
33	100/0	47.5	30.5	8.0	14.0	8.0	18	17
33	100/0	47.5	30.5	8.0	14.0	8.5	22	19
33	100/0	47.5	30.5	8.0	14.0	9.0	28	22
34	65/35	47.5	27.5	9.0	16.0	8.0	32	9
34	65/35	47.5	27.5	9.0	16.0	8.5	43	11
34	65/35	47.5	27.5	9.0	16.0	9.0	61	13
34	100/0	47.5	27.5	9.0	16.0	8.0	20	18
34	100/0	47.5	27.5	9.0	16.0	8.5	25	20
34	100/0	47.5	27.5	9.0	16.0	9.0	32	23
35	65/35	40.0	40.0	7.0	13.0	8.0	23	7
35	65/35	40.0	40.0	7.0	13.0	8.5	29	10
35	65/35	40.0	40.0	7.0	13.0	9.0	38	12
35	100/0	40.0	40.0	7.0	13.0	8.0	15	16
35	100/0	40.0	40.0	7.0	13.0	8.5	19	19
35	100/0	40.0	40.0	7.0	13.0	9.0	23	23
36	65/35	40.0	38.0	8.0	14.0	8.0	28	11
36	65/35	40.0	38.0	8.0	14.0	8.5	37	12
36	65/35	40.0	38.0	8.0	14.0	9.0	56	15
36	100/0	40.0	38.0	8.0	14.0	8.0	19	11
36	100/0	40.0	38.0	8.0	14.0	8.5	22	21
36	100/0	40.0	38.0	8.0	14.0	9.0	27	25
37	65/35	40.0	36.0	9.0	15.0	8.0	31	13
37	65/35	40.0	36.0	9.0	15.0	8.5	40	12
37	65/35	40.0	36.0	9.0	15.0	9.0	61	15
37	100/0	40.0	36.0	9.0	15.0	8.0	19	16
37	100/0	40.0	36.0	9.0	15.0	8.5	24	18
37	100/0	40.0	36.0	9.0	15.0	9.0	31	23
40	65/35	45.0	35.0	7.0	13.0	8.0	23	10
40	65/35	45.0	35.0	7.0	13.0	8.5	29	10
40	65/35	45.0	35.0	7.0	13.0	9.0	39	11
40	100/0	45.0	35.0	7.0	13.0	8.0	16	15
40	100/0	45.0	35.0	7.0	13.0	8.5	19	18
40	100/0	45.0	35.0	7.0	13.0	9.0	24	23
28	90/10	42.5	33.5	8.0	14.0	8.0	18	13
28	90/10	42.5	35.5	8.0	14.0	9.0	22	14
28	85/15	42.5	35.5	8.0	14.0	8.0	19	11
28	85/15	42.5	35.5	8.0	14.0	9.0	24	13
28	80/20	42.5	35.5	8.0	14.0	8.0	23	9
28	80/20	42.5	35.5	8.0	14.0	9.0	28	11
41	65/35	45.0	31.0	9.0	15.0	8.0	31	10
41	65/35	45.0	31.0	9.0	15.0	8.5	42	12
41	65/35	45.0	31.0	9.0	15.0	9.0	57	15
41	100/0	45.0	31.0	9.0	15.0	8.0	20	15
41	100/0	45.0	31.0	9.0	15.0	8.5	24	22
41	100/0	45.0	31.0	9.0	15.0	9.0	30	27
38	65/35	42.5	37.5	7.0	13.0	8.0	23	11
38	65/35	42.5	37.5	7.0	13.0	8.5	33	13
38	65/35	42.5	37.5	7.0	13.0	9.0	49	14
38	100/0	42.5	37.5	7.0	13.0	8.0	17	16

38	100/0	42.5	37.5	7.0	13.0	8.5	21	20
38	100/0	42.5	37.5	7.0	13.0	9.0	26	22
28	65/35	42.5	35.5	8.0	14.0	8.0	29	12
28	65/35	42.5	35.5	8.0	14.0	8.5	40	14
28	65/35	42.5	35.5	8.0	14.0	9.0	56	16
28	100/0	42.5	35.5	8.0	14.0	8.0	18	24
28	100/0	42.5	35.5	8.0	14.0	8.5	23	32
28	100/0	42.5	35.5	8.0	14.0	9.0	29	43
39	65/35	42.5	33.5	9.0	15.0	8.0	32	13
39	65/35	42.5	33.5	9.0	15.0	8.5	43	14
39	65/35	42.5	33.5	9.0	15.0	9.0	58	16
39	100/0	42.5	33.5	9.0	15.0	8.0	19	21
39	100/0	42.5	33.5	9.0	15.0	8.5	24	26
39	100/0	42.5	33.5	9.0	15.0	9.0	31	33
28	65/35	42.5	35.5	8.0	14.0	8.0	33	15
28	65\35	42.5	35.5	8.0	14.0	9.0	47	20
28	100 % Sulfate	42.5	35.5	8.0	14.0	8.0	19	31
28	100 % Sulfate	42.5	35.5	8.0	14.0	9.0	23	34
		0.0	0.0	0.0	0.0	0.0	0	0

BLEND#	DENSITY	KINDEX	NPRIME	PHASE	COMPST	REYNUM	FPRES	CRTFW	HPRES
4	14.00	0.024	0.42	0.0	524	2500	4.0	45	2.3
V5	12.10	0.038	0.38	0.0	642	1933	5.1	53	2.8
V5	11.95	0.024	0.41	0.0	551	2560	3.8	44	2.3
8	12.16	0.023	0.42	0.0	655	2583	3.8	44	3.2
6	12.21	0.022	0.41	1.3	351	2849	3.5	41	3.2
V7	12.00	0.013	0.49	1.8	644	2932	3.3	40	2.0
V5	11.78	0.016	0.43	1.8	516	3249	2.9	38	2.0
V4	11.98	0.017	0.43	1.8	595	3294	3.0	38	2.7
V7	11.90	0.010	0.45	2.1	547	3729	2.6	34	1.8
V4	12.18	0.025	0.40	2.2	708	2658	3.7	43	2.8
1	12.12	0.024	0.42	2.4	182	2356	4.2	46	3.3
5	12.13	0.019	0.45	2.5	403	2698	3.7	43	3.0
V2	11.85	0.015	0.43	2.9	352	3689	2.6	35	2.0
7	12.23	0.021	0.49	1.6	620	1894	5.3	54	2.7
V5	12.20	0.011	0.49	1.6	798	3430	2.9	36	2.8
V7	12.15	0.008	0.53	1.9	278	4052	2.4	32	2.3
5	11.62	0.009	0.51	0.0	467	3613	2.6	35	2.2
5	11.92	0.033	0.41	2.5	603	1798	5.5	55	2.8
4	11.92	0.043	0.40	2.6	522	1529	6.3	61	4.2
3	11.65	0.004	0.61	0.0	354	5144	1.8	26	1.8
2	11.65	0.007	0.54	0.0	412	4040	2.3	32	3.8
1	11.95	0.051	0.38	0.0	626	1408	6.9	64	8.7
3	12.30	0.032	0.44	0.0	823	1639	6.1	59	6.7
2	11.90	0.020	0.48	0.0	565	2132	4.5	50	6.0
3	11.95	0.009	0.55	0.0	380	3158	3.1	38	3.8
6	11.70	0.004	0.59	0.0	430	5061	1.9	27	3.8
4	11.95	0.028	0.44	0.0	724	1836	5.3	55	5.3
5	11.95	0.035	0.41	0.0	602	1729	5.6	56	5.3
6	12.32	0.041	0.42	0.0	917	1458	6.9	63	3.3
6	12.05	0.011	0.53	0.0	625	2871	3.4	40	4.0
9	12.38	0.046	0.40	0.0	928	1426	7.1	64	6.5
9	11.76	0.004	0.62	0.0	456	4859	2.0	27	1.8
9	12.12	0.014	0.50	0.0	654	2719	3.6	42	4.0
5	11.61	0.006	0.58	1.0	355	3750	2.5	33	3.8
7	11.93	0.042	0.39	1.1	615	1598	6.1	59	2.8
1	11.62	0.011	0.50	1.2	324	3115	3.0	38	5.2
8	11.97	0.029	0.43	1.4	698	1910	5.1	53	3.2
V4	12.16	0.011	0.48	1.7	732	3900	2.5	33	2.2
V5	12.15	0.013	0.50	2.0	714	2794	3.5	41	2.0
V5	12.02	0.009	0.52	2.3	646	3641	2.7	34	2.0
7	12.18	0.039	0.36	1.4	478	2044	4.8	51	2.5
40	12.15	0.007	0.52	3.3	588	4808	2.1	29	3.5
9	12.30	0.025	0.39	3.5	653	2785	3.6	42	3.3
6	11.92	0.012	0.45	4.3	287	4142	2.3	32	2.8
3	12.18	0.016	0.44	4.3	317	3180	3.1	38	2.7
V4	11.82	0.012	0.44	4.8	547	4005	2.4	33	2.0
V5	11.50	0.008	0.48	4.9	370	5070	1.8	28	1.5
V7	11.75	0.006	0.55	5.2	567	4652	2.1	29	1.5
V2	11.75	0.010	0.46	5.3	240	4383	2.2	31	1.7
7	11.88	0.014	0.45	5.3	303	3524	2.7	36	2.3
2	12.17	0.019	0.43	5.3	278	2860	3.5	41	2.0
4	10.00	0.012	0.45	6.6	351	3990	2.4	33	1.7
V2	11.55	0.006	0.51	6.9	292	5419	1.7	26	1.3

41	12.50	0.007	0.53	7.3	535	4873	2.1	28	4.3
1	11.80	0.011	0.49	7.5	133	3755	2.6	34	2.5
9	11.95	0.012	0.44	7.5	452	4126	2.4	32	2.5
V4	11.58	0.007	0.49	8.8	386	5945	1.6	25	1.7
8	11.85	0.011	0.47	8.9	446	3952	2.4	33	2.7
3	11.82	0.010	0.45	9.1	245	4674	2.1	30	2.2
5	11.86	0.009	0.50	9.2	335	4180	2.3	32	2.2
9	11.60	0.006	0.50	9.4	385	6015	1.6	25	2.0
2	11.86	0.007	0.53	9.4	177	4623	2.1	29	2.3
40	11.80	0.006	0.50	9.5	469	5998	1.6	25	2.8
V3	12.20	0.008	0.52	10.0	701	4246	2.3	31	1.7
8	11.60	0.006	0.51	10.0	294	5661	1.7	26	1.8
V3	12.02	0.006	0.53	10.3	522	5050	1.9	27	1.5
1	11.45	0.005	0.52	10.7	114	5923	1.6	25	2.0
4	11.95	0.004	0.54	10.8	287	7130	1.4	22	1.5
6	11.56	0.004	0.53	11.2	261	6769	1.4	23	1.7
V2	11.38	0.004	0.54	11.4	255	6790	1.4	22	1.3
V6	12.17	0.007	0.49	11.5	937	6137	1.6	25	2.0
V7	11.45	0.004	0.57	11.7	527	6668	1.4	22	1.2
V8	12.02	0.005	0.51	12.2	1097	7420	1.3	21	1.7
2	11.50	0.002	0.66	12.6	146	7373	1.3	20	1.7
7	11.56	0.005	0.53	13.4	219	5700	1.6	25	2.0
V3	11.86	0.005	0.54	14.1	345	5943	1.6	25	1.3
41	11.50	0.004	0.52	14.4	421	8944	1.0	19	2.2
3	11.53	0.003	0.58	14.4	140	7036	1.3	21	1.8
V1	11.96	0.005	0.55	15.1	262	5648	1.7	25	1.3
40	11.48	0.004	0.53	15.8	347	8016	1.2	20	2.0
V1	11.80	0.003	0.59	16.3	483	6571	1.5	22	1.0
V6	11.86	0.005	0.48	16.8	800	7552	1.3	22	1.8
5	11.50	0.006	0.50	17.4	224	6327	1.5	24	1.7
V8	11.75	0.003	0.53	18.7	964	9055	1.1	18	1.2
41	11.82	0.004	0.55	19.1	446	6780	1.4	22	2.0
V3	11.52	0.003	0.59	19.8	305	8295	1.1	19	0.7
V1	11.48	0.003	0.58	20.7	355	8937	1.0	18	0.3
V8	11.35	0.002	0.61	24.3	991	11485	0.8	15	0.5
V1	11.68	0.002	0.63	25.8	239	8180	1.2	19	0.5
V6	11.48	0.003	0.55	27.7	592	8552	1.1	19	1.2
V6	11.10	0.003	0.48	30.9	447	11108	0.8	17	0.7
V8	11.02	0.002	0.54	32.2	608	12721	0.7	15	0.3
1	12.15	0.043	0.45	1.9	299	1167	8.5	73	2.8
4	12.10	0.028	0.49	3.2	588	1444	6.8	64	2.5
V5	12.08	0.007	0.54	3.3	532	4326	2.3	30	2.3
5	12.20	0.040	0.44	3.9	540	1290	7.7	68	2.0
V7	11.92	0.005	0.57	4.6	271	4925	2.0	28	1.8
2	12.16	0.022	0.49	5.6	434	1752	5.6	56	2.3
V5	11.90	0.006	0.54	6.5	450	5148	1.9	27	1.8
4	11.80	0.015	0.50	6.6	469	2424	4.0	45	1.5
9	12.35	0.013	0.53	6.8	707	2598	3.9	43	1.8
1	11.82	0.020	0.48	7.0	234	2063	4.7	51	2.0
V7	11.80	0.004	0.57	7.5	241	5887	1.6	24	1.5
8	12.15	0.014	0.52	7.9	634	2450	4.0	45	0.8
5	11.90	0.017	0.49	9.1	382	2297	4.2	47	1.7
3	12.20	0.013	0.53	9.4	493	2443	4.1	45	1.8
2	11.86	0.009	0.57	9.8	348	2878	3.4	40	1.2
6	12.22	0.014	0.53	10.0	591	2355	4.2	46	2.0
7	11.92	0.009	0.54	11.1	455	3152	3.1	38	1.8
8	11.95	0.007	0.57	11.9	422	3643	2.7	34	1.3
1	11.50	0.007	0.55	12.9	160	3725	2.5	34	1.3

3	11.90	0.006	0.59	12.9	463	4019	2.4	32	1.5
V5	11.52	0.004	0.54	13.1	340	7446	1.3	21	1.2
V7	11.46	0.002	0.60	13.5	152	8308	1.1	19	1.0
9	12.00	0.005	0.60	13.5	635	4221	2.3	30	1.3
4	11.00	0.006	0.58	13.6	329	3822	2.3	33	1.2
2	11.52	0.005	0.57	15.7	225	4790	2.0	28	1.2
5	11.60	0.008	0.52	16.8	323	4119	2.3	32	2.2
6	11.90	0.006	0.60	16.8	500	3691	2.6	33	1.3
7	11.58	0.005	0.57	17.1	370	5185	1.8	27	1.3
3	11.46	0.003	0.62	20.9	334	6050	1.5	23	1.0
8	9.55	0.003	0.62	20.9	385	4805	1.6	27	1.2
6	11.56	0.004	0.57	22.6	404	5677	1.7	25	1.0
9	11.65	0.003	0.63	23.1	536	6306	1.5	32	1.0
1	11.90	0.064	0.35	0.0	426	1334	7.3	66	5.3
1	12.22	0.126	0.36	0.0	603	653	15.2	102	8.3
2	12.21	0.074	0.36	0.0	604	1095	9.1	74	5.5
5	12.25	0.111	0.34	0.0	787	839	11.9	87	4.8
4	12.18	0.102	0.36	0.0	751	795	12.5	90	6.5
7	12.25	0.097	0.35	0.0	765	914	10.9	83	3.0
1	11.58	0.014	0.46	3.5	311	3140	3.0	38	2.3
2	11.92	0.022	0.45	4.0	465	2119	4.6	50	1.5
7	11.90	0.028	0.45	4.2	531	1772	5.5	56	2.7
8	12.25	0.070	0.38	4.6	672	1057	9.4	76	3.3
3	11.98	0.012	0.52	4.7	432	2870	3.4	41	2.2
4	11.46	0.011	0.51	5.1	438	3112	3.0	38	2.2
6	12.25	0.036	0.44	7.1	710	1487	6.7	62	3.7
3	12.22	0.029	0.46	7.2	575	1687	5.9	58	2.5
9	12.45	0.027	0.47	8.0	813	1656	6.1	58	3.8
2	11.62	0.007	0.53	8.6	378	4	2.3	32	1.7
8	11.92	0.014	0.51	9.6	591	2471	3.9	45	2.2
3	11.56	0.004	0.60	9.7	369	5043	1.9	27	1.2
9	12.05	0.011	0.53	12.1	657	2979	3.3	39	1.8
6	12.01	0.014	0.50	12.5	558	2706	3.6	42	1.7
9	11.71	0.004	0.59	14.2	628	4970	1.9	27	1.3
7	11.60	0.008	0.54	14.3	468	3416	2.8	36	2.3
8	11.65	0.005	0.58	18.3	476	4246	2.2	30	1.8
6	11.70	0.004	0.61	19.3	444	4855	2.0	27	1.7
1	12.25	0.184	0.31	0.0	785	579	17.2	107	9.3
2	12.22	0.106	0.32	0.0	986	971	10.2	79	7.2
4	12.25	0.115	0.33	0.0	961	839	11.9	87	11.3
5	12.30	0.138	0.31	0.0	805	784	12.8	90	12.2
8	12.25	0.094	0.34	0.0	824	956	10.4	80	4.8
7	12.22	0.114	0.34	0.0	733	819	12.1	88	5.3
V7	12.10	0.012	0.51	3.0	340	2952	3.3	40	1.7
V4	12.20	0.008	0.53	3.3	797	3866	2.6	33	2.3
V2	12.10	0.008	0.51	3.9	387	4261	2.3	31	1.8
8	11.62	0.008	0.53	4.0	350	3931	2.4	33	2.0
V2	11.92	0.006	0.53	4.8	332	5123	1.9	27	1.5
V4	12.02	0.007	0.52	5.4	573	4894	2.0	28	1.8
V4	12.05	0.006	0.54	5.6	734	4773	2.1	28	1.8
V7	11.85	0.009	0.53	5.9	280	3577	2.7	35	1.7
V5	11.85	0.007	0.54	6.0	584	4394	2.2	30	1.7
V2	12.12	0.007	0.56	6.6	385	3985	2.5	32	1.8
V4	11.85	0.005	0.56	8.0	567	5717	1.7	25	1.3
V2	11.72	0.005	0.54	8.3	265	6008	1.6	24	1.3
V7	11.77	0.006	0.55	8.6	308	4651	2.1	29	1.5
V2	11.95	0.005	0.57	9.0	388	4949	2.0	27	1.5
7	11.60	0.011	0.51	9.0	510	3210	2.9	38	2.0

4	11.65	0.009	0.53	9.2	479	3606	2.6	35	3.3
V5	11.50	0.004	0.58	10.4	417	6565	1.4	22	1.0
V4	11.82	0.005	0.53	10.4	554	5871	1.6	25	1.5
V2	11.75	0.004	0.58	11.3	360	5783	1.7	24	1.3
V2	11.38	0.003	0.58	12.2	242	8200	1.1	19	1.2
V7	11.40	0.003	0.62	14.4	174	6772	1.4	21	1.0
V4	11.52	0.003	0.56	15.5	314	7941	1.2	20	1.2
V4	11.50	0.003	0.61	16.8	528	7812	1.2	19	1.0
V2	11.36	0.003	0.61	17.5	192	7608	1.2	20	0.8
40	12.06	0.007	0.53	2.3	420	4444	2.2	30	3.3
41	12.15	0.007	0.51	2.4	458	4632	2.1	29	3.2
43	12.15	0.008	0.51	2.4	390	4127	2.4	32	3.8
40	11.65	0.006	0.49	6.9	288	6079	1.6	25	2.5
43	11.85	0.006	0.52	8.2	303	5694	1.7	25	2.7
41	11.85	0.005	0.54	9.2	374	6529	1.5	23	2.3
41	11.52	0.003	0.55	12.4	332	8582	1.1	19	1.5
40	11.46	0.003	0.55	15.2	273	8537	1.1	19	1.5
43	11.47	0.004	0.53	18.5	277	7427	1.3	21	1.5
10	11.88	0.015	0.42	1.7	272	3738	2.6	35	2.8
10	12.10	0.025	0.38	1.3	403	3013	3.3	40	2.7
10	12.18	0.037	0.35	0.6	403	2279	4.4	48	2.5
10	11.90	0.007	0.58	11.8	485	3427	2.8	35	1.5
10	12.02	0.011	0.55	12.1	515	2606	3.8	43	1.7
10	12.15	0.015	0.53	7.0	580	2248	4.4	48	1.7
11	11.88	0.019	0.41	1.5	437	3206	3.0	38	2.3
11	12.08	0.028	0.38	0.4	369	2600	3.8	44	3.0
11	12.22	0.036	0.37	0.4	423	2113	4.7	50	3.3
11	11.90	0.008	0.56	11.9	413	3174	3.1	38	1.7
11	12.12	0.029	0.45	0.0	373	1728	5.7	57	4.0
11	12.20	0.016	0.52	5.0	678	2028	4.9	51	1.7
12	12.00	0.021	0.40	1.7	354	3045	3.2	40	2.8
12	12.18	0.028	0.39	1.7	445	2429	4.1	46	3.3
12	12.32	0.043	0.37	0.0	574	1817	5.5	55	3.5
12	11.98	0.010	0.55	6.6	488	2853	3.4	41	1.5
12	12.15	0.017	0.51	4.1	547	2109	4.7	50	1.7
12	12.21	0.023	0.49	2.6	618	1706	5.8	57	1.8
10	11.92	0.012	0.46	3.4	245	3959	2.5	33	2.7
10	12.04	0.016	0.44	0.7	358	3243	3.0	38	3.3
10	12.20	0.024	0.41	0.2	424	2542	3.9	44	3.7
11	11.92	0.014	0.45	1.8	319	3593	2.7	35	2.7
11	12.05	0.021	0.41	1.2	381	2853	3.4	41	3.3
11	12.17	0.024	0.41	0.0	479	2535	3.9	44	3.8
12	11.92	0.018	0.43	1.4	356	2999	3.2	40	3.3
12	12.12	0.029	0.39	0.5	437	2305	4.3	47	3.7
12	12.22	0.049	0.35	0.0	533	1718	5.8	57	4.7
10	11.90	0.009	0.57	2.9	312	2780	3.5	41	1.4
10	12.03	0.020	0.46	1.2	387	2331	4.2	47	2.2
10	12.18	0.041	0.36	0.0	453	1932	5.1	53	4.3
11	11.90	0.016	0.49	3.9	330	2459	3.9	45	3.9
11	12.10	0.022	0.45	0.6	409	2247	4.4	48	3.8
11	12.22	0.042	0.38	0.0	520	1755	5.7	56	3.6
12	11.92	0.035	0.38	0.0	394	2022	4.8	51	2.9
12	12.11	0.040	0.38	0.0	486	1775	5.6	55	5.1
12	12.22	0.064	0.33	0.0	527	1545	6.4	60	5.2
13	11.92	0.010	0.53	20.0	562	2966	3.3	40	1.5
13	12.10	0.016	0.51	4.9	627	2262	4.4	48	2.0
13	12.22	0.023	0.49	5.0	650	1709	5.8	57	1.8
13	12.37	0.036	0.46	1.2	759	1321	7.6	68	2.3

14	11.90	0.015	0.51	6.8	326	2453	3.9	45	1.7
14	12.02	0.021	0.49	5.9	449	1891	5.2	54	1.8
14	12.09	0.033	0.46	5.4	530	1378	7.1	66	2.2
14	12.28	0.052	0.44	1.2	567	1004	9.9	80	5.3
15	11.86	0.019	0.49	5.1	287	2079	4.6	50	1.8
15	12.02	0.032	0.45	4.2	372	1521	6.4	62	2.2
15	12.14	0.042	0.44	2.5	407	1226	8.1	71	2.3
15	12.32	0.065	0.42	0.0	524	925	10.8	84	3.3
8	11.99	0.007	0.58	9.5	642	3271	3.0	37	1.5
8	12.13	0.010	0.56	5.7	687	2547	3.9	44	1.7
8	12.25	0.017	0.53	2.4	700	1937	5.1	53	1.7
16	11.98	0.010	0.56	5.9	417	2680	3.6	42	1.8
16	12.07	0.017	0.52	3.9	488	1950	5.0	53	1.8
16	12.25	0.023	0.51	2.5	528	1582	6.3	61	1.8
17	11.88	0.018	0.51	9.6	323	1953	4.9	53	1.7
17	12.03	0.028	0.48	6.9	396	1516	6.5	62	2.3
17	12.13	0.046	0.45	2.3	487	1095	9.0	76	2.5
18	11.85	0.026	0.49	5.1	282	1543	6.3	61	2.0
18	12.10	0.044	0.44	4.1	350	1146	8.6	74	2.3
18	12.16	0.084	0.40	0.4	358	782	12.7	93	3.5
19	11.56	0.002	0.62	22.6	176	8410	1.1	18	0.5
19	12.00	0.003	0.61	15.2	238	6087	1.6	23	1.0
19	12.25	0.006	0.58	10.5	284	4159	2.4	31	1.3
19	11.65	0.002	0.66	20.9	303	6210	1.5	22	1.0
19	11.96	0.005	0.62	15.3	261	3915	2.5	32	1.5
19	12.26	0.017	0.50	8.2	371	2233	4.5	48	2.2
20	11.66	0.002	0.71	21.9	351	6592	1.4	21	1.2
20	12.01	0.004	0.65	15.5	389	4045	2.4	31	1.5
20	12.33	0.018	0.50	8.5	486	2162	4.6	49	2.3
20	11.65	0.002	0.63	23.1	300	8337	1.1	18	0.5
20	11.98	0.003	0.64	18.0	369	6327	1.5	22	1.0
20	12.29	0.006	0.58	14.1	490	4225	2.4	31	1.3
21	11.50	0.003	0.61	17.3	185	7431	1.3	20	0.7
21	11.92	0.004	0.59	12.1	223	5230	1.9	26	1.0
21	12.25	0.010	0.53	7.0	249	3291	3.0	37	1.5
21	11.58	0.005	0.59	16.0	206	4703	2.0	28	1.7
21	11.98	0.016	0.49	8.0	263	2484	3.9	45	2.0
21	12.20	0.059	0.38	1.9	353	1215	8.2	70	3.3
22	11.60	0.002	0.64	21.9	310	7637	1.2	19	0.7
22	12.00	0.004	0.58	15.3	382	5431	1.8	26	1.0
22	12.30	0.008	0.55	12.3	461	3526	2.8	35	1.3
22	11.65	0.003	0.63	17.7	345	5184	1.8	26	1.5
22	12.00	0.010	0.54	11.5	365	2914	3.4	40	1.8
22	12.30	0.048	0.40	5.2	462	1394	7.2	65	2.5
23	11.50	0.002	0.64	18.9	372	8547	1.1	18	1.2
23	11.82	0.003	0.60	14.2	516	6607	1.5	22	1.8
23	12.15	0.005	0.59	7.7	672	4953	2.0	27	1.8
24	11.48	0.002	0.62	16.5	355	8176	1.1	19	1.2
24	11.80	0.003	0.59	12.8	479	6329	1.5	23	1.5
24	12.11	0.005	0.58	8.6	614	4775	2.1	28	2.3
25	11.54	0.002	0.64	15.2	365	8049	1.2	19	1.2
25	11.80	0.003	0.62	11.6	419	6153	1.6	23	1.5
25	12.10	0.004	0.62	7.9	602	4573	2.2	29	1.8
26	11.42	0.002	0.67	19.4	508	8734	1.1	17	1.0
26	11.85	0.002	0.65	15.7	562	6944	1.4	21	1.3
26	12.15	0.003	0.63	9.8	618	5512	1.8	25	1.8
26	11.62	0.002	0.69	4.3	306	6780	1.4	20	1.2
26	11.92	0.003	0.66	1.1	391	4660	2.1	28	1.3

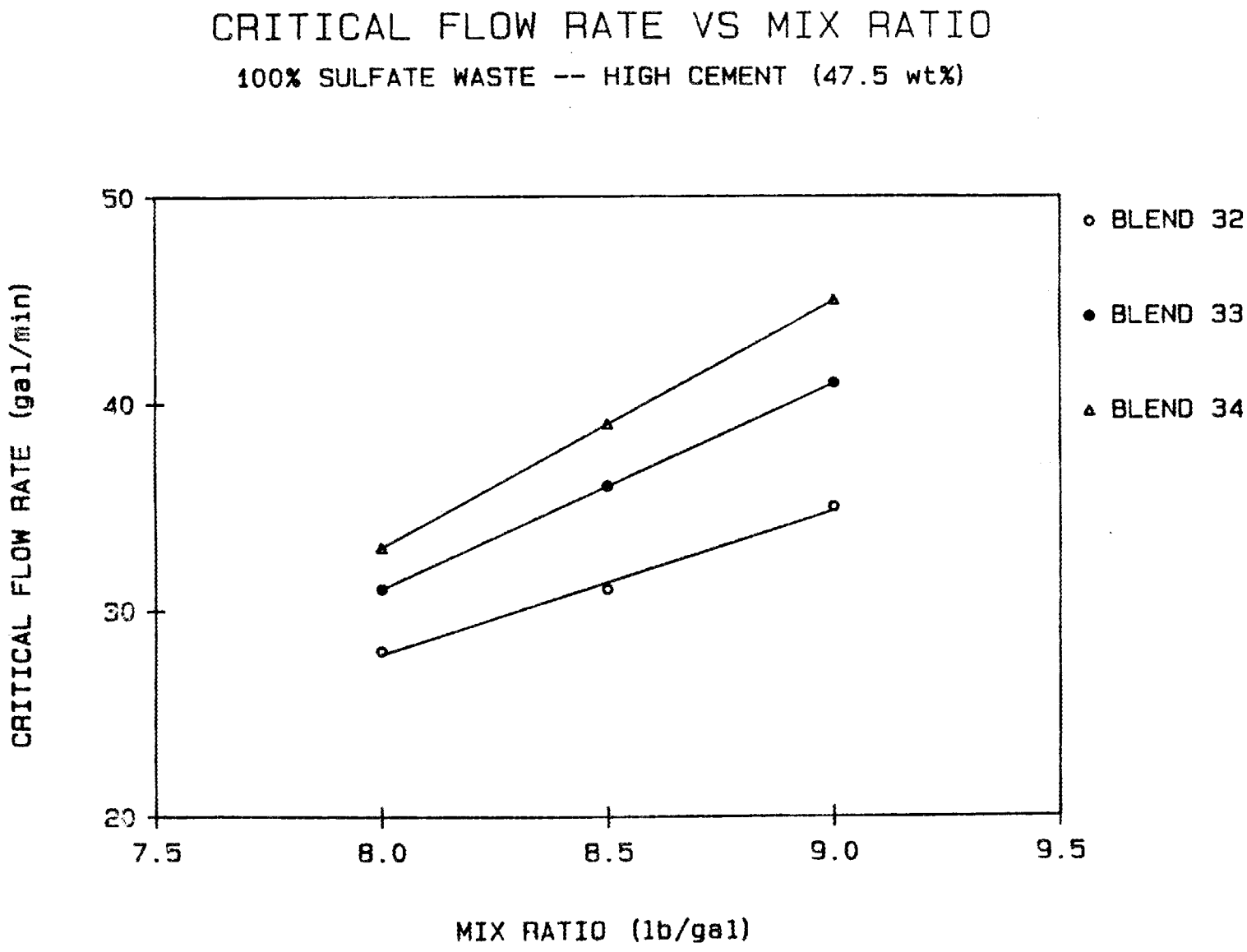
26	12.23	0.008	0.58	0.0	511	2965	3.4	39	2.2
26	11.60	0.003	0.58	5.4	163	7845	1.2	20	2.3
26	11.92	0.006	0.51	2.5	209	5433	1.8	26	3.3
26	12.22	0.013	0.46	0.4	308	3636	2.7	35	4.5
5	11.63	0.002	0.67	5.8	288	5868	1.6	23	1.2
5	11.95	0.005	0.61	1.5	340	3709	2.6	33	1.5
5	12.30	0.017	0.51	0.5	528	2089	4.8	50	2.0
5	11.50	0.005	0.53	7.4	163	6358	1.5	23	2.7
5	11.95	0.010	0.47	2.7	230	4197	2.3	32	4.0
5	12.25	0.021	0.43	0.0	324	2740	3.6	42	5.5
26	11.60	0.001	0.77	22.8	0	8852	1.1	16	0.5
26	11.90	0.001	0.77	15.5	0	6538	1.5	20	0.5
26	12.21	0.002	0.76	11.9	0	4465	2.2	27	1.0
26	11.50	0.001	0.68	16.7	219	11536	0.8	14	1.8
26	11.88	0.002	0.64	11.8	298	8307	1.2	18	2.3
26	12.18	0.003	0.64	6.6	252	6128	1.6	23	3.0
5	11.60	0.001	0.74	17.7	0	7183	1.3	19	1.0
5	11.93	0.002	0.75	13.2	0	4956	2.0	25	0.8
5	12.23	0.004	0.71	8.0	0	2987	3.3	38	1.2
5	11.55	0.001	0.68	14.7	217	10180	0.9	15	2.2
5	11.90	0.003	0.62	10.9	224	7281	1.3	20	2.8
5	12.28	0.004	0.61	6.4	276	5319	1.9	26	4.8
27	11.93	0.005	0.61	3.3	368	3901	2.5	32	1.3
27	12.11	0.007	0.58	0.6	374	3372	2.9	36	1.8
27	12.22	0.013	0.53	0.0	498	2400	4.1	46	2.2
27	11.92	0.006	0.52	3.2	212	5516	1.8	26	3.3
27	12.10	0.007	0.52	0.6	251	4564	2.2	30	4.2
27	12.26	0.010	0.51	0.0	326	3744	2.7	34	5.2
28	11.92	0.007	0.59	3.2	249	3243	3.0	37	1.8
28	12.11	0.011	0.55	0.6	265	2557	3.9	44	2.0
28	12.20	0.029	0.46	0.0	383	1647	6.0	59	2.5
28	11.93	0.007	0.52	3.3	203	4720	2.1	29	3.3
28	12.11	0.012	0.48	2.4	256	3658	2.7	35	4.2
28	12.25	0.015	0.46	0.0	310	3066	3.3	39	4.3
29	11.93	0.013	0.53	0.2	162	2474	3.9	45	2.2
29	12.10	0.029	0.45	0.0	221	1662	5.9	58	2.7
29	12.22	0.054	0.42	0.0	376	1117	8.9	75	2.3
29	11.92	0.010	0.50	0.6	161	3885	2.5	33	4.2
29	12.05	0.013	0.48	0.0	216	3146	3.1	38	4.5
29	12.25	0.022	0.44	0.0	285	2359	4.2	46	5.3
30	11.95	0.004	0.64	3.1	298	4405	2.2	29	1.5
30	12.11	0.005	0.62	1.7	478	3533	2.8	34	1.7
30	12.30	0.007	0.61	1.5	511	3015	3.3	39	2.0
30	11.94	0.005	0.55	5.1	354	5877	1.7	25	3.2
30	12.12	0.007	0.52	2.1	353	4929	2.0	28	4.0
30	12.26	0.009	0.52	0.6	376	3984	2.5	32	5.3
5	11.95	0.007	0.58	3.5	214	3310	2.9	36	1.7
5	12.13	0.011	0.55	1.1	361	2581	3.8	43	2.0
5	12.28	0.023	0.49	0.0	470	1772	5.6	56	2.3
5	11.97	0.009	0.48	5.2	246	4381	2.2	31	4.0
5	12.15	0.013	0.46	1.7	292	3500	2.8	36	4.3
5	12.27	0.020	0.43	0.0	415	2826	3.5	41	4.8
31	11.92	0.017	0.50	3.7	311	2174	4.5	49	1.5
31	12.11	0.037	0.45	1.0	454	1352	7.3	66	2.0
31	12.26	0.057	0.42	0.4	544	1018	9.8	79	2.3
31	11.99	0.010	0.49	2.3	278	3850	2.5	34	2.8
31	12.10	0.015	0.47	0.4	336	3012	3.3	40	3.0
31	12.26	0.024	0.43	0.0	425	2317	4.3	47	3.7

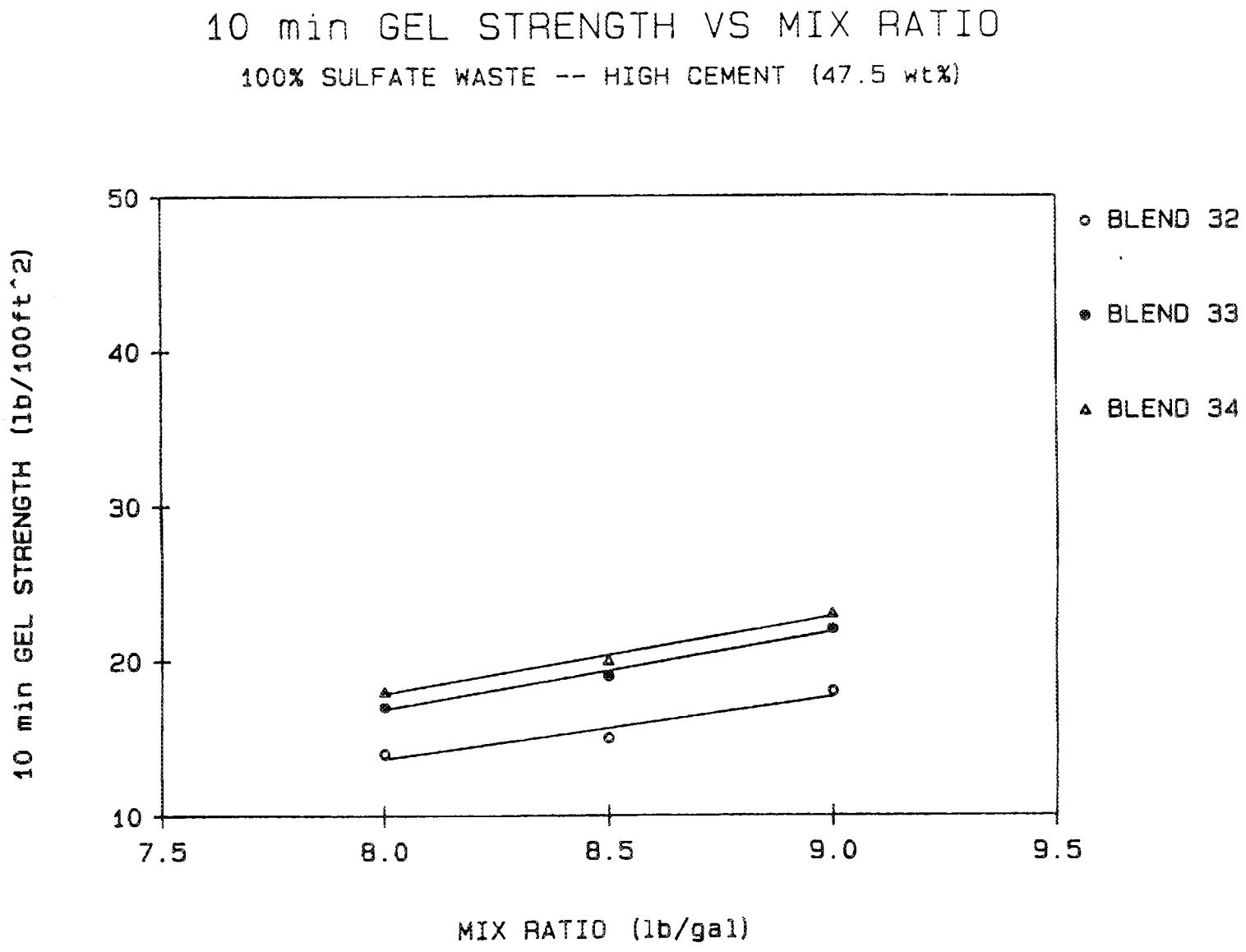
32	12.00	0.004	0.63	6.5	428	4498	2.2	29	1.3
32	12.12	0.007	0.57	5.5	523	3399	2.9	36	1.5
32	12.35	0.009	0.58	5.9	550	2869	3.5	40	1.5
32	11.95	0.007	0.52	5.5	266	4889	2.0	28	2.3
32	12.18	0.009	0.50	3.6	318	4245	2.3	31	2.5
32	12.30	0.012	0.47	1.5	382	3551	2.8	35	3.0
33	12.10	0.008	0.57	7.2	574	3416	2.9	36	1.5
33	12.18	0.014	0.52	5.0	666	2391	4.1	46	1.7
33	12.29	0.024	0.49	3.6	682	1708	5.9	57	1.8
33	11.99	0.009	0.49	1.7	387	4356	2.2	31	2.8
33	12.12	0.012	0.48	1.9	458	3492	2.8	36	3.2
33	12.29	0.017	0.45	0.3	521	2823	3.5	41	3.7
34	12.00	0.013	0.52	6.8	387	2526	3.9	44	1.5
34	12.15	0.020	0.50	4.7	528	1866	5.3	54	1.8
34	12.30	0.036	0.46	2.8	611	1294	7.7	68	2.2
34	12.02	0.010	0.49	2.7	405	2440	4.1	45	3.8
34	12.10	0.016	0.46	1.6	346	3043	3.2	39	3.3
34	12.30	0.021	0.44	0.0	405	2440	4.1	45	3.8
35	11.90	0.004	0.64	3.8	295	3803	2.6	32	1.2
35	12.06	0.009	0.57	2.6	377	2907	3.4	40	1.7
35	12.21	0.017	0.51	1.2	428	2116	4.7	50	2.0
35	11.91	0.006	0.54	2.9	191	5284	1.8	27	2.7
35	12.08	0.006	0.56	2.4	220	4296	2.3	30	3.2
35	12.23	0.009	0.53	0.0	260	3547	2.8	35	3.8
36	11.90	0.011	0.53	2.6	236	2869	3.4	40	1.8
36	12.04	0.021	0.47	1.6	302	2068	4.7	51	2.0
36	12.20	0.046	0.41	0.0	357	1344	7.4	66	2.5
36	11.90	0.008	0.52	2.4	177	4075	2.4	32	1.8
36	12.10	0.009	0.53	1.4	186	3634	2.7	34	3.5
36	12.22	0.013	0.49	0.0	233	2933	3.4	40	4.2
37	11.91	0.013	0.51	2.5	278	2588	3.7	43	2.2
37	12.10	0.023	0.47	0.8	288	1949	5.1	53	2.0
37	12.19	0.057	0.39	0.0	380	1216	8.2	70	2.5
37	11.90	0.008	0.51	3.6	155	4243	2.3	31	2.7
37	12.00	0.011	0.50	1.9	189	3347	2.9	37	3.0
37	12.20	0.014	0.51	0.3	216	2577	3.9	44	3.8
40	12.00	0.008	0.55	5.6	291	3634	2.7	34	1.7
40	12.15	0.013	0.51	4.6	380	2797	3.5	41	1.7
40	12.24	0.020	0.49	3.5	480	2027	4.9	51	1.8
40	12.00	0.007	0.50	4.9	241	4955	2.0	28	2.5
40	12.10	0.009	0.49	3.6	267	4114	2.4	32	3.0
40	12.22	0.012	0.49	2.0	329	3297	3.0	37	3.8
28	12.00	0.005	0.58	6.0	195	4593	2.1	29	2.2
28	12.12	0.006	0.58	2.9	212	3816	2.6	33	2.3
28	11.94	0.006	0.56	6.6	188	4246	2.3	31	1.8
28	12.09	0.007	0.57	5.4	243	3473	2.8	35	2.2
28	11.93	0.006	0.60	8.2	236	3662	2.7	34	1.5
28	12.09	0.011	0.52	5.0	269	2910	3.4	40	1.8
41	11.95	0.015	0.50	3.0	444	2548	3.8	44	1.7
41	12.10	0.021	0.49	3.2	404	1874	5.3	54	2.0
41	12.26	0.035	0.46	1.4	535	1361	7.3	66	2.5
41	11.96	0.009	0.51	2.0	231	4044	2.4	32	2.5
41	12.15	0.013	0.48	1.0	278	3251	3.0	37	3.7
41	12.26	0.020	0.45	0.0	353	2564	3.9	44	4.5
38	11.95	0.007	0.56	5.9	291	3509	2.8	35	1.8
38	12.08	0.017	0.48	4.8	347	2407	4.1	46	2.2
38	12.24	0.032	0.45	2.1	438	1586	6.3	60	2.3
38	11.93	0.007	0.53	4.8	193	4839	2.0	28	2.7

38	12.17	0.008	0.53	4.1	215	3973	2.5	32	3.3
38	12.19	0.014	0.48	1.3	240	3064	3.2	39	3.7
28	11.98	0.013	0.51	8.3	591	2707	3.6	42	2.0
28	12.03	0.015	0.54	6.1	507	2037	4.8	51	2.3
28	12.20	0.039	0.44	2.5	515	1365	7.3	66	2.7
28	11.95	0.009	0.50	1.7	220	4290	2.3	31	4.0
28	12.07	0.010	0.50	0.8	240	3526	2.8	35	5.3
28	12.20	0.015	0.49	0.2	354	2765	3.6	42	7.2
39	11.91	0.015	0.49	4.3	313	2459	3.9	45	2.2
39	12.11	0.024	0.47	3.4	393	1824	5.4	55	2.3
39	12.21	0.037	0.45	0.9	395	1335	7.4	67	2.7
39	11.91	0.010	0.49	3.5	248	4024	2.4	33	3.5
39	12.09	0.014	0.46	0.7	303	3235	3.0	38	4.3
39	12.25	0.020	0.45	0.0	350	2520	4.0	44	5.5
28	11.92	0.020	0.46	0.9	402	2348	4.1	46	2.5
28	12.11	0.052	0.36	0.0	476	1543	6.4	60	3.3
28	11.93	0.008	0.51	1.1	256	4126	2.4	32	5.2
28	12.10	0.012	0.48	0.0	327	3521	2.8	36	5.7
	0.00	0.000	0.00	0.0	0	0	0.0	0	0.0

APPENDIX J

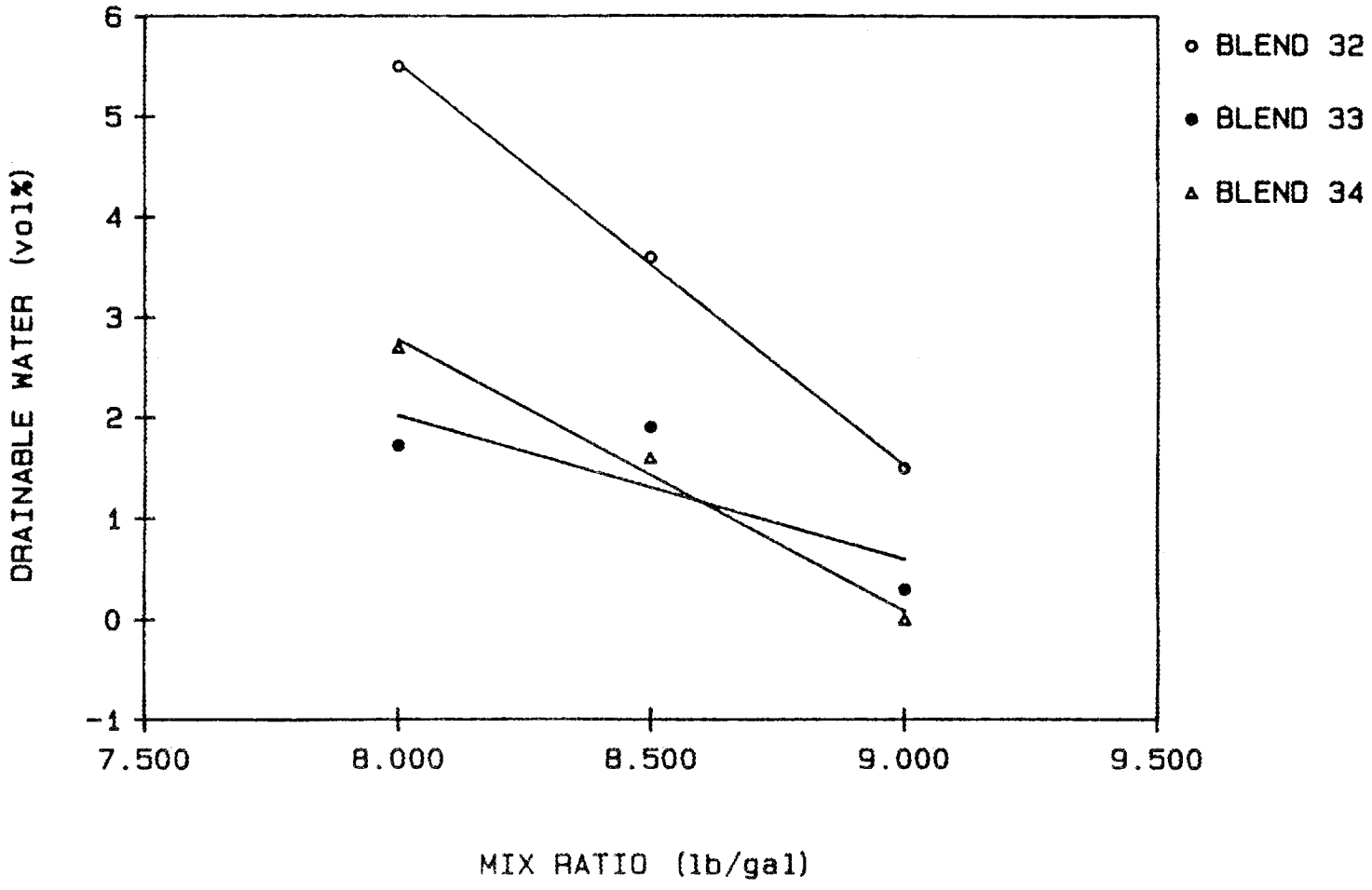
This appendix contains graphical representations of the results from experiments performed using aluminum phosphate (Table 13). The plots illustrate the effect of mix ratio and cement content on the various grout properties.

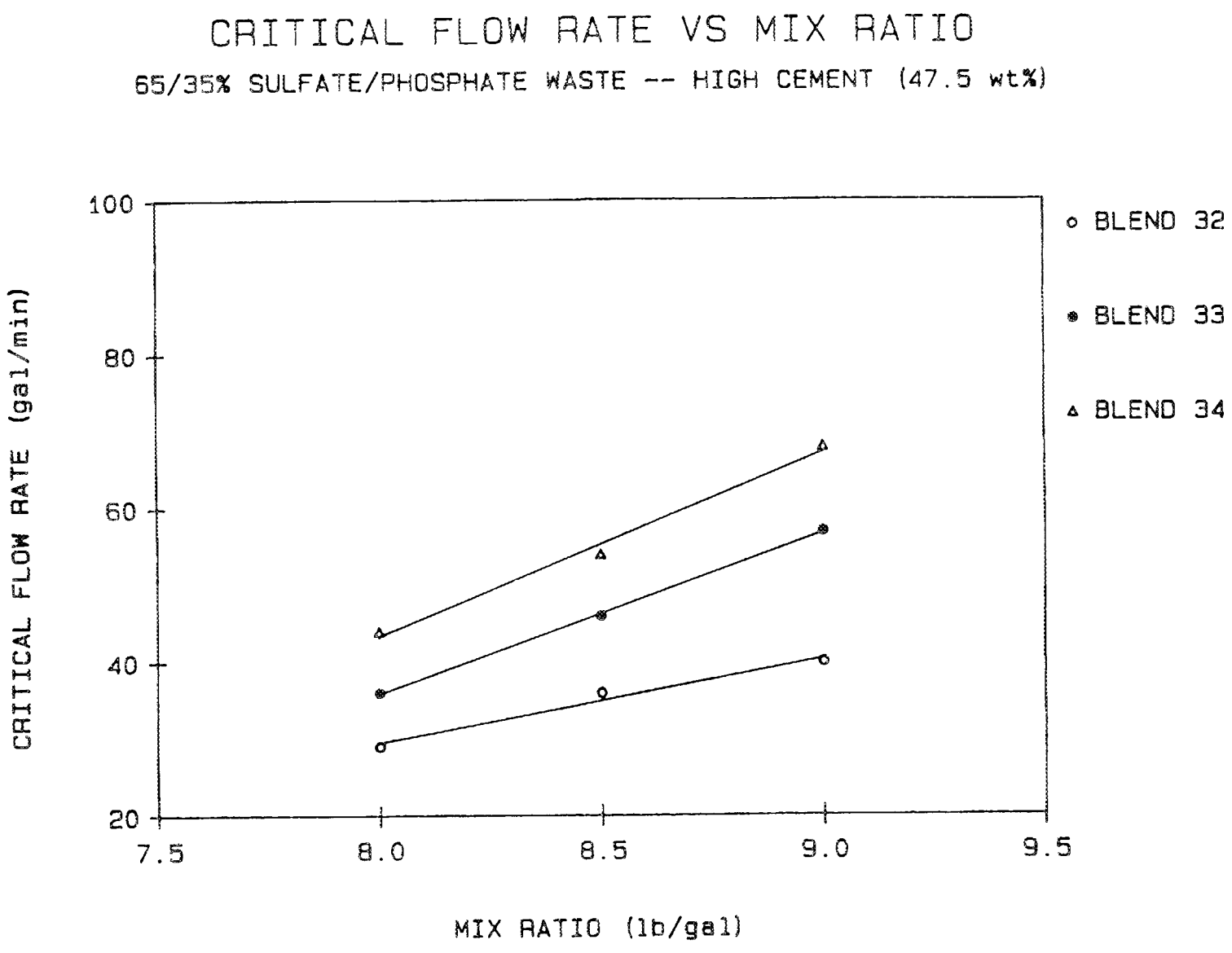

CRITICAL FLOW RATE VS MIX RATIO
100% SULFATE WASTE -- HIGH CEMENT (47.5 wt%)
CRITICAL FLOW RATE (gal/min)
50
40
30
20
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 32
BLEND 33
BLEND 34


10 min GEL STRENGTH VS MIX RATIO
100% SULFATE WASTE -- HIGH CEMENT (47.5 wt%)
10 min GEL STRENGTH (lb/100ft^2)
50
40
30
20
10
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 32
BLEND 33
BLEND 34

DRAINABLE WATER VS. MIX RATIO

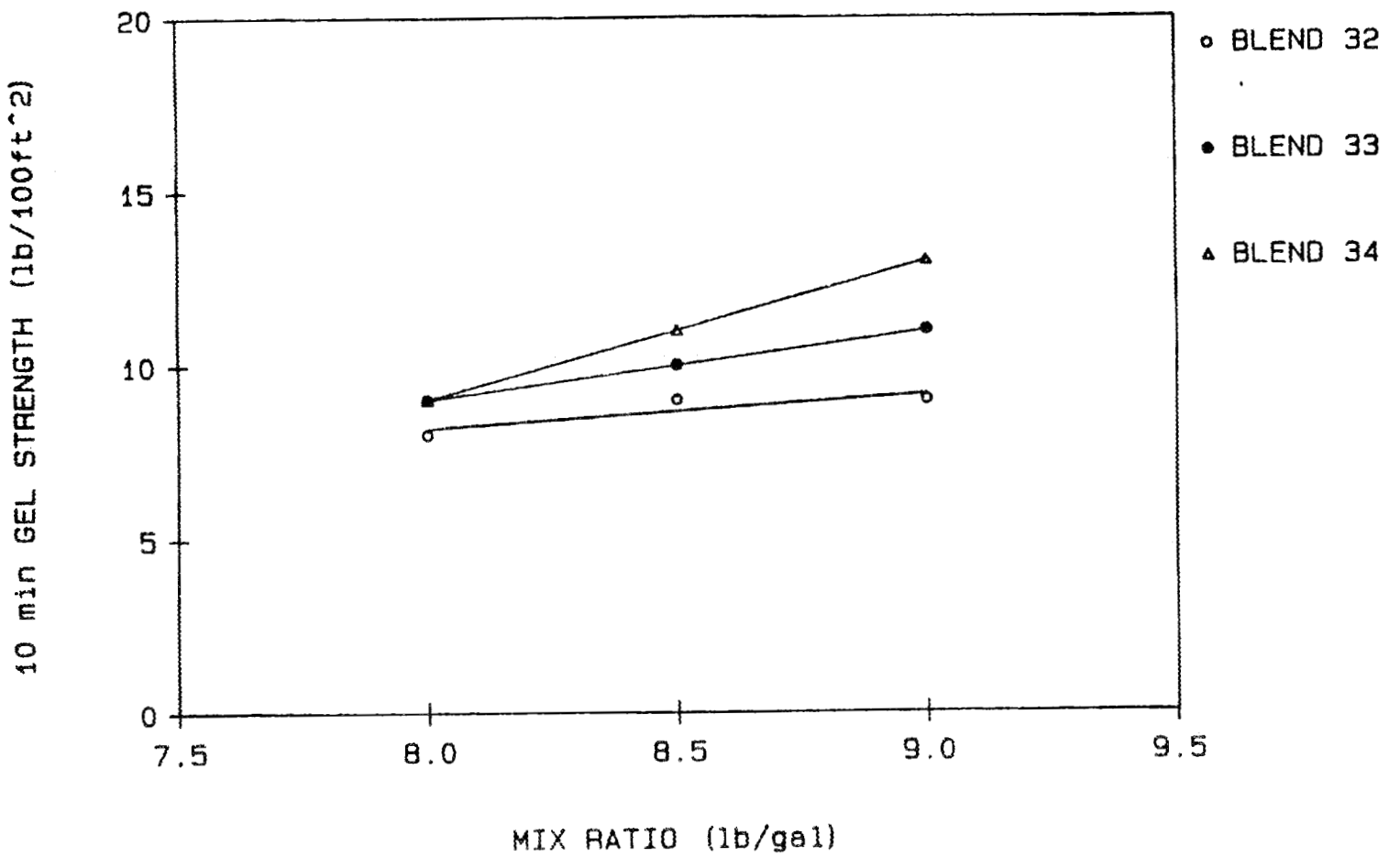
100 % SULFATE WASTE -- HIGH CEMENT (47.5 wt%)




CRITICAL FLOW RATE VS MIX RATIO
65/35% SULFATE/PHOSPHATE WASTE -- HIGH CEMENT (47.5 wt%)
CRITICAL FLOW RATE (gal/min)
100
80
60
40
20
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 32
BLEND 33
BLEND 34

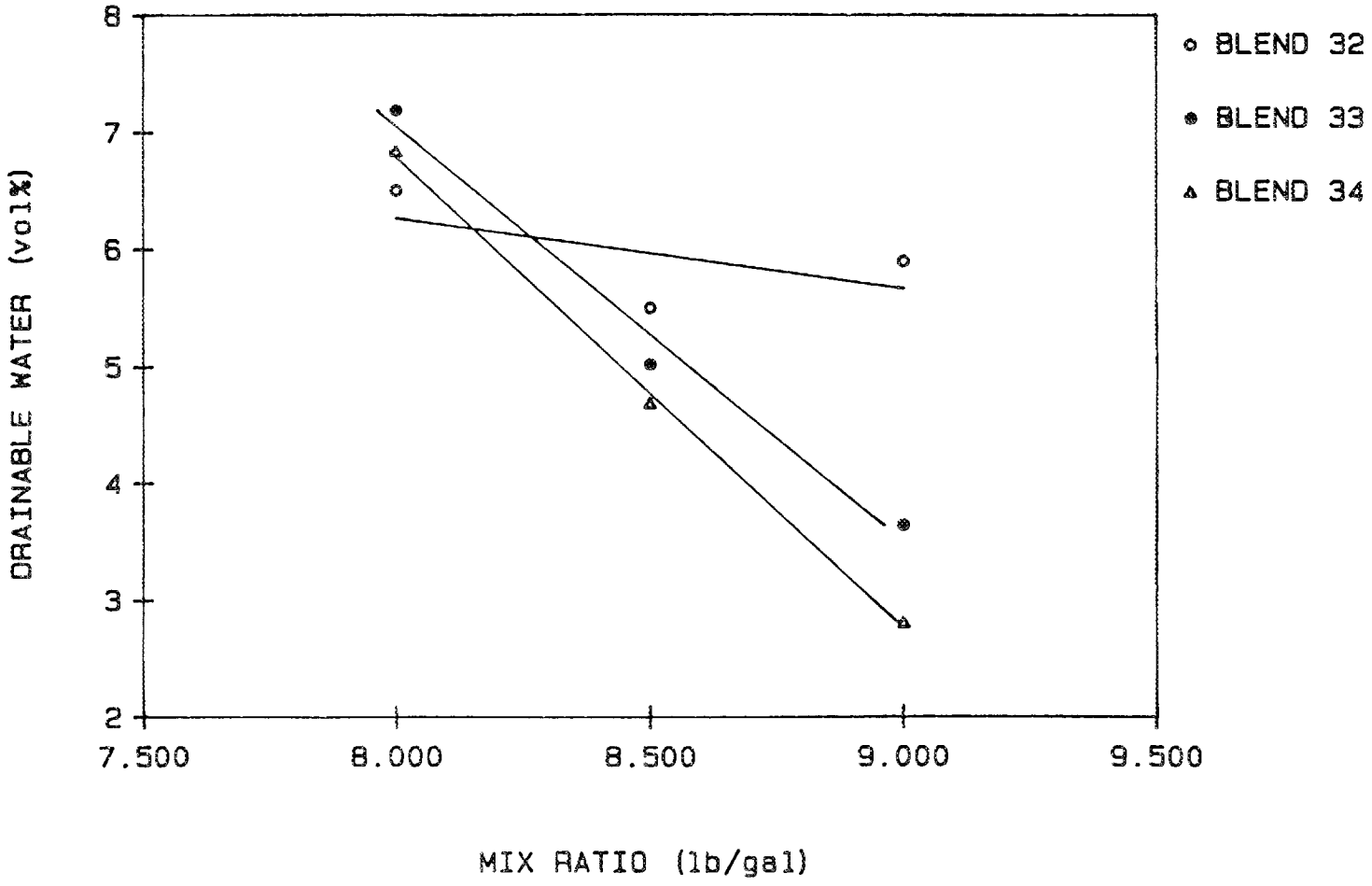
10 min GEL STRENGTH VS MIX RATIO

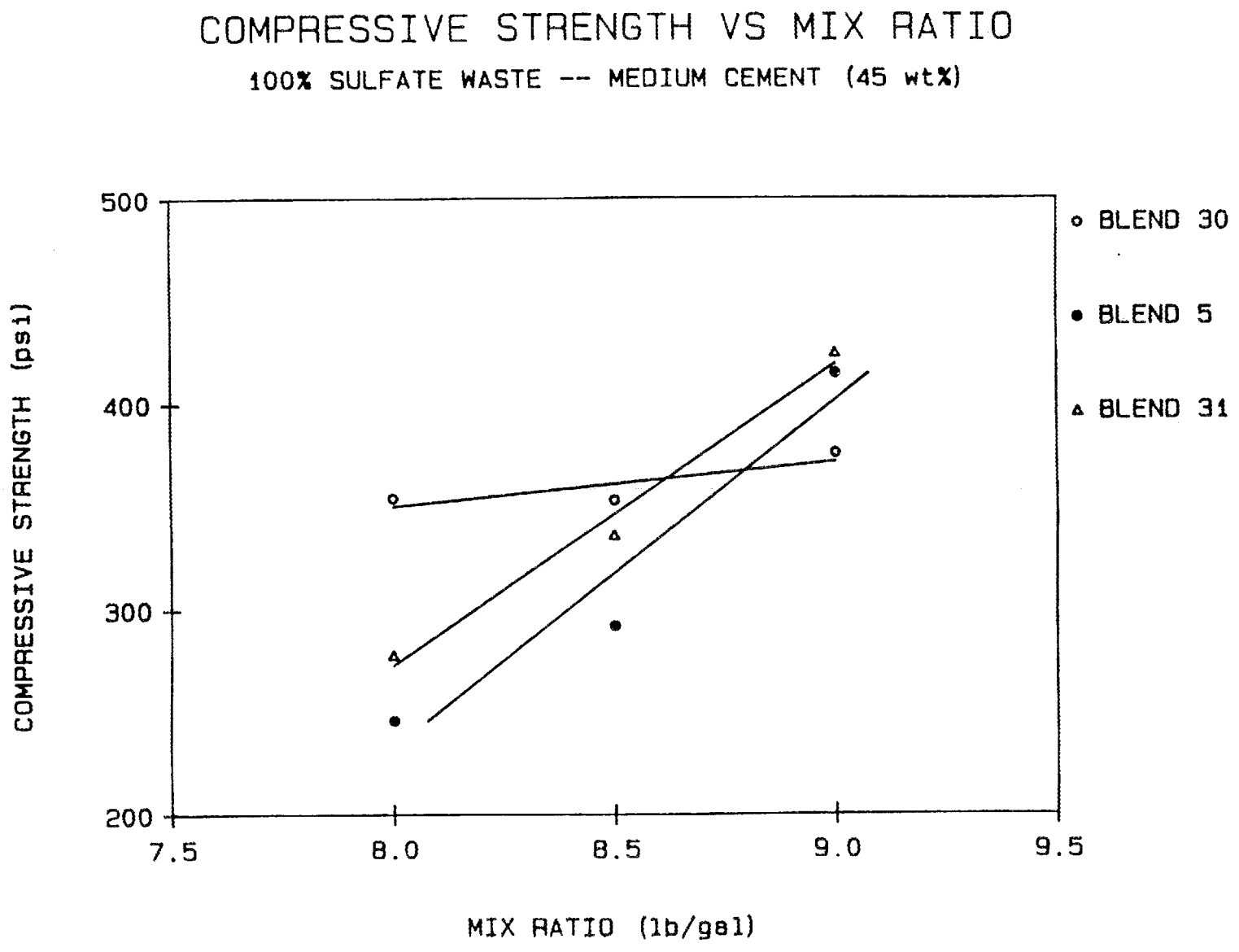
65/35% SULFATE/PHOSPHATE WASTE -- HIGH CEMENT (47.5 wt%)

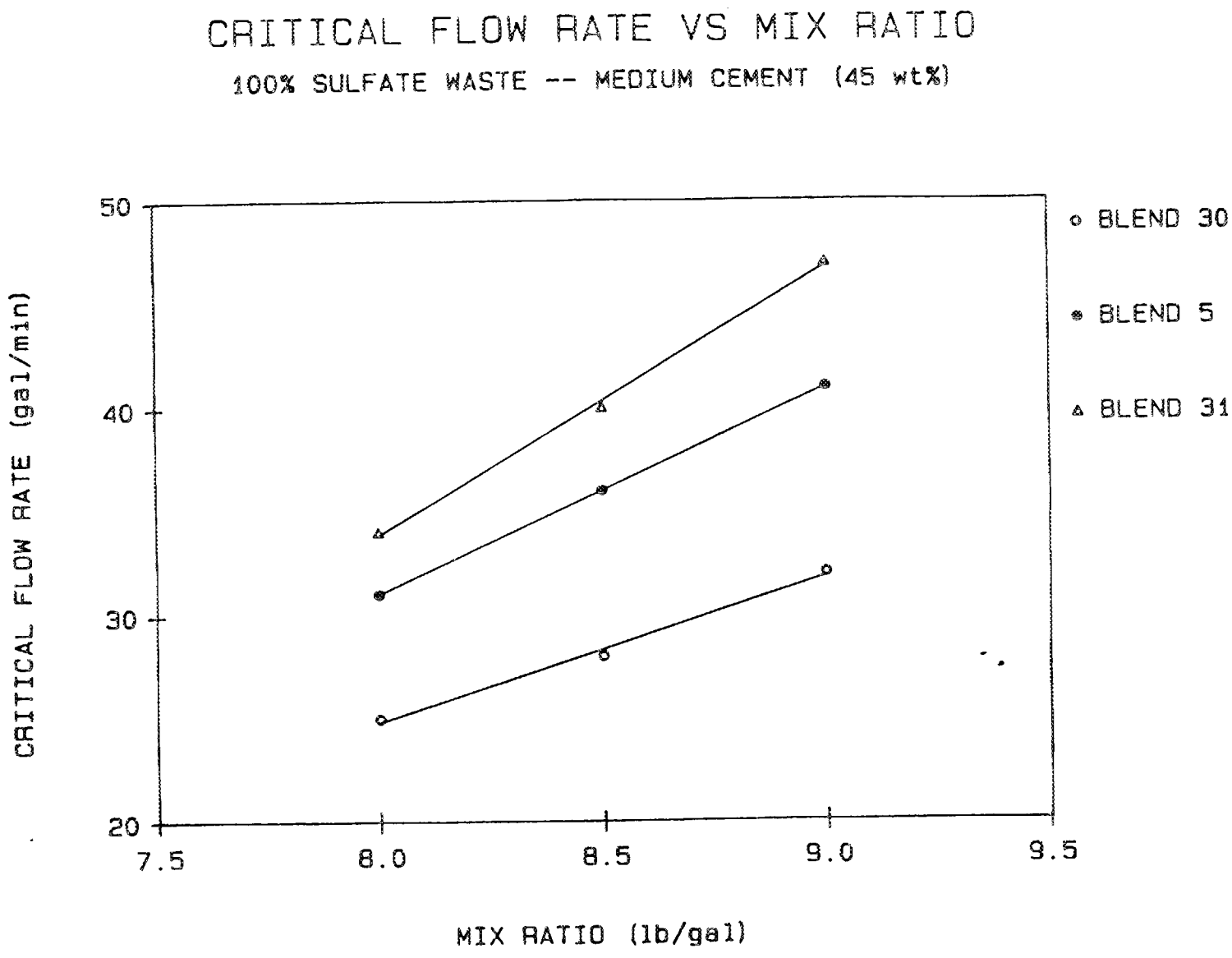


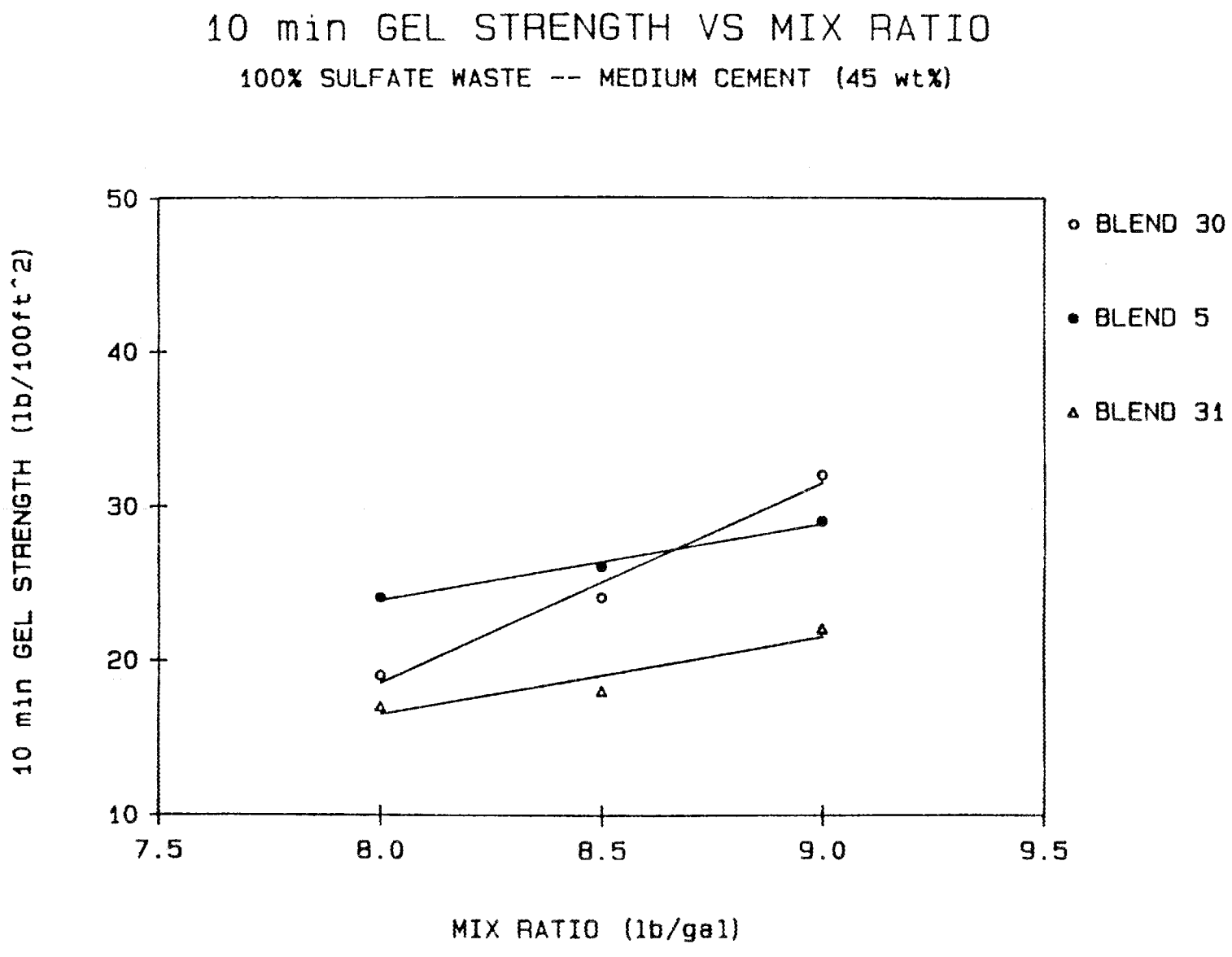
DRAINABLE WATER VS. MIX RATIO

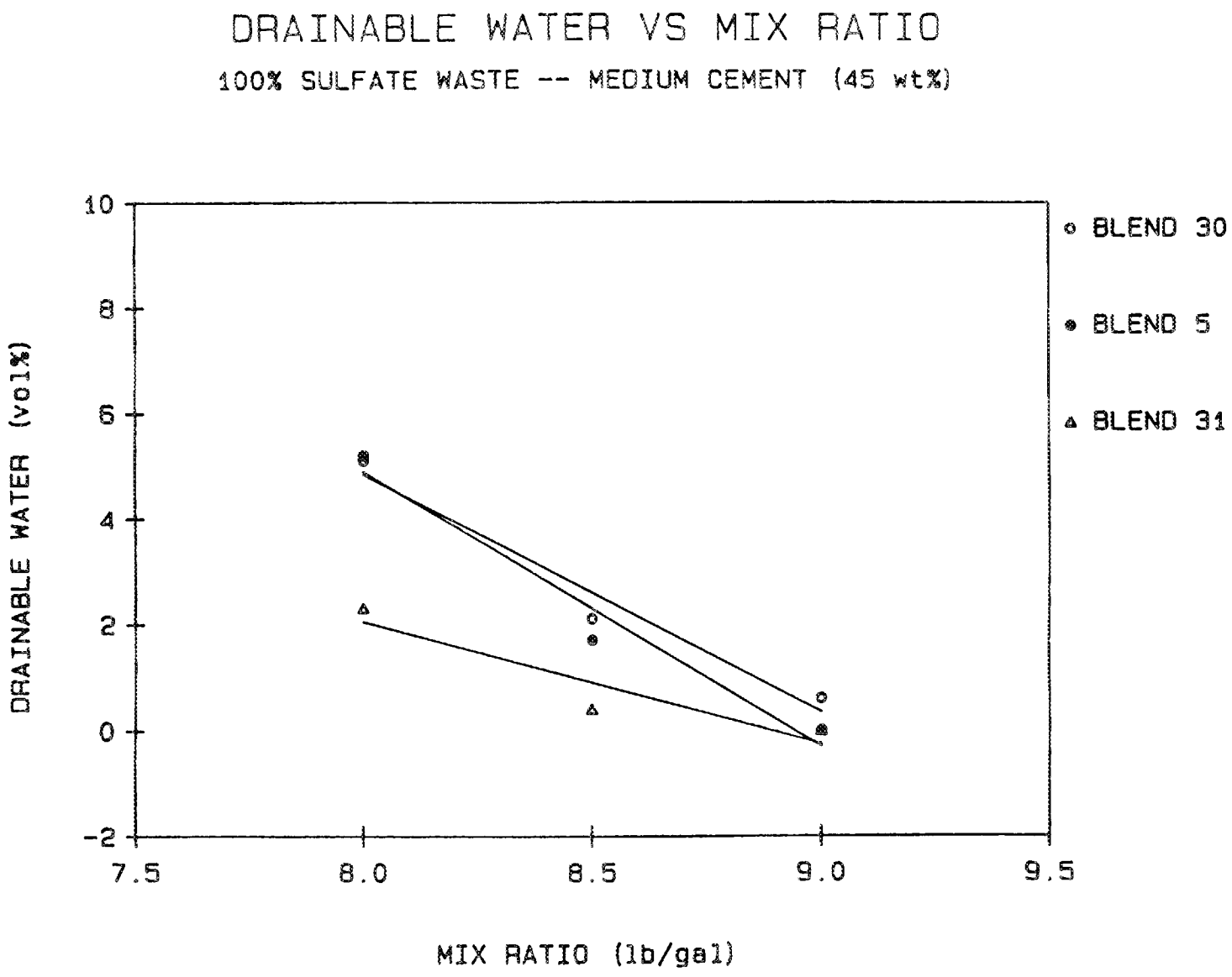
65/35 SULFATE/PHOSPHATE WASTE -- HIGH CEMENT (47.5 wt%)




COMPRESSIVE STRENGTH VS MIX RATIO
100% SULFATE WASTE -- MEDIUM CEMENT (45 wt%)
COMPRESSIVE STRENGTH (psi)
500
400
300
200
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 30
BLEND 5
BLEND 31

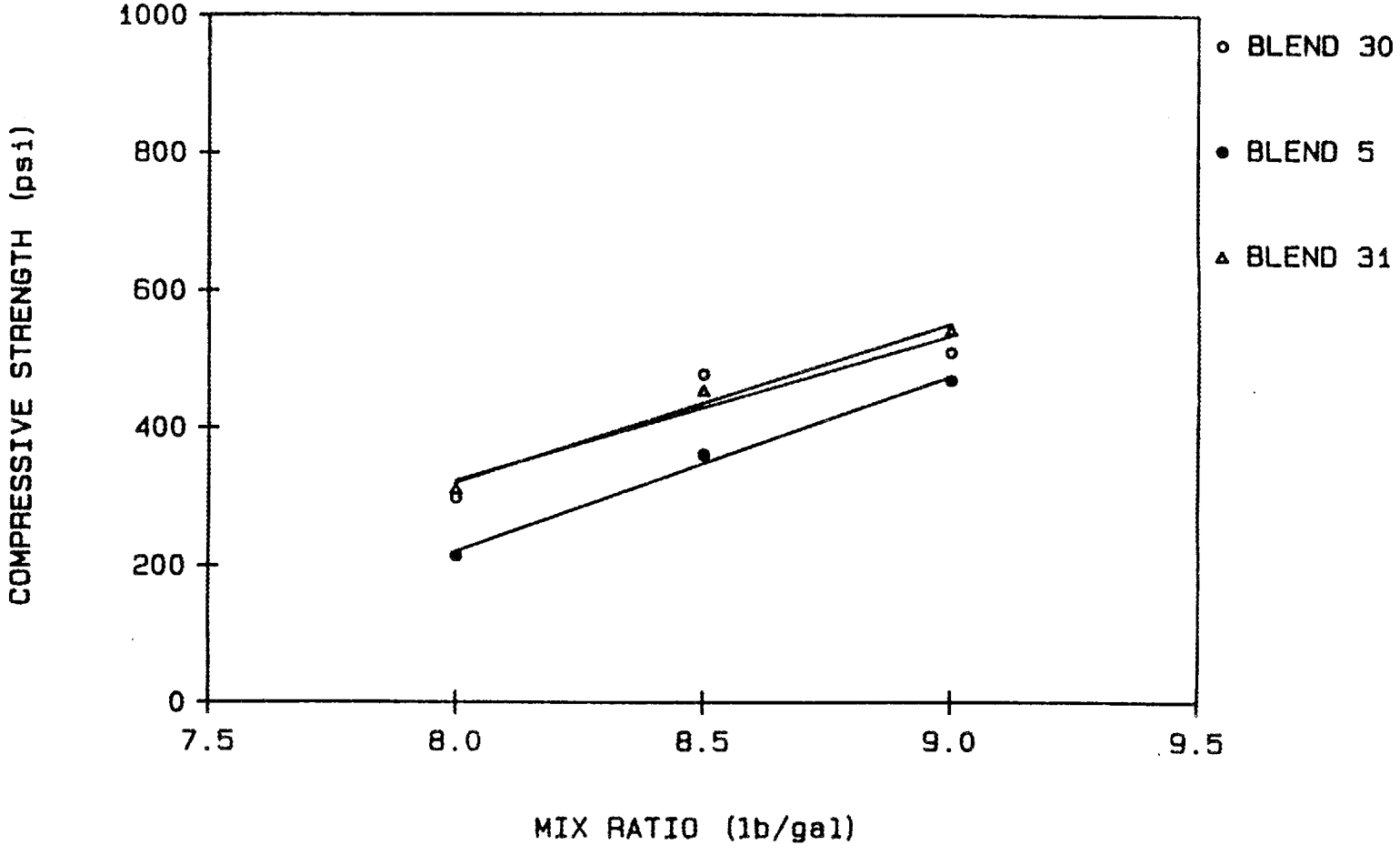

CRITICAL FLOW RATE VS MIX RATIO
100% SULFATE WASTE -- MEDIUM CEMENT (45 wt%)
CRITICAL FLOW RATE (gal/min)
50
40
30
20
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 30
BLEND 5
BLEND 31

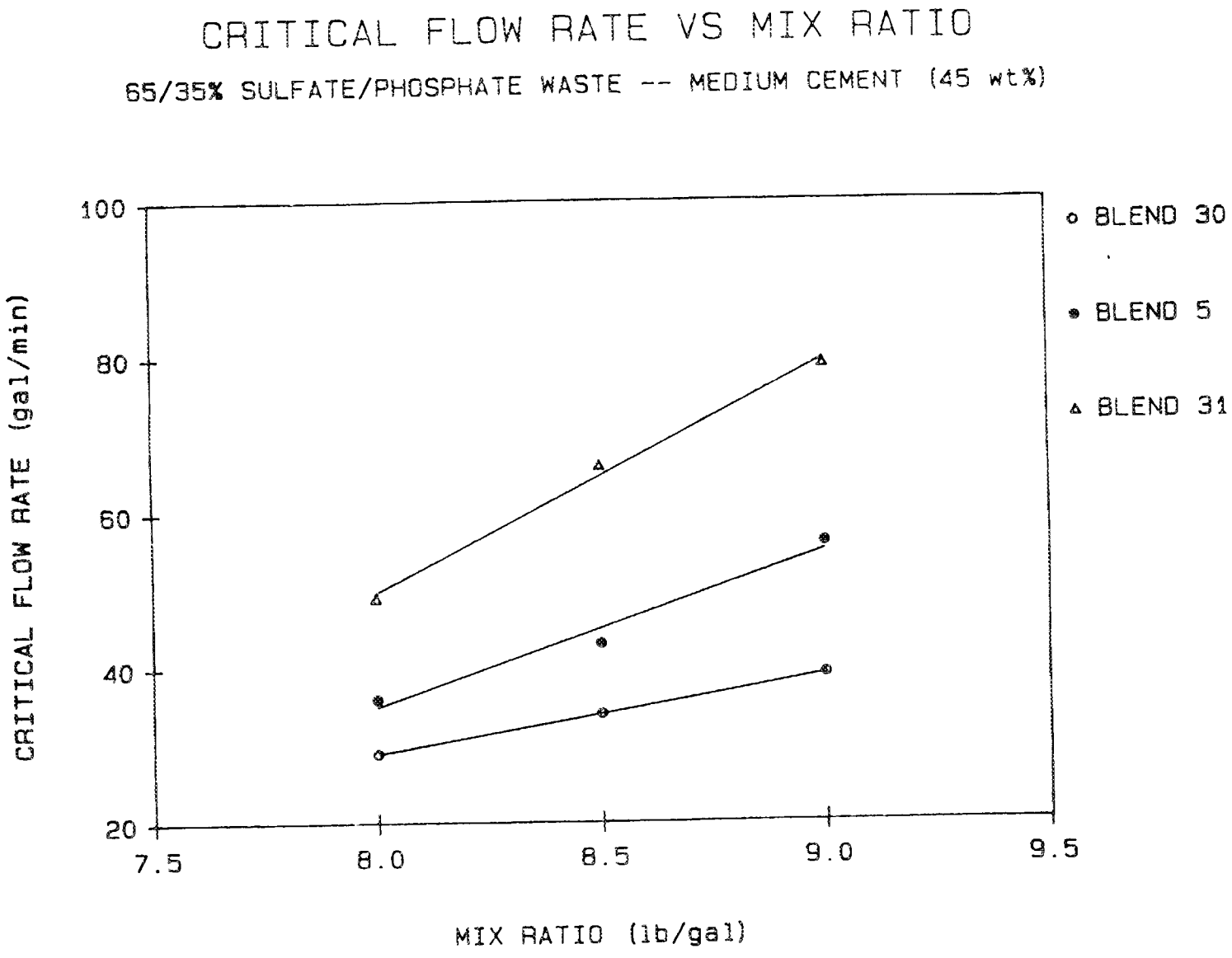

10 min GEL STRENGTH VS MIX RATIO
100% SULFATE WASTE -- MEDIUM CEMENT (45 wt%)
10 min GEL STRENGTH (lb/100ft^2)
50
40
30
20
10
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 30
BLEND 5
BLEND 31


DRAINABLE WATER VS MIX RATIO
100% SULFATE WASTE -- MEDIUM CEMENT (45 wt%)
DRAINABLE WATER (vol%)
10
8
6
4
2
0
-2
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 30
BLEND 5
BLEND 31

COMPRESSIVE STRENGTH VS MIX RATIO

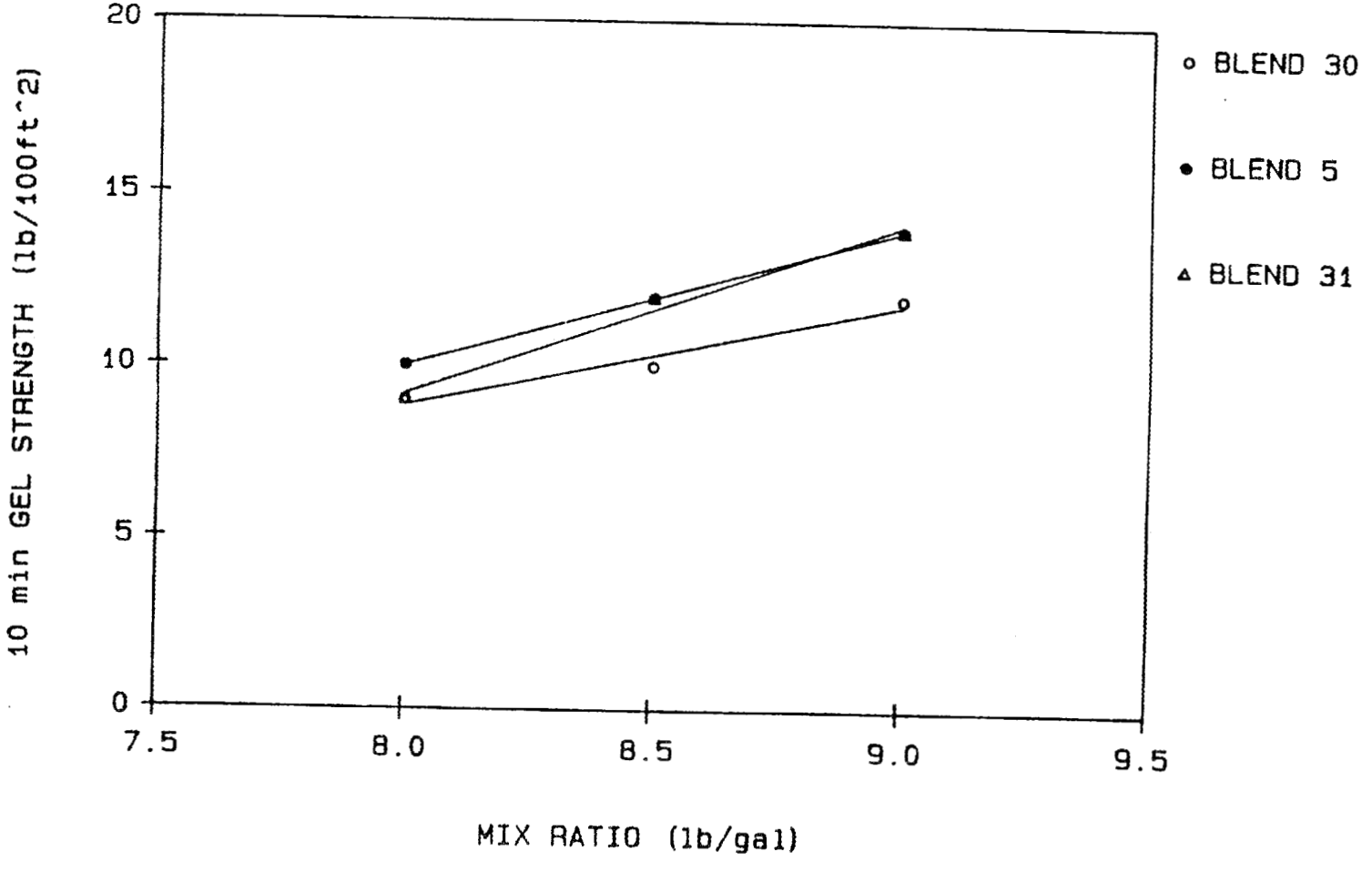
65/35% SULFATE/PHOSPHATE WASTE -- MEDIUM CEMENT (45 wt%)




CRITICAL FLOW RATE VS MIX RATIO
65/35% SULFATE/PHOSPHATE WASTE -- MEDIUM CEMENT (45 wt%)
CRITICAL FLOW RATE (gal/min)
100
80
60
40
20
7.5
8.0
8.5
9.0
9.5
MIX RATIO (lb/gal)
BLEND 30
BLEND 5
BLEND 31

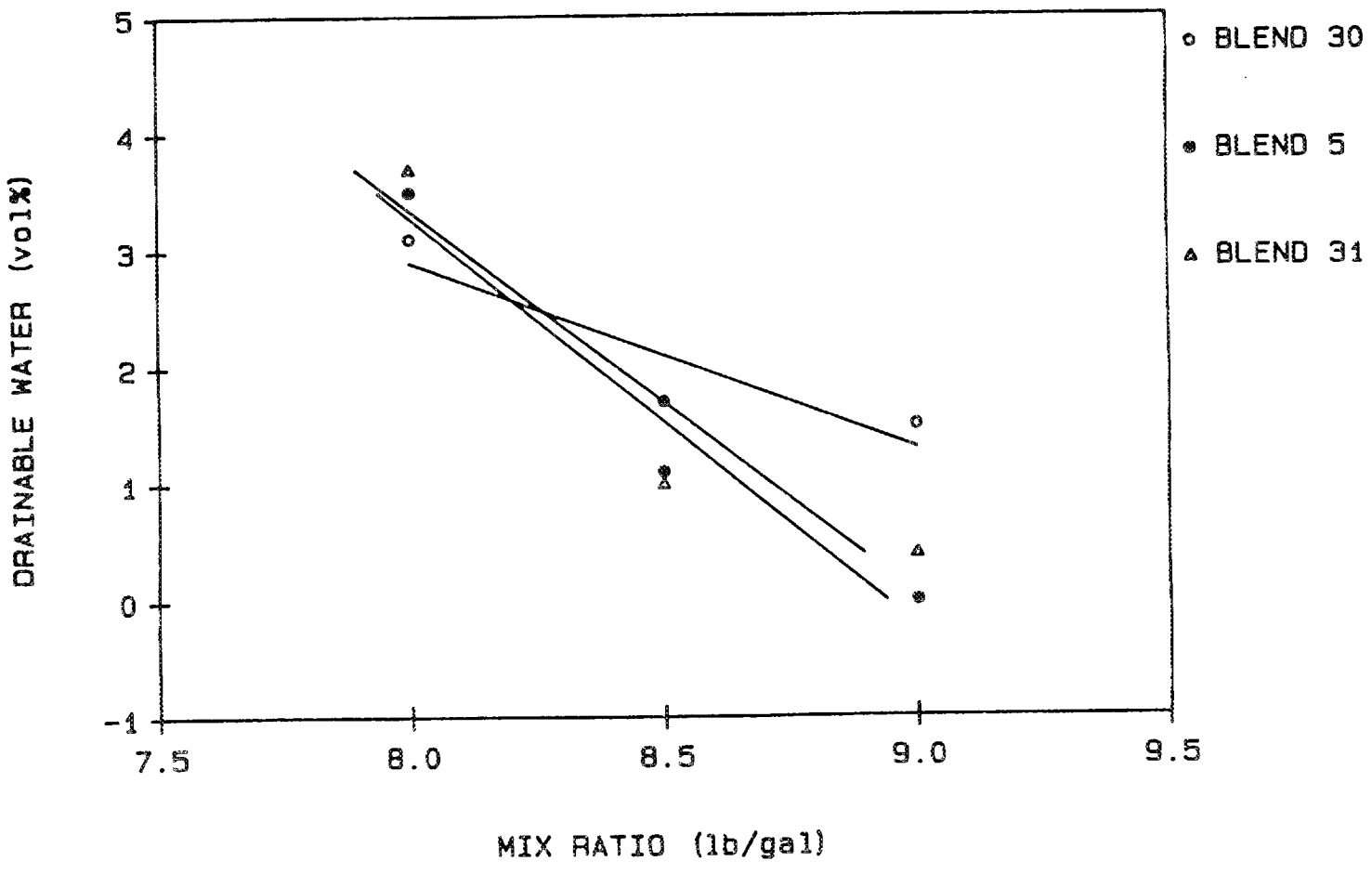
10 min GEL STRENGTH VS MIX RATIO

65/35% SULFATE/PHOSPHATE WASTE -- MEDIUM CEMENT (45 wt%)



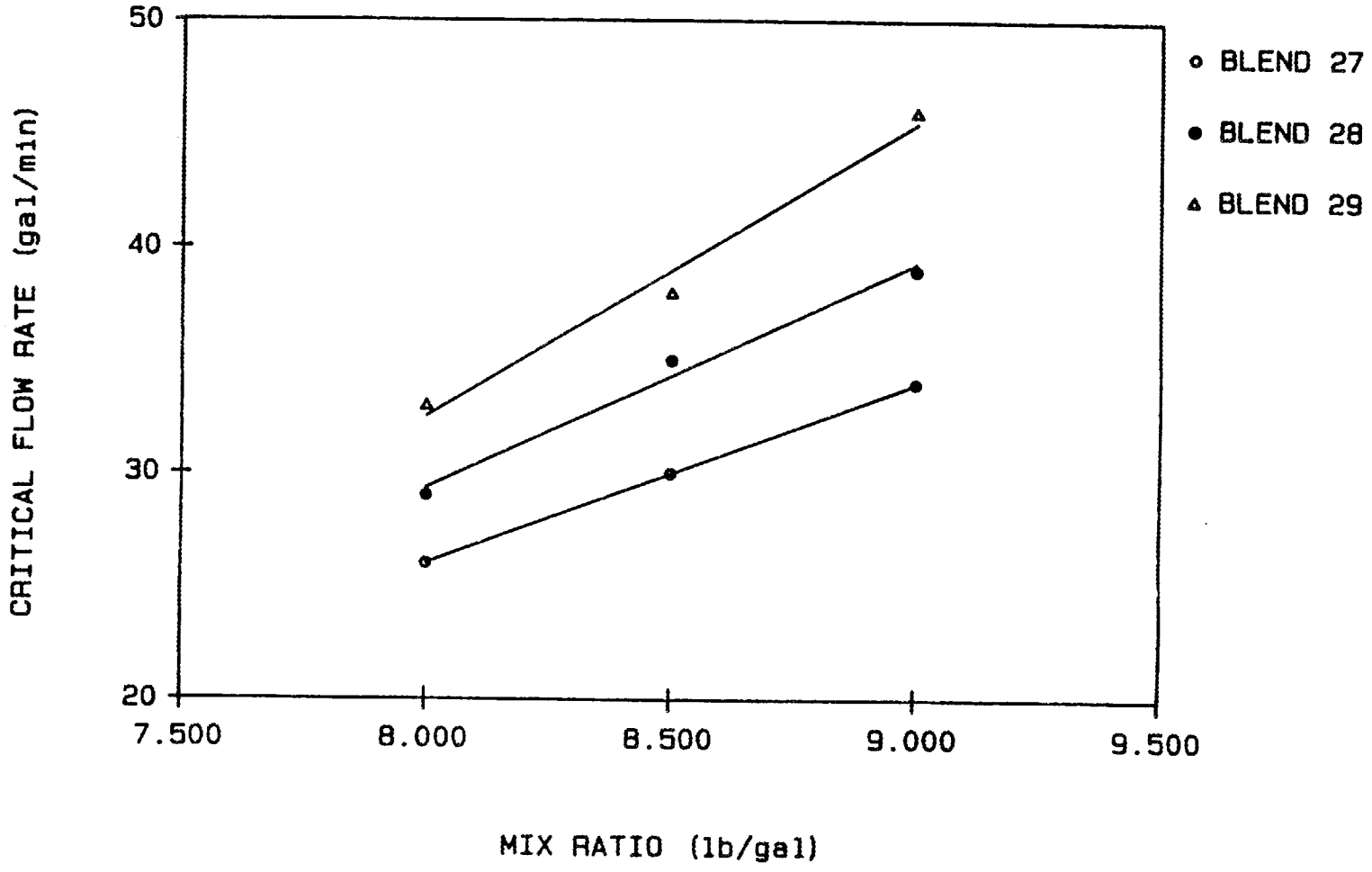
DRAINABLE WATER VS MIX RATIO

65/35% SULFATE/PHOSPHATE WASTE -- MEDIUM CEMENT (45 wt%)



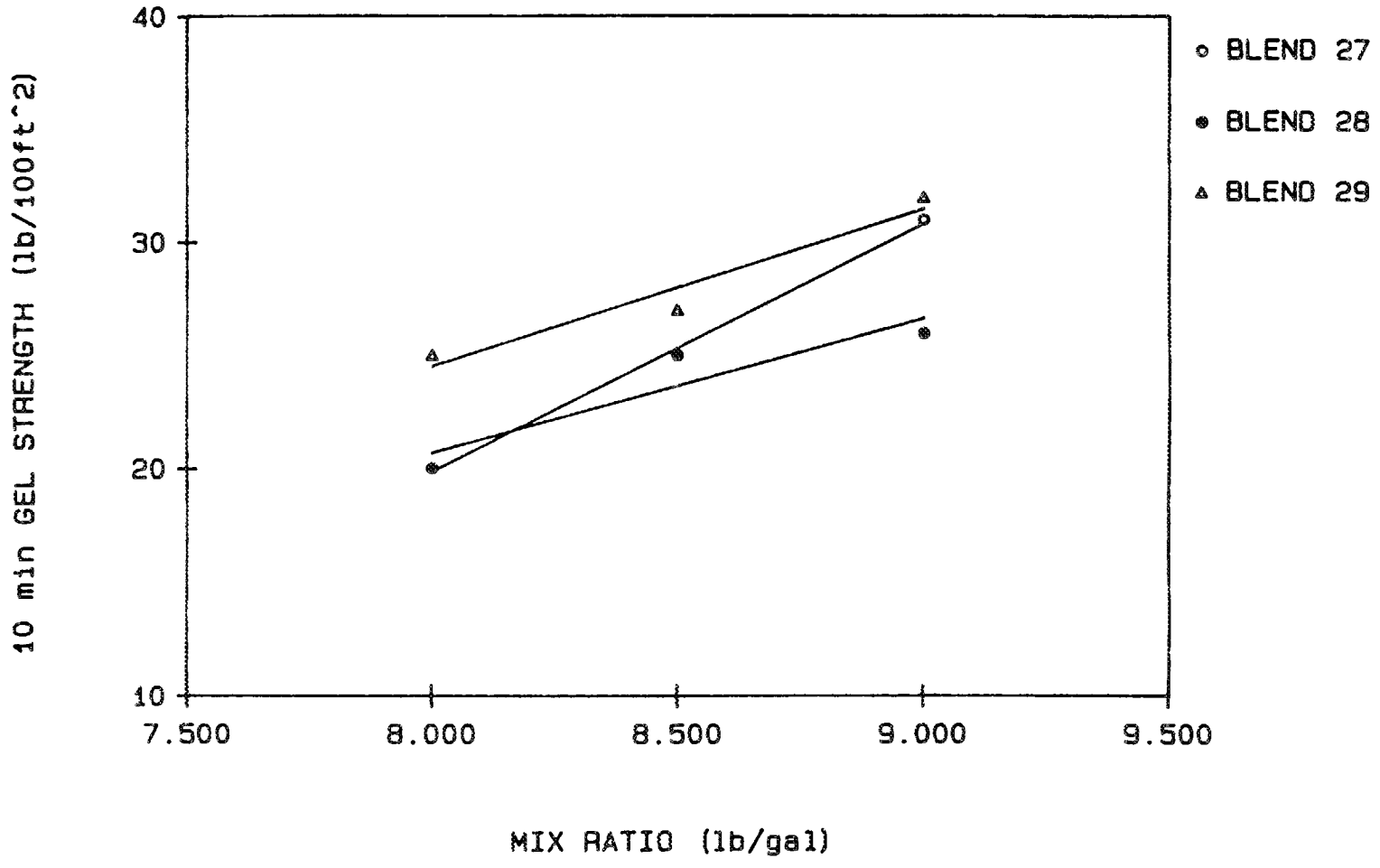
CRITICAL FLOW RATE VS MIX RATIO

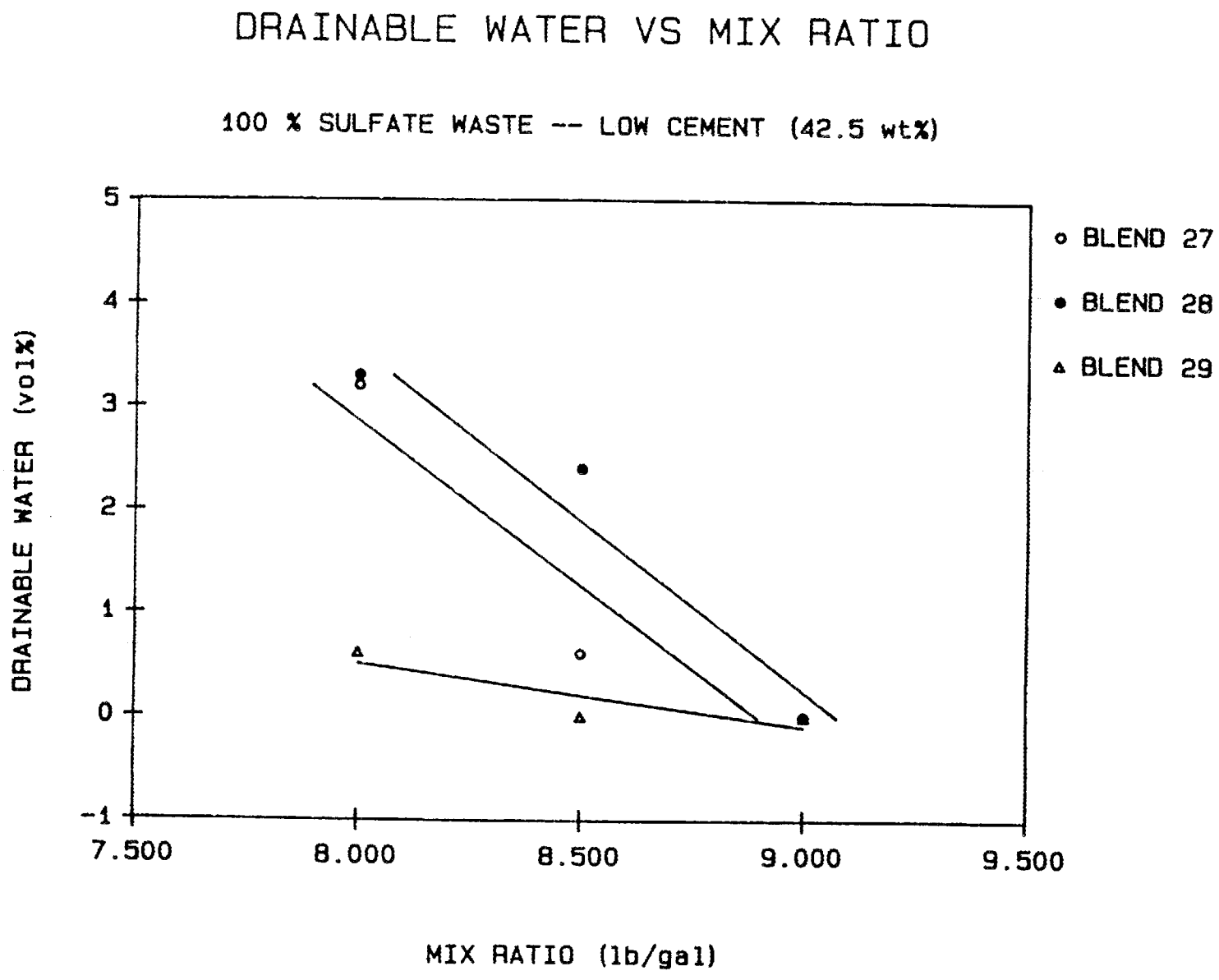
100 % SULFATE WASTE -- LOW CEMENT (42.5 wt%)

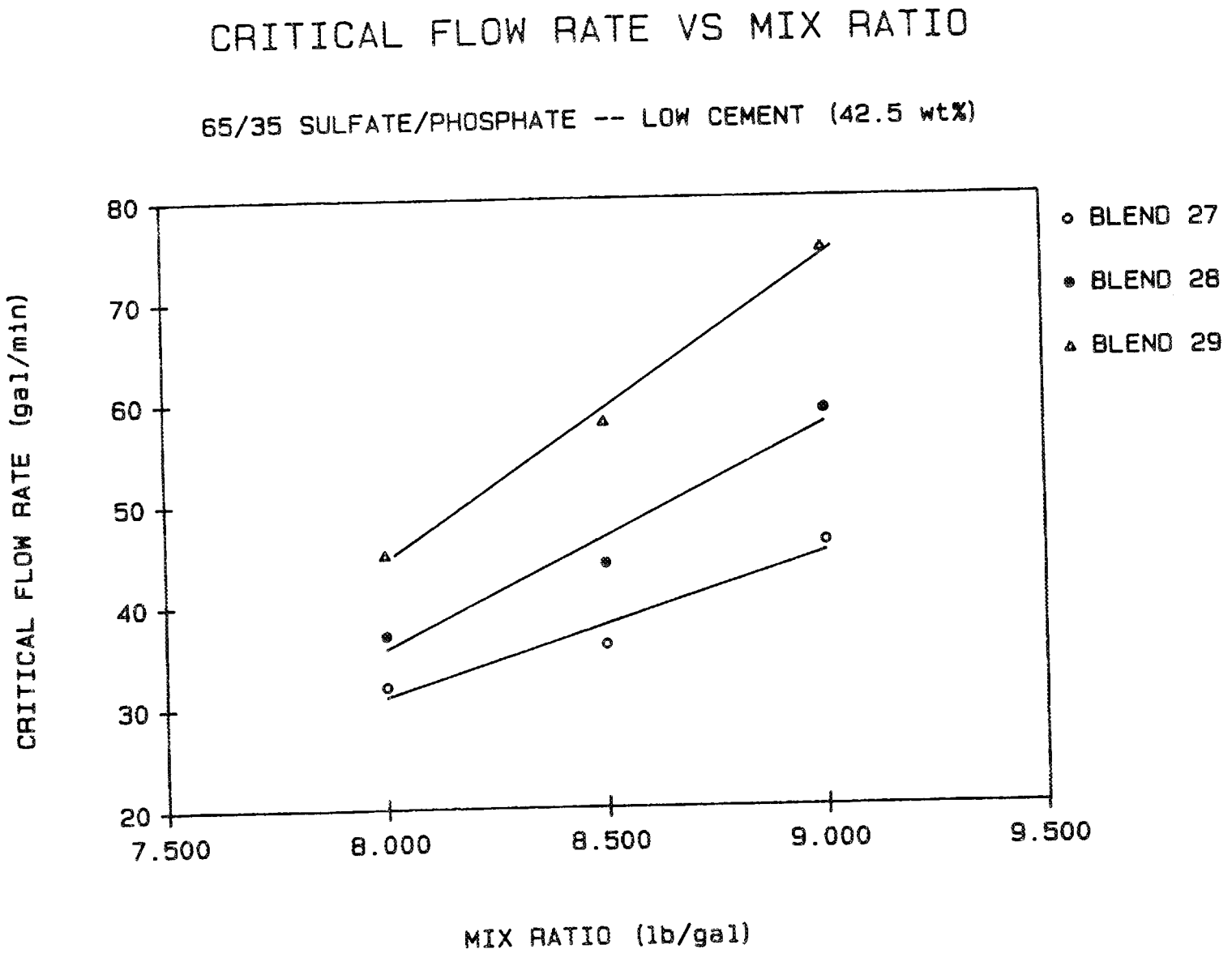


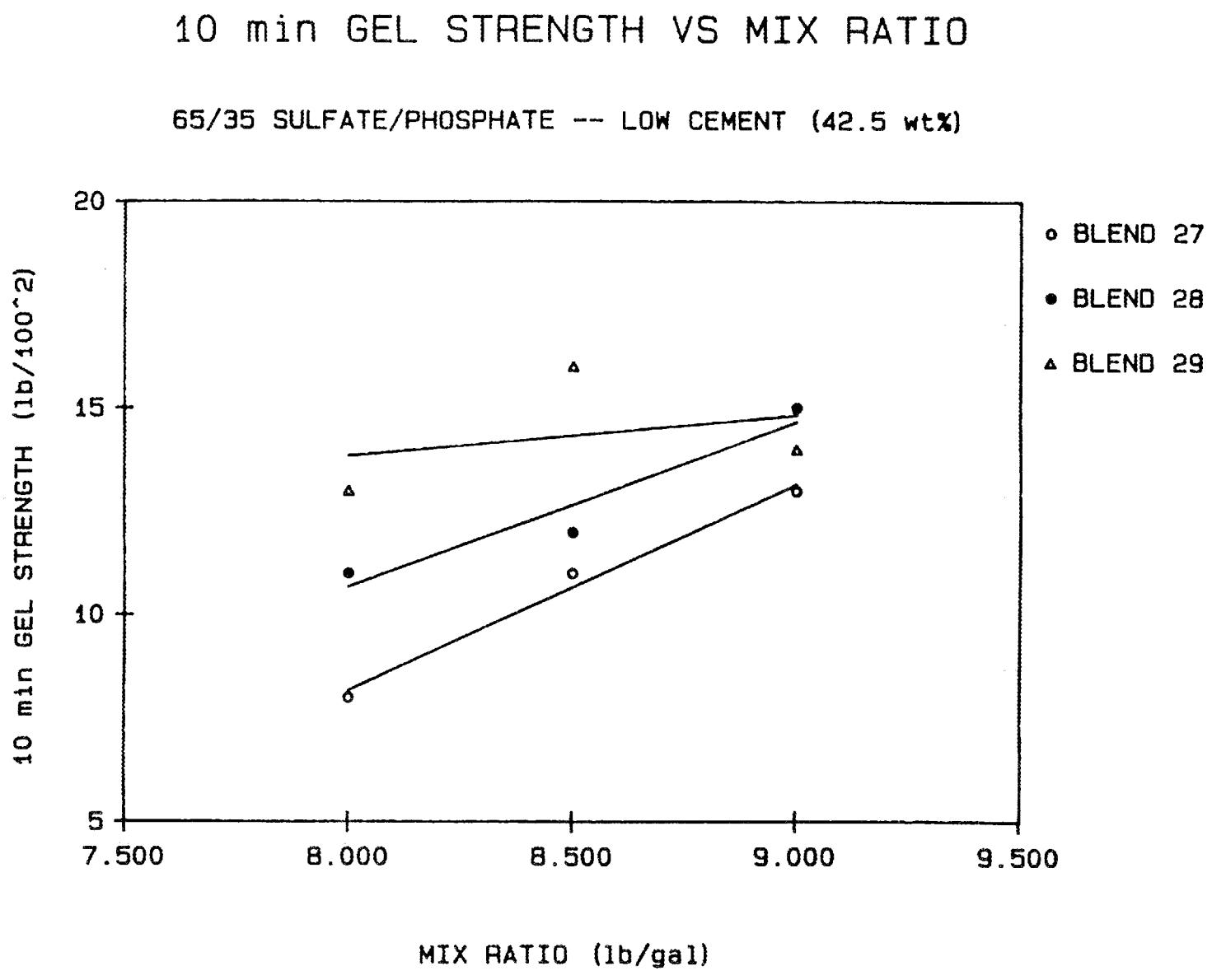
10 min GEL STRENGTH VS MIX RATIO

100 % SULFATE WASTE -- LOW CEMENT (42.5 wt%)



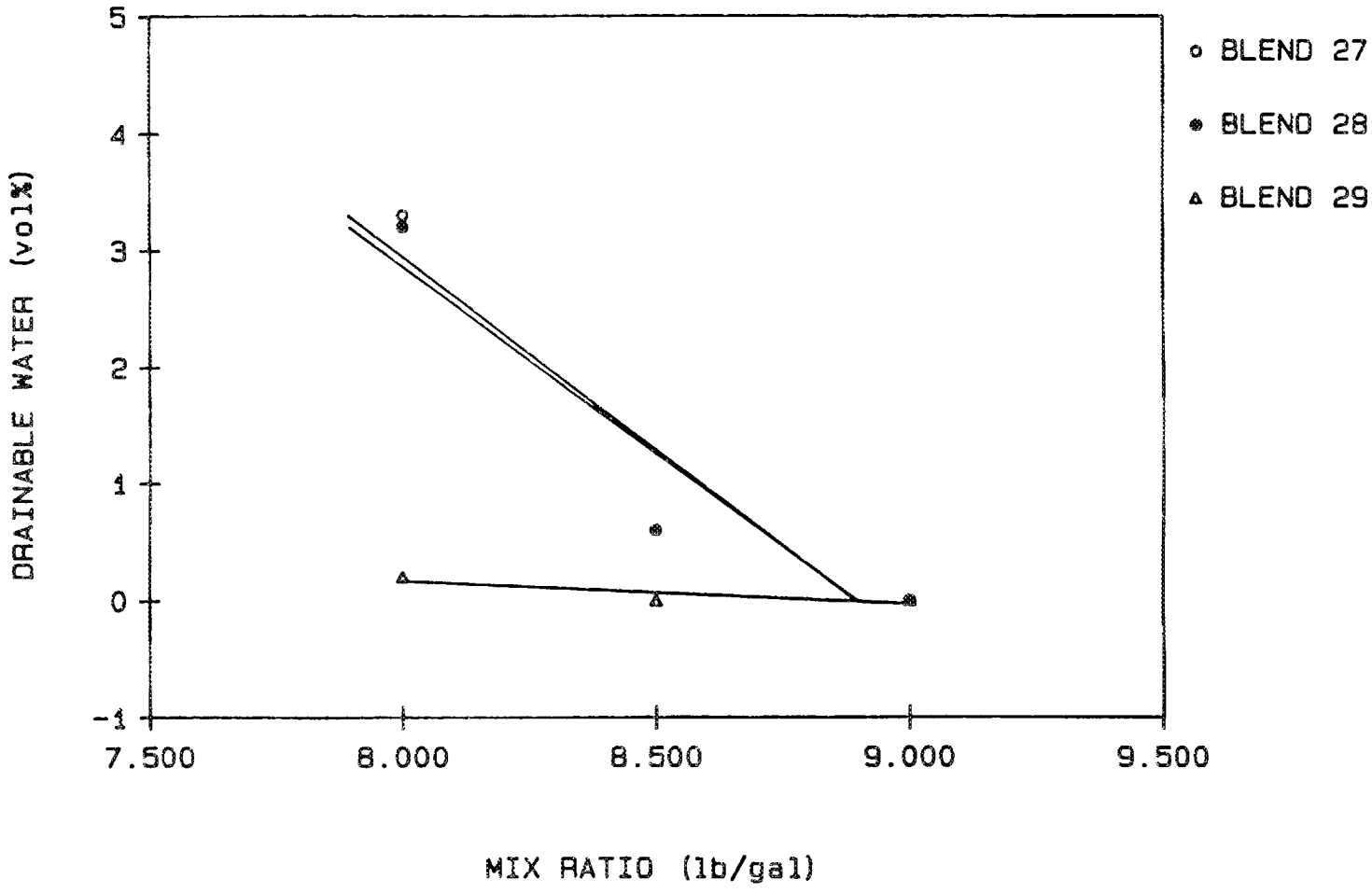

DRAINABLE WATER VS MIX RATIO
100 % SULFATE WASTE -- LOW CEMENT (42.5 wt%)
DRAINABLE WATER (vol%)
5
4
3
2
1
0
-1
7.500
8.000
8.500
9.000
9.500
MIX RATIO (lb/gal)
BLEND 27
BLEND 28
BLEND 29


CRITICAL FLOW RATE VS MIX RATIO
65/35 SULFATE/PHOSPHATE -- LOW CEMENT (42.5 wt%)
CRITICAL FLOW RATE (gal/min)
80
70
60
50
40
30
20
7.500
8.000
8.500
9.000
9.500
MIX RATIO (lb/gal)
BLEND 27
BLEND 28
BLEND 29


10 min GEL STRENGTH VS MIX RATIO
65/35 SULFATE/PHOSPHATE -- LOW CEMENT (42.5 wt%)
10 min GEL STRENGTH (lb/100^2)
20
15
10
5
7.500
8.000
8.500
9.000
9.500
MIX RATIO (lb/gal)
BLEND 27
BLEND 28
BLEND 29

DRAINABLE WATER VS MIX RATIO

65/35 SULFATE/PHOSPHATE -- LOW CEMENT (42.5 wt%)



APPENDIX K

RESULTS OF ACCEPTABLE GROUTS PRODUCED WITHOUT THE USE OF AN ADMIXTURE

This appendix contains the results of acceptable grouts produced without the use of an admixture. Acceptability is based on the new criteria of ≤5 vol % drainable water and a critical flow rate ≤60 gpm.

BLEND#	SULF/PHOS	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
4	100/0	45.0	33.0	6.0	16.0	9.0	31	5
V5	100/0	50.0	28.0	8.0	14.0	9.0	38	17
V5	100/0	50.0	28.0	8.0	14.0	8.5	29	14
8	100/0	50.0	28.0	8.0	14.0	9.0	30	19
6	100/0	45.0	33.0	10.0	12.0	9.0	27	19
V7	100/0	41.0	37.0	8.0	14.0	9.0	27	12
V5	100/0	50.0	28.0	8.0	14.0	8.0	23	12
V4	100/0	50.0	31.0	8.0	11.0	8.5	22	16
V7	100/0	41.0	37.0	8.0	14.0	8.5	15	11
V4	100/0	50.0	31.0	8.0	11.0	9.0	28	17
1	100/0	40.0	38.0	6.0	16.0	9.0	31	20
5	100/0	45.0	33.0	8.0	14.0	9.0	29	18
V2	100/0	41.0	40.0	8.0	11.0	8.5	20	12
7	75/25	50.0	28.0	6.0	16.0	9.0	42	16
V5	75/25	50.0	28.0	8.0	14.0	9.0	22	17
V7	75/25	41.0	37.0	8.0	14.0	9.0	20	14
5	50/50	45.0	33.0	8.0	14.0	7.0	20	13
5	50/50	45.0	33.0	8.0	14.0	8.0	40	17
3	25/75	40.0	38.0	10.0	12.0	7.0	18	11
2	25/75	40.0	38.0	8.0	14.0	7.0	19	23
3	25/75	40.0	38.0	10.0	12.0	9.0	50	40
2	25/75	40.0	38.0	8.0	14.0	8.0	37	36
3	25/75	40.0	38.0	10.0	12.0	8.0	27	23
6	25/75	45.0	33.0	10.0	12.0	7.0	15	23
4	25/75	45.0	33.0	6.0	16.0	8.0	41	32
5	25/75	45.0	33.0	8.0	14.0	8.0	42	32
6	25/75	45.0	33.0	10.0	12.0	8.0	28	24
9	25/75	50.0	28.0	10.0	12.0	7.0	18	11
9	25/75	50.0	28.0	10.0	12.0	8.0	29	24
5	25/75	45.0	33.0	8.0	14.0	7.0	21	23
7	25/75	50.0	28.0	6.0	16.0	8.0	45	17
1	25/75	40.0	38.0	6.0	16.0	7.0	23	31
8	25/75	50.0	28.0	8.0	14.0	8.0	40	19
V4	75/25	50.0	31.0	8.0	11.0	9.0	21	13
V5	25/75	50.0	28.0	8.0	14.0	9.0	28	12
V5	25/75	50.0	28.0	8.0	14.0	8.5	22	12
7	100/0	50.0	28.0	6.0	16.0	9.0	35	15
9	100/0	50.0	28.0	10.0	12.0	9.0	27	20
6	100/0	45.0	33.0	10.0	10.0	8.0	19	17
3	100/0	40.0	38.0	10.0	12.0	9.0	25	16
V4	100/0	50.0	31.0	8.0	11.0	8.0	19	12
V5	100/0	50.0	28.0	8.0	14.0	7.0	15	9
V5	75/25	50.0	28.0	8.0	14.0	8.5	19	14
V7	75/25	41.0	37.0	8.0	14.0	8.5	16	11
1	50/50	40.0	38.0	6.0	16.0	7.0	21	14
2	50/50	40.0	38.0	8.0	14.0	8.0	34	9
7	50/50	50.0	28.0	6.0	16.0	8.0	43	16
3	50/50	40.0	38.0	10.0	12.0	8.0	29	13
V7	25/75	41.0	37.0	8.0	14.0	9.0	27	10
V4	25/75	50.0	31.0	8.0	11.0	9.0	20	14
V2	25/75	41.0	40.0	8.0	11.0	9.0	18	11
8	25/75	50.0	28.0	8.0	16.0	7.0	20	12
V2	25/75	41.0	40.0	8.0	11.0	8.5	15	9

10	100/0	44.5	34.5	7.0	14.0	8.0	20	17
10	100/0	44.5	34.5	7.0	14.0	8.5	24	16
10	100/0	44.5	34.5	7.0	14.0	9.0	31	15
11	100/0	47.0	30.0	8.0	15.0	8.0	23	14
11	100/0	47.0	30.0	8.0	15.0	8.5	28	18
11	100/0	47.0	30.0	8.0	15.0	9.0	35	20
11	70/30	47.0	30.0	8.0	15.0	8.5	44	24
11	70/30	47.0	30.0	8.0	15.0	9.0	40	10
12	100/0	49.5	25.5	9.0	16.0	8.0	24	17
12	100/0	49.5	25.5	9.0	16.0	8.5	30	20
12	100/0	49.5	25.5	9.0	16.0	9.0	40	21
12	70/30	49.5	25.5	9.0	16.0	8.5	38	10
12	70/30	49.5	25.5	9.0	16.0	9.0	47	11
10	100/0	44.5	34.5	7.0	14.0	8.0	19	16
10	100/0	44.5	34.5	7.0	14.0	8.5	23	20
10	100/0	44.5	34.5	7.0	14.0	9.0	29	22
11	100/0	47.0	30.0	8.0	15.0	8.0	21	16
11	100/0	47.0	30.0	8.0	15.0	8.5	26	20
11	100/0	47.0	30.0	8.0	15.0	9.0	29	23
12	100/0	49.5	25.5	9.0	16.0	8.0	25	20
12	100/0	49.5	25.5	9.0	16.0	8.5	32	22
12	100/0	49.5	25.5	9.0	16.0	9.0	42	28
10	100/0	44.5	34.5	7.0	14.0	8.0	30	9
10	100/0	44.5	34.5	7.0	14.0	8.5	33	13
10	100/0	44.5	34.5	7.0	14.0	9.0	37	26
11	100/0	47.0	30.0	8.0	15.0	8.0	32	23
11	100/0	47.0	30.0	8.0	15.0	8.5	34	23
11	100/0	47.0	30.0	8.0	15.0	9.0	42	22
12	100/0	49.5	25.5	9.0	16.0	8.0	36	18
12	100/0	49.5	25.5	9.0	16.0	8.5	41	31
12	100/0	49.5	25.5	9.0	16.0	9.0	46	31
13	70/30	47.0	31.0	8.0	14.0	8.5	35	12
13	70/30	47.0	31.0	8.0	14.0	9.0	47	11
8	75/25	50.0	28.0	8.0	14.0	9.0	42	10
16	75/25	46.0	30.0	8.0	16.0	8.5	41	11

APPENDIX L

RESULTS OF ACCEPTABLE GROUTS PRODUCED WHEN AN ALUMINUM PHOSPHATE WAS USED

This appendix contains the results of acceptable grouts produced when an aluminum phosphate admixture was used. The admixture was added to the waste prior to the addition of the dry solids blend. The amount of admixture is 1 wt% of the amount of dry-solids blend.

BLEND#	SULF/PHOS	CEMENT	FLY ASH	IRPC	ATTAG	MIXRAT	VISC	GELST
26	65/35	43.0	38.0	8.0	11.0	7.0	13	7
26	65/35	43.0	38.0	8.0	11.0	8.0	19	8
26	65/35	43.0	38.0	8.0	11.0	9.0	29	13
26	100/0	43.0	38.0	8.0	11.0	8.0	15	20
26	100/0	43.0	38.0	8.0	11.0	9.0	21	27
5	65/35	45.0	33.0	8.0	14.0	8.0	23	9
5	65/35	45.0	33.0	8.0	14.0	9.0	39	12
5	100/0	45.0	33.0	8.0	14.0	8.0	18	24
5	100/0	45.0	33.0	8.0	14.0	9.0	28	33
27	65/35	42.5	38.5	7.0	12.0	8.0	22	8
27	65/35	42.5	38.5	7.0	12.0	8.5	25	11
27	65/35	42.5	38.5	7.0	12.0	9.0	34	13
27	100/0	42.5	38.5	7.0	12.0	8.0	14	20
27	100/0	42.5	38.5	7.0	12.0	8.5	18	25
27	100/0	42.5	38.5	7.0	12.0	9.0	22	31
28	65/35	42.5	35.5	8.0	14.0	8.0	26	11
28	65/35	42.5	35.5	8.0	14.0	8.5	32	12
28	65/35	42.5	35.5	8.0	14.0	9.0	47	15
28	100/0	42.5	35.5	8.0	14.0	8.0	17	20
28	100/0	42.5	35.5	8.0	14.0	8.5	21	25
28	100/0	42.5	35.5	8.0	14.0	9.0	26	26
29	65/35	42.5	32.5	9.0	16.0	8.0	32	13
29	65/35	42.5	32.5	9.0	16.0	8.5	46	16
29	100/0	42.5	32.5	9.0	16.0	8.0	20	25
29	100/0	42.5	32.5	9.0	16.0	8.5	25	27
29	100/0	42.5	32.5	9.0	16.0	9.0	33	32
30	65/35	45.0	36.0	7.0	12.0	8.0	20	9
30	65/35	45.0	36.0	7.0	12.0	8.5	25	10
30	65/35	45.0	36.0	7.0	12.0	9.0	29	12
30	100/0	45.0	36.0	7.0	12.0	8.5	16	24
30	100/0	45.0	36.0	7.0	12.0	9.0	20	32
5	65/35	45.0	33.0	8.0	14.0	8.0	25	10
5	65/35	45.0	33.0	8.0	14.0	8.5	32	12
5	65/35	45.0	33.0	8.0	14.0	9.0	45	14
5	100/0	45.0	33.0	8.0	14.0	8.5	22	26
5	100/0	45.0	33.0	8.0	14.0	9.0	27	29
31	65/35	45.0	30.0	9.0	16.0	8.0	36	9
31	100/0	45.0	30.0	9.0	16.0	8.0	20	17
31	100/0	45.0	30.0	9.0	16.0	8.5	26	18
31	100/0	45.0	30.0	9.0	16.0	9.0	33	22
32	100/0	47.5	33.5	7.0	12.0	8.5	19	15
32	100/0	47.5	33.5	7.0	12.0	9.0	22	18
33	65/35	47.5	30.5	8.0	14.0	9.0	47	11
33	100/0	47.5	30.5	8.0	14.0	8.0	18	17
33	100/0	47.5	30.5	8.0	14.0	8.5	22	19
33	100/0	47.5	30.5	8.0	14.0	9.0	28	22
34	65/35	47.5	27.5	9.0	16.0	8.5	43	11
34	100/0	47.5	27.5	9.0	16.0	8.0	20	18
34	100/0	47.5	27.5	9.0	16.0	8.5	25	20
34	100/0	47.5	27.5	9.0	16.0	9.0	32	23
35	65/35	40.0	40.0	7.0	13.0	8.0	23	7
35	65/35	40.0	40.0	7.0	13.0	8.5	29	10
35	65/35	40.0	40.0	7.0	13.0	9.0	38	12

35	100/0	40.0	40.0	7.0	13.0	8.0	15	16
35	100/0	40.0	40.0	7.0	13.0	8.5	19	19
35	100/0	40.0	40.0	7.0	13.0	9.0	23	23
36	65/35	40.0	38.0	8.0	14.0	8.0	28	11
36	65/35	40.0	38.0	8.0	14.0	8.5	37	12
36	100/0	40.0	38.0	8.0	14.0	8.0	19	11
36	100/0	40.0	38.0	8.0	14.0	8.5	22	21
36	100/0	40.0	38.0	8.0	14.0	9.0	27	25
37	65/35	40.0	36.0	9.0	15.0	8.0	31	13
37	65/35	40.0	36.0	9.0	15.0	8.5	40	12
37	100/0	40.0	36.0	9.0	15.0	8.0	19	16
37	100/0	40.0	36.0	9.0	15.0	8.5	24	18
37	100/0	40.0	36.0	9.0	15.0	9.0	31	23
40	65/35	45.0	35.0	7.0	13.0	8.5	29	10
40	65/35	45.0	35.0	7.0	13.0	9.0	39	11
40	100/0	45.0	35.0	7.0	13.0	8.0	16	15
40	100/0	45.0	35.0	7.0	13.0	8.5	19	18
40	100/0	45.0	35.0	7.0	13.0	9.0	24	23
28	90/10	42.5	35.5	8.0	14.0	9.0	22	14
28	80/20	42.5	35.5	8.0	14.0	9.0	28	11
41	65/35	45.0	31.0	9.0	15.0	8.0	31	10
41	65/35	45.0	31.0	9.0	15.0	8.5	42	12
41	100/0	45.0	31.0	9.0	15.0	8.0	20	15
41	100/0	45.0	31.0	9.0	15.0	8.5	24	22
41	100/0	45.0	31.0	9.0	15.0	9.0	30	27
38	65/35	42.5	37.5	7.0	13.0	8.5	33	13
38	65/35	42.5	37.5	7.0	13.0	9.0	49	14
38	100/0	42.5	37.5	7.0	13.0	8.0	17	16
38	100/0	42.5	37.5	7.0	13.0	8.5	21	20
38	100/0	42.5	37.5	7.0	13.0	9.0	26	22
28	100/0	42.5	35.5	8.0	14.0	8.0	18	24
28	100/0	42.5	35.5	8.0	14.0	8.5	23	32
28	100/0	42.5	35.5	8.0	14.0	9.0	29	43
39	65/35	42.5	33.5	9.0	15.0	8.0	32	13
39	65/35	42.5	33.5	9.0	15.0	8.5	43	14
39	100/0	42.5	33.5	9.0	15.0	8.0	19	21
39	100/0	42.5	33.5	9.0	15.0	8.5	24	26
39	100/0	42.5	33.5	9.0	15.0	9.0	31	33
28	65/35	42.5	35.5	8.0	14.0	8.0	33	15
28	65\35	42.5	35.5	8.0	14.0	9.0	47	20
28	100 % Sulfate	42.5	35.5	8.0	14.0	8.0	19	31
28	100 % Sulfate	42.5	35.5	8.0	14.0	9.0	23	34

APPENDIX M

This appendix contains the results of EP Toxicity leach testing performed on the following samples:

28-L-65-35-E: Blend 28, mix ratio of 65/35 sulfate/phosphate waste — 9 lb/gal,

28-L-100-E: Blend 28, mix ratio of 100% sulfate waste — 9 lb/gal,

35-L-65-35-E: Blend 35, mix ratio of 65/35 sulfate/phosphate waste — 9 lb/gal,

35-L-100-E: Blend 35, mix ratio of 100% sulfate waste — 9 lb/gal,

Duplicate testing was performed on each of the samples.

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analyses

Customer Name: SAMS
Customer Sample Number: 28-L-65-35-E Lab Sample Number: 870227-191
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.49	mg/L	EA HESTER	9-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	9-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.022	mg/L	EA HESTER	9-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	9-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	9-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NR HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NR HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0005	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	0		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 28-L-65-35-E Lab Sample Number: 870227-191
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.49	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.022	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0005	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 28-L-100-E Lab Sample Number: 870227-192
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.67	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.049	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0013	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 28-L-100-E Lab Sample Number: 870227-192
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.67	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.049	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0013	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 35-L-65-35-E
Lab Sample Number: 870227-193
Date Sample Received: 27-FEB-1987
Date Sample Completed: 9-APR-1987
Date Sampled:
Sampled By:
Material Description: EP TOXICITY TEST SAMPLES
Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.67	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.037	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0008	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 35-L-65-35-E Lab Sample Number: 870227-193
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.67	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.037	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	<0.010	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0008	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 35-L-100-E
Date Sample Received: 27-FEB-1987
Date Sampled:
Material Description: EP TOXICITY TEST SAMPLES

Lab Sample Number: 870227-194
Date Sample Completed: 9-APR-1987
Sampled By:
Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.68	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.057	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	0.011	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0011	mg/l	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C. CRUTCHFIELD JR	2-APR-1987

Spike Recovery Data

Analysis	Amount Spiked	Amount Recovered	Percent Recovered
ARSENIC (EP-TOX)	0.020	0.017	85.00
MERCURY (EP-TOX)	0.0020	0.0020	100.00
SELENIUM (EP-TOX)	0.020	0.017	85.00

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Oak Ridge Gaseous Diffusion Plant
Analytical Chemistry Department
Results of Analysess

Customer Name: SAMS
Customer Sample Number: 35-L-100-E Lab Sample Number: 870227-194
Date Sample Received: 27-FEB-1987 Date Sample Completed: 9-APR-1987
Date Sampled: Sampled By:
Material Description: EP TOXICITY TEST SAMPLES Req. Number:

Activity Number	Preparation Procedure No.	Analysis Procedure No.	Analysis	Result	Units	Analyst	Date Completed
090207	EPA-6010	EPA-6010	Barium (EP-TOX)	0.68	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Cadmium (EP-TOX)	<0.0030	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Chromium (EP-TOX)	0.057	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Lead (EP-TOX)	<0.050	mg/L	EA HESTER	8-APR-1987
	EPA-6010	EPA-6010	Silver (EP-TOX)	0.011	mg/L	EA HESTER	8-APR-1987
102007		EPA-7060	Arsenic (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
		EPA-7740	Selenium (EP-TOX)	<0.005	mg/L	NB HAROLD	9-APR-1987
103008	EPA-7470	EPA-7470	Mercury (EP-TOX)	0.0011	mg/L	C. SCHAEFER	7-APR-1987
170303		EPA-1310	EP-TOX Extraction	C		C CRUTCHFIELD JR	2-APR-1987

Program Manager: LW McMahon
Date Approved: 9-APR-1987

Spike Recovery Data

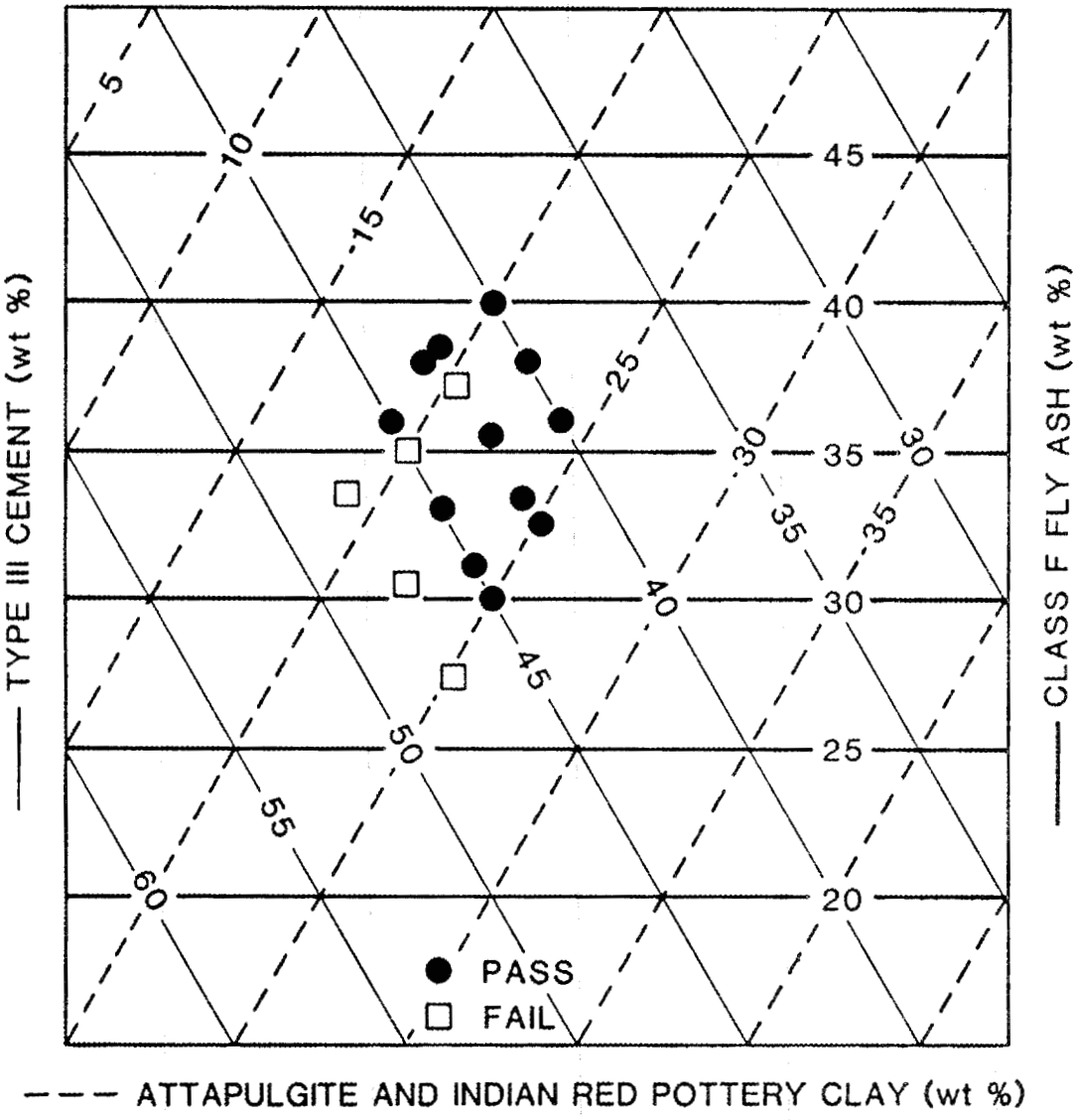
Analysis	Amount Spiked	Amount Recovered	Percent Recovered
ARSENIC (EP-TOX)	0.020	0.017	85.00
MERCURY (EP-TOX)	0.0020	0.0020	100.00
SELENIUM (EP-TOX)	0.020	0.017	85.00

APPENDIX N

This appendix contains three plots of grouts prepared with 35/65 phosphate/sulfate waste. These plots are on expanded triangular coordinates and may be useful as an engineering aide.

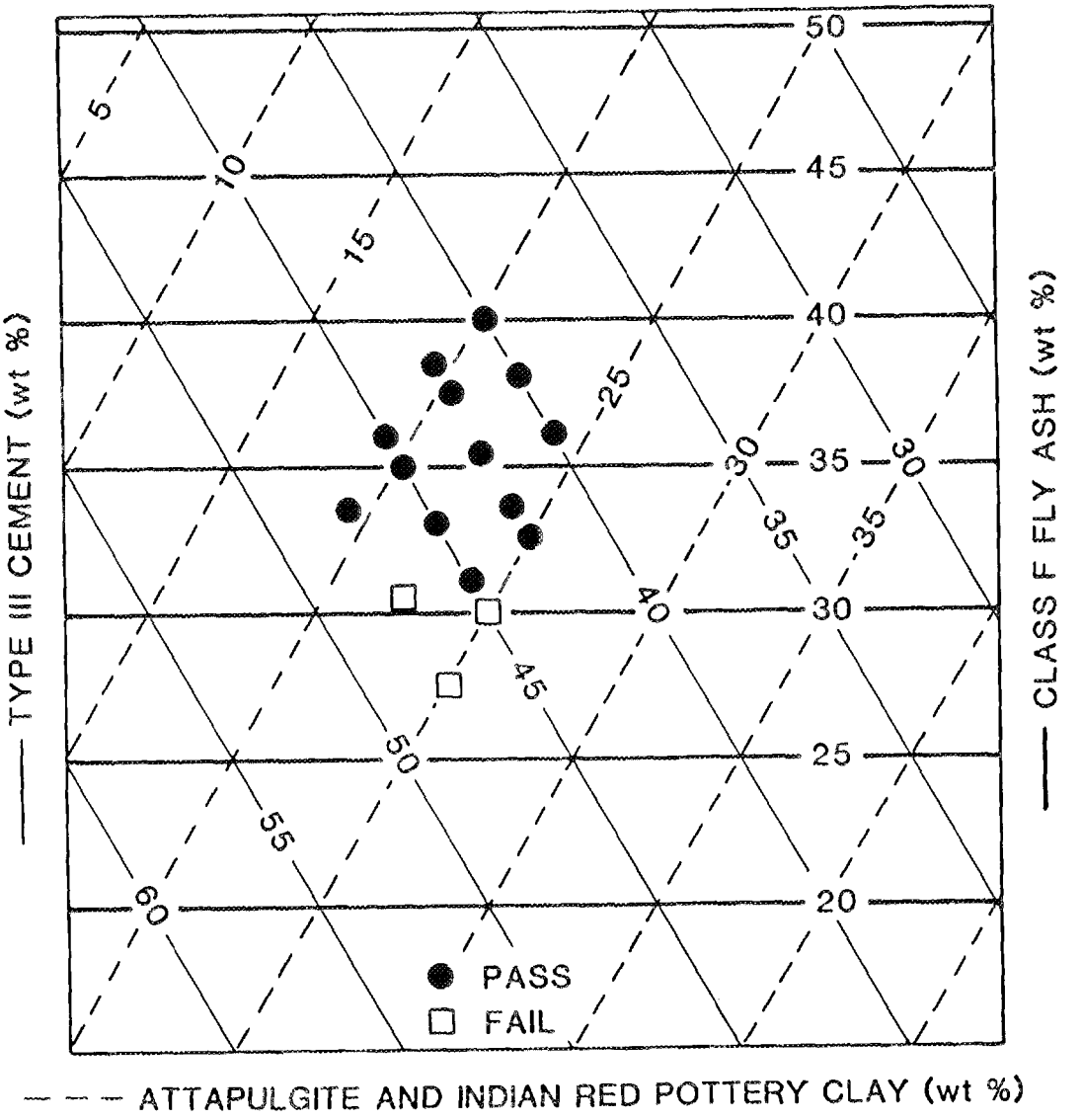
ORNL DWG 87-940

GROUTS PREPARED WITH 35/65 PHOSPHATE/SULFATE WASTE AT 8.0 lbs/gal



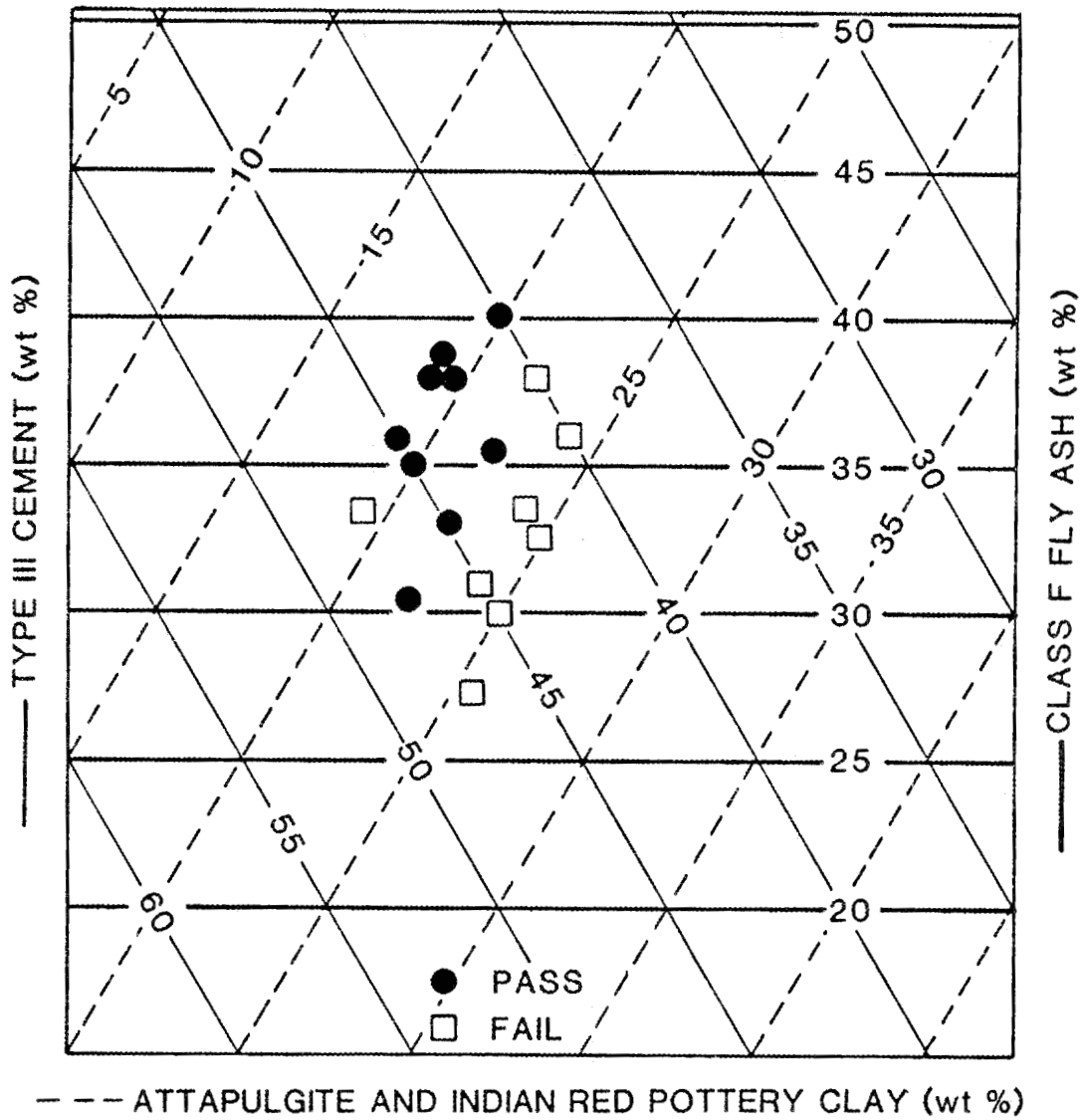
ORNL DWG 87-941

GROUTS PREPARED WITH 35/65 PHOSPHATE/SULFATE WASTE AT 8.5 lbs/gal



ORNL DWG 87-942

GROUTS PREPARED WITH 35/65 PHOSPHATE/SULFATE WASTE AT 9.0 lbs/gal



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