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RECYCLING OF BITUMINOUS SHOULDERS: MIXTURE AND ASPHALT EVALUATION

by
SAMUEL H. CARPENTER

A Report of the Investigation of
Recycling of Bituminous Shoulders
Project IHR-410
Illinois Cooperative Highway Research Program

conducted by the
TRANSPORTATION RESEARCH LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

in cooperation with the
STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
and
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16. Abstract

Recycled bituminous materials have proven economical when compared to the costs involved in constructing a pavement from all new materials. Long term performance comparisons have not been developed to illustrate the long term maintenance requirements. This report is the first of two reports detailing the examination of recycled mixes to predict long term performance. Two reclaimed pavements and two additional aged materials were selected. Procedures are developed for selecting the type and amount of recycling agent to minimize compatability problems and not necessitate special handling problems. The testing on the recycled mixes indicated the need to allow for diffusion of the recycling agent into the aged binder. The type of recycling agent is shown to affect asphalt cement performance properties and the mix design parameters, although acceptable mixture parameters were obtained for all recycled mixes.

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DISCLAIMER

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INTRODUCTION

The recent increased interest in the recycling of bituminous pavements can be attributed to any number of factors ranging from material conservation to expediency. All of the reasons can be boiled down to the consideration that the recycling of bituminous materials provides a cost savings over using all new materials for a bituminous pavement. If the cost savings does not remain over time, contractors and State Transportation agencies will not continue to utilize recycled materials and the market for the materials will disappear.

The cost effectiveness of recycling bituminous materials has been demonstrated solely for initial construction. The recycled materials can be processed, placed, and compacted cheaper than all new materials. This comparison is not a true life cycle cost analysis because it does not include all the costs each pavement type (recycled vs. all new construction) would incur over it's life. These costs which develop after construction are the maintenance expenditures incurred as the pavement deteriorates when exposed to traffic loadings and the environment. To date, equal rates of deterioration have been assumed for new and recycled materials.

Depending on the percentage of reclaimed pavement being recycled these assumptions may be nearly correct. Recycled materials containing low percentages of reclaimed pavement (30 percent) will be similar to an all new material, assuming the reclaimed pavement is a sound material to begin with. When the percentage of reclaimed pavement increases to the range of 50 to 70 percent with a corresponding increase in the amount of recycling agent, the recycled mixture may no longer be similar to an all new mix because of the influence of the recycling agent. The long term performance of these mixes must be examined to provide a true life cycle cost comparison. This comparison has not been developed at present. The studies of recycled pavements that have been made have investigated only the deflection characteristics of new recycled pavements. These analyses have produced favorable comparisons with all new materials, but they do not address the long term performance characteristics of the recycled material.

The research effort undertaken at the University of Illinois addresses the problem of evaluating and comparing long term performance characteristics of recycled mixes and a typical all new mix. This examination is broken into the following topics:

1. General mix design considerations
2. Recycling agent influence
3. Mix design results
4. Performance testing results
5. Performance comparisons
6. Recommendations for use of recycled materials

This interim report will address items 1 thru 3 for the materials collected in this study. The study of recycling agent influence on asphalt properties and the considerations imposed on mix design considerations are significant and have an influence on the long term properties. While a large number of recycling agents and reclaimed material combinations were not investigated, the results validate previously held concepts and produce new considerations which must be recognized in structural characterization of recycled mixes, and in mix design testing.

This report is divided into the following sections:

1. Material collection and processing.
2. Evaluation of recycling agents.
3. Implications for Mix Design Considerations.
4. Mix design for materials selected.

MATERIAL COLLECTION AND PROCESSING

Two pavement materials were obtained for use as reclaimed pavement to be recycled in the laboratory investigation. These consist of a shoulder removed from FAI-74 for construction of the by-pass around Peoria and cold millings from State Highway 51 in Decatur, removed prior to overlay. Two additional materials were obtained to furnish reclaimed asphalt cement samples to be used as additional samples in the recycling agent evaluation tests. Subsequent sections contain detailed information about the reclaimed materials.

Peoria Shoulder

The shoulder section consisted of six inches of Bituminous Aggregate Mixture with a dense graded hot mix asphalt concrete (Class I) surface mix. The shoulder was broken on site using a front end loader and transported to the University of Illinois campus where the pieces were further processed through a jaw crusher and broken down to 100 percent passing 1.0 inch size. The reclaimed pavement had an asphalt content of 5.16 percent by weight of aggregate and an aggregate gradation as shown in Figure 1. The jaw crusher did not produce any increase in the fines content as is typical for cold milled material. The properties of the recovered asphalt cement are given in Table 1.

Chemical analysis data using the modified Rostler Acid Precipitation method developed by Rowan J. Peters of the Arizona DOT (1) were collected and are given in Table 2 for the Peoria shoulder material.

These data will be further explained in the subsequent section detailing the recycling agent influences and considerations.

Decatur Pavement

The Decatur pavement was collected from a stockpile at the asphalt batch plant. This material was used in a recycled binder material placed on State Route 105 in Decatur. The material was cold milled for removal and thus represented a normally processed material. The gradation is shown in Figure 2. The reclaimed pavement had an asphalt content of 4.55 percent by weight of aggregate. The asphalt cement properties are given in Table 1 and the chemical properties are given in Table 2. This material represented a mixture typical of a Class I mix.

Asphalt Cement Samples

Two pavements were sampled solely for their asphalt cement to provide a wider variety of asphalt cement properties to study with the recycling agents. One sample was recovered from cold millings removed from University Avenue, a city street in Champaign, Illinois during the summer of 1978. The other sample was taken from a BAM shoulder being reworked as part of a rehabilitation project on FAI 57 near Mattoon, Illinois. This shoulder was processed by a pulverizer and represents a typically processed shoulder material. The properties of the recovered asphalt cements are given in Table 1 and the corresponding chemical properties are given in Table 2. The gradations are given in Figure 3. The material milled from the Champaign city street was the only material of these two that was examined later for structural considerations. It should be noted that these milled materials did contain a relatively high percentage of fines that may be attributed to the milling process.

EVALUATION OF RECYCLING AGENTS

Two recycling agents were selected for this study to represent two materials that have been used in recycling projects around the United States. There are many different types of recycling agents on the market from extender to aromatic oils and a testing and evaluation procedure is needed to carefully evaluate each material used. An example of the importance of a thorough testing program is shown by the study completed by Texas A&M University for the FHWA which indicated that used crankcase oil could function as a recycling agent to some extent (2). A recycling agent can be generally defined as a hydrocarbon product with physical characteristics selected to restore aged asphalts to the requirements of current asphalt specifications.

The two recycling agents selected for this study were Paxole and Cyclogen. Paxole is an aromatic oil produced directly in the refining process with specified chemical properties designed to produce a good chemical balance in the recycled asphalt. Cyclogen is a Reclamite formulation with an amount of asphalt cement added to allow the recycling agent to serve as a stand alone additive in the recycling process. New asphalt cement needed when Paxole is used is supposedly eliminated when Cyclogen is used.

The physical and chemical properties of the two recycling agents are given in Table 3. These materials represent two different modifiers or recycling agents as is indicated visibly by their different viscosities. Specifications have been proposed by the West Coast Users group for recycling agents. These specifications are presented in Table 4. The recycling agents are graded on viscosity in the same manner as is done for asphalt cements.

The function of a recycling agent is to restore the viscosity of the reclaimed asphalt cement. Along with this new lower viscosity the bonding and resiliency of the aged asphalt cement should also be restored. The restoration of these properties has never been adequately documented as they relate to long term performance. Work performed at Texas A&M University indicated some general considerations which should be considered. In general, laboratory testing on rejuvenated asphalt cements has shown that they can be rejuvenated to have similar properties to an all new asphalt cement. However, if only one parameter is controlled, such as viscosity at 60 C, the penetration at 25 C may vary quite excessively (2,3). Initial results indicate that viscosity can be utilized as an indicator of adequate rejuvenation if the standard specification tests show that acceptable properties are also developed in the rejuvenated asphalt cement.

Amount of Recycling Agent

There are two different procedures for adding recycling agents to a mixture:

1. Add recycling agent to the mixture until the total fluids content reaches a predetermined (optimum) value.
2. Add a predetermined percentage of the recycling agent to

restore the viscosity of the aged asphalt cement to a target viscosity.

The first procedure is easier to perform than the second procedure but it does not provide enough control during testing to ensure the quality of the material that has been recycled. The second procedure provides more control over the properties obtained in the recycled pavement, an easier mix design procedure, and a straightforward procedure to evaluate compatibility of the recycling agent and the aged asphalt. These items are important in development of a mix with good long term performance characteristics.

The amount of recycling agent is determined by mixing varying amounts of the recycling agents being investigated with the recovered, aged asphalt cement and measuring the viscosity. There is a linear relationship between the double logarithm of the viscosity of the aged asphalt cement and the blend index of the recycling agent as shown in Figure 4. The blend index is the ratio of the volume of recycling agent to the volume of total fluids (asphalt cement plus recycling agent). In this study the blend index has been calculated on a weight basis rather than volume. This imposes no inaccuracies unless the specific gravities of the recycling agent and the aged asphalt cement are very different in which case the plot will differ from the straight line relationship as will be demonstrated presently.

A target viscosity of 1000 Poise was selected for this study. This viscosity corresponds to that of an AC-10 material and represents a typical asphalt cement used in Illinois. By rejuvenating to an established asphalt cement grade, comparisons can be made between the specification properties of both materials. This procedure also produces an asphalt concrete with an asphalt cement that is similar to what has been used previously and direct comparisons of performance should be much more meaningful. For this reason, a viscosity grade similar to that currently in use should be used as the target viscosity.

Ointment tins with approximately 50 gm of the aged asphalt were prepared and varying amounts of the different recycling agents were added and thoroughly mixed while the asphalt cement was liquid (approximately 150 F). The prepared tins were allowed cure for several days to ensure that the recycling agent had ample opportunity to chemically combine with the aged asphalt cement. Absolute viscosity tests were performed at 60 C and the viscosity data were plotted on the blending charts for each asphalt material. The results are shown in Figure 5 through Figure 8 for the asphalt cements collected in this study.

The exact blend index required to obtain a viscosity of 1000 Poise can be obtained directly from the blending charts once the viscosity test data have been plotted. The deviation from the theoretical straight line relationship evident in several of the charts is due to the differences in specific gravities, as mentioned earlier. The blend indexes for each material are shown in Table 5. Exact blends were prepared for each material and tested to determine how well they compared with an all new AC-10. The test results for all materials are presented in Table 6. It is apparent that the rejuvenation process produces an asphalt cement with properties that are very similar to those of an all new AC-10. This same procedure may be used to select a blend index that will produce any desired viscosity in the rejuvenated asphalt cement depending on the target viscosity selected.

Compatability Considerations

Due to chemical or physical considerations, recycling agents have different affinities for different aged asphalt cements. This affinity influences how the recycling agent combines with the asphalt cement and also how completely the rejuvenation process is accomplished. There are procedures using microcalorimeters to measure the heats of immersion or wetting which indicate the tenacity and completeness with which the two components combine. These tests cannot be run on a production basis because of the complexity and length of time required for the test.

In an FHWA study of recycling agents performed by Texas A&M University, it is suggested that the Thin Film Oven Test (TFOT) may provide an indication of the "compatibility" of the recycling agent and aged asphalt cement (3). The results of Thin Film Oven Testing on the rejuvenated asphalt cement samples for this study clearly indicate that various combinations of recycling agent and aged asphalt cement behave very differently.

The Thin Film Oven Test was developed as a procedure to harden or "age" an asphalt cement in a manner similar to what would develop in the mixing operation at the plant. Thus, the test shows the relative ability of an asphalt cement to resist "aging" as indicated by measuring the viscosity of the material before and after the Thin Film Oven Test. This ratio of viscosities indicates how rapidly the asphalt cement may be expected to age in service. ASTM specifications limit the change in viscosity after the Thin Film Oven Test to a maximum of 4 times the original value. Any factor larger than this indicates unacceptable aging.

The TFOT viscosity aging ratios (expressed as a change in Poise per minute of heating) and chemical data are given in Table 7. In general, the chemical data should show a direct relationship with the aging potential. This relationship was demonstrated in a Navy research effort which is shown in Figure 9 with the data from this study included (4). The data indicate that the proper amount of aging is being obtained for the chemical reactivity ratio (CRR) but the CRR does not vary enough to establish a valid pattern for the materials investigated in this study. The values for the CRR data indicate that the aged asphalt and rejuvenated asphalt cement possess a good chemical composition. Previous studies have indicated that CRR values in the range of 0.5 to 1.0 ensure a durable asphalt cement (5).

It is expected, however, that even with CRR values in this optimum range the aging characteristics may be highly variable depending on the asphalt cement and the type of recycling agent used. The Thin Film Oven Test represents an easy and practical method to evaluate the compatability of an asphalt cement-recycling agent combinations. The recycling agent that produces the desired aging should be selected for the recycling project. The desired aging could be the combination that shows the lowest increase in viscosity, or the one that develops a change of the same magnitude as occurs in the asphalt cement normally used. The important point is that the procedure is a tool with a potential for eliminating improper combinations of recycling agents and aged asphalt cements. This makes the selection process easier to apply in ruling out specific recycling agents. The problem of asphalt-modifier compatibility has been addressed by other research studies. The Thin Film Oven Test is not the final answer and does not guarantee the performance of the asphalt concrete in service. It can be used as an effective screening tool with the high levels of change in viscosity indicating potential incompatibility and a long term reaction being required for complete rejuvenation to occur.

Initial Selection Process

The number of recycling agents under consideration can be reduced by consideration of their viscosity. The higher the viscosity of the recycling agent the larger the amount of recycling agent needed to rejuvenate the aged binder to the target viscosity. This is illustrated in Figure 10 for the tentative recycling agent specification viscosities. The addition of an excessive amount of recycling agent should be avoided because this can place an excessive amount of total fluids in the mixture. This is particularly critical as the percentage of reclaimed pavement in the recycled mixture increases. Mixes with 60-70 percent reclaimed pavement may be susceptible to flushing if an excess amount of recycling agent is added. Mixes with 30 percent reclaimed pavement are less likely to flush or become unstable because the total amount of recyclng agent is so much less and the amount of virgin asphalt cement can be varied over a larger range to compensate.

When a recycling agent is added to a reclaimed pavement mixture it coats the old asphalt coated aggregate particles and begins to combine with and rejuvenate the layer of aged asphalt cement. This combination takes time as will be discussed later. If large amounts of the recycling agent are added, a very thick layer of recycling agent will be produced around the old aggregate. When the new aggregate and asphalt cement are added they will attract this extra recycling agent far more easily than if the coating of recycling agent were thinner. By attracting the recycling agent away from the aged asphalt it will be more likely to combine with the new asphalt producing a soft mix for a time period following compaction, which is not desireable.

The amount of recycling agent added to a mix should be limited to the amount of aged asphalt in the mix. This produces a blend index of 50 percent which can be considered as an upper limit. An example is shown in Figure 11 for the Decatur aged asphalt cement. Several of the higher viscosity recycling agents are eliminated from consideration because they require too large an amount to be added to produce the target viscosity.

If the blend index becomes too small, the controls at the mixing plant may not be able to add the proper amount with sufficient accuracy and repeatability to satisfy the quality control for the specifications. This becomes important for the recycled mixes containing lower percentages of the reclaimed pavement (30 percent) that are going to use a recycling agent. These low percentage mixes have been effectively recycled using soft asphalt cements (AC-2.5) rather than a recycling agent. However, a soft asphalt cement must not be confused with a recycling agent as their effect on the aged binder is very different, and not all soft asphalts are suitable. When the asphalt cements are not excessively aged or hardened, recycling agents may not be needed and soft asphalts should be investigated. Newer mixing plants are being equipped with metering devices capable of accurately adding small amounts of recycling agents and may prove suitable in the future. The percentage any plant can accurately meter into a mix cannot be known beforehand, but should be based on experience.

A sample calculation illustrates the small amounts of recycling agents used in certain mixes. The formula for the Blend Index is:

$$BI = Wra/(Wra+Wac)100$$

where:

BI= blend index

Wra = weight of recycling agent

Wac = weight of aged asphalt cement.

This formula can be rewritten to show the amount of recycling agent required:

$$Wra = (Wac)(BI)/(1-BI)$$

The typical mix, in a ton , will require 21 pounds of rejuvenating agent in a 50-50 blend with a Blend Index of 0.30. Typical weights and percentages of recycling agent for several blend indexes are shown in Table 8.

Current specifications typically call for a control on asphalt content of $\pm$ 0.3 percent so most plants should be capable of operating down to a Blend Index of 10 percent with normal precautions. The adequacy of this level of control (or lack) cannot be addressed in this study. The problem then becomes one of ensuring that the recycling agent has been thoroughly mixed with the reclaimed pavement material. Work done for FHWA at the University of Washington will show how completely this mixing is, and will develop a test to determine the efficiency of the mixing. Initial results indicate that a dye added to the recycling agent will be used to allow the distribution of the recycling agent to be visually evaluated in both uncompacted and compacted mixes (6).

Lower limits set for the addition of recycling agents will make the initial selection process easier by providing another limit to be used to eliminate recycling agents with viscosities that are too low for the aged asphalt being rejuvenated. An example is shown in Figure 12 for assumed upper and lower limits.

Influence of Recycling Agents

Recycling agents are added to the reclaimed pavement to soften or rejuvenate the aged asphalt. This softening is accomplished by a gradual diffusion of the recycling agent into the aged asphalt cement coating the aggregate. This gradual diffusion process is depicted schematically in Figure 13. This diffusion is a time dependent phemonomon that is influenced by the compatibility of the two materials. The Thin Film Oven test as discussed earlier may be the easiest test to perform to obtain an approximate indication of the compatability. Further testing would be required to fully evaluate the accuracy of such a relationship as this, but it is felt that a large change in viscosity in the Thin Film Oven Test could correlate with a very slow rate of diffusion. Studies have shown that the viscosity of the oil added can control the rate of the diffusion process, but the chemical makeup must also be considered in the long term performance of the rejuvenated asphalt cement, as well as the compatibility. Studies that have examined this diffusion of a low viscosity oil into asphalt coated aggregates have determined time periods of up to 60 days depending on film thickness, oil type, and method of application (7).

In a recycled mix that has been compacted this diffusion process produces a binder in the mix that is constantly changing until equilibrium is reached. The structural characteristics of the mix could also be expected to be changing continuously and the magnitude of the change would vary with the proportion of the reclaimed pavement in the recycled mix. While it would present a larger influence in a 100 percent reclaimed pavement than it would in a 30 percent reclaimed pavement mix the phenomonon is the same.

The University Avenue material was selected to investigate this diffusion phenomonon by examining the following:

1. Completeness of the rejuvenation process.
2. Time required for rejuvenation process.
3. Property changes during the rejuvenation process (i.e. diffusion)

A large quantity of asphalt cement was recovered from the reclaimed pavement and rejuvenated to an AC-10 level of viscosity (1000 Poise) with the Paxole recycling agent. This rejuvenated asphalt cement was then re-mixed with the original aggregate from which it was extracted and the samples were compacted. The second batch of samples was made by mixing recycling agent with the reclaimed pavement in the proper amount as determined by running viscosity tests and plotting the data on the blend index charts. These two mixes were compacted to the same density using the double plunger method. Thus, the two mixes were nearly identical except for the method of preparation of the aged binder and recycling agent. The diametral resilient modulus values for the compacted Marshall size sample (4 inch diameter by -2.5 inch thickness) are shown in Figure 14. The stiffness of the two samples did eventually reach the same value, indicating that the two binders reached the same consistency, illustrating the gradual diffusion and alteration of the binder during the diffusion process. The density of the mix does not change during the diffusion process because the change in viscosity of the binder occurs after compaction, and both samples were forced to have the same density.

This time effect was also evaluated directly. Recycled mixes were prepared in the standard manner and left to stand and cure for specified times following mixing. At preset time intervals a mix container was taken out and a double extraction was performed. The mix was placed in a glass beaker and covered with trichloroethylene solvent for a set time (1 minute). The solvent was poured off and the asphalt cement recovered from the solvent in the normal fashion. This first sample represents the outer layer of aged asphalt cement and recycling agent.

The mix in the beaker was then rinsed with trichloroethylene repeatedly until all of the aged asphalt cement and recycling agent was removed. This second sample, representing the inner layer of aged asphalt cement, was also recovered. Thus, each mix furnished two samples of asphalt cement, representing an inner and outer layer, that should show a change in consistency as the diffusion time increases. At an infinitely long time the two samples should aproach the same consistency and this value should be the same as that measured for the samples of recovered aged asphalt cement mixed directly with the recycling agent as done earlier to select the proper amount of recycling agent.

The penetration tests performed on these samples clearly illustrates the diffusion of the recycling agent into the aged binder. The results are shown in Figure 15. The penetration values indicate approximately the same diffusion time as the diametral resilient modulus data. The consistency of the rejuvenated asphalt cement was the same regardless of the preparation technique as is shown by the equal penetrations from the lab samples and mix samples. The equal penetrations indicate that the binder being produced in the recycling process should be similar to that obtained in the laboratory analysis done on recovered asphalt cement samples.

This change in structural properties due to diffusion is shown in Figure 16 for the other reclaimed pavement materials examined. The diffusion process produces a mix with a low resistance to deformation during the time immediately after compaction. This could explain observations during early recycling projects that recycled mixes tended to exhibit acceptable stability but developed high flow values during testing. The test results in this study indicate that a curing period may have to be observed before accurate test results can be obtained that would be meaningful for long term performance predictions as well as normal mix design considerations.

Indirect tensile strength tests performed on the mixes (to be reported in the Final Report) also indicate a gradual development of strength as the aged asphalt cement is softened and its bonding capabilities are improved. Tests for Marshall Stability were inconclusive as a trend with time was not evident. With the other properties demonstrating this alteration of properties over time, the stable Marshall design parameters taken by themselves may not give a true indication of the mix behavior following placement and may give a false impression of mix stability.

MIX DESIGN

A material evaluation and testing program was set up to examine the Peoria shoulder and Decatur materials as they represented typical materials that would be encountered in a normal recycling operation. The levels of reclaimed pavement in the recycled mix included 100, 50, and 30 percent. A crushed stone aggregate from the Fairmont quarry with a Class I gradation was selected as the aggregate to be used in the recycling process as well as in a mixture composed of all new materials to be used for comparison purposes.

Recycled Mixes

The amount of recycling agent for each mix was determined from the blend index formula developed previously:

$$Wra = \{(Pbrp)(Wsm)/([1/BI]-1\}Prp$$

where:

Wra = weight of recycling agent

Pbrp = asphalt content of reclaimed pavement (by weight of aggregate)

Wsm = weight of aggregate target in the sample to be compacted

BI = blend index, defined earlier

Prp = percent of mix to be composed of reclaimed pavement

The weight of reclaimed pavement used was selected from the following:

$$Wrp = (prp)(Wsn)(1+Ppbr)$$

where:

Wsn = weight of new aggregate needed,

Wrp = weight of reclaimed pavement needed, and the other parameters are as previously defined.

The weight of new aggregate added is selected from:

$$Wsn = (1-Prp)Wsm$$

All materials were weighed and placed in separate containers. The reclaimed pavement was heated at 140 F for 20-30 minutes. The recycling agent was poured into a trigger type oil can which was then warmed by placing it in a water bath. The warm reclaimed pavement was placed in a tared mixing bowl and the weight of the reclaimed pavement was accurately recorded. While still on the scale, the recycling agent was added and the exact amount recorded. This material was mixed 15 seconds. The new aggregate was then added after it had been heated to approximately 375 F, and the exact weight recorded. The new asphalt cement was added and the exact amount recorded. This material was mixed for approximately one minute or until all particles were thoroughly and uniformly coated. The recycled mixture was then placed in a Marshall compaction mold and compacted when the temperature reached 260 - 275 F. The compaction effort consisted of 75 blows per side in an automatic compactor. A complete mix design was done by varying only the amount of new asphalt cement added with all other quantities remaining the same for the entire mix design.

New Materials

The new aggregate is a crushed limestone from the Fairmont quarry with the gradation shown in Figure 17. This aggregate was used in all recycled mixes and was also used as the aggregate in the all new mix evaluated for comparison with the recycled mixes.

A standard Marshall mix design was performed to determine the optimum asphalt content. The new asphalt cement used in all mixes was an AMOCO AC-10 with the properties as shown in Table 8.

Mix Design Results

The results of the mix design are presented in Figure 18 through Figure 26. The optimum values are presented in Table 10. These values represent the parameters selected for the samples to be made for the structural evaluation testing to be reported in the Final Report. All testing and evaluation was done following a two week curing period at 72 F.

General Observations

The Fairmont aggregate by itself produced a mix with acceptable mix design parameters. The high stability results from the use of the crushed limestone fines which produced a good granular interlock in the mix.

The maximum stability for all the mixes occurred at an asphalt content near 4.5 percent. To obtain satisfactory air voids, however, it was necessary to increase the asphalt content to 5.0 percent for several of the mixes. The mixes with the Cyclogen recycling agent did not show a peak in the stability curve within the range of asphalt contents examined. The 30/70 mix ratios had a higher stability primarily due to the high stability nature of the all new Fairmont aggregate and the larger amount of that aggregate present in the 30/70 mix. This difference in stabilities would be smaller if a different all new aggregate, one which had a lower stability, or one closer to that found in the original mixture now being recycled was used.

The Paxole recycling agent mixes generally had higher air voids than the Cyclogen mixes. More Cyclogen, by volume, was required which may have produced more of a lubricating effect during compaction than the smaller amount of Paxole as both initially coated the same amount of aged asphalt/aggregate. This may have facilitated compaction in the Cyclogen mixes, producing the denser mixes, lower air voids, and higher strengths that were found in the Cyclogen mixes. As the Cyclogen diffuses into the aged asphalt cement producing the rejuvenated binder, the stiffness of this binder would increase as the recycling agent gradually combined with the aged asphalt cement. This change would stiffen the original layer of recycling agent and soften the original layer of aged asphalt (see Figure 13), resulting in an overall stiffer more cohesive binder than the recycling agent alone provided during compaction.

This method of compaction (drop hammer) produces different densities when binders of different viscosity are used, similar to what happens in the field. Compaction by the double plunger method used earlier forces every mix to have the same density and therefore is not a suitable procedure to use in investigations of mix performance unless different densities are purposefully produced. Because the Cyclogen and Paxole produce a very different binder viscosity when they are first added (before diffusion) different densities and air voids are to be expected. Consideration of the mix properties may play an important role in selecting the recycling agent to be used if these densities are important.

COLD MIX DESIGN

The Cyclogen recycling agent was also obtained in emulsion formulation for use in a cold mix recycling evaluation of the reclaimed pavements given in Table 11.

Using this emulsion formulation it was not possible to obtain optimum values given the material constraints produced by the amount of samples needed for the hot mix recycling and difficulties in preparing the samples. Because of these difficulties, recycled cold mixes using varying percentages of reclaimed pavement were not constructed and the structural evaluation concentrated primarily on the hot mix recycled materials.

CONCLUSIONS AND RECOMMENDATIONS

This evaluation of the asphalt cements, recycling agents, and mix characterization was designed to provide initial data concerning problems which might need to be addressed in the material evaluation portion of a recycling project that could cause problems to develop later in the project. The testing and evaluation of materials contained in this report do show significant influences that must be considered in obtaining the optimal recycled mix from the asphalt and mix design viewpoints. The Final Report will examine how well the optimal mixes perform as a pavement material over time. The important conclusions or considerations from this initial work may be listed as follows.

1. An adequate sampling plan must be developed to ensure that the asphalt samples obtained for analysis are representative of the project.

2. A procedure must be established to be followed in adding recycling agents to the reclaimed pavement. This procedure affects the optimal amount of recycling agent determined. The selection of a target viscosity provides good control and produces a rejuvenated binder which more closely resembles asphalt cements currently in use.

3. Guidelines can and should be established beforehand that limit

the maximum and minimum percentages of recycling agents to be allowed in the recycled mix.

4. Every recycling agent-aged asphalt combination should be evaluated separately to determine if properties are within or close to specification values for a new asphalt cement. This includes viscosity at other temperatures, penetration, and aging in the TFOT (or RTFOT Continuous) ovens. It is evident that recycling agents will produce very different results in the same asphalt cement, particularly in temperature susceptibility and aging.

5. The mix design procedure used should follow the normal procedure typically used as closely as possible. Only one parameter should be varied during the mix design, typically the asphalt cement. Several mix designs can be run at different new aggregate ratios, or even different percentages of recycling agents if it is believed to present a problem.

6. The structural testing done on the recycled mixes should recognize the diffusion process and allow the mix to cure for a period of time (1-2 weeks). Because this is not always possible, values collected in the normal time frame should be considered as tentative, particularly if high flow values are obtained. It may be adviseable to retain a set of samples for testing following the cure period as a validation for the

original tests. Sophisticated structural testing such as fatigue, indirect tensile strength and diametral resilient modulus testing should never be performed prior to the completion of the diffusion process. The diametral resilient modulus test is well suited to monitoring these property changes.

7. Acceptable mixes can be produced following the procedures outlined in this report. It must be recognized that different results can be achieved with different recycling agents and different old/new aggregate ratios.

Recycled mixes have been prepared, examined and found to be suitable for use as a bituminous mix by normal testing procedures. Some initial testing reported here has implications for long term performance that will be developed more thoroughly in the Final Report. The Final Report will detail the structural testing and analytical procedures used to compare the long term performance of an all new mix with the recycled mixes made with the procedures and parameters developed in this report.

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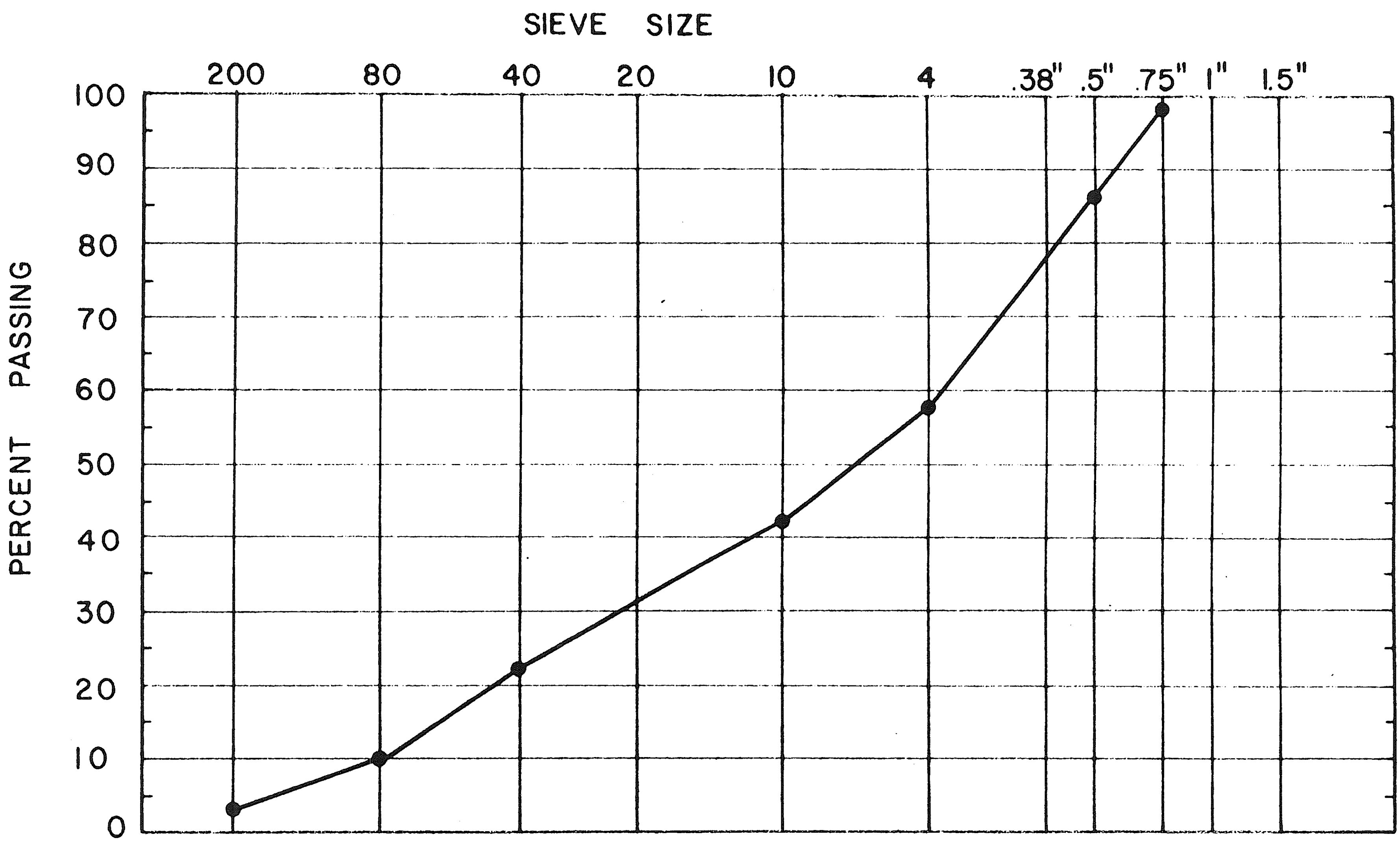

Figure 1. Gradation Curve for Peoria Shoulder Material.

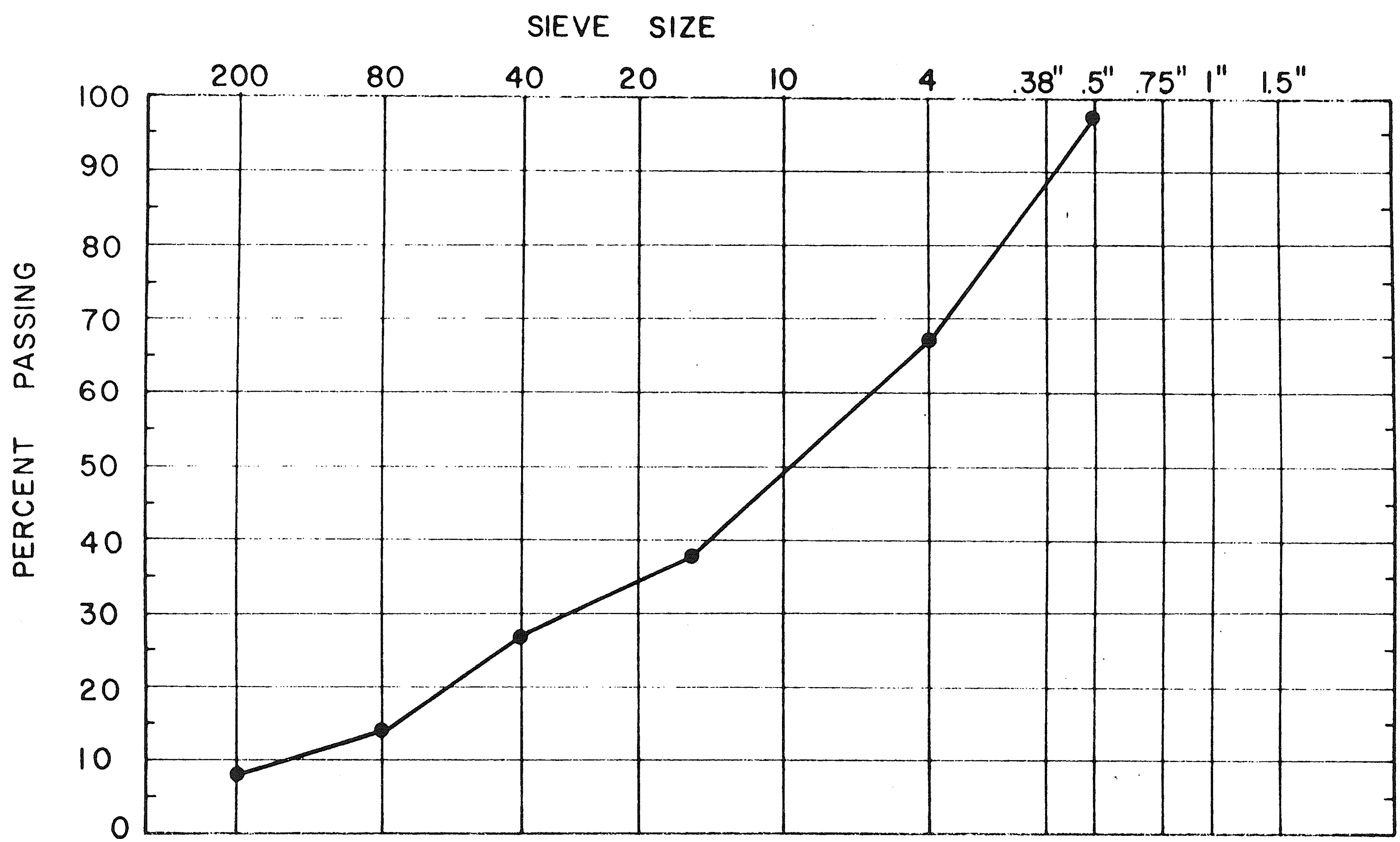

Figure 2. Gradation for Decatur Cold Milled Material.

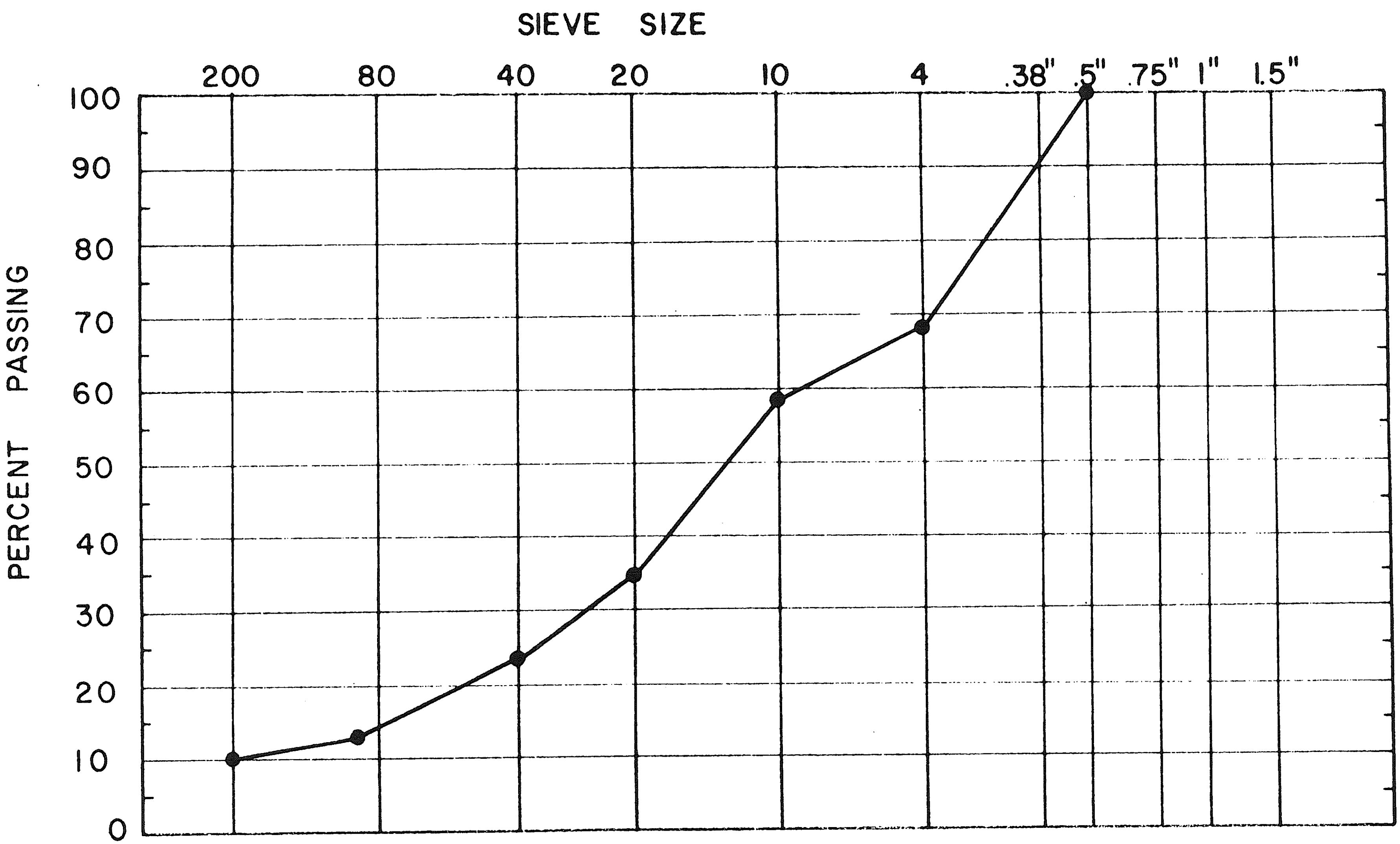

Figure 3. Gradation for University Avenue Cold Milled Material.

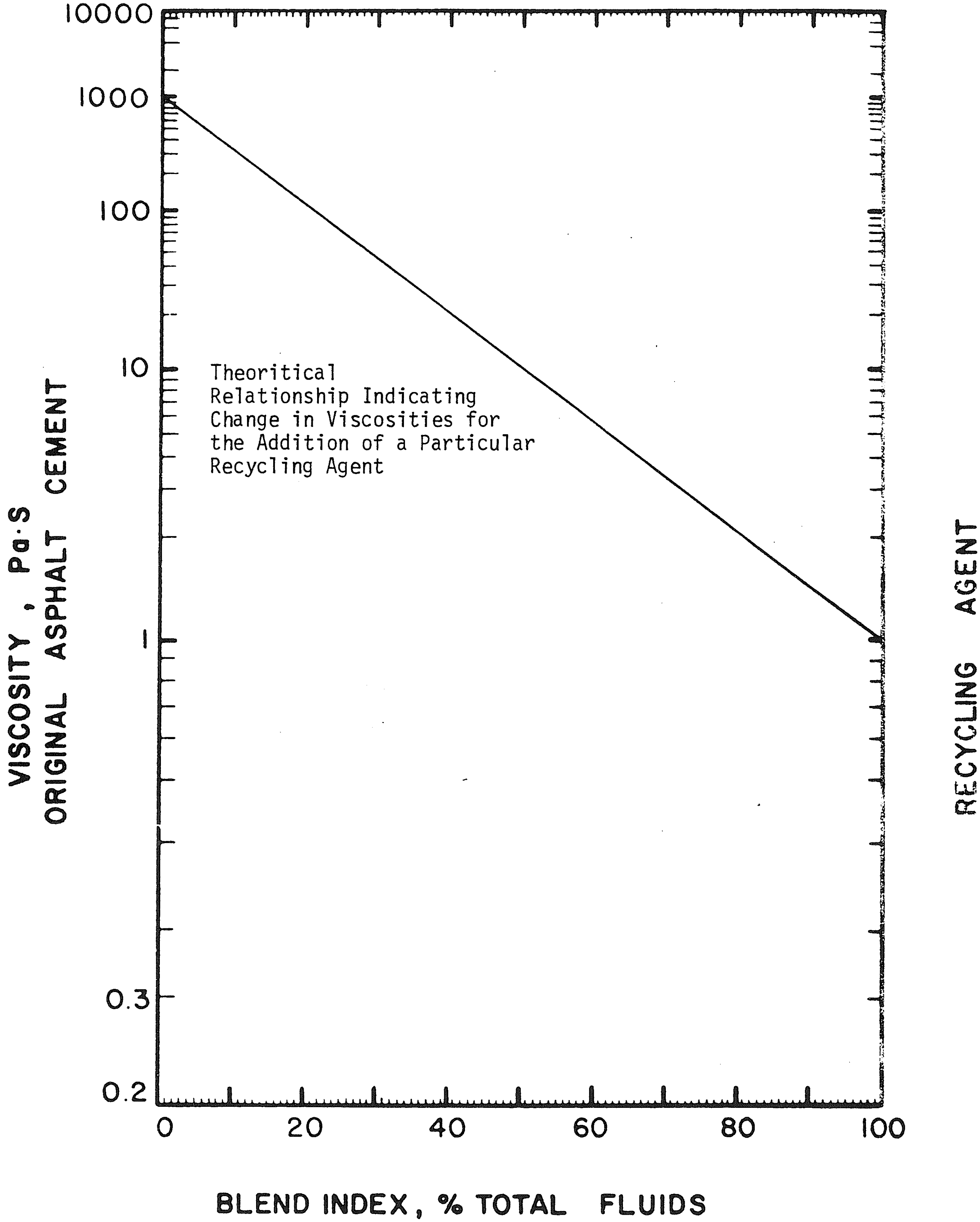

Figure 4. Blend Chart for Addition of Recycling Agent to Aged Asphalt Cement.

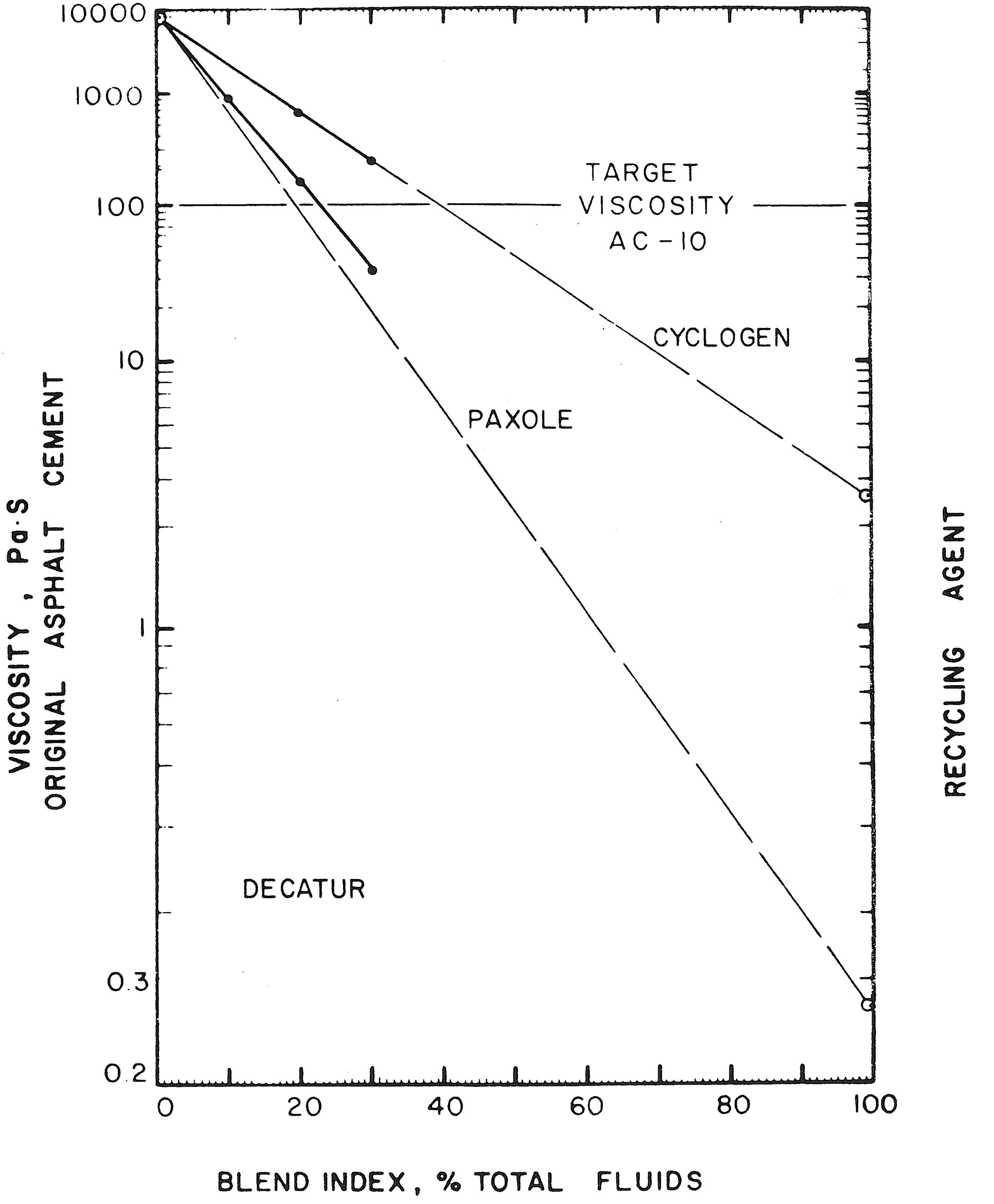

Figure 5. Influence of Recycling Agents on the Viscosity of the Decatur Asphalt Cement.

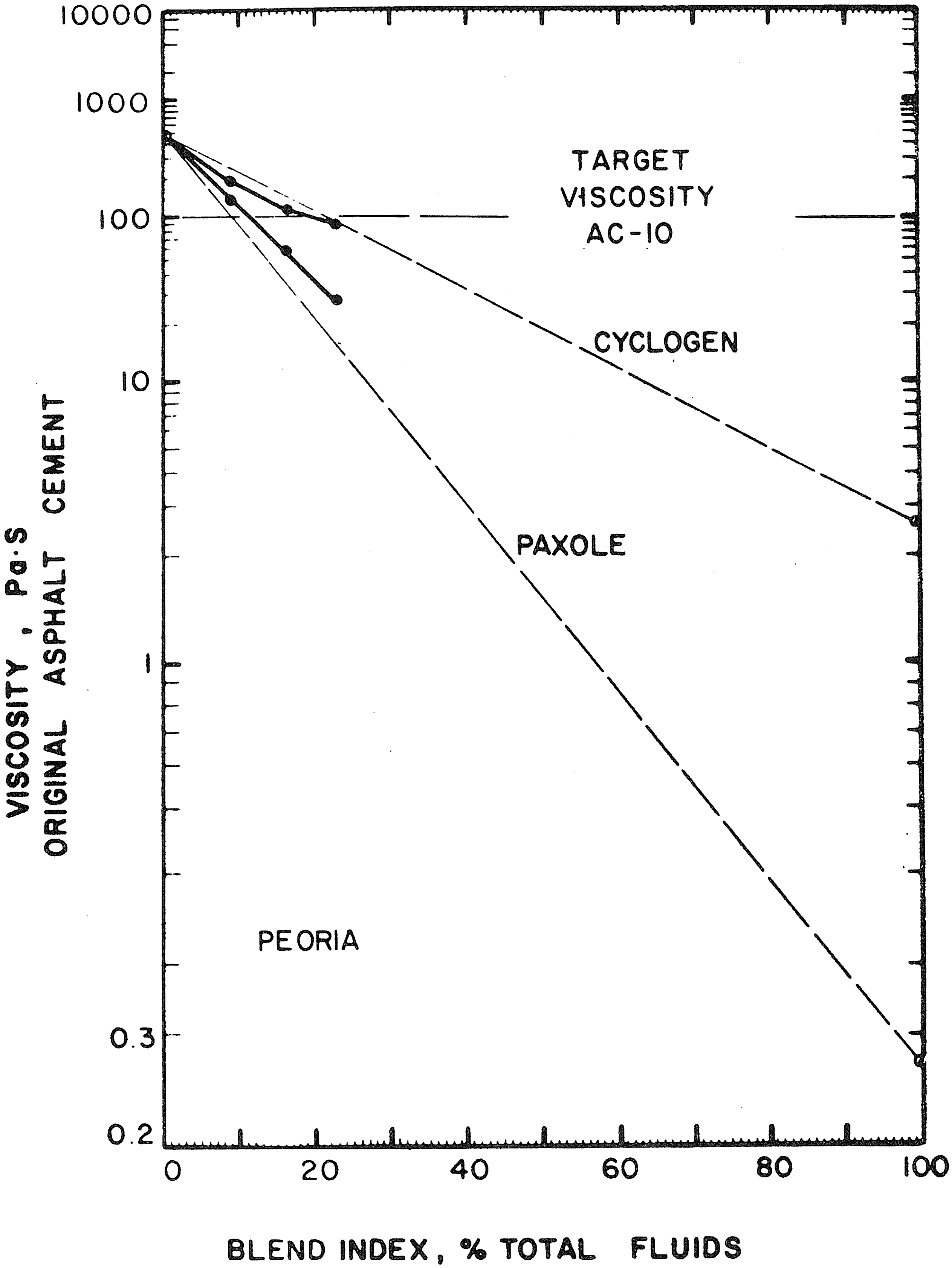

Figure 6. Influence of Recycling Agent on the Viscosity of the Peoria Asphalt Cement.

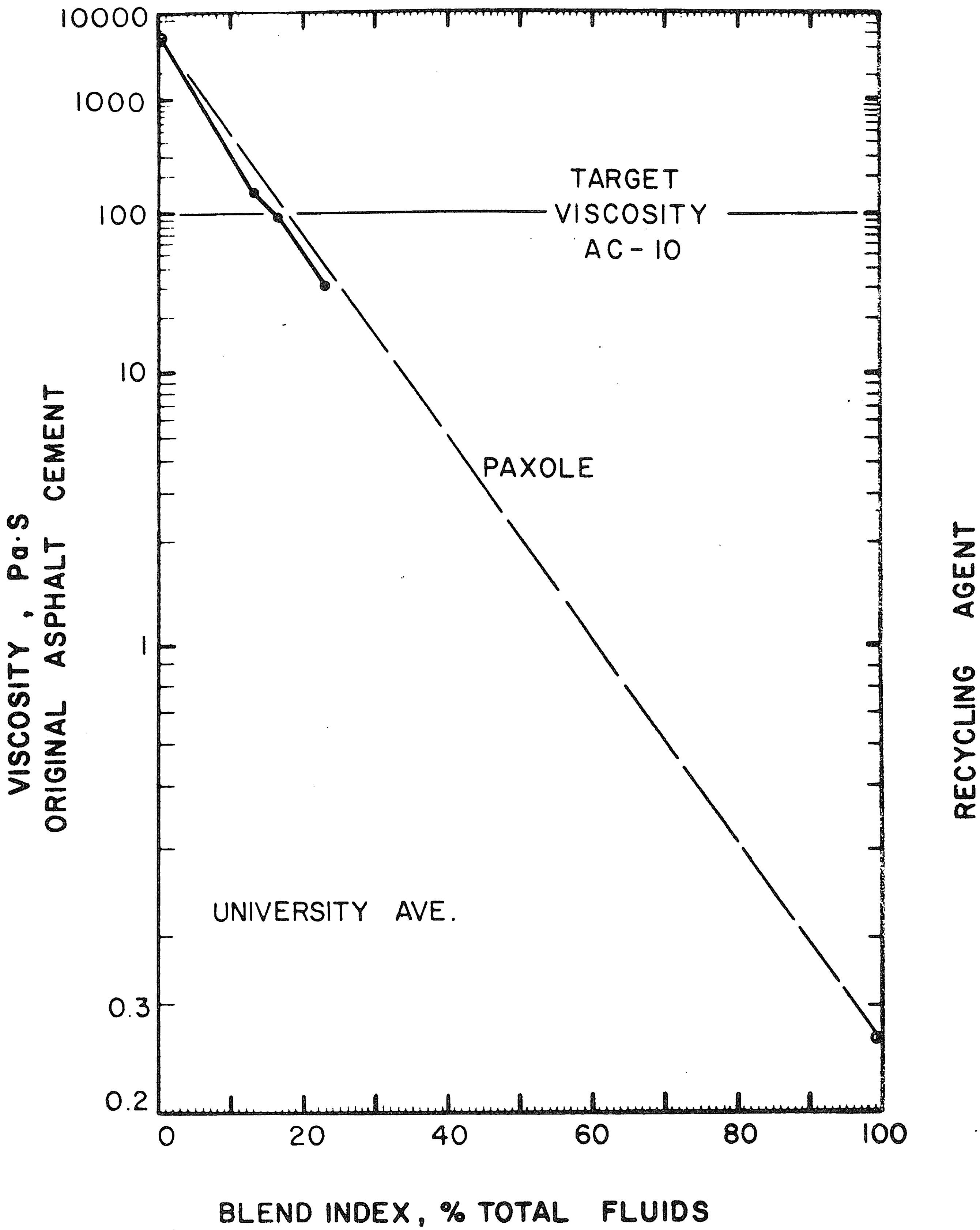

Figure 7. Influence of Recycling Agent on the Viscosity of the University Avenue Asphalt Cement.

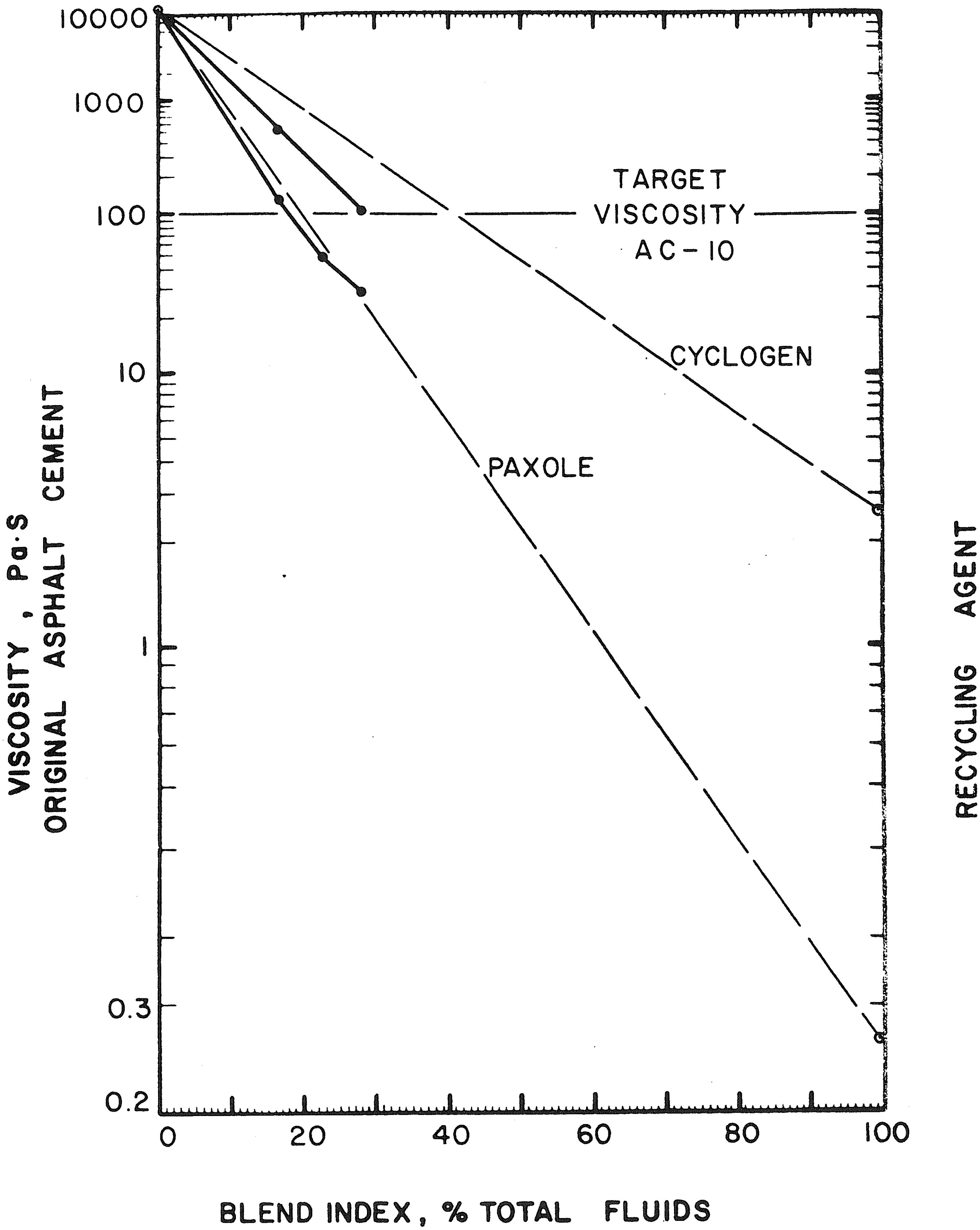

Figure 8. Influence of the Recycling Agent on the Viscosity of the Mattoon Shoulder Asphalt Cement.

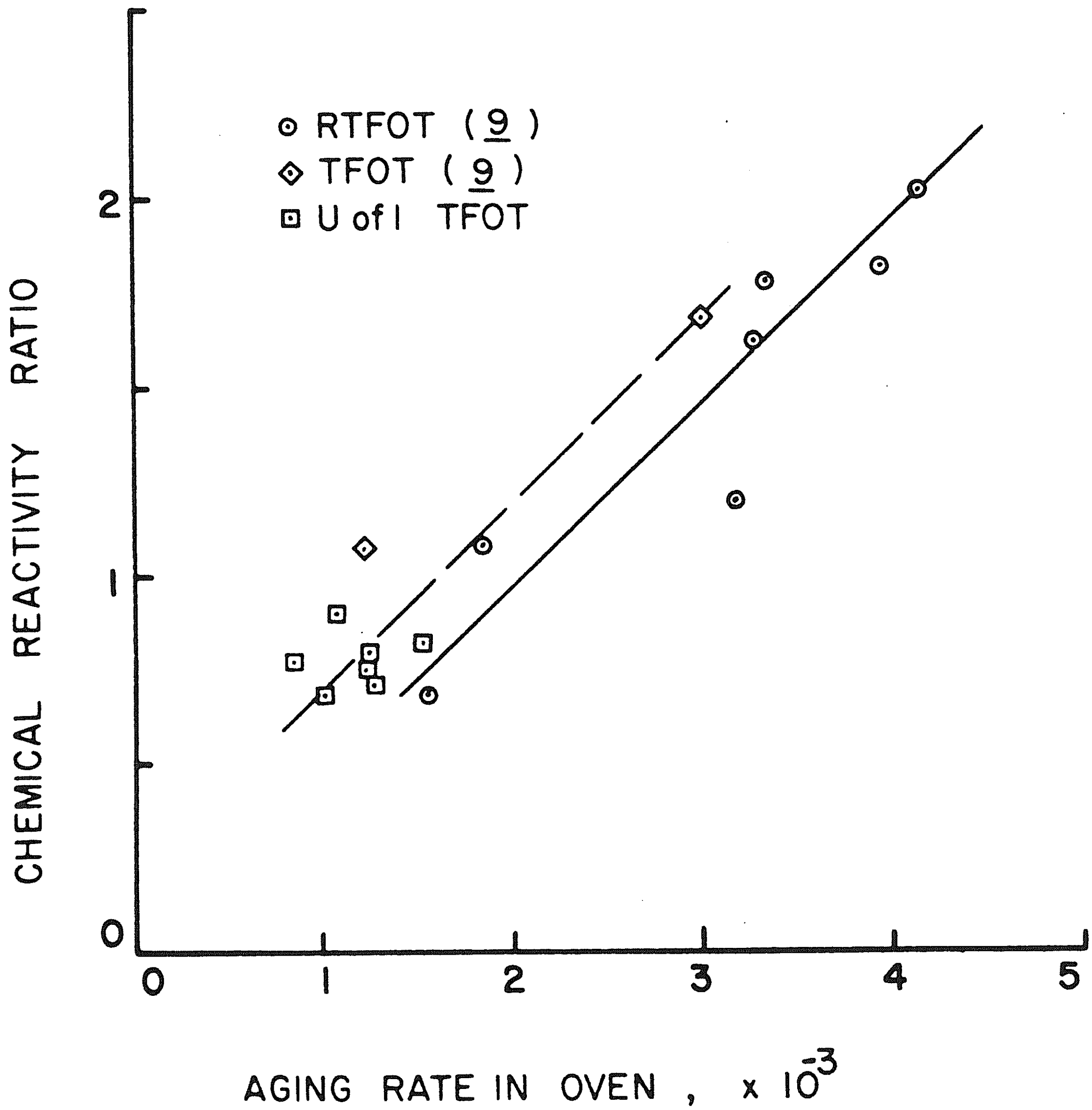

Figure 9. Relationship Between Chemical Composition and Aging in the Thin Film Oven Test.

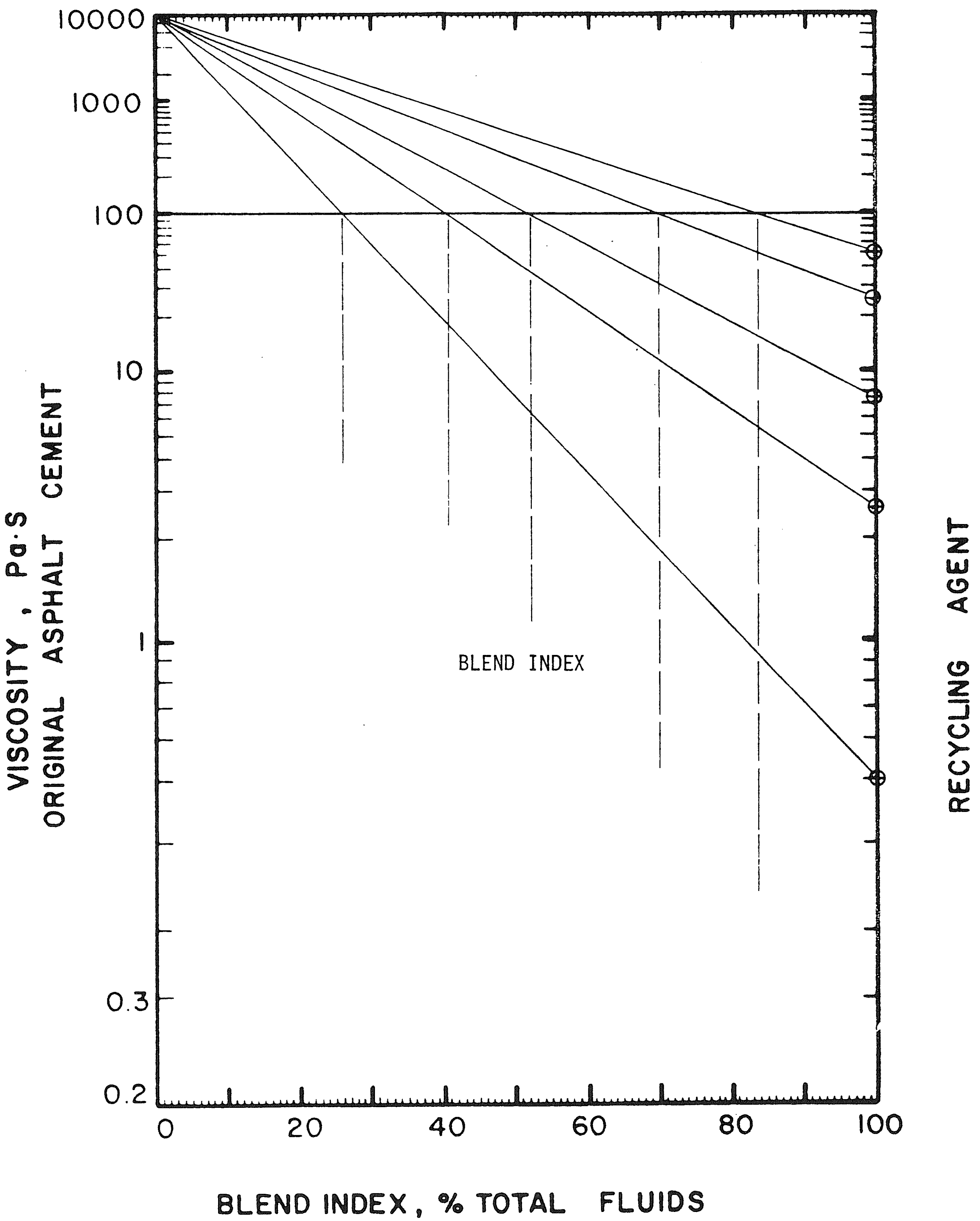

Figure 10. Changes in the Amount of Recycling Agent Required as the Viscosity of the Recycling Agent Increases.

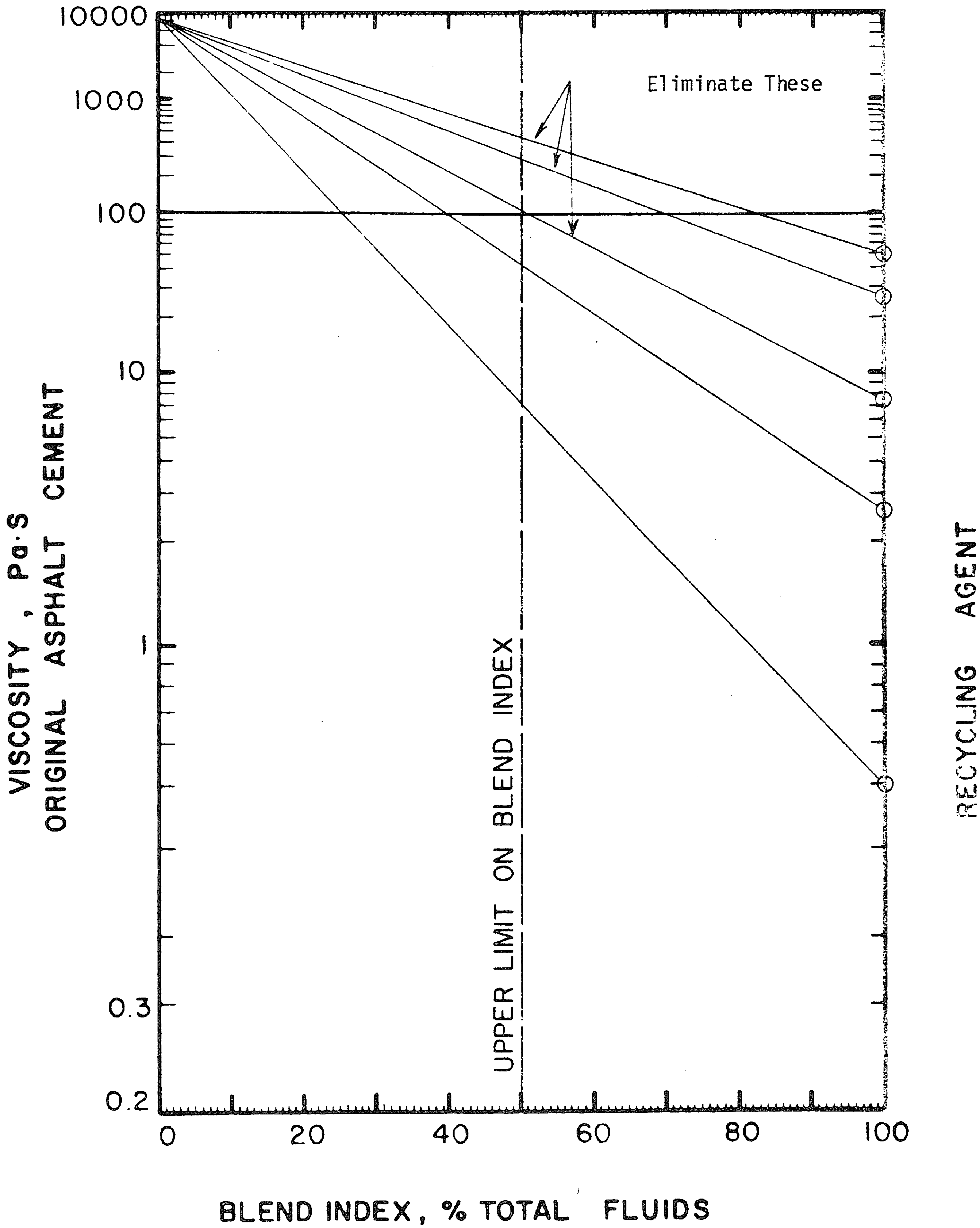

Figure 11. Use of Upper Limit to Eliminate Recycling Agents Requiring too Large an Amount to be Added.

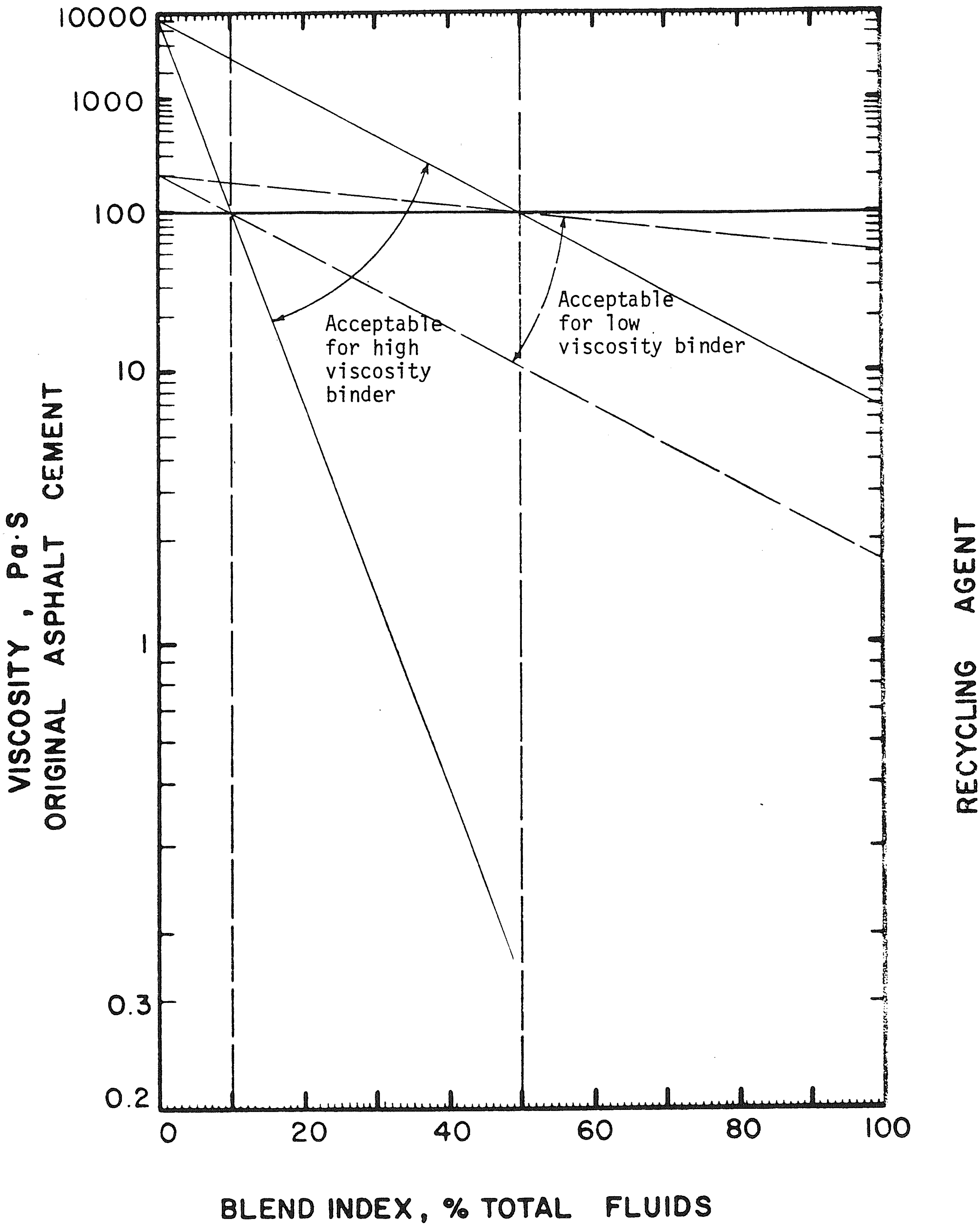

Figure 12. Influence of the Viscosity in the Aged Binder on the Acceptable Viscosities of the Recycling Agents to Remain Within the Limits.

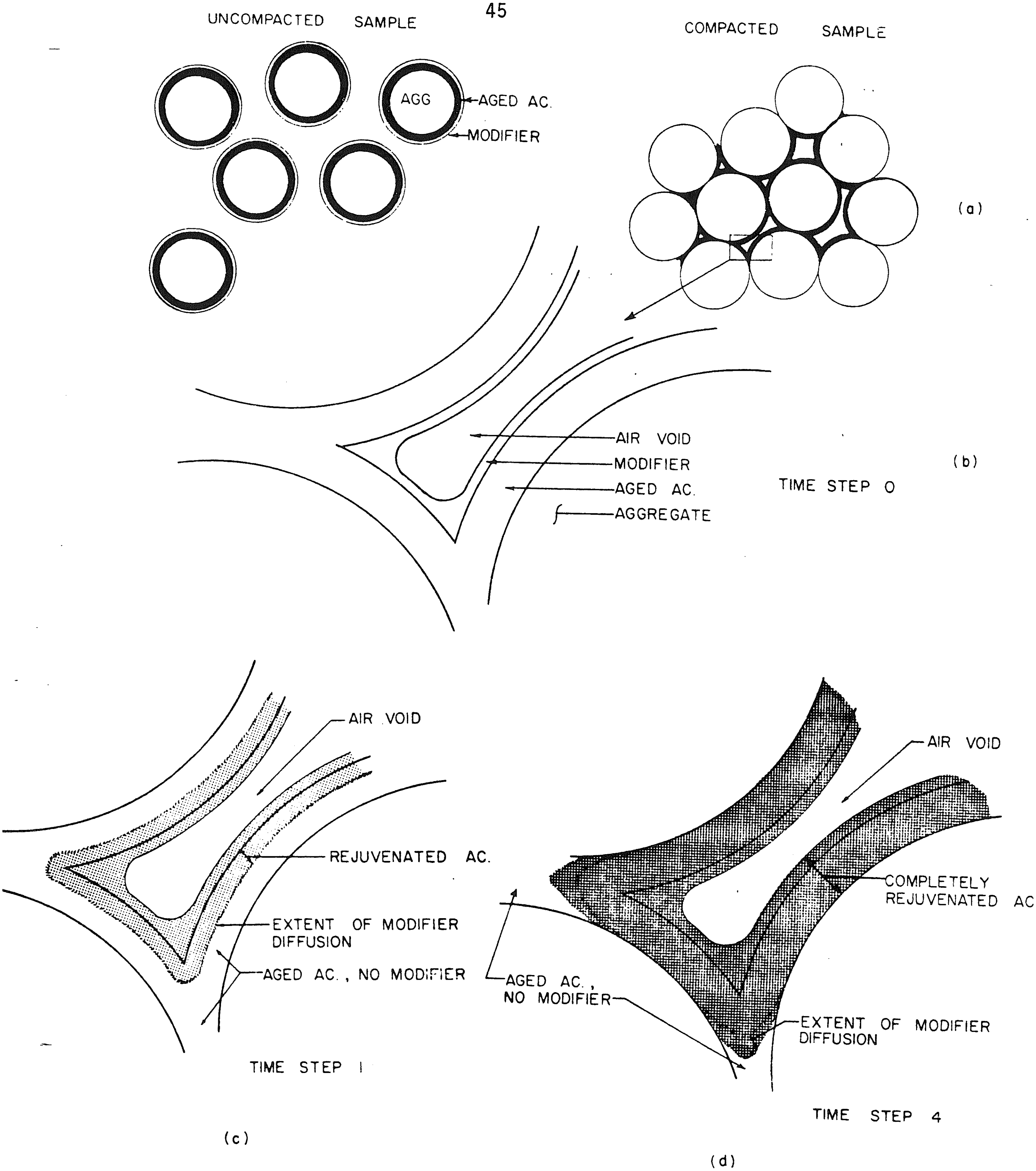

Figure 13. Schematic of Diffusion in a Compacted Sample.

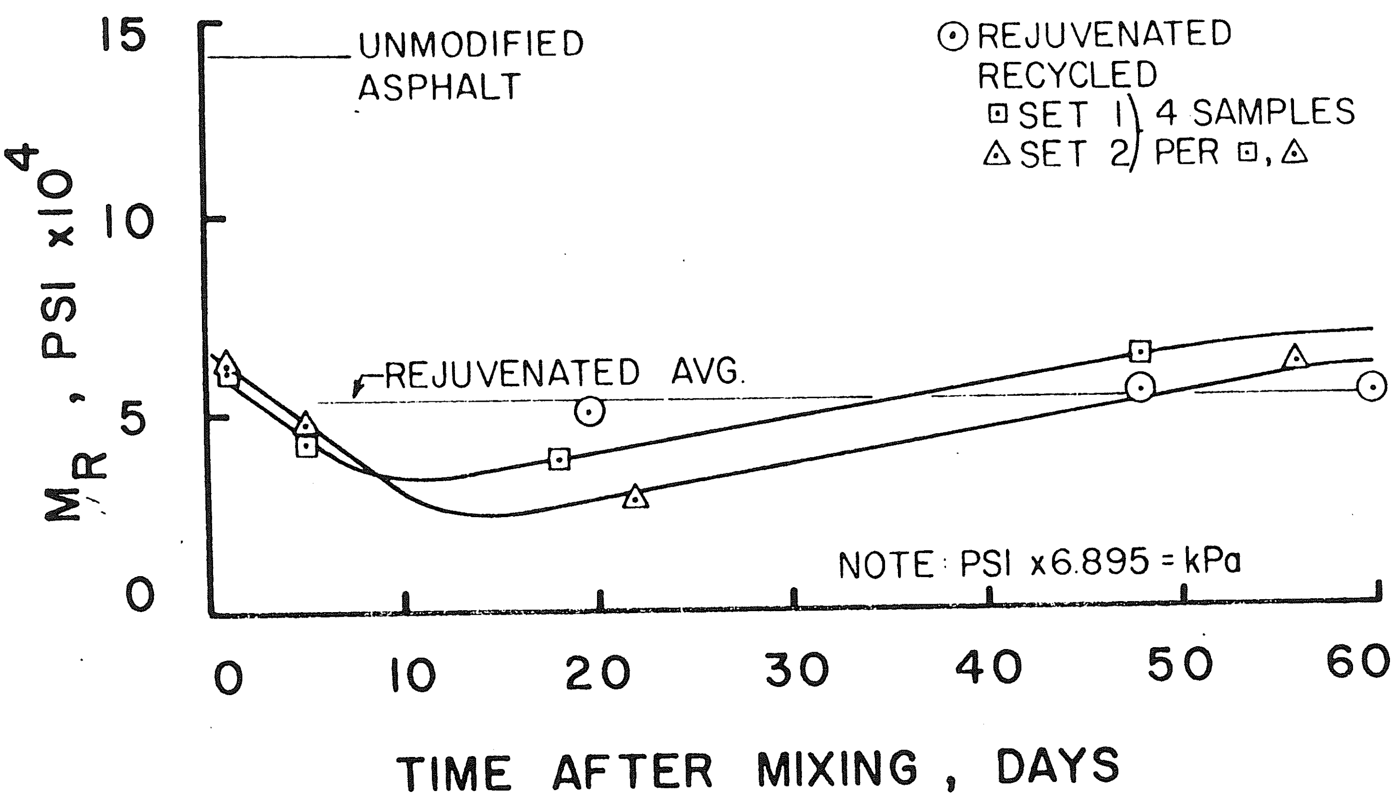

Figure 14. Variation in Resilient Modulus as a Function of Time.

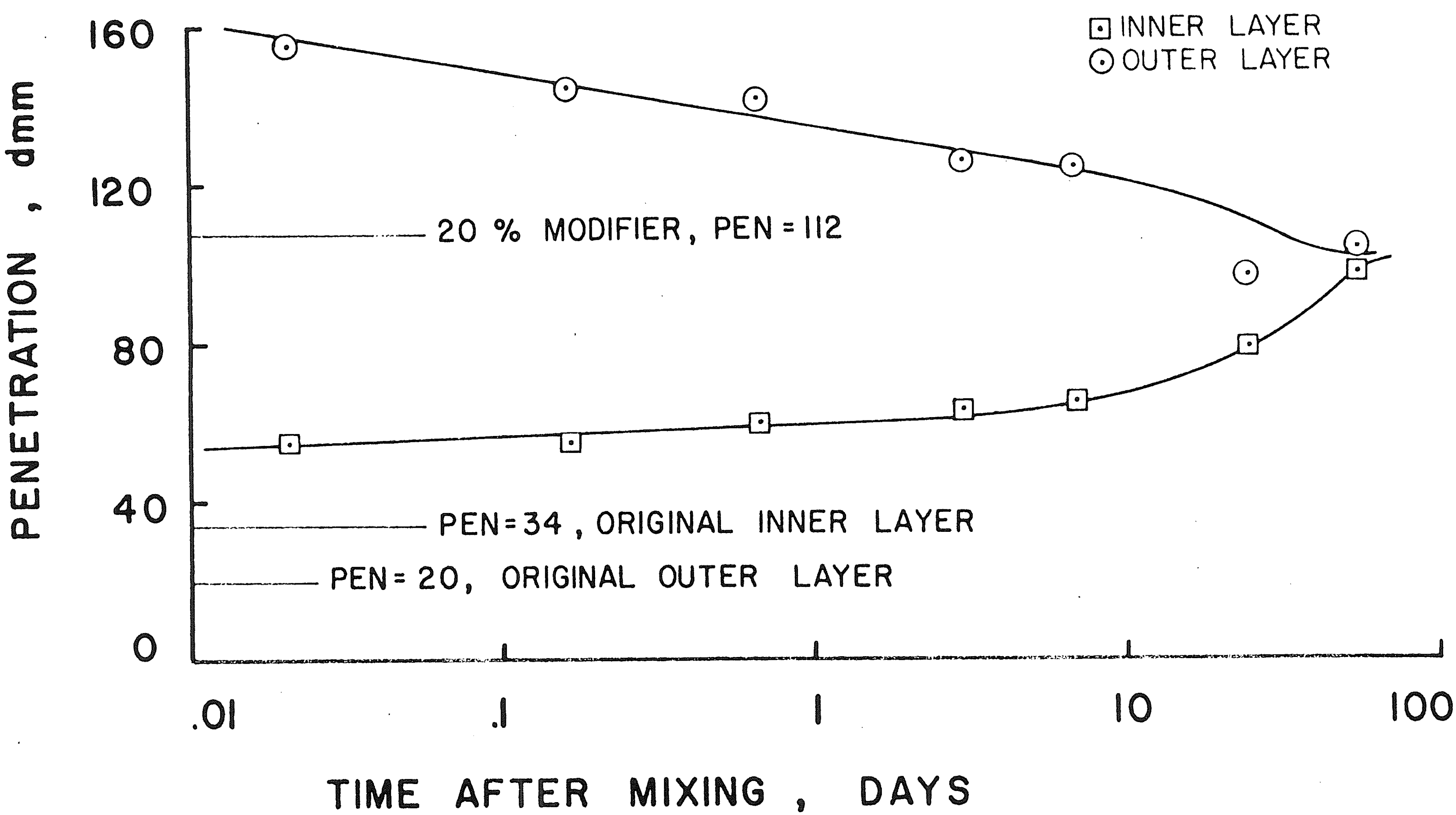

Figure 15. Penetration of the Outer and Inner Layers as a Function of Time.

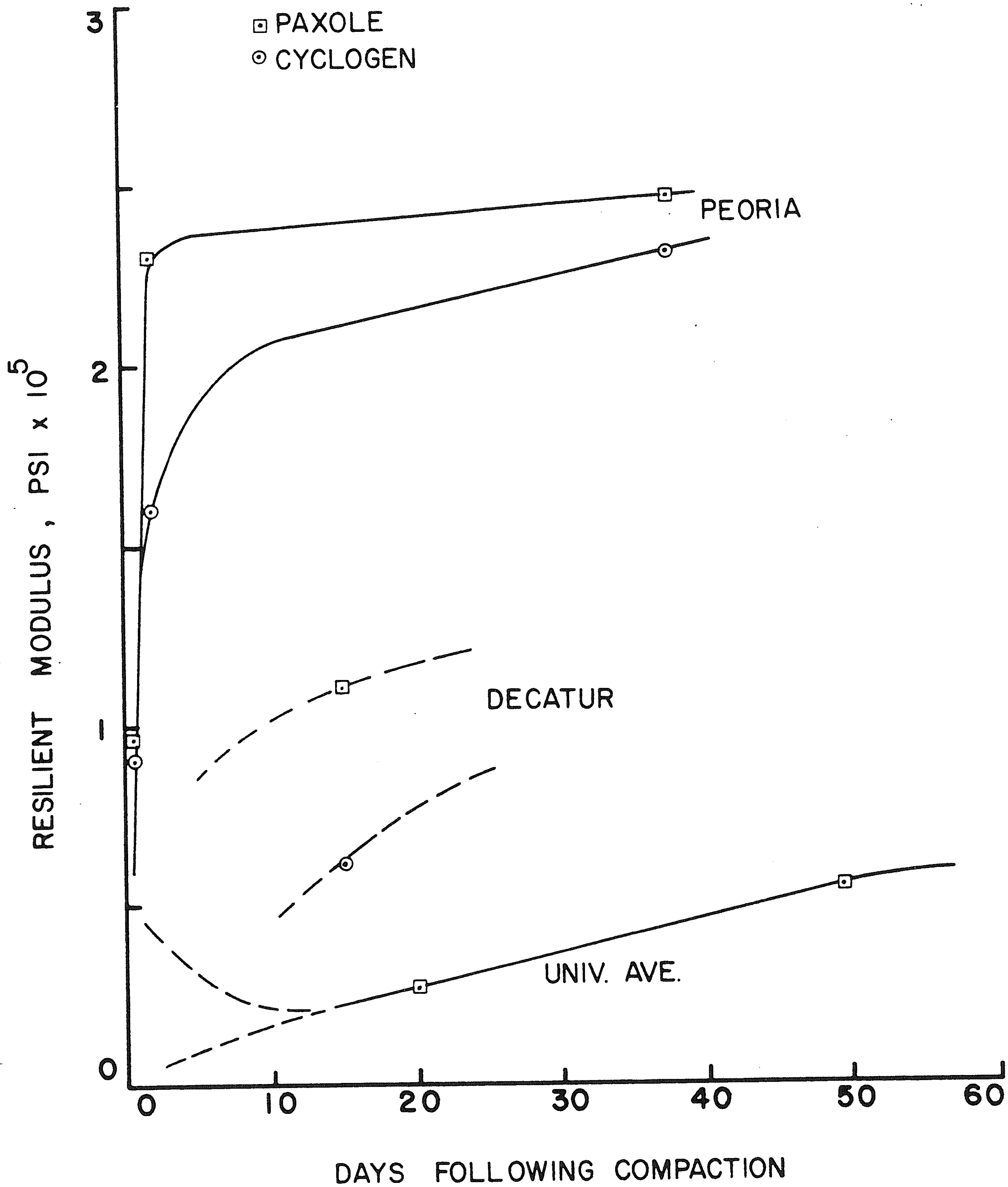

Figure 16. Change in Stiffness as a Function of the Diffusion of Recycling Agent into the Aged Binder.

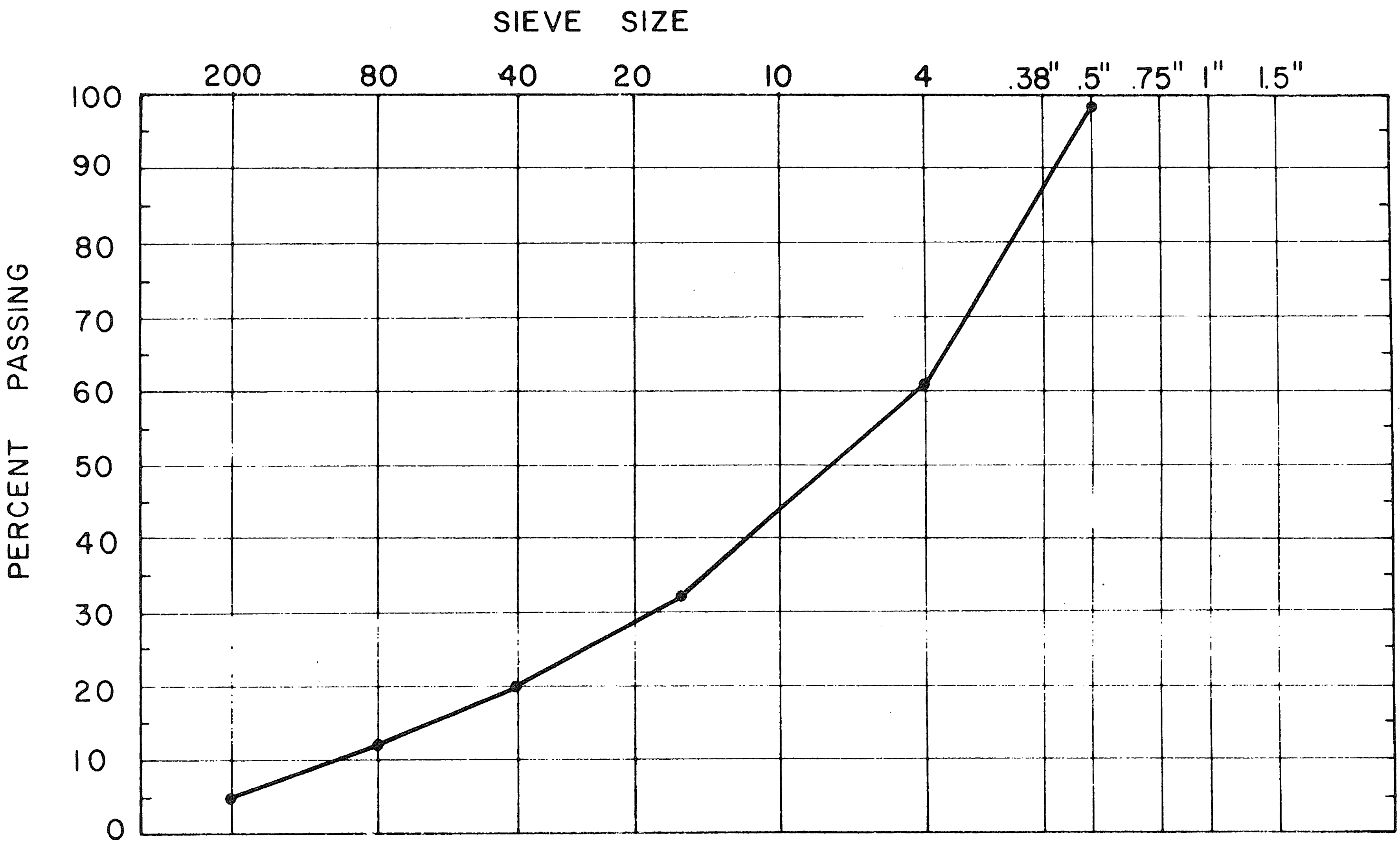

Figure 17. Gradation of the Fairmont Aggregate (Class I) Used as the New Aggregate.

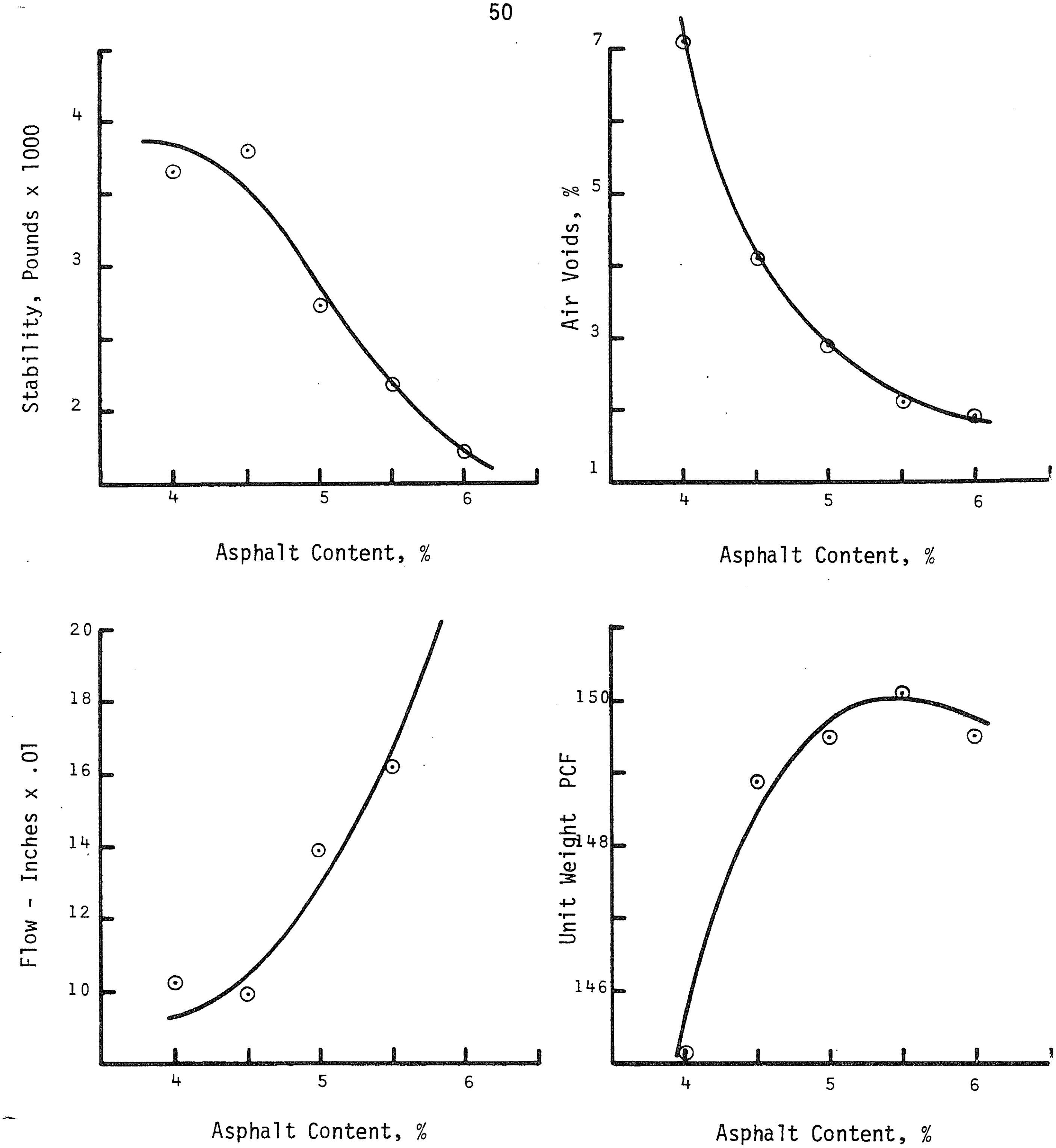

Figure 18. Mix Design Curves for the Fairmont All New Aggregate.

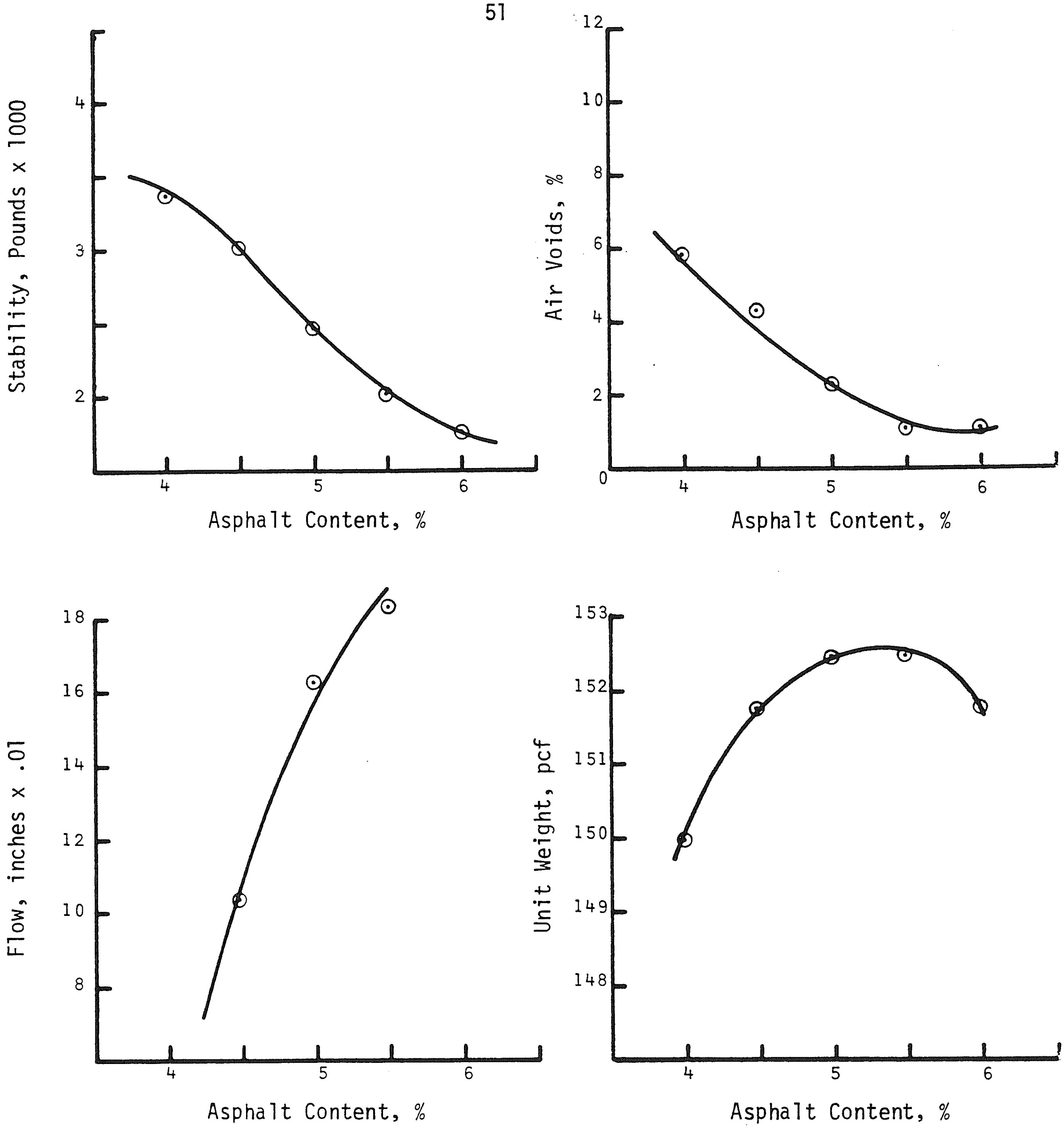

Figure 19. Mix Design Curves for the Decatur Cyclogen 50/50 Combination.

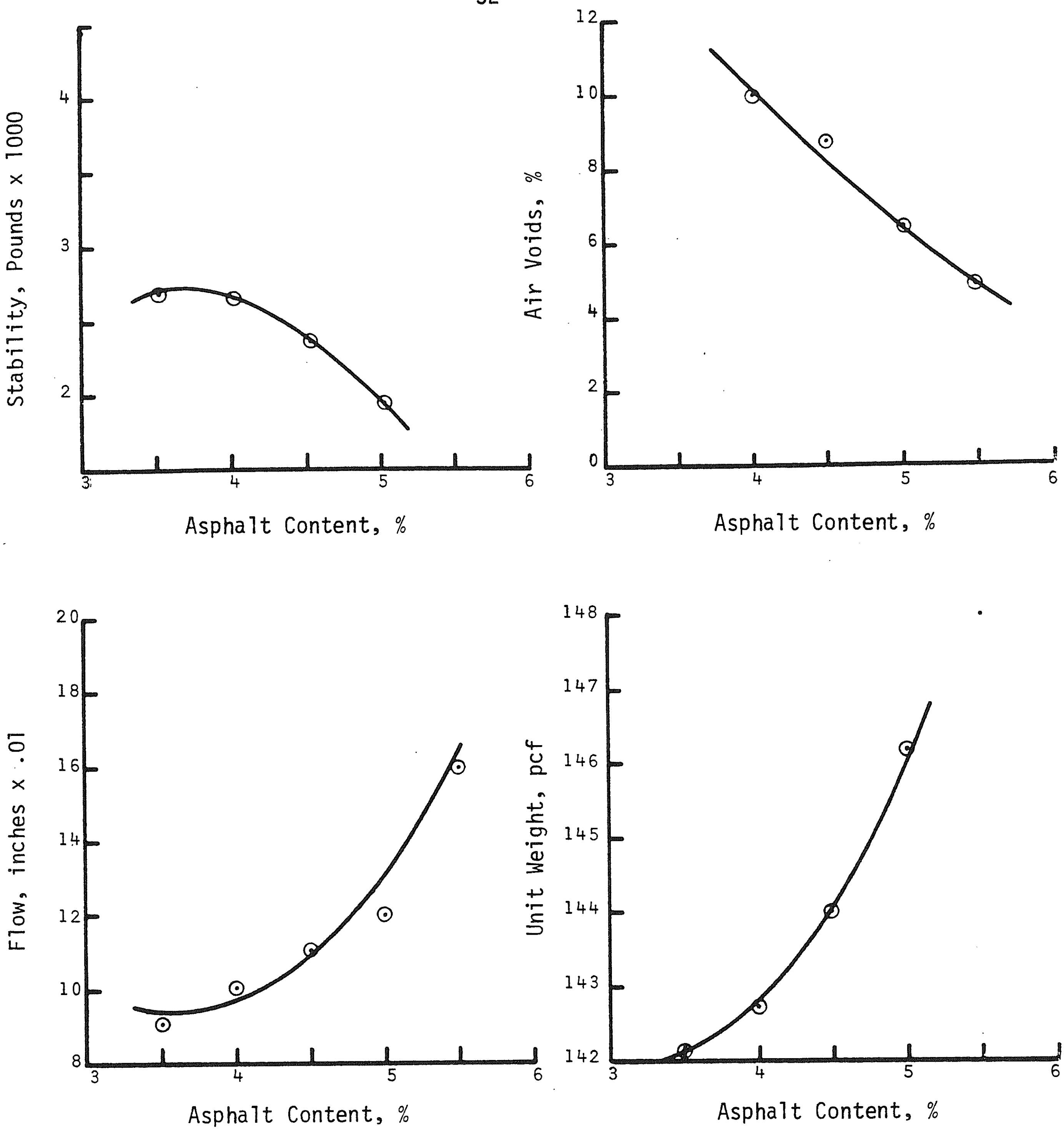

Figure 20. Mix Design Curves for the Decatur Paxole 50/50 Combination.

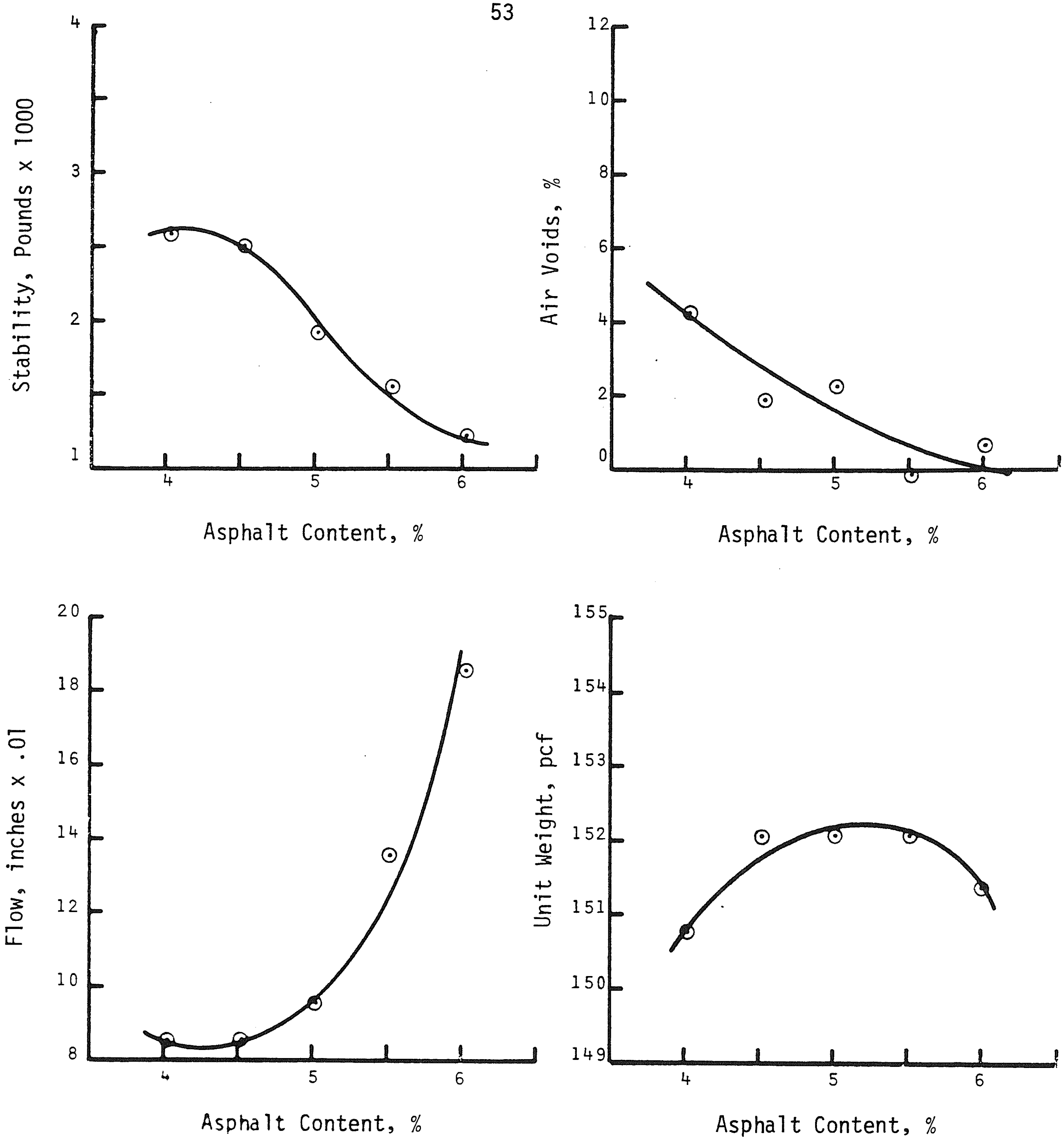

Figure 21. Mix Design Curves for the Peoria Cyclogen 50/50 Combination.

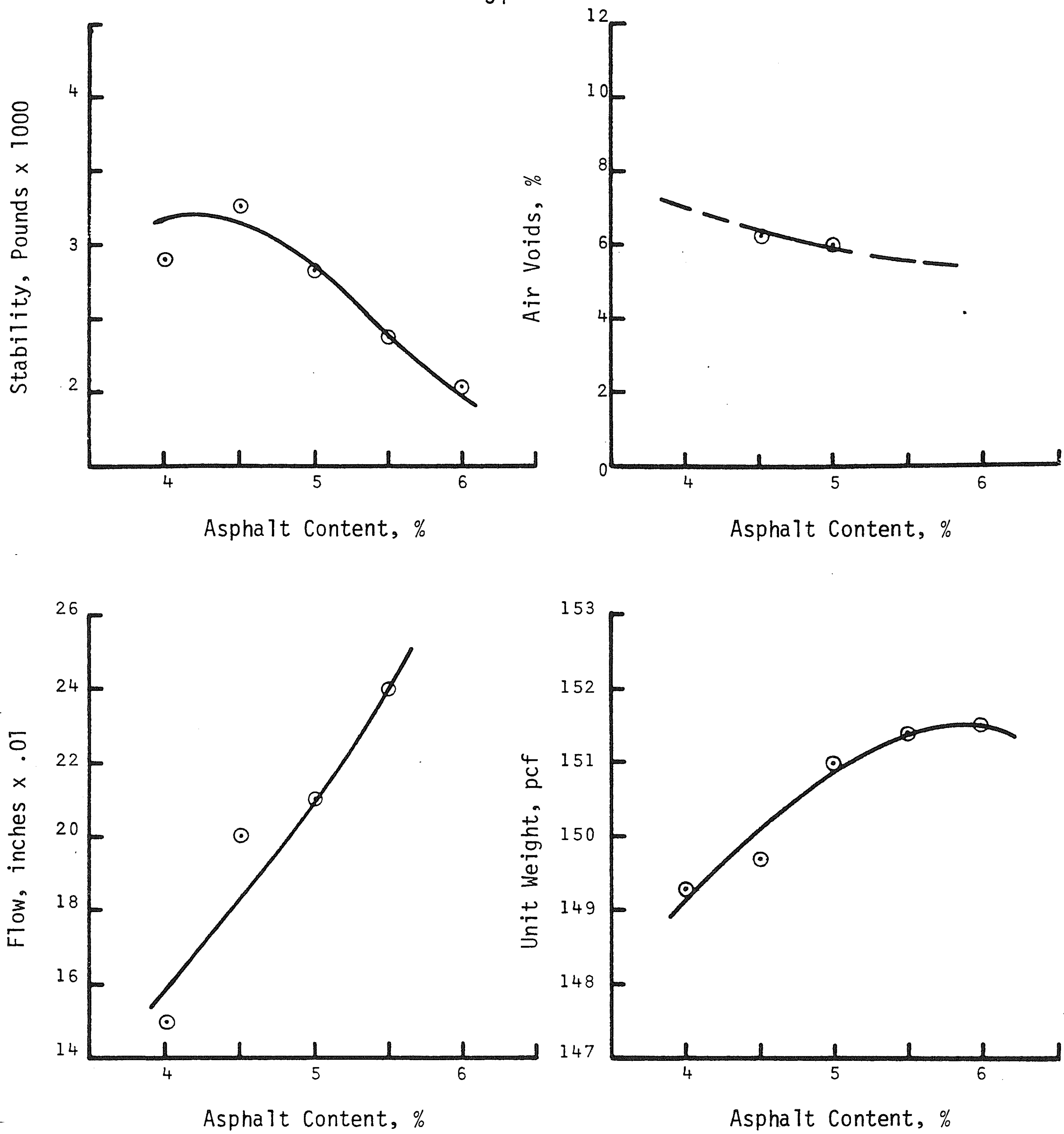

Figure 22. Mix Design Curves for the Peoria Paxole 50/50 Combination.

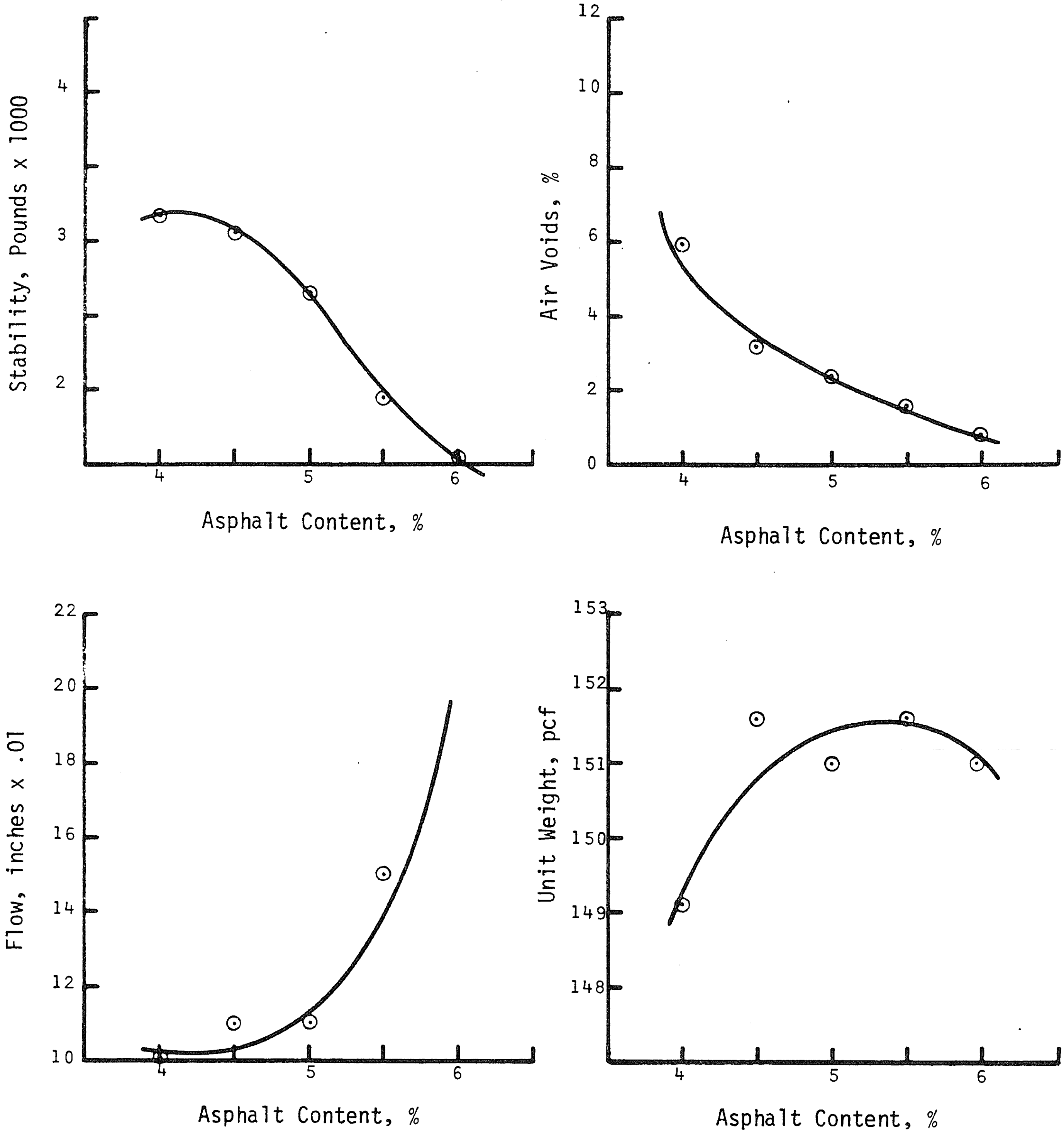

Figure 23. Mix Design Curves for the Decatur Cyclogen 30/70 Combination.

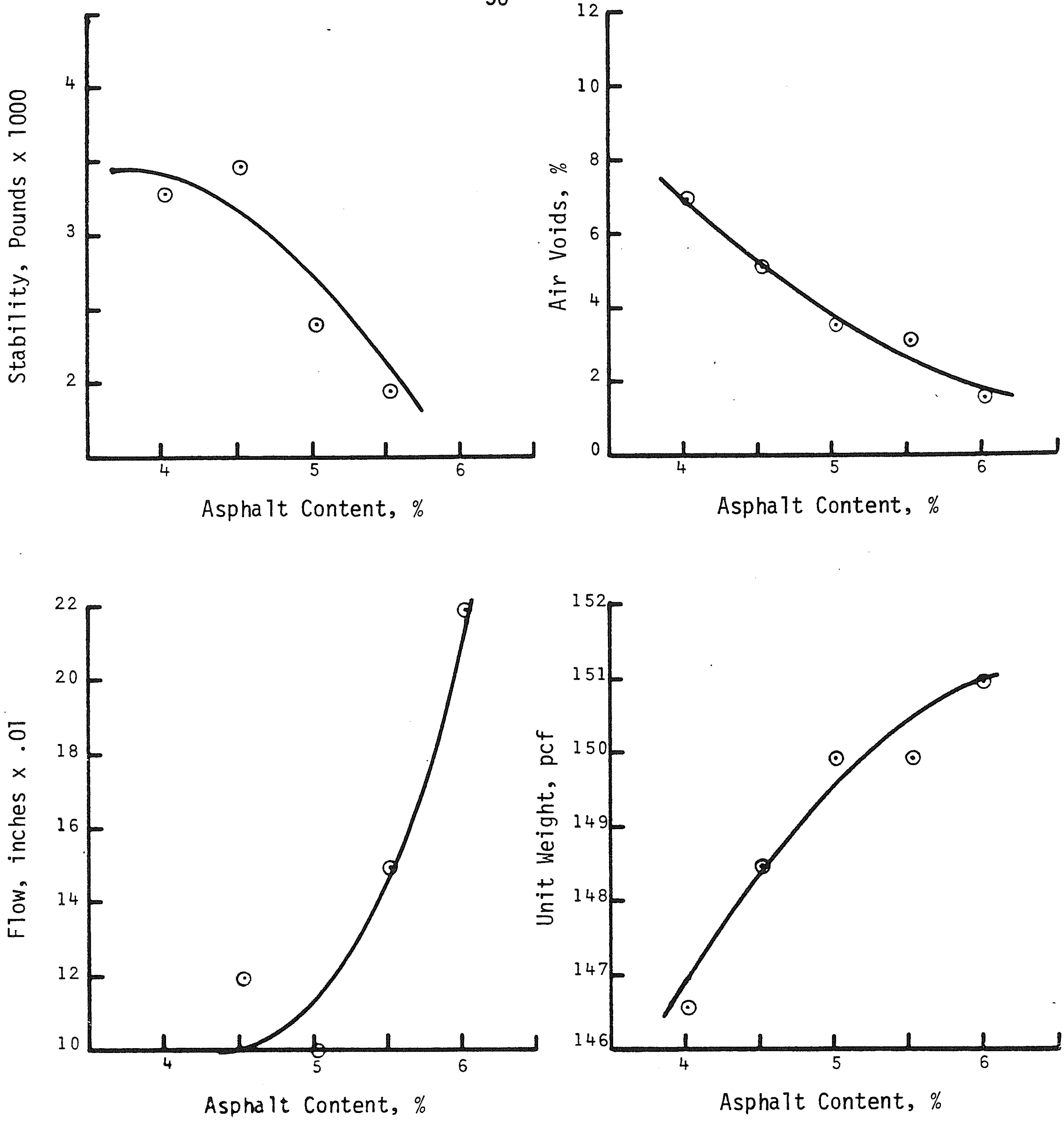

Figure 24. Mix Design Curves for the Decatur Paxole 30/70 Combination.

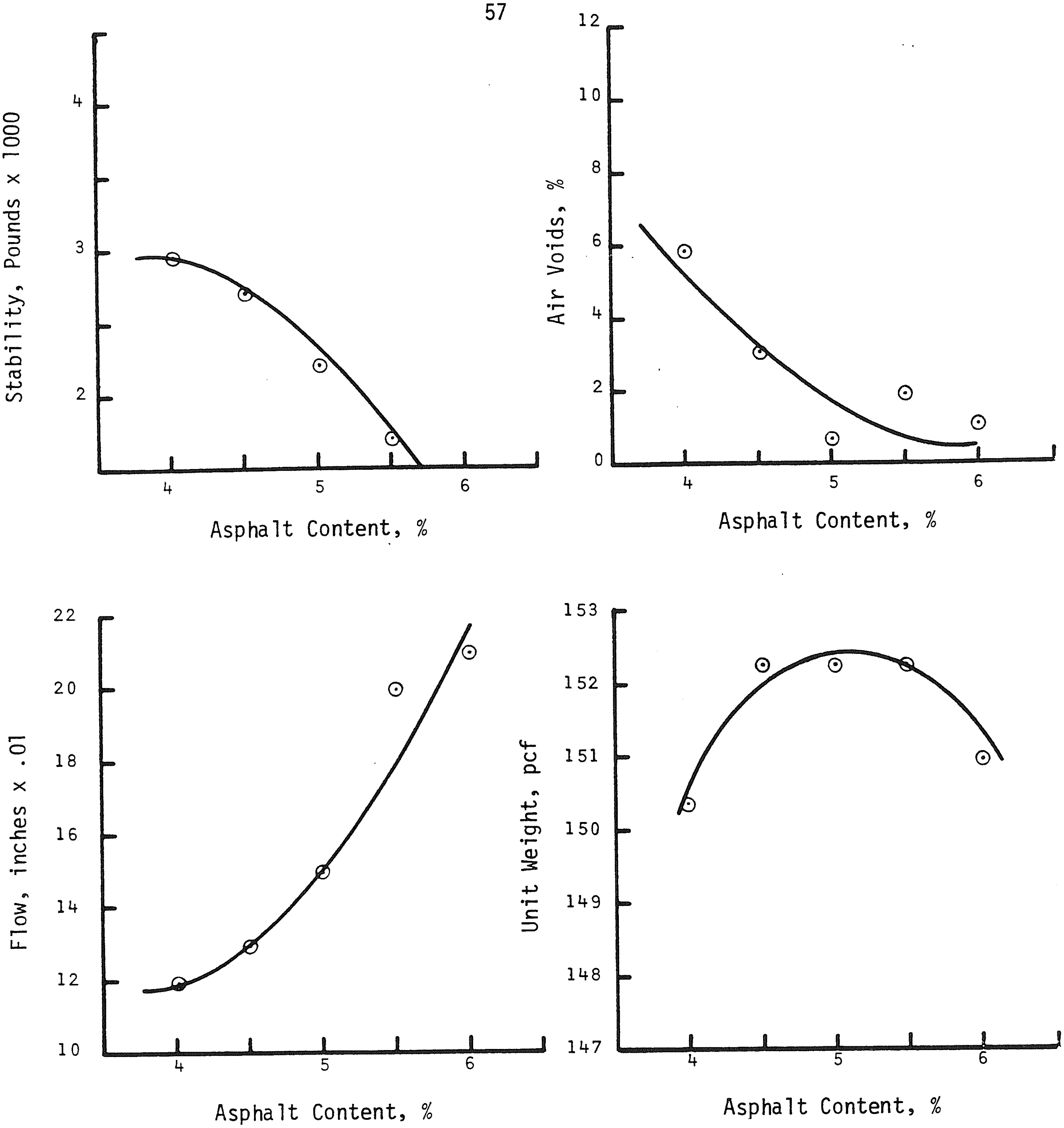

Figure 25. Mix Design Curves for the Peoria Cyclogen 30/70 Combination.

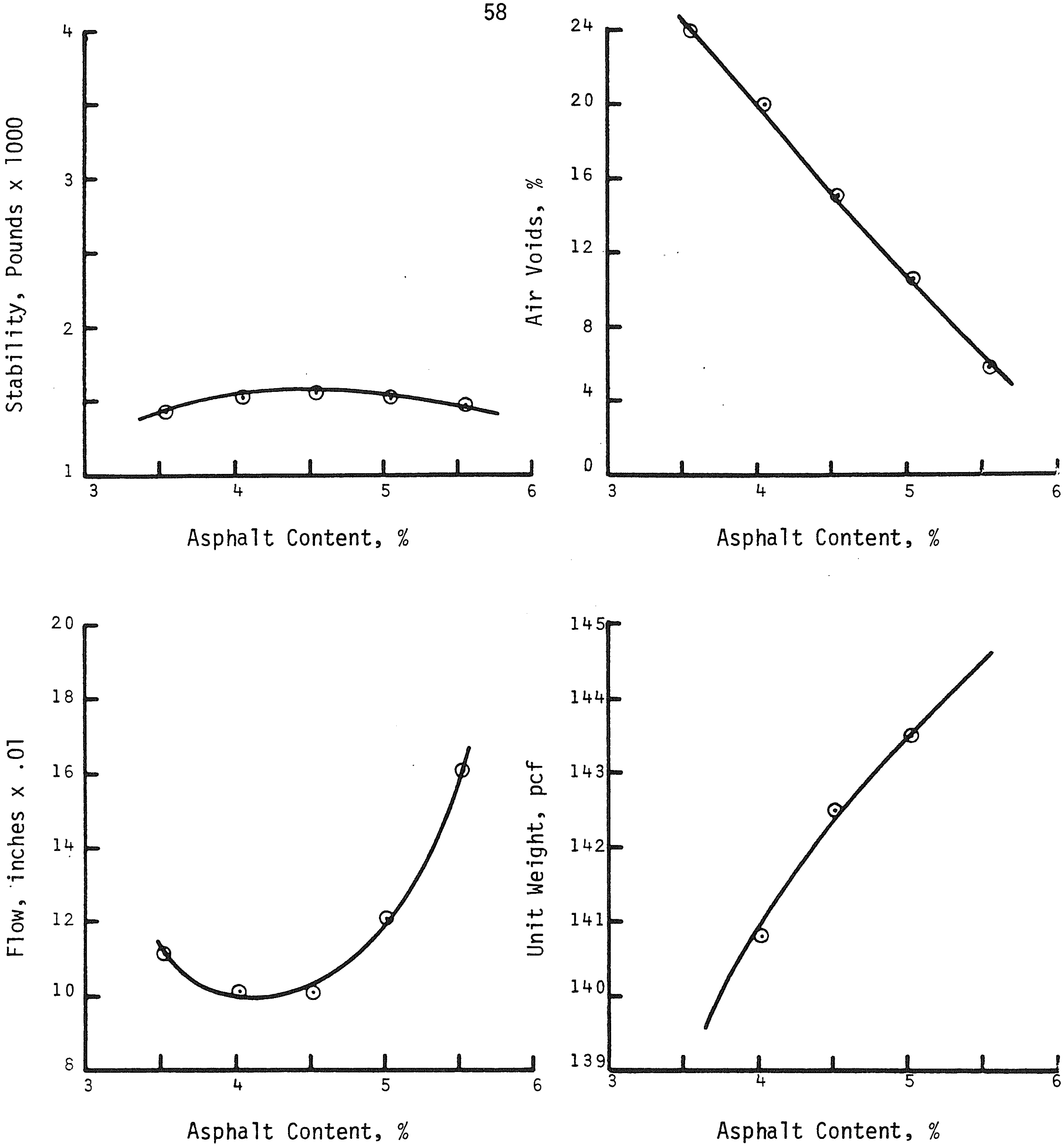

Figure 26. Mix Design Curves for the Peoria Paxole 30/70 Combination.

Table 1. Properties of Recovered Asphalt Cements

Material	Penetration (dmm)	Viscosity (Poise)	R&B Softening (°C)
Peoria	35	4,800	50.5
Decatur	14	90,800	69.0
University Ave.	26	44,900	63.0
Mattoon Shoulder	18	109,800	69.5

Table 2. Chemical Composition of Recovered Asphalt Cements

Material	% Asphaltenes	Chemical Reactivity Ratio
Peoria	36.0	0.86
Decatur	36.4	0.37
University Ave.	41.2	0.64
Mattoon Shoulder	40.7	0.78

Table 3. Properties of Recycling Agents

Material	Viscosity Poise	% Asphaltenes	Chemical Reactivity Ratio
Paxole	2.5	7.0	0.72
Cyclogen	25	11.2	0.69

Table 4. Prototype Specifications for Recycling Agents Used in Hot Mix Recycling

	ASTM TEST Method	RA 5 min.	RA 5 max.	RA 25 min.	RA 25 max.	RA 75 min.	RA 75 max.	RA 250 min.	RA 250 max.	RA 500 min.	RA 500 max.
Viscosity @140°F, cSt	D2170 or 2171	200	800	1000	4000	5000	10000	15000	35000	40000	60000
Flash Point COC, °F	D92	400	---	425	---	450	---	450	---	450	---
Saturates, wt. %	D2007	---	30	---	30	---	30	---	30	---	30
Residue from RTF-C Oven Test @325° F	D2872[2]										
Viscosity Ratio[3]	---	---	3	---	3	---	3	---	3	---	3
RTF-C Oven Weight Change, ±, %	D2872[2]	---	4	---	3	---	2	---	2	---	2
Specific Gravity	D 70 or D1298	Report		Report		Report		Report		Report	

1. The final acceptance of recycling agents meeting this specification is subject to the compliance of the reconstituted asphalt blends with current asphalt specifications.

2. The use of ASTM D1754 has not been studied in the context of this specification, however, it may be applicable. In cases of dispute the reference method shall be ASTM D2872.

3. $$\text{Viscosity Ratio} = \frac{\text{RTF-C Viscosity at 140°F, cSt}}{\text{Original Viscosity at 140° F, cSt}}$$

Table 5. Blend Indexes For Asphalt Cements Studied

Material	Recycling Agent	Blend Index % Wrd/(Wra+Wac)
Peoria	Paxole	13
	Cyclogen	25
Decatur	Paxole	28
	Cyclogen	65
University Avenue	Paxole	20
	Cyclogen	
Mattoon Shoulder	Paxole	22
	Cyclogen	41

Table 6. Properties of Rejuvenated Asphalt Cements

Test Property	Peoria		Decatur		University Avenue		Mattoon Shoulder	
	Cyclogen	Paxole	Cyclogen	Paxole	Cyclogen	Paxole	Cyclogen	Paxole
Penetration (25 C) (100 gm 5 sec)	86	95	100	98	---	94	95	83
Penetration (4 C) (200 gm 60 sec)	30	35			---		36	37
Viscosity 60 C Poise	1000	900	1120	1109	---	1000	1900	1600
Viscosity 140 C cst.	198	322			---		253	254
Ring & Ball Softening Pt. (° C)	45.5	45.0	44.0	44.0		44.0	47.0	46.5

Table 7. Properties of Rejuvenated Asphalt Cements After TFOT Aging

Test Property	Peoria		Decatur		University Avenue		Mattoon Shoulder	
	Cyclogen	Paxole	Cyclogen	Paxole	Cyclogen	Paxole	Cyclogen	Paxole
Penetration (25° C)	58	53	53	47	---	94	49	48
Penetration (4° C)	23	21			---		26	20
Viscosity (60° C)	1700	1900	3226	1109	---	2600	--- 4600	324 3800
Viscosity (140°C)	231	322			---		---	---
Ring & Ball Softening Pt. (° C)	48.0	50.0	52.0	44.0	---	44.0	52.0	51.0
TFOT Ratio	1.7	2.1	2.9	1.0		2.6	2.4	2.4

Table 8. Amounts of Recycling Agents Required for Typical Blend Indexes.

Blend Index	Weight of Recycling Agent (lb/ton of mix)	Percent of Recycling Agent (by weight of aggregate) (5% aged asphalt)
5	1.58	.08
10	3.33	.17
20	7.50	.38
30	12.86	.60
40	20.00	1.0
50	30.00	1.50

Table 9. Properties of All New AC Materials

Test Property	AC-10 (AMOCO)		AC-10 (AMOCO)		AC-10 (old)		AC-5		AC-20	
Penetration	80	56	91	55	75	42	133	74	55	36
Viscosity 60° C	1100	2900	1100	3000	1200	4300	600	1250	2100	5500
Ring & Ball Softening Pt. (° C)	46.0	51.5	46.0	52.0	49.0	56	41.5	47.0	52.0	57.0
TFOT Ratio	2.6		2.7		3.6		2.1		2.6	

Values are given before and after TFOT aging.

Table 10. Mix Design Values

Value	F	DFP		DFC		PFP		PFC	
	100%	50/50	30/70	50/50	30/70	50/50	30/70	50/50	30/70
Stability lbs	3754	2360	2406	2924	3065	2833	1505	2023	2728
Air Voids %	4.0	6.4	3.6	4.0	3.2	6.0	7.3	2.8	3.2
Asphalt Content %	4.5	5.0	5.0	4.5	4.5	5.0	5.0	5.0	4.5
Flow (in x .01)	10	12	10	12	11	21	12	10	13