Report No. CDOT-DTD-94-7

# Influence of Refining Processes and Crude Oil Sources Used in Colorado On Results from the Hamburg Wheel-Tracking Device

Tim Aschenbrener
Colorado Department of Transportation
4201 East Arkansas Avenue
Denver, Colorado 80222

Final Report
April 1994

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

**Acknowledgements**

The refineries that provide asphalt cement to Colorado were very cooperative in their assistance with this research study. Their cooperation was greatly appreciated. The laboratory mixture tests were performed by Kim Gilbert and Nava Far (CDOT). Benja Bemelen (CDOT) performed the asphalt cement tests.

The CDOT research panel provided many excellent comments and suggestions for the study. It included: Byron Lord and Kevin Stuart (FHWA - Turner Fairbank Highway Research Center), Doyt Bolling (FHWA - Region 8), Jerry Cloud (FHWA - Colorado Division), Steve Horton and Bob LaForce (CDOT - Staff Materials), Ken Wood (CDOT - Region 4 Materials), and Donna Harmelink (CDOT- Research).

Special thanks to the panel of Colorado asphalt paving experts who provided numerous ideas and suggestions which made this study more informational: Bud Brakey (Brakey Consulting Engineers), Jim Fife (Western Colorado Testing), Joe Proctor (Morton International), Scott Shuler (Colorado Asphalt Pavement Association) and Eric West (Western Mobile).

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| CDOT-DTD-R-94-7 | | |
| 4. Title and Subtitle<br>Influence of Refining Processes and Crude Oil Sources Used in Colorado On Results from the Hamburg Wheel-Tracking Device | | 5. Report Date<br>April 1994<br>6. Performing Organization Code |
| 7. Author(s)<br>Tim Aschenbrener | | 8. Performing Organization Rpt.No.<br>CDOT-DTD-R-94-7 |
| 9. Performing Organization Name and Address<br>Colorado Department of Transportation<br>4201 E. Arkansas Ave.<br>Denver, CO. 80222 | | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>Colorado Department of Transportation<br>4201 E. Arkansas Ave.<br>Denver, CO. 80222 | | 13. Type of Rpt. and Period Covered<br>Final Report<br>14. Sponsoring Agency Code |

15. Supplementary Notes

Prepared in Cooperation with the U.S. Department of Transportation Federal Highway Administration

16. Abstract


The Hamburg wheel-tracking device is known to be very sensitive to aggregate quality. It was considered important to investigate how the asphalt-aggregate interaction can influence the results.

The purpose of this report is to identify the influence of the asphalt-aggregate interaction by using results from the Hamburg wheel-tracking device. Ten grading AC-10 asphalt cements were used from four refineries who supply asphalt in Colorado that used various refining processes and crude oil sources. The refining process and crude oil sources do influence the test results from the Hamburg wheel-tracking device. Each refinery was able to produce an asphalt cement that passed in the Hamburg wheel-tracking device with the better aggregates.


| 17. Key Words | | 18. Distribution Statement |
|---|---|---|
| Crude Oil Source<br>Refining Process | Hamburg Wheel-Tracking Device | No Restrictions: This report is available to the public through the National Technical Info. Service. Springfield, VA 22161 |

| 19.Security Classif. (report) | 20.Security Classif. (page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 61 | |

## Table of Contents

## List of Tables



## List of Figures



## Appendices

**Influence of Refining Processes and Crude Oil Sources**
**Used in Colorado**
**On Results from the Hamburg Wheel-Tracking Device**

Tim Aschenbrener

# 1.0 Introduction

In September 1990, a group of individuals representing AASHTO, FHWA, NAPA, SHRP, AI, and TRB participated in a 2-week tour of six European countries. Information on this tour has been published in a "Report on the 1990 European Asphalt Study Tour" (1). Several areas for potential improvement of hot mix asphalt (HMA) pavements were identified, including the use of performance-related testing equipment used in several European countries. The Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center (TFHRC) were selected to demonstrate this equipment.

The first priority of the demonstration was to verify the predictive capabilities of this equipment by performing tests on mixtures of known field performance. The Hamburg wheel-tracking device was compared to several mixtures of known stripping performance (2), both good and bad. Results from the test correlated very well with field performance.

The next step was to attempt to improve the stripping resistance of the HMA placed in Colorado by using the Hamburg wheel-tracking device. The test is known to be very sensitive to aggregate quality (2), and methods to determine potential areas of improvement with the aggregate were investigated (3). Besides aggregate quality, asphalt-aggregate interaction is also important. On one project the results were very sensitive to the asphalt-aggregate interaction (4). Since the asphalt-aggregate interaction could influence the results, it was considered important to investigate the potential frequency and magnitude of this occurrence in a systematic manner.

The purpose of this report is to identify the influence of the various refining processes and crude oil sources used in Colorado on the test results from the Hamburg wheel-tracking device. The results of this study will provide important guidance to asphalt paving contractors that bid on future projects that use the Hamburg wheel-tracking device as a specification.

# 2.0 Experimental Grid

## 2.1 Materials

### *2.1.1 Asphalt Cements*

The four refineries that provide most of the asphalt cement used for CDOT projects provided the asphalt cement in this study. The asphalt cement from each refinery was labeled A, B, C, or D. The refineries produced different "types" of asphalt cement by changing crude oil sources or refining processes. Asphalt cements were all grading AC-10 (AASHTO M 226, Table 2). For this study, the refineries produced 1 to 3 different types of AC-10.

Additionally, an asphalt cement refined from a Venezuelan crude oil was used. This was used primarily for information and labeled "Vn". There was only one "type".

### *2.1.2 Aggregates*

Aggregates used for this study came from a variety of sources with a variety of performance histories. The aggregate combinations were selected to provide a variety of results, good to poor, in the Hamburg wheel-tracking device. All mixtures used quarried aggregate. Two different types of natural sands were added to help vary the performance of each mixture. All aggregates were treated with 1% hydrated lime prior to mixing with the asphalt cement.

The aggregates for Mix 1 were entirely from a quarried source that has had a history of good performance. The aggregates for Mix 2 were primarily from a different quarry with a good history of performance. However, a poor quality natural sand was added. Although the natural sand is non-plastic, it does have clay present.

The aggregate for Mix 3 was from a quarry with a mixed history of good and marginal performance. A problematic natural sand that has been associated with many HMA pavements that have stripped was added. The natural sand does not adhere to asphalt cement very well and contains clay. The aggregate for Mix 4 was from a quarry with a history of poor performance. The poor quality natural sand with clay used in Mix 2 was also added to Mix 4.

### *2.1.3 Hot Mix Asphalt*

The optimum asphalt content for each of the mixtures was determined with the Texas gyratory in general accordance with ASTM D 4013. The pre-gyration stress, end point stress and consolidation stress used were 210, 690, and 17,240 kPa (30, 100, 2500 psi), respectively. These stresses simulate the loads applied to the HMA pavements by high levels of traffic in Colorado. All mixes contained 1% hydrated lime.

## 2.2 Tests

### *2.2.1 Hamburg Wheel-Tracking Device*

The Hamburg wheel-tracking device is manufactured by Helmut-Wind Inc. of Hamburg, Germany as shown in Figs. 1 and 2. A pair of samples are tested simultaneously. A sample is typically 260 mm (10.2 in.) wide, 320 mm (12.6 in.) long, and 40 mm (1.6 in.) deep. A sample's mass is approximately 7.5 kg (16.5 lbs.), and it is compacted to 6% $\pm$ 1% air voids. For this study, samples were compacted with the linear kneading compactor. The samples are submerged under water at 50°C (122°F), although the temperature can vary from 25°C to 70°C (77°F to 158°F). For this study, all of the samples were an AC-10 grading so the test was performed at 45°C (5). A steel wheel, 47 mm (1.85 in.) wide, loads the samples with 705 N (158 lbs.) The wheel makes 50 passes per minute over each sample. The maximum velocity of the wheel is 34 cm/sec (1.1 ft/sec) in the center of the sample. Each sample is loaded for 20,000 passes or until 20 mm of deformation occurs. Approximately 6-1/2 hours are required for a test.

The results from the Hamburg wheel-tracking device include the creep slope, stripping slope and stripping inflection point as shown in Fig. 3. These results have been defined by Hines (6). The <u>creep slope</u> relates to rutting from plastic flow. It is the inverse of the rate of deformation in the linear region of the deformation curve, after post compaction effects have ended and before the onset of stripping. The <u>stripping slope</u> is the inverse of the rate of deformation in the linear region of the deformation curve, after stripping begins and until the end of the test. It is the number of passes required to create a 1 mm impression from stripping. The stripping slope is related to the severity of moisture damage. The <u>stripping inflection point</u> is the number of passes at the intersection of the creep slope and the stripping slope. It is related to the resistance of the HMA to moisture damage.

Fig. 1. The Hamburg Wheel-Tracking Device.

Fig. 2. Close-Up of the Hamburg Wheel-Tracking Device.

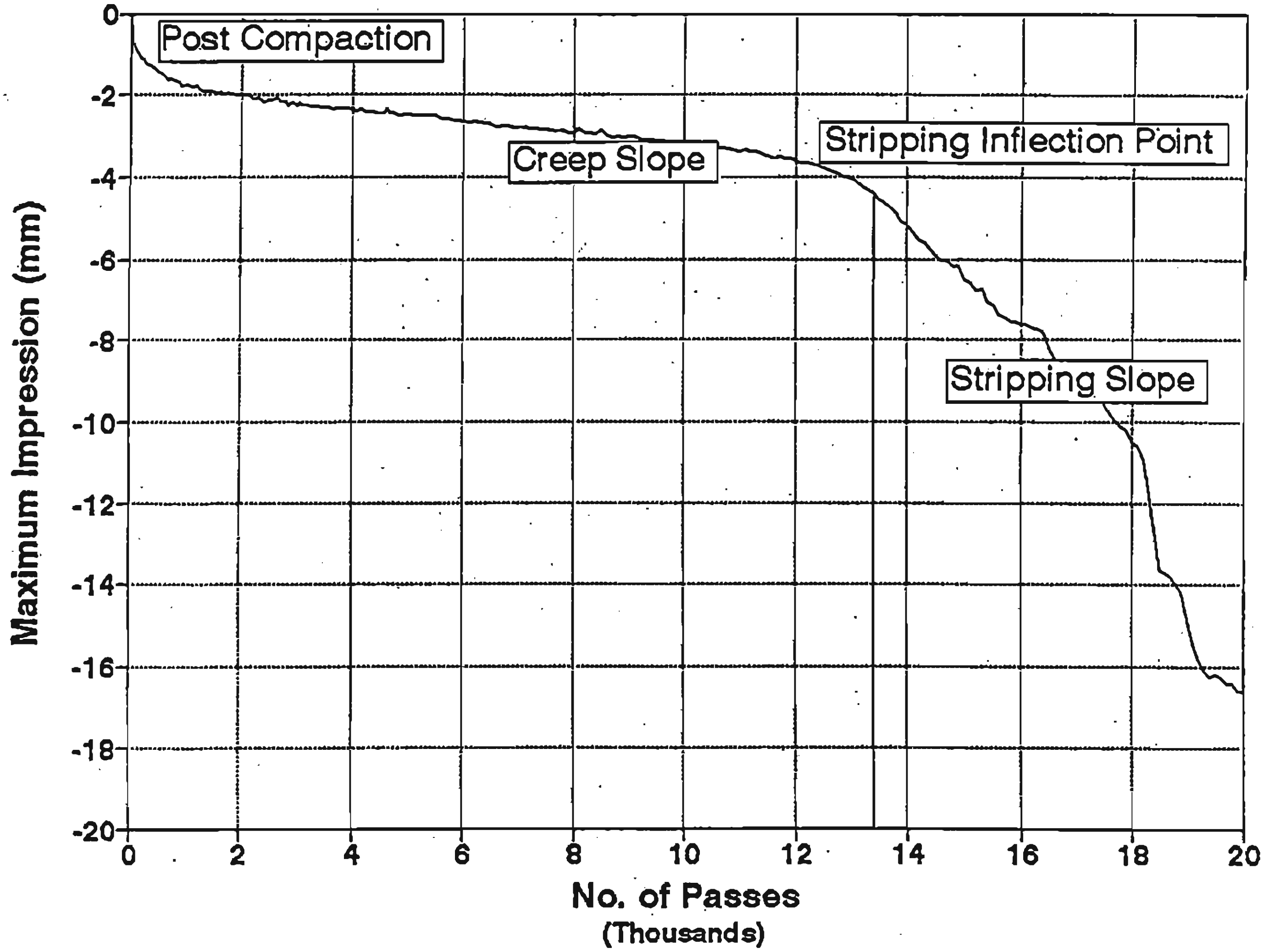



Fig. 3. Summary of Results from the Hamburg Wheel-Tracking Device.

The City of Hamburg requires less than 4 mm rut depth after 20,000 passes. The CDOT has indicated this specification is very severe (2). A more reasonable specification for the traffic and environment in Colorado is a deformation less than either 4 mm after 10,000 passes, or 10 mm after 20,000 passes. A project in Colorado will be using the results from the Hamburg wheel-tracking device as a specification for incentive payment only. Since that specification requires less than 10 mm after 20,000 passes, the deformation after 20,000 passes is used in this report.

### *2.2.2 Asphalt Cement Tests*

A series of tests were performed to characterize the asphalt cements used in this study. If results from the Hamburg wheel-tracking device indicated differences between the asphalt cements, the asphalt cement tests might potentially explain differences.

The traditional asphalt cement tests specified by CDOT were performed: penetration at 25°C (AASHTO T 49) and absolute viscosity at 60°C (AASHTO T 202). Additionally, the asphalt cement tests developed by SHRP were also performed. A full series of tests were performed to determine the high temperature SHRP Performance Grade of each asphalt cement. The testing device was the Dynamic Shear Rheometer (DSR) and tests were performed on asphalt cements that were unaged (tank) and Thin Film Oven Test (TFOT) aged (AASHTO T 179).

The DSR is used to measure the ability of the asphalt cement to resist permanent deformation at high temperatures. Since the Hamburg wheel-tracking device is performed at high temperatures, results from the DSR may be appropriate to understand differences in test results.

## 2.3 Experimental Grid

Each of the types of asphalt cement from each refinery were mixed with the four different aggregates and tested in the Hamburg wheel-tracking device. The experimental grid is shown in Table 1. All samples were tested at 45°C in the Hamburg wheel-tracking device since each asphalt cement was an AC-10 grading (5).

**Table 1. Experimental Grid for the Hamburg Wheel-Tracking Device Tests.**

| Refinery | Vn. | A | | | B | | | C | | D |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 1 |
| Mix 1 | X | X | X | X | X | X | X | X | X | X |
| Mix 2 | X | X | X | X | X | X | X | X | X | X |
| Mix 3 | X | X | X | X | X | X | X | X | X | X |
| Mix 4 | X | X | X | X | X | X | X | X | X | X |

X - Replicate samples were mixed with AC-10 grading asphalt cement and tested at 45°C.

For characterization purposes, all of the asphalt cements were tested with the current asphalt cement tests specified by the CDOT and the high temperature asphalt cement tests developed by SHRP. If any differences between the asphalt cements were identified by the results from the Hamburg wheel-tracking device, the tests on the asphalt cement might potentially explain the differences. The experimental grid of the asphalt cement tests performed is shown in Table 2.

**Table 2. Experimental Grid for the Asphalt Cement Tests.**

| Refinery | Vn. | A | | | B | | | C | | D |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 1 |
| Penetration and Viscosity | X | X | X | X | X | X | X | X | X | X |
| DSR (tank) | X | X | X | X | X | X | X | X | X | X |
| DSR (TFOT) | X | X | X | X | X | X | X | X | X | X |

# 3.0 Results and Discussion

## 3.1 Asphalt Cement Test Results

Each of the asphalt cements used in this study was tested with the standard asphalt cement tests specified by the CDOT and the new SHRP binder tests. The results are summarized in Table 3 and all of the tests are reported in Appendix A. The absolute viscosity of all of the asphalt cements meets the requirement for an AC-10 grading (AASHTO M 226, Table 2). Additionally, the high temperature properties of the asphalt cements meet the SHRP high temperature performance grade of 58. In general, a penetration range of 85 to 100 dmm is expected to be approximately an AC-10. Although most of the penetration results fell within this range, there were two that were quite a bit softer: particularly Refinery B Type 2 and Vn.

**Table 3. Results from the Asphalt Cement Testing.**

| Refinery | Type | Pen. (25°C) dmm | Vis. (60°C) poises | DSR (tank) °C @ 1.0 kPa | DSR (TFOT) °C @ 2.2 kPa | High Temp PG |
|---|---|---|---|---|---|---|
| A | 1 | 92 | 1300 | 58.0 | 64.1 | 58 |
| | 2 | 110 | 940 | 61.7 | 62.1 | 58 |
| | 3 | 100 | 1060 | 62.4 | 62.7 | 58 |
| B | 1 | 105 | 1030 | 62.1 | 62.3 | 58 |
| | 2 | 128 | 820 | 60.2 | 59.8 | 58 |
| | 3 | 103 | 1060 | 62.5 | 62.7 | 58 |
| C | 1 | 100 | 1010 | 61.8 | 62.6 | 58 |
| | 2 | 90 | 1000 | 62.4 | 61.2 | 58 |
| D | 1 | 87 | 1100 | 62.3 | 60.7 | 58 |
| Vn. | 1 | 129 | 1040 | 61.7 | 62.1 | 58 |

## 3.2 Hamburg Wheel-Tracking Device Test Results

The test results from each mix tested in the Hamburg wheel-tracking device for each refinery and type of asphalt produced from each refinery are shown in Table 4. The results are plotted in Appendix B. The results shown are the mm of deformation at 20,000 passes. Each test had a replicate sample, so the left (L), right (R), and average (Avg) are reported in Table 4. In some instances, the samples in the Hamburg wheel-tracking device had greater than 20 mm of deformation before 20,000 passes. These samples failed dramatically and are reported as ">20" in Table 4. The test results were considered acceptable when the average of the two samples had a deformation of less than 10 mm after 20,000 passes. The cells in Table 4 were shaded to indicate when the average of the two samples were greater than 10 mm after 20,000 passes.

**Table 4. Results from the Hamburg Wheel-Tracking Device - Deformation (mm) After 20,000 Passes.**

| Mix | | Refinery A | | | Refinery B | | | Ref. C | | D | Vn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 1 | |
| 1 | L | 10.4 | 5.1 | 7.9 | 9.4 | 12.3 | 12.2 | 9.9 | 6.9 | >20 | 12.1 |
| | R | 8.1 | 11.8 | 7.8 | 5.0 | 17.2 | 16.3 | 6.8 | 1.9 | >20 | 10.8 |
| | Avg | 9.2 | 8.5 | 7.9 | 7.2 | 14.8* | 14.3* | 8.4 | 4.4 | >20* | 11.5* |
| 2 | L | 6.3 | 4.8 | 15.2 | 8.4 | >20 | 18.5 | 6.0 | 10.1 | 5.1 | 11.3 |
| | R | 9.0 | 8.9 | 14.3 | 10.0 | >20 | 14.8 | 2.0 | 15.3 | 9.4 | 9.7 |
| | Avg | 7.6 | 6.9 | 14.8* | 9.2 | >20* | 16.7* | 4.0 | 12.7 | 7.3 | 10.5* |
| 3 | L | 14.4 | >20 | 11.6 | 9.4 | >20 | 17.5 | 9.5 | 4.9 | >20 | >20 |
| | R | 21.3 | 16.4 | 12.5 | 20.8 | >20 | 15.7 | 19.7 | 5.6 | >20 | >20 |
| | Avg | 17.9* | >20 | 12.1* | 15.1* | >20* | 16.6* | 14.6* | 5.2 | >20* | >20* |
| 4 | L | 3.2 | 14.6 | 18.0 | 9.9 | >20 | 22.8 | >20 | 7.0 | >20 | >20 |
| | R | 5.2 | 17.1 | 17.3 | 21.4 | >20 | 11.9 | >20 | 4.8 | >20 | >20 |
| | Avg | 4.2 | 15.9* | 17.6* | 15.6* | >20* | 17.4* | >20* | 5.9 | >20* | >20* |

* Failing test result (shaded)    L - Left sample    R - Right sample    Avg - Average

### *3.2.1 Refinery A*

The Types 1 and 2 asphalt cements performed as expected by passing with the better mixes (Mixes 1 and 2). The Type 2 asphalt cement also performed as expected by failing with the poorer mixes (Mixes 3 and 4). It was pleasantly surprising that Type 1 passed with one of the poorer mixes (Mix 4). Only one of the mixes (Mix 1) passed with the Type 3 asphalt cement. Refinery A's Type 1 asphalt cement would be very desirable to use on projects with these aggregates.

### *3.2.2 Refinery B*

The Type 1 asphalt cement performed as expected. The better mixes (Mixes 1 and 2) passed, and the poorer mixes (Mixes 3 and 4) failed. No mixes passed with the Type 2 asphalt cement, and three failed dramatically. It would be desirable to avoid Refinery B's Type 2 asphalt cement.

Although Types 1 and 2 were supplied by the refinery, the Type 3 asphalt cement was sampled from an asphalt paving contractor's plant. Based on the asphalt cement tests, Types 1 and 3 appeared identical. Therefore, it might be expected that the results from the Hamburg wheel-tracking device would also be similar. For the poorer mixes (Mixes 3 and 4), the results were very similar as expected. However, for the better mixes (Mixes 1 and 2) the Type 3 asphalt cement had twice the deformation as the Type 1. This difference is perplexing.

### *3.2.3 Refinery C*

The Type 1 asphalt cement performed as expected. The better mixes (Mixes 1 and 2) had passing results and the poorer mixes (Mixes 3 and 4) had failing results. Only Mix 4 failed dramatically. The Type 2 asphalt cement is the only asphalt cement that had passing results with both of the poorer mixes (Mixes 3 and 4). Mix 2 barely failed with the Type 2 asphalt cement. Refinery C's Type 2 asphalt cement would be very desirable to use on projects with these aggregates.

### *3.2.4 Refinery D*

Only one type of asphalt cement was provided by Refinery D and it performed miserably. Three of the mixes (Mixes 1, 3, and 4) failed, and they all failed dramatically. This asphalt cement did not perform very well with the aggregates used in this study.

### *3.2.5 Venezuelan*

The crude oil source of the Venezuelan asphalt tested was not known. All four of the mixes failed the requirement. The two better mixes (Mixes 1 and 2) barely failed, and the two poorer mixes (Mixes 3 and 4) failed dramatically.

### *3.2.6 Summary*

All of the refineries were able to produce an asphalt cement that performed well in the Hamburg wheel-tracking device when using the better aggregates, except Refinery D. It appears there may be a unique asphalt-aggregate interaction that is dependent on each asphalt cement and each aggregate used in the mixture.

## 3.3 Correlation of Asphalt Cement and Hamburg Wheel-Tracking Results

### *3.3.1 Refinery A*

The Type 1 asphalt cement was the stiffest of Refinery A's grading AC-10, and it also performed the best. The Type 1 not only passed with the better aggregates, but it also did exceptionally well with one of the poorer aggregates (Mix 4). Although the Type 2 asphalt cement was softer than Type 3, the Type 2 performed better. Type 2 passed with all of the better aggregate, while Type 3 did not.

### *3.3.2 Refinery B*

The Type 2 asphalt cement was an exceptionally soft grading of AC-10, and it performed very poorly. Types 1 and 3 had virtually identical stiffnesses to each other and were closer to the middle of the expected ranges for AC-10 than Type 2. Despite Types 1 and 3's similarity, they performed dramatically differently. Type 1 passed with the better aggregates, while Type 3 failed with all aggregates.

### *3.3.3 Refinery C*

The Types 1 and 2 asphalt cements both performed remarkably well in the Hamburg wheel-tracking device. The stiffnesses were fairly similar to each other and in the middle of the range normally expected for a typical grading AC-10 asphalt cement.

### 3.3.4 *Refinery D*

With the aggregates used in this study, this was one of the poorest performing asphalt cements. Although the viscosity was in the middle of the expected range of stiffness; the penetration indicated a very stiff AC-10; and the DSR indicated one of the softest grading AC-10 asphalt cements. Although the asphalt cement tests provided conflicting information about the stiffness, the results in the Hamburg wheel-tracking device clearly indicated this was one of the poorer asphalt cements with the aggregates used in this study.

### 3.3.5 *Venezuelan*

The viscosity and DSR of this asphalt cement was in the range of expected values. The penetration indicated this was a very soft grading AC-10. Although the asphalt cement tests provided conflicting information about the stiffness, the results in the Hamburg wheel-tracking device clearly indicated this was one of the poorer asphalt cements with the aggregates used in this study.

### 3.3.6 *Summary*

The deformation recorded in the Hamburg wheel-tracking device is plotted versus the asphalt cement stiffness as measured by the absolute viscosity (Fig. 4), penetration (Fig. 5), and dynamic shear rheometer (Fig. 6). In each of the plots, it is not possible to identify a direct correlation between the asphalt cement stiffness and results in the Hamburg wheel-tracking device. However, each of the points are labeled with their aggregate mixture. In general, the distinction between the mixtures with the better aggregates (Mixes 1 and 2) can be made from the mixtures with the poorer aggregates (Mixes 3 and 4), regardless of asphalt cement stiffness.

Some of the Types of asphalt cement tested indicated the softer grading AC-10 asphalt cements did poorer than the stiffer grading AC-10 asphalt cements. However, there were numerous samples with very similar stiffnesses that performed dramatically differently in the Hamburg wheel-tracking device. The variable that influence the results from the Hamburg wheel-tracking device are a function of: 1) aggregate quality, 2) refining process and crude oil source, and 3) asphalt cement stiffness.

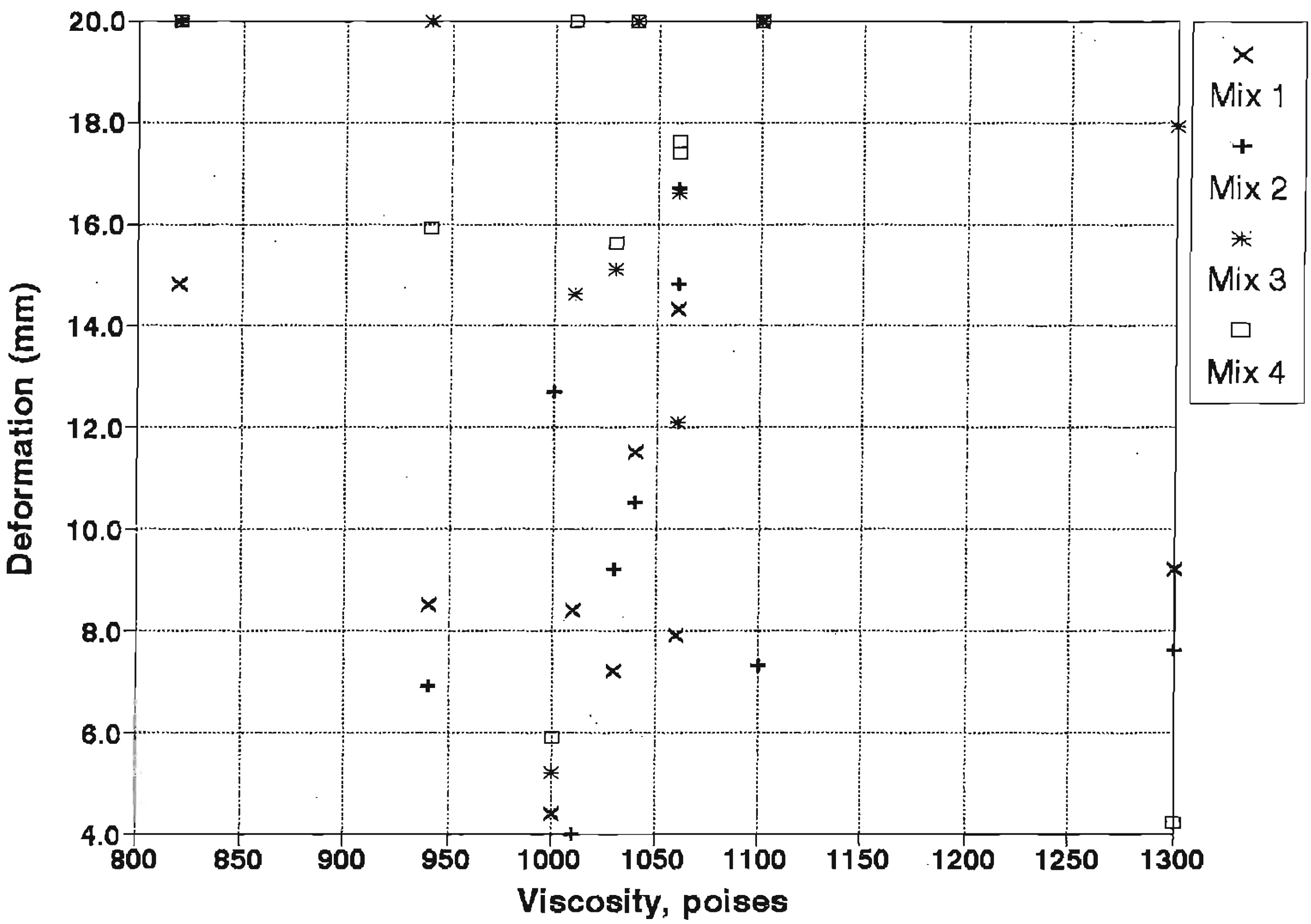



**Fig. 4. Results from the Hamburg Wheel-Tracking Device as a Function of Asphalt Cement Stiffness as Measured by Absolute Viscosity.**

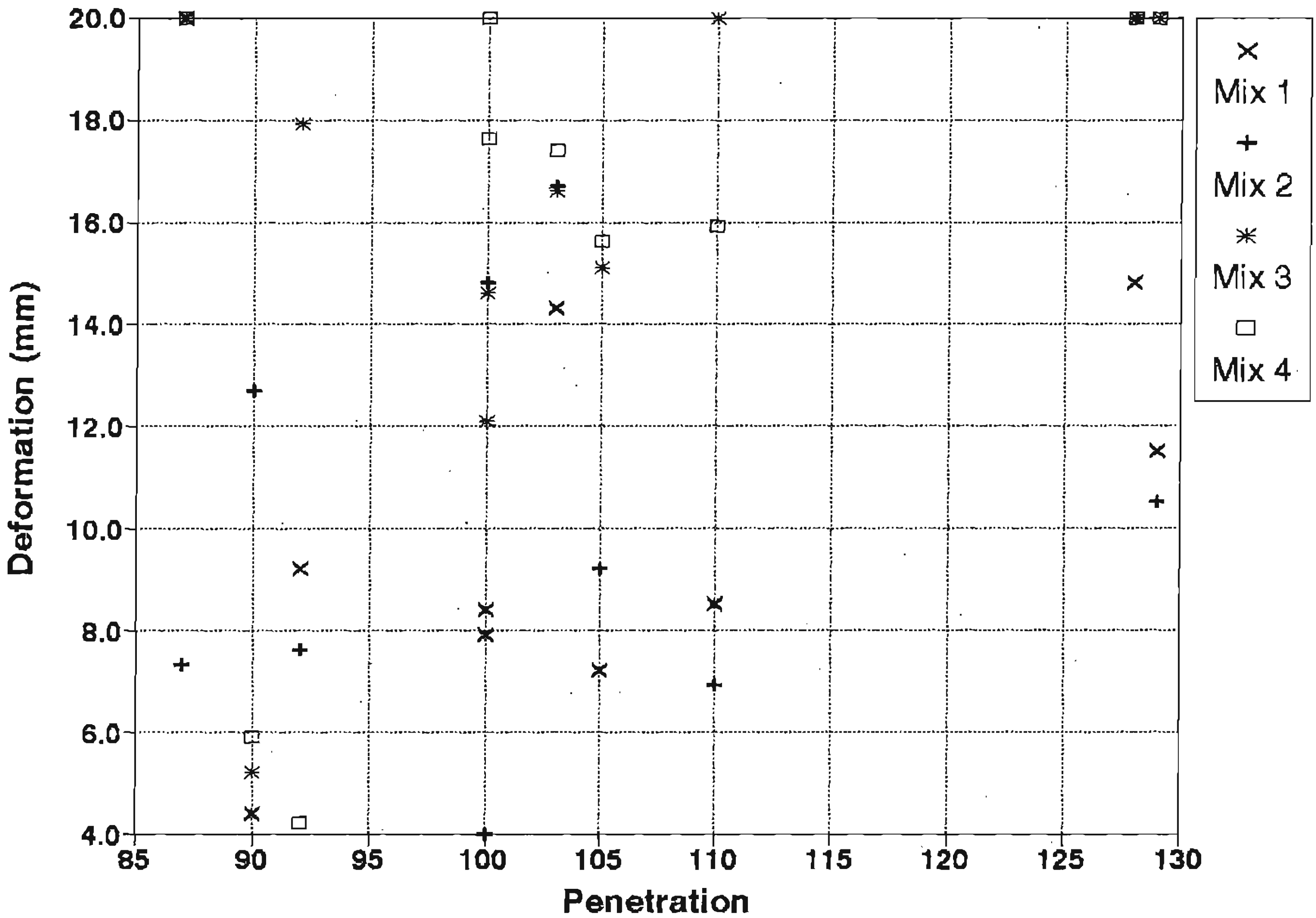



**Fig. 5. Results from the Hamburg Wheel-Tracking Device as a Function of Asphalt Cement Stiffness as Measured by Penetration.**

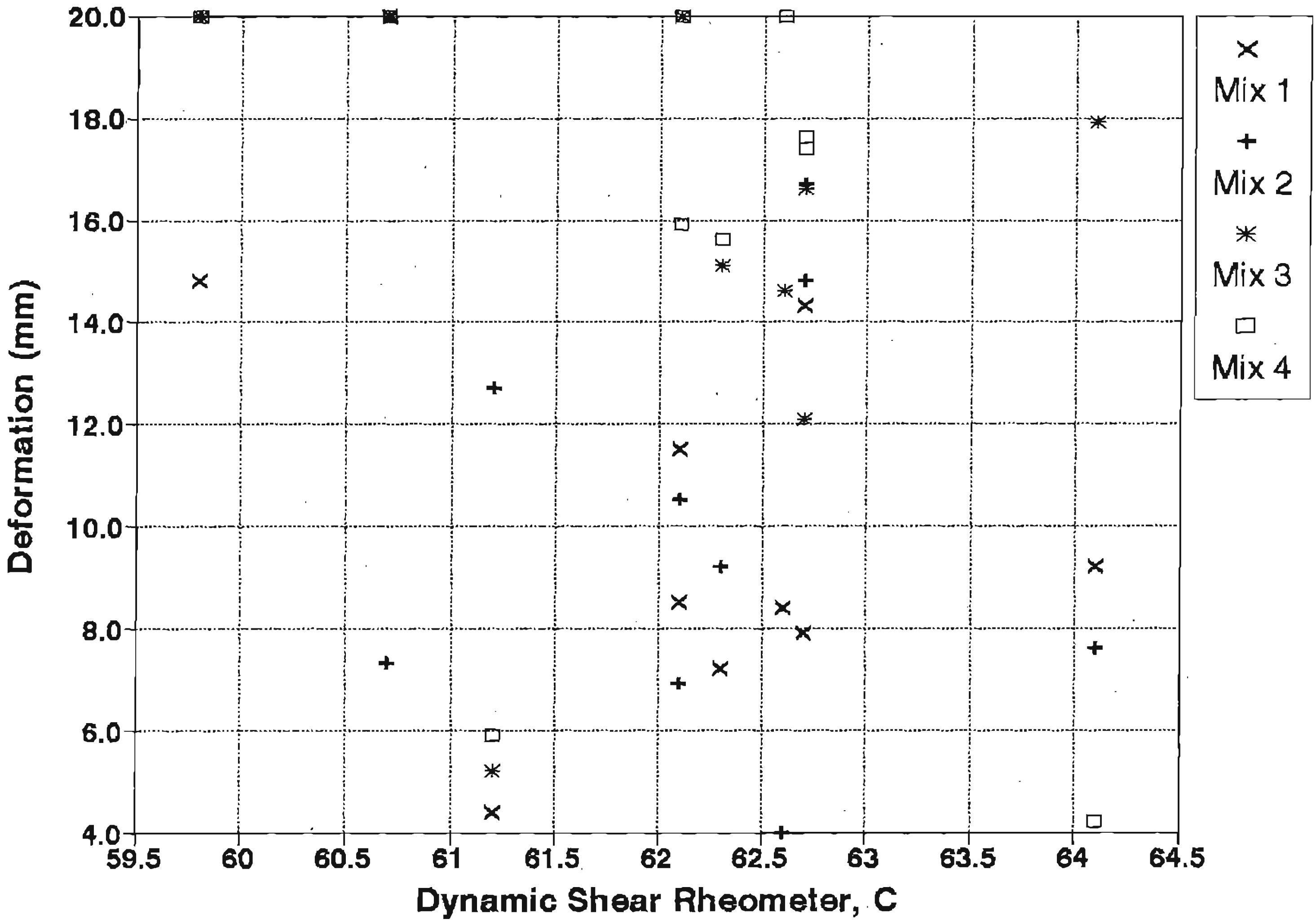



**Fig. 6. Results from the Hamburg Wheel-Tracking Device as a Function of Asphalt Cement Stiffness as Measured by the Dynamic Shear Rheometer.**

## 3.4 Summary

Results shown in Table 5 indicate that aggregate differences can make a large difference in the results. The better mixes, Mix 1 and Mix 2, had passing test results with many of the asphalt cements used. For the poorer aggregates, virtually none of the samples tested passed, regardless of the asphalt cement. However, there were a few asphalt cements that worked well with the poor aggregates.

When a sample has greater than 20 mm of deformation before the entire 20,000 passes, the failure is dramatic. This occurred only once each for the better mixes (Mix 1 and 2). For the poorer aggregate, the dramatic failure occurred for almost half of the asphalt cements tested.

**Table 5. Comparison of Results By Mixture.**

| Mix | Pass | Fail | |
|---|---|---|---|
| | < 10 mm | > 10 mm | > 20 mm |
| 1 | 6 | 4 | 1 |
| 2 | 5 | 5 | 1 |
| 3 | 1 | 9 | 4 |
| 4 | 2 | 8 | 4 |

Results from the Hamburg wheel-tracking device are significantly influenced by the aggregate. When results from the device are unacceptable, making changes to the aggregate should be considered. These changes might include limiting the amount of natural sands or using aggregates without thick dust coatings.

Results in Table 6 indicate that the asphalt-aggregate interaction created because of varying the refining process or crude oil source used by the refinery may also influence the results from the Hamburg wheel-tracking device. Some of the asphalt cements from a specific refinery and refining process did not work with any of the aggregates (Refinery B's Types 2 and 3 and Vn.) while other asphalt cements worked with 3 of the 4 mixtures tested (Refinery A's Type 1 and Refinery C's Type 2).

**Table 6. Comparison of Results By Refinery.**

| Ref. | Type | Pass | Fail | |
|---|---|---|---|---|
| | | < 10 mm | > 10 mm | > 20 mm |
| A | 1 | 3 | 1 | 0 |
| | 2 | 2 | 2 | 1 |
| | 3 | 1 | 3 | 0 |
| B | 1 | 2 | 2 | 0 |
| | 2 | 0 | 4 | 3 |
| | 3 | 0 | 4 | 0 |
| C | 1 | 2 | 2 | 1 |
| | 2 | 3 | 1 | 0 |
| D | 1 | 1 | 3 | 3 |
| Vn. | | 0 | 4 | 2 |

## 4.0 Conclusions

The results of this study are based on the use of only four aggregates and the ten grading AC-10 asphalt cements provided by the refineries. It is known that there are more than four different types of aggregate in Colorado, and it is likely that different asphalt cements could be used other than those in this study. However, the conclusions are limited to the materials used.

1) The quality of aggregates have a significant influence on the test results from the Hamburg wheel-tracking device. When results from the Hamburg wheel-tracking device indicate a mixture is unacceptable, the aggregate quality should be investigated.

2) All of the refineries were able to produce an asphalt cement that performed well in the Hamburg wheel-tracking device when using the better aggregates, except Refinery D. It appears there may be a unique asphalt-aggregate interaction that is dependent on each asphalt cement and each aggregate used in the mixture. The refining process and/or crude oil source can influence the results in the Hamburg wheel-tracking device.

3) Tests on the asphalt cement alone do not fully explain the adhesion between the asphalt cement and aggregate in the presence of water. Some of the Types of asphalt cement tested indicated the softer grading AC-10 asphalt cements did poorer than the stiffer grading AC-10 asphalt cements. However, there were numerous samples with very similar stiffnesses that performed dramatically differently in the Hamburg wheel-tracking device. Although the stiffness of the grading AC-10 asphalt cement may influence the results, the refining process or crude oil source may also have a dramatic effect on the results from the Hamburg wheel-tracking device.

4) It is not justifiable to eliminate any refinery from selling asphalt cement in Colorado. Each refinery (except Refinery D) was capable of producing an asphalt cement that gave acceptable results on the Hamburg wheel-tracking device with the better aggregates. It should be noted that Refinery D had one type and only four different aggregates were used in this study.

## 5.0 Implementation

A repeatability study should be performed with the Hamburg wheel-tracking device. There are numerous factors that can influence the test results, and we now have a better understanding of many of the factors that can cause problems with repeatability. A detailed testing procedure should be written and then a within-laboratory and between-laboratory study should be performed.

The completion of the repeatability study is necessary before any statewide implementation plan for the Hamburg wheel-tracking device is developed.

## 6.0 References


1. Report on the 1990 European Asphalt Study Tour (June 1991), American Association of State Highway and Transportation Officials, Washington, D.C., 115+ pages.

2. Aschenbrener, T.B., R.L. Terrel, and R.A. Zamora (1994), "Comparison of the Hamburg Wheel-Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance," Colorado Department of Transportation, CDOT-DTD-R-94-1, 101 pages.

3. Aschenbrener, T.B. (1992), "Comparison of Colorado Component Hot Mix Asphalt Materials with Some European Specifications," Colorado Department of Transportation, CDOT-DTD-R-92-14, 65 pages.

4. Aschenbrener, T.B. (1993), "I-70, Silverthorne to Copper Mountain: A Case History of the Use of European Testing Equipment," Colorado Department of Transportation, CDOT-DTD-R-93-19, 52 pages.

5. Aschenbrener, T.B., and Gray Currier (1993), "Influence of Testing Variables on the Results from the Hamburg Wheel-Tracking Device," Colorado Department of Transportation, CDOT-DTD-R-93-22, 116 pages.

6. Hines, Mickey (1991), "The Hamburg Wheel-Tracking Device," Proceedings of the Twenty-Eighth Paving and Transportation Conference, Civil Engineering Department, The University of New Mexico, Albuquerque, New Mexico.

# Appendix A

## Summary of Asphalt Cement Tests

**Refinery A**

| Aging | Test | Test Temp. °C | Units of Results | Type | | |
|---|---|---|---|---|---|---|
| | | | | 1<br>58-22 | 2<br>58-22 | 3<br>58-22 |
| Tank | Sp.Gr. | 25 | | 1.028 | 1.029 | 1.024 |
| | Flash | | °C | 230+ | 230+ | 230+ |
| | Ab.Vis. | 60 | poises | 1300 | 940 | 1060 |
| | Pen | 25 | dmm | 92 | 110 | 100 |
| | DSR | 52 | kPa | 4.74 | 3.34 | 3.75 |
| | | 58 | kPa | 2.21 | 1.54 | 1.74 |
| | | 64 | kPa | 1.00 | 0.67 | 0.74 |
| TFOT | LOH | 163 | % | 0.16 | 0.13 | 0.10 |
| | Ab.Vis. | 60 | poises | 3270 | 2180 | 2660 |
| | DSR | 52 | kPa | 11.50 | 8.26 | 8.92 |
| | | 58 | kPa | 5.03 | 3.53 | 4.04 |
| | | 64 | kPa | 2.22 | 1.60 | 1.69 |
| PAV | DSR | 25 | kPa | 3280 | 1620 | |
| | | 22 | kPa | 4620 | 2280 | 3540 |
| | | 19 | kPa | 6370 | 3224 | 4940 |
| | | 16 | kPa | | 4450 | 6890 |
| | | 13 | kPa | | 5950 | |
| | BBR Stiffness (S) | -12 | MPa | 159 | 139 | 145 |
| | | -18 | MPa | 704 | 673 | 655 |
| | BBR Slope (m) | -12 | | 0.33 | 0.34 | 0.34 |
| | | -18 | | 0.22 | 0.25 | 0.23 |

The low temperature grading would be identical whether the low temperature stiffness (S) or slope (m) were used.

**Refinery B**

| Aging | Test | Test Temp. °C | Units of Results | Type | | |
|---|---|---|---|---|---|---|
| | | | | 1<br>58-22 | 2<br>58-22 | 3<br>58-22 |
| Tank | Sp.Gr. | 25 | | 1.031 | 1.026 | 1.035 |
| | Flash | | °C | 230+ | 230+ | 230+ |
| | Ab.Vis. | 60 | poises | 1030 | 820 | 1060 |
| | Pen | 25 | dmm | 105 | 128 | 103 |
| | DSR | 52 | kPa | 3.43 | 2.72 | 3.78 |
| | | 58 | kPa | 1.57 | 1.24 | 1.68 |
| | | 64 | kPa | 0.73 | 0.59 | 0.77 |
| TFOT | LOH | 163 | % | 0.15 | 0.16 | 0.12 |
| | Ab.Vis. | 60 | poises | 2400 | 1780 | 2700 |
| | DSR | 52 | kPa | 8.24 | 5.87 | 8.92 |
| | | 58 | kPa | 3.68 | 2.63 | 4.04 |
| | | 64 | kPa | 1.63 | 1.16 | 1.70 |
| PAV | DSR | 25 | kPa | | | 2560 |
| | | 22 | kPa | 3410 | 2750 | 3490 |
| | | 19 | kPa | 4840 | 4110 | 5100 |
| | | 16 | kPa | 6760 | 6150 | |
| | | 13 | kPa | | | |
| | BBR Stiffness (S) | -12 | MPa | 155 | 149 | 164 |
| | | -18 | MPa | 692 | 611 | 738 |
| | BBR Slope (m) | -12 | | 0.35 | 0.39 | 0.36 |
| | | -18 | | 0.22 | 0.22 | 0.22 |

**Refinery C**

| Aging | Test | Test Temp. °C | Units of Results | Type | | |
|---|---|---|---|---|---|---|
| | | | | 1<br>58-22 | 2<br>58-22 | 3 |
| Tank | Sp.Gr. | 25 | | 1.027 | 1.000 | |
| | Flash | | °C | 305 | 330 | |
| | Ab.Vis. | 60 | poises | 1010 | 1000 | |
| | Pen | 25 | dmm | 100 | 90 | |
| | DSR | 52 | kPa | 3.50 | 3.74 | |
| | | 58 | kPa | 1.57 | 1.73 | |
| | | 64 | kPa | 0.68 | 0.74 | |
| TFOT | LOH | 163 | % | 0.18 | 0.01 | |
| | Ab.Vis. | 60 | poises | 2580 | 1940 | |
| | DSR | 52 | kPa | 8.65 | 7.42 | |
| | | 58 | kPa | 3.83 | 3.17 | |
| | | 64 | kPa | 1.69 | 1.36 | |
| PAV | DSR | 25 | kPa | 4630 | 3540 | |
| | | 22 | kPa | 4670 | 5150 | |
| | | 19 | kPa | 6570 | | |
| | | 16 | kPa | | | |
| | | 13 | kPa | | | |
| | BBR Stiffness (S) | -12 | MPa | 130 | 256 | |
| | | -18 | MPa | 746 | 908 | |
| | BBR Slope (m) | -12 | | 0.33 | 0.32 | |
| | | -18 | | 0.23 | 0.20 | |

**Refinery D**

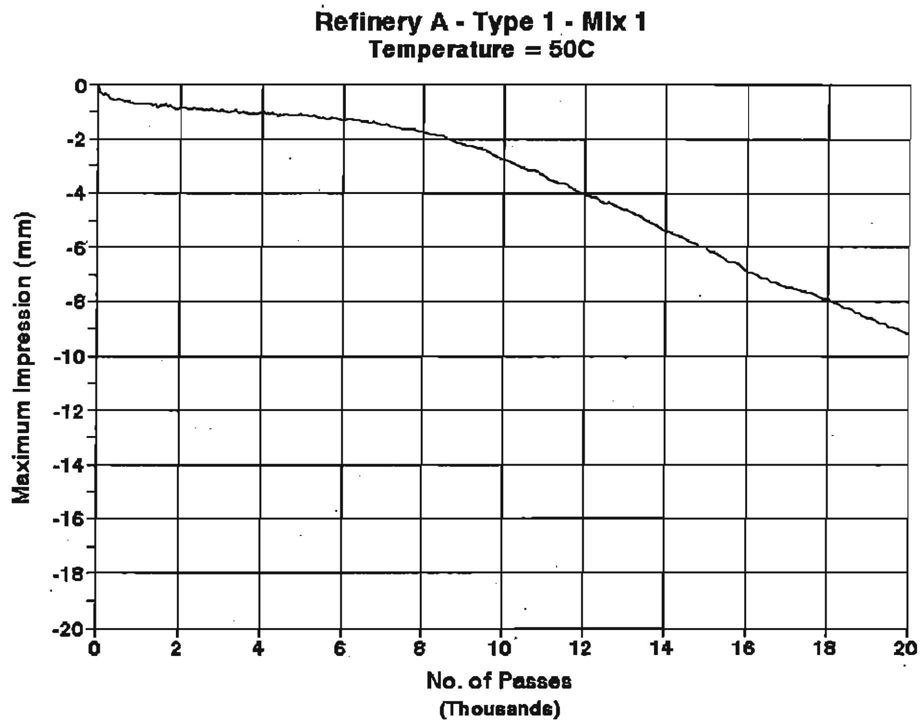
| Aging | Test | Test Temp. °C | Units of Results | Type | | |
|---|---|---|---|---|---|---|
| | | | | 1<br>58-22 | 2 | 3 |
| Tank | Sp.Gr. | 25 | | 0.994 | | |
| | Flash | | °C | 300+ | | |
| | Ab.Vis. | 60 | poises | 1100 | | |
| | Pen | 25 | dmm | 87 | | |
| | DSR | 52 | kPa | 3.38 | | |
| | | 58 | kPa | 1.62 | | |
| | | 64 | kPa | 0.76 | | |
| TFOT | LOH | 163 | % | 0.02 | | |
| | Ab.Vis. | 60 | poises | 2020 | | |
| | DSR | 52 | kPa | 6.38 | | |
| | | 58 | kPa | 2.92 | | |
| | | 64 | kPa | 1.34 | | |
| PAV | DSR | 25 | kPa | 2230 | | |
| | | 22 | kPa | 3340 | | |
| | | 19 | kPa | 5000 | | |
| | | 16 | kPa | 7000 | | |
| | | 13 | kPa | | | |
| | BBR Stiffness (S) | -12 | MPa | 245 | | |
| | | -18 | MPa | 1020 | | |
| | BBR Slope (m) | -12 | | 0.31 | | |
| | | -18 | | 0.18 | | |

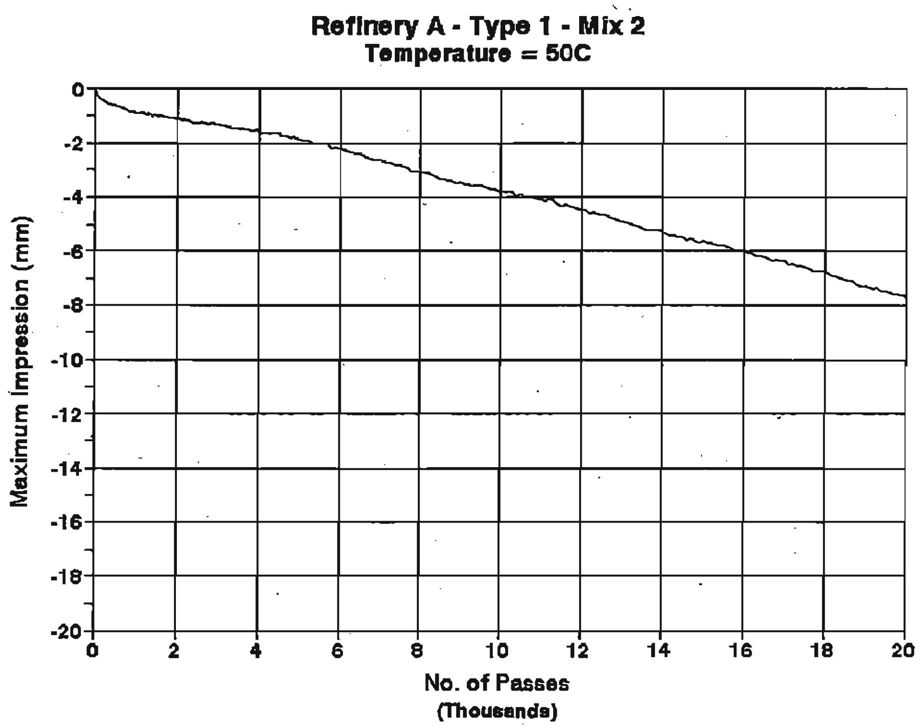
**Refinery Vn.**

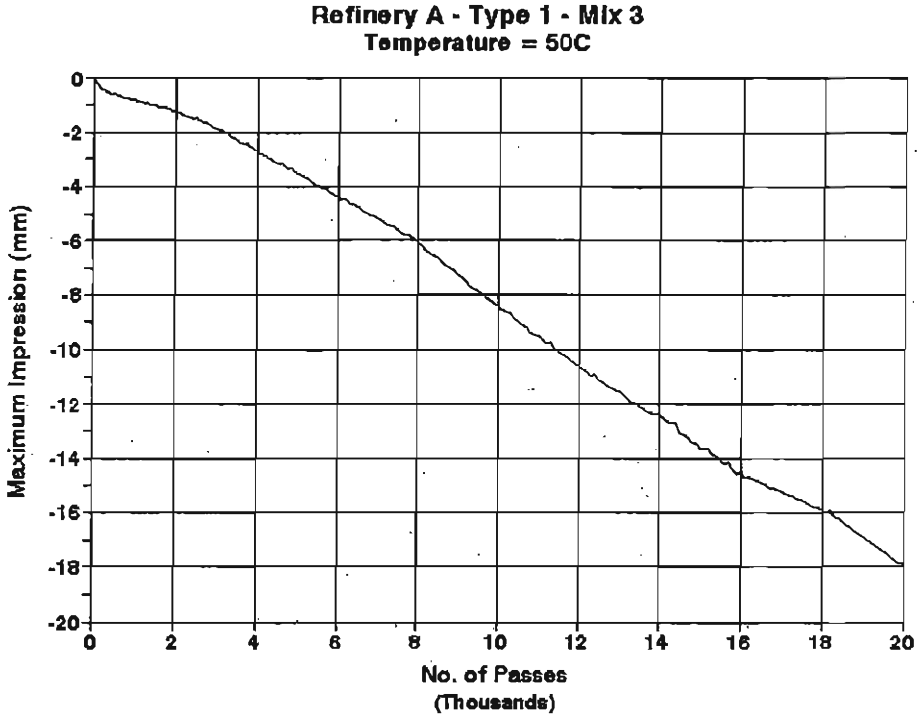
| Aging | Test | Test Temp. °C | Units of Results | Type | | |
|---|---|---|---|---|---|---|
| | | | | 1<br>58-22 | 2 | 3 |
| Tank | Sp.Gr. | 25 | | 1.013 | | |
| | Flash | | °C | 303 | | |
| | Ab.Vis. | 60 | poises | 1040 | | |
| | Pen | 25 | dmm | 129 | | |
| | DSR | 52 | kPa | 3.16 | | |
| | | 58 | kPa | 1.49 | | |
| | | 64 | kPa | 0.70 | | |
| TFOT | LOH | 163 | % | 0.18 | | |
| | Ab.Vis. | 60 | poises | 2640 | | |
| | DSR | 52 | kPa | 7.47 | | |
| | | 58 | kPa | 5.34 | | |
| | | 64 | kPa | 1.56 | | |
| PAV | DSR | 25 | kPa | 1480 | | |
| | | 22 | kPa | 2140 | | |
| | | 19 | kPa | 3050 | | |
| | | 16 | kPa | 4340 | | |
| | | 13 | kPa | 6050 | | |
| | BBR Stiffness (S) | -12 | MPa | 96 | | |
| | | -18 | MPa | 561 | | |
| | BBR Slope (m) | -12 | | 0.37 | | |
| | | -18 | | 0.27 | | |

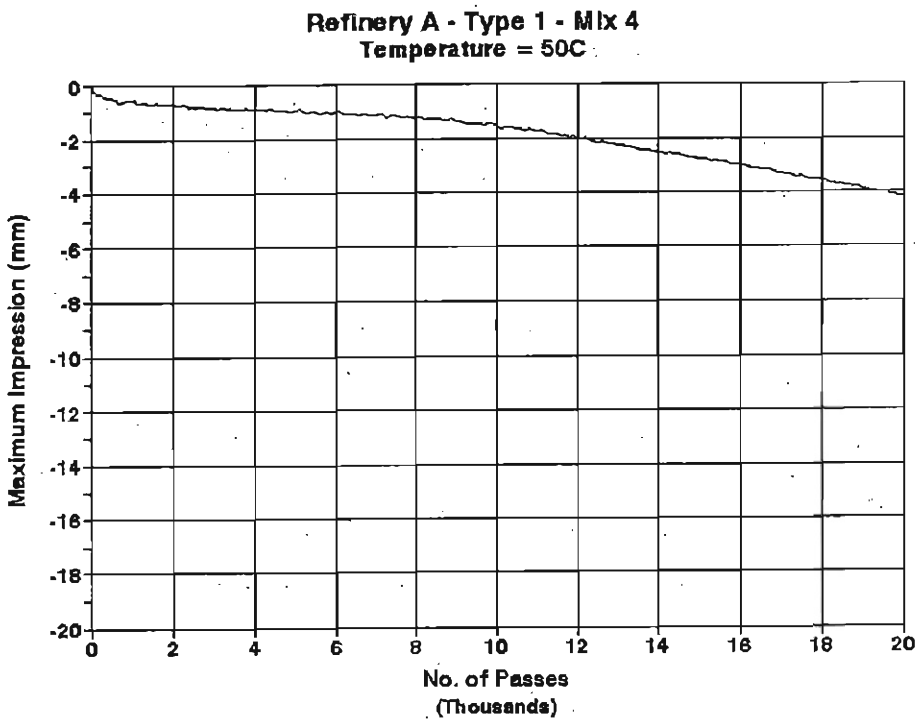
# Appendix B

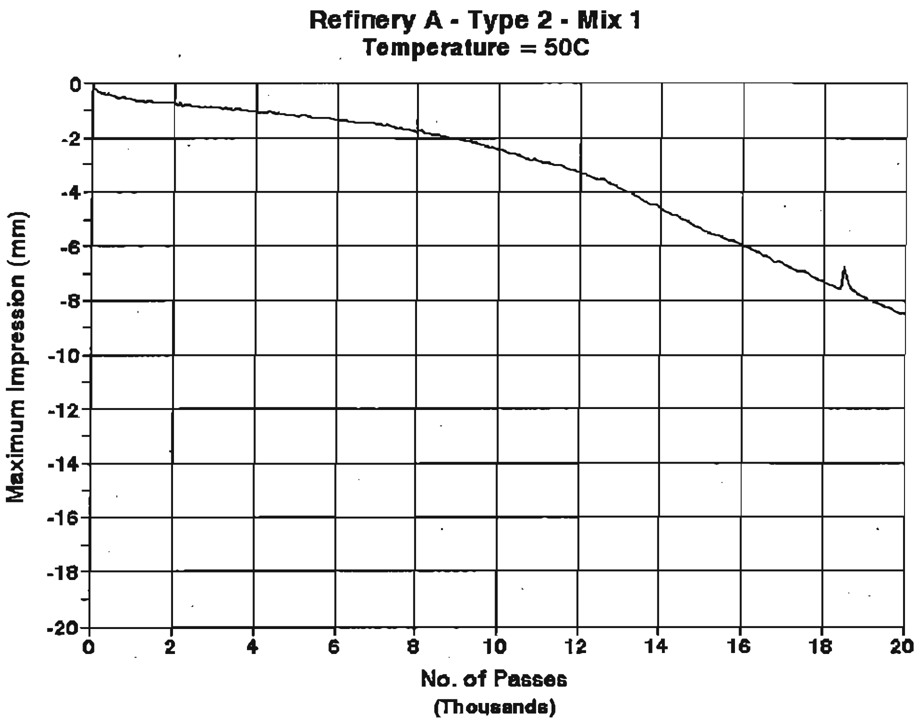
## Summary of Hamburg Wheel-Tracking Results

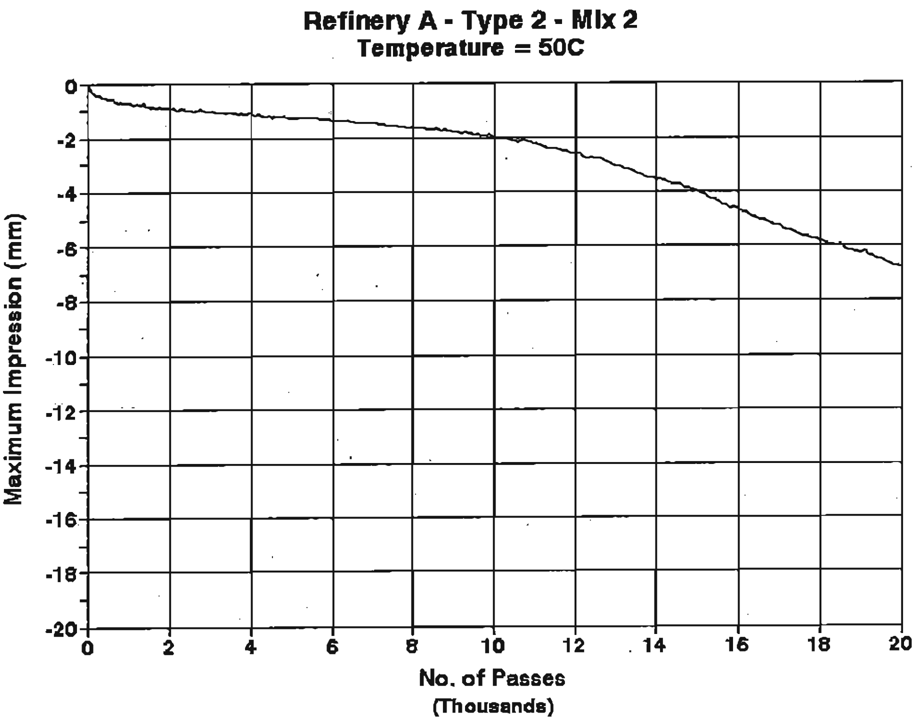

Refinery A - Type 1 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

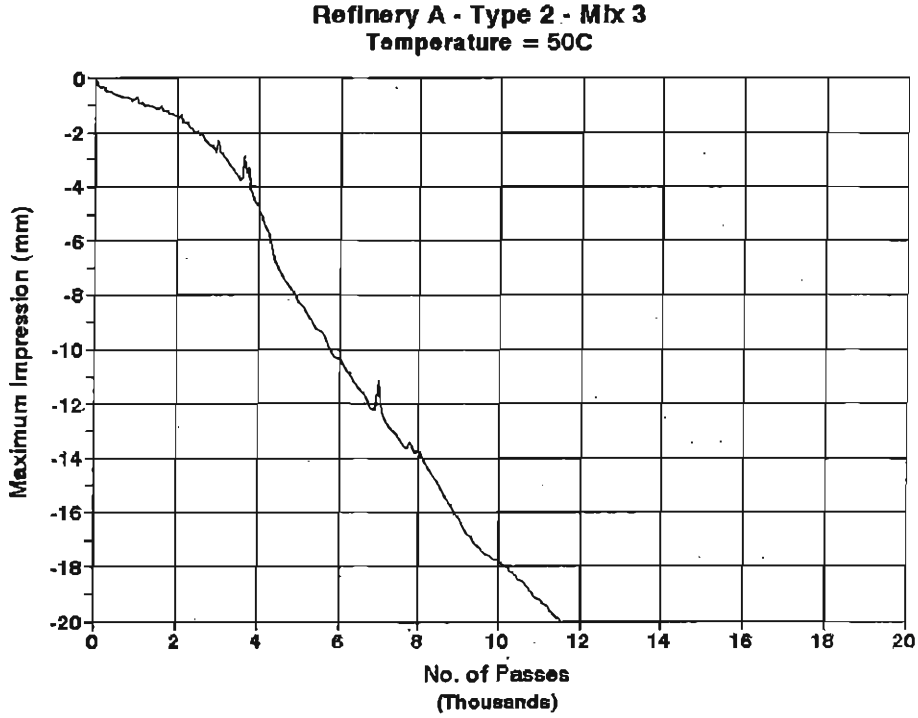

Refinery A - Type 1 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery A - Type 1 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

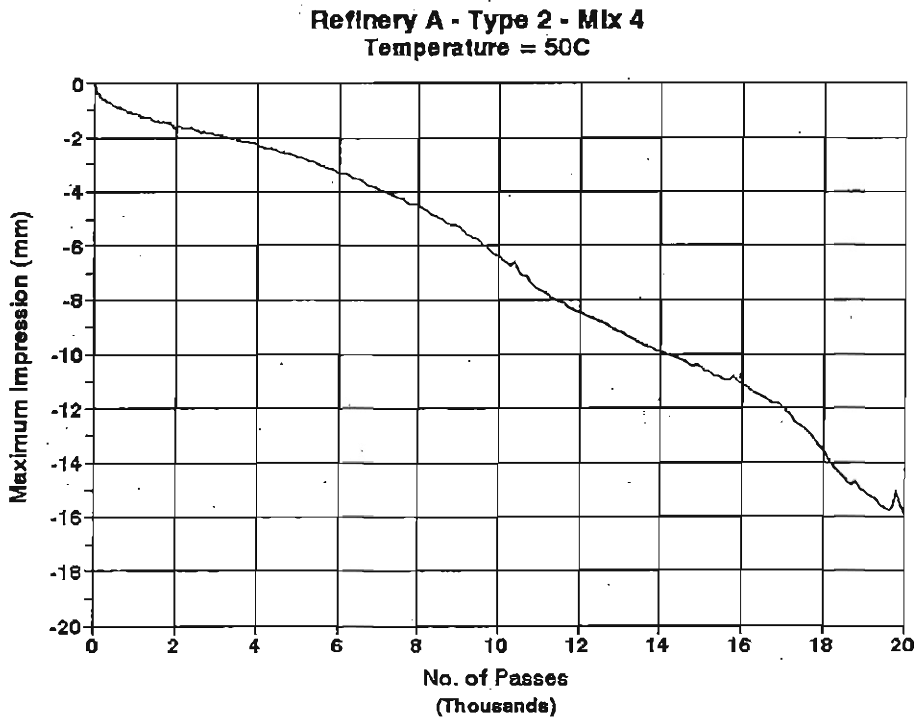

Refinery A - Type 1 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery A - Type 2 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

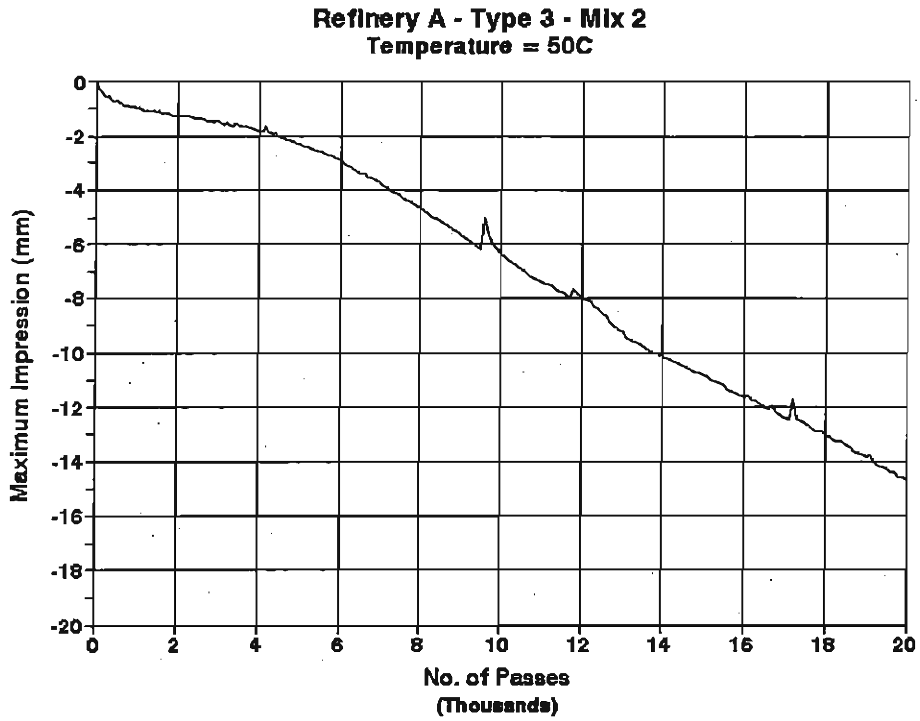

Refinery A - Type 2 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

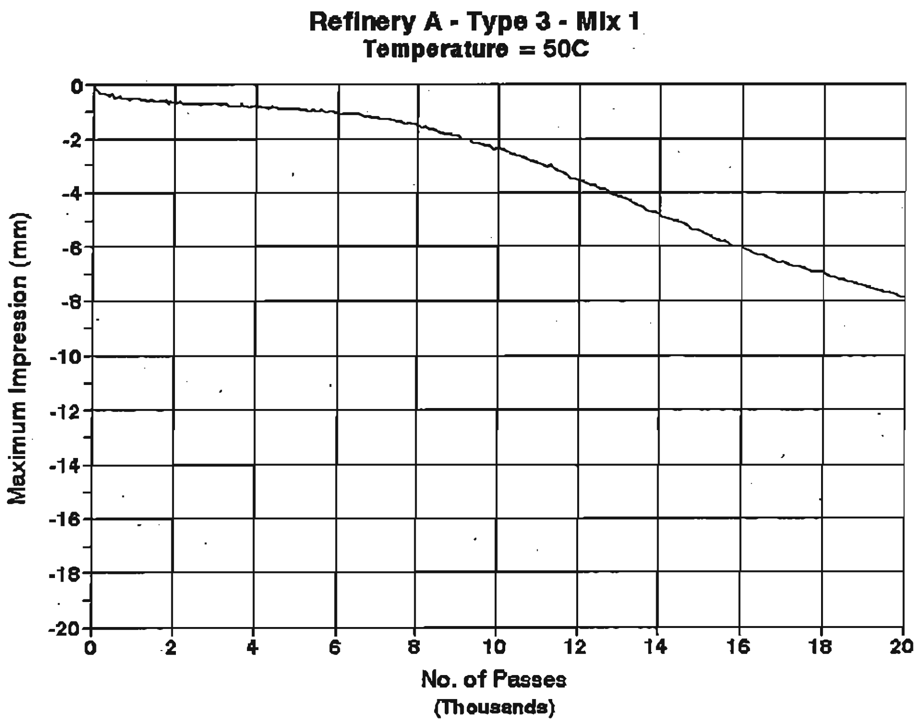


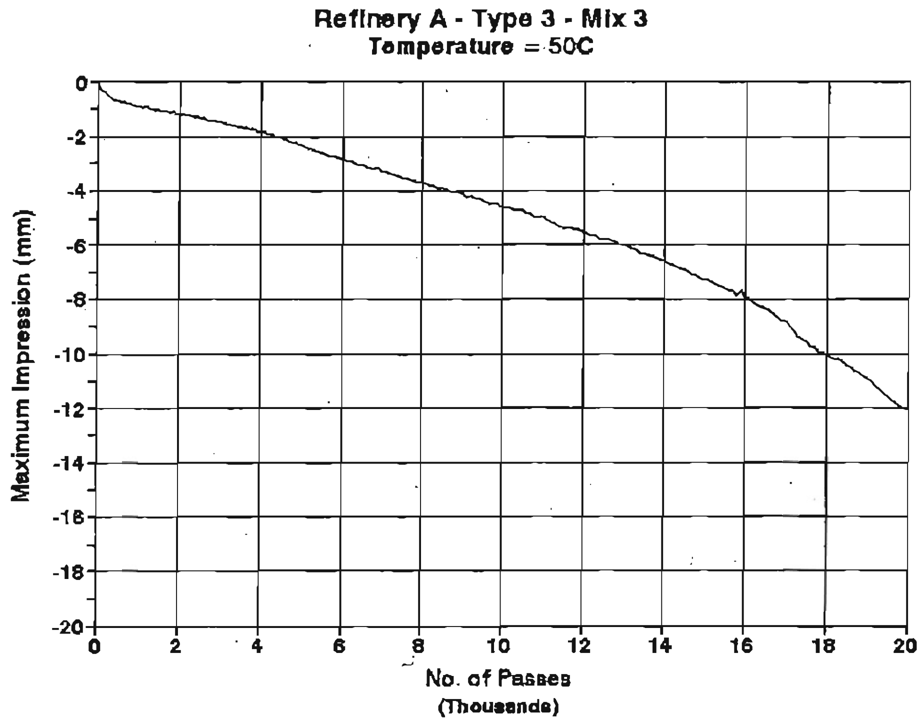
Refinery A - Type 2 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

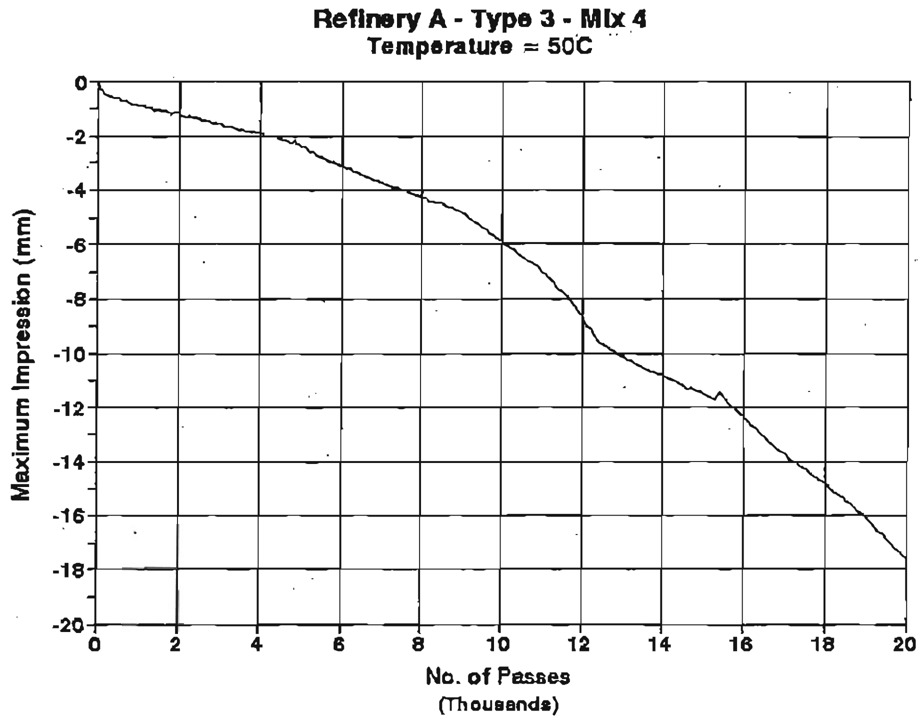



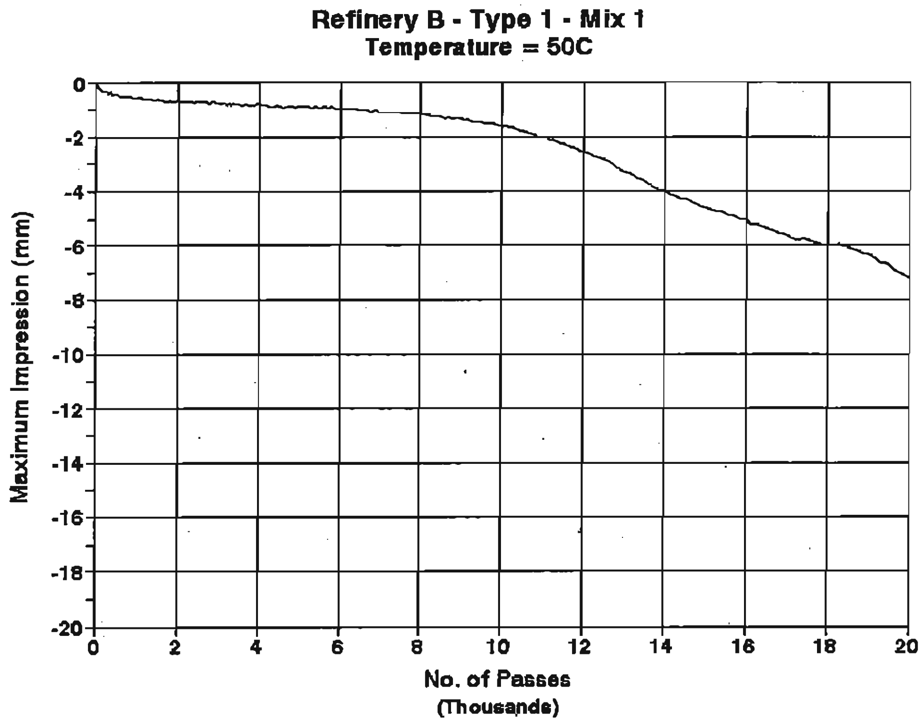
Refinery A - Type 2 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

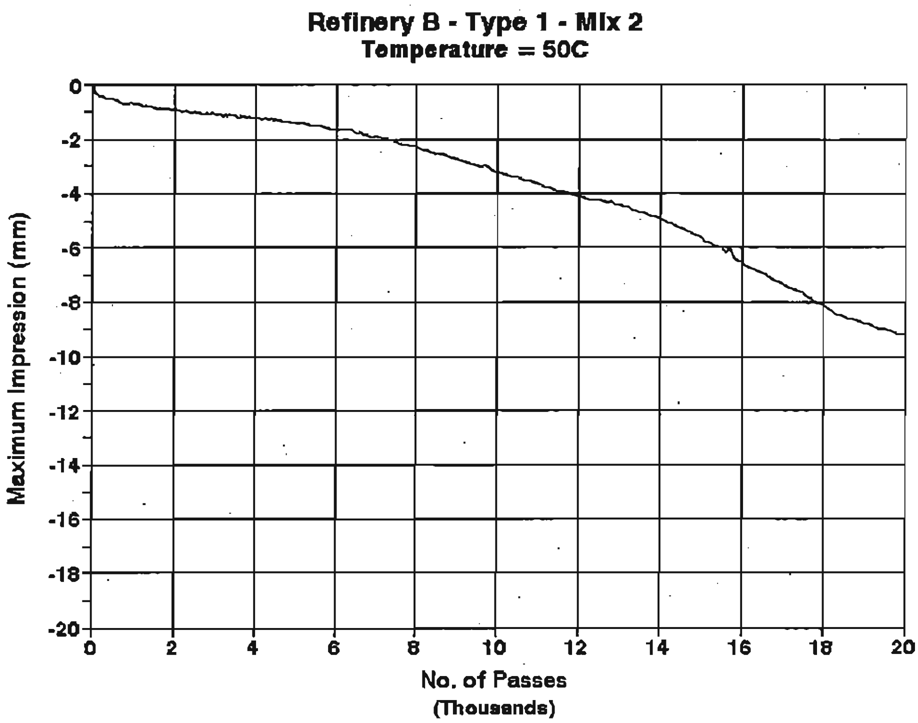

Refinery A - Type 3 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

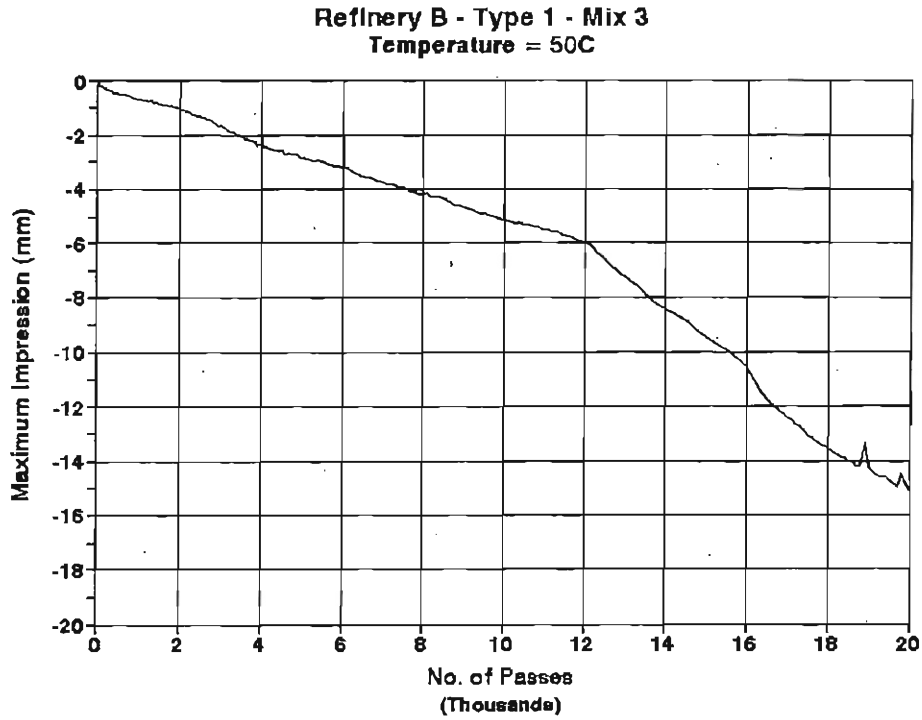

Refinery A - Type 3 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

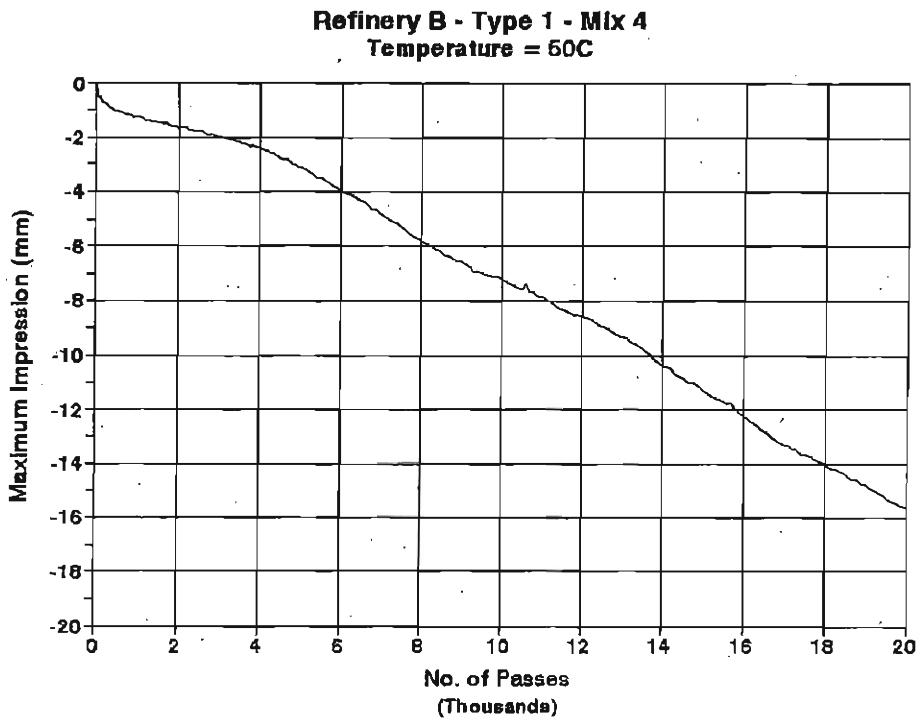

Refinery A - Type 3 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

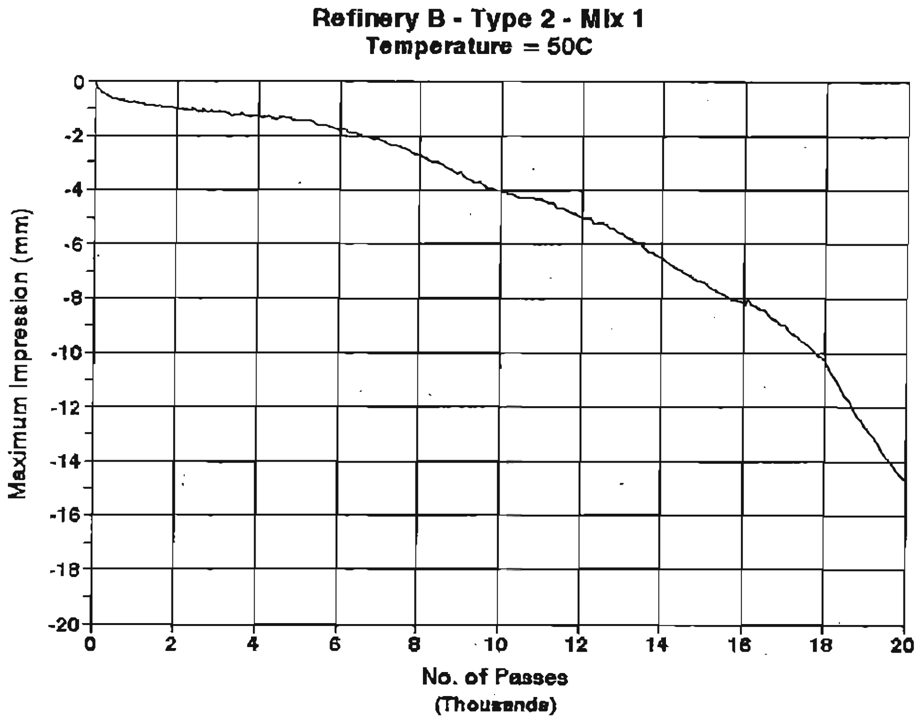

Refinery A - Type 3 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

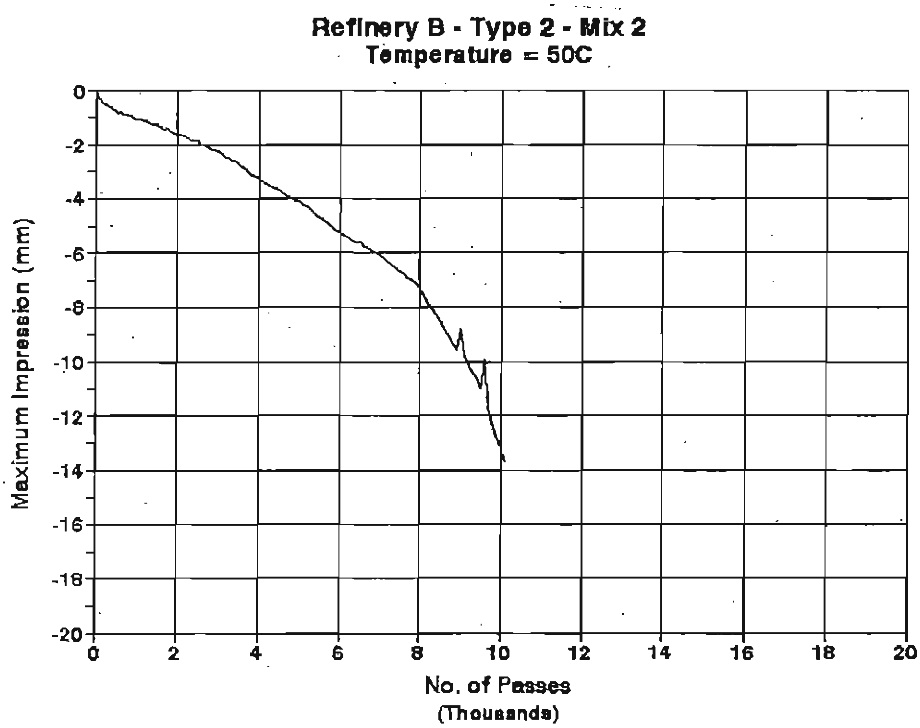

Refinery B - Type 1 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery B - Type 1 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

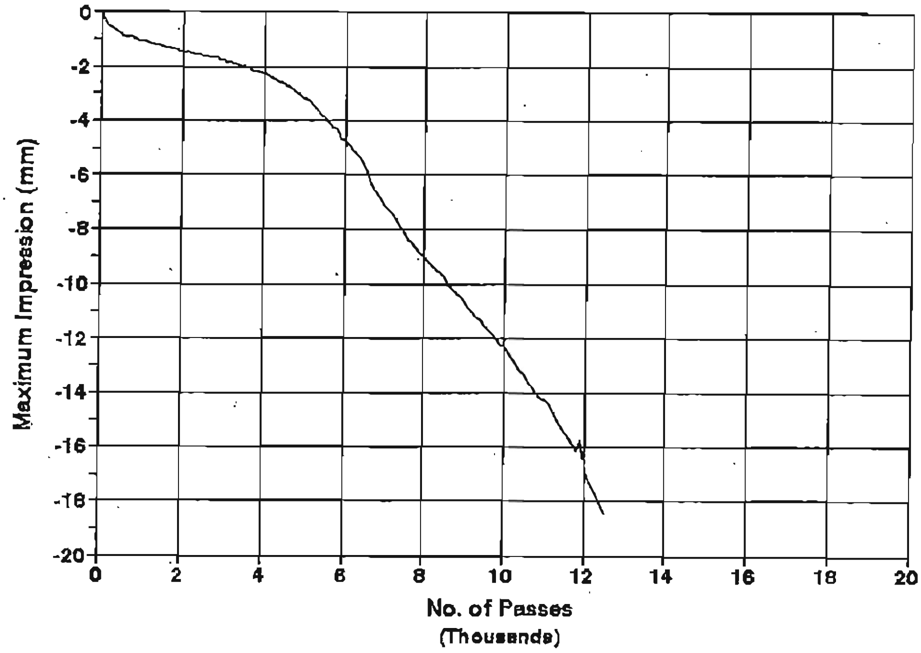

Refinery B - Type 1 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery B - Type 1 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

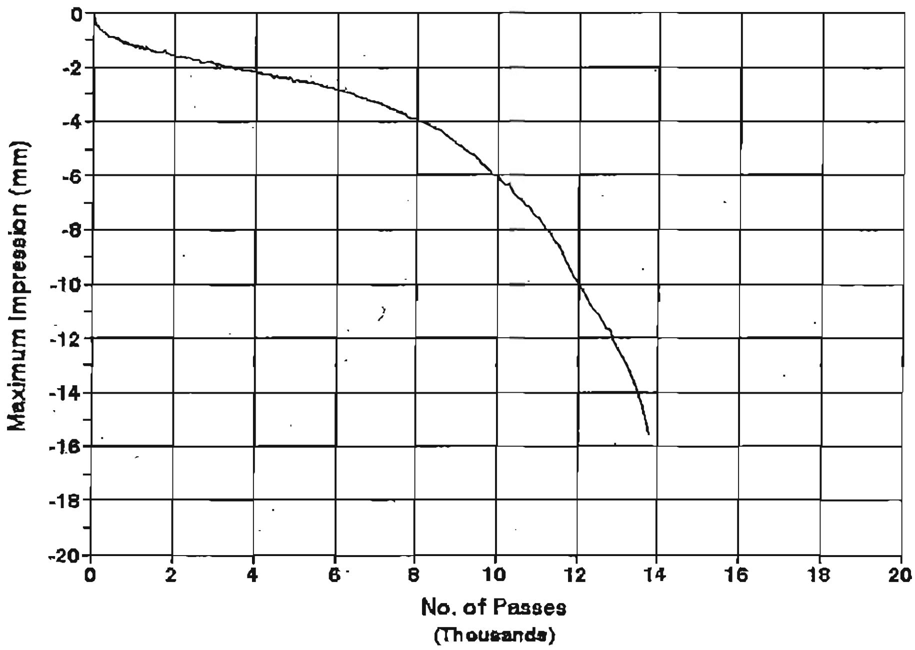

Refinery B - Type 2 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

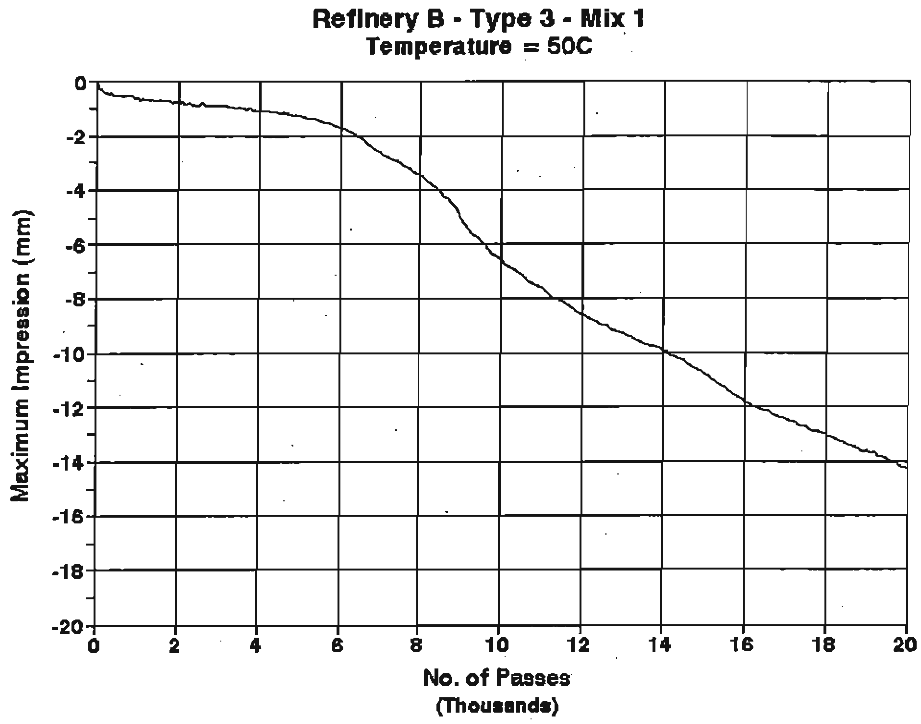

Refinery B - Type 2 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

Refinery B - Type 2 - Mix 3
Temperature = 50C

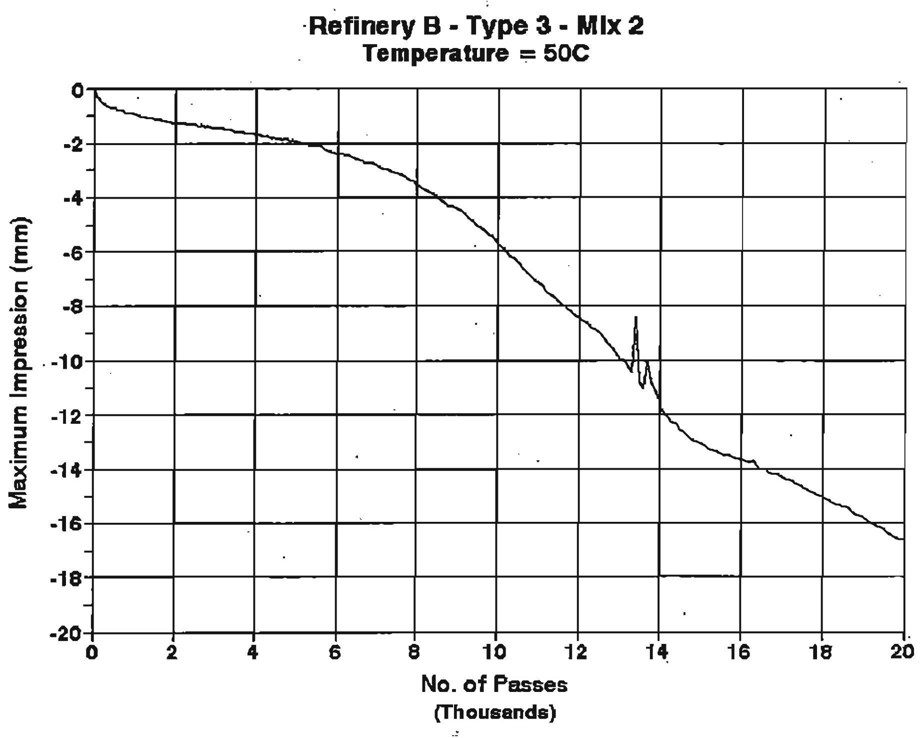



Refinery B - Type 2 - Mix 4
Temperature = 50C

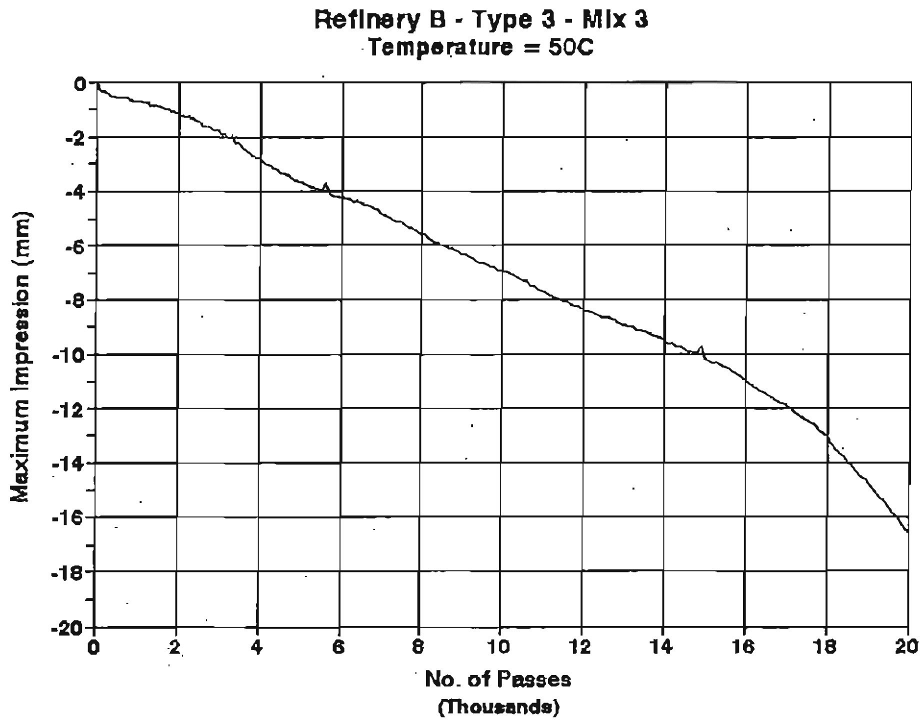


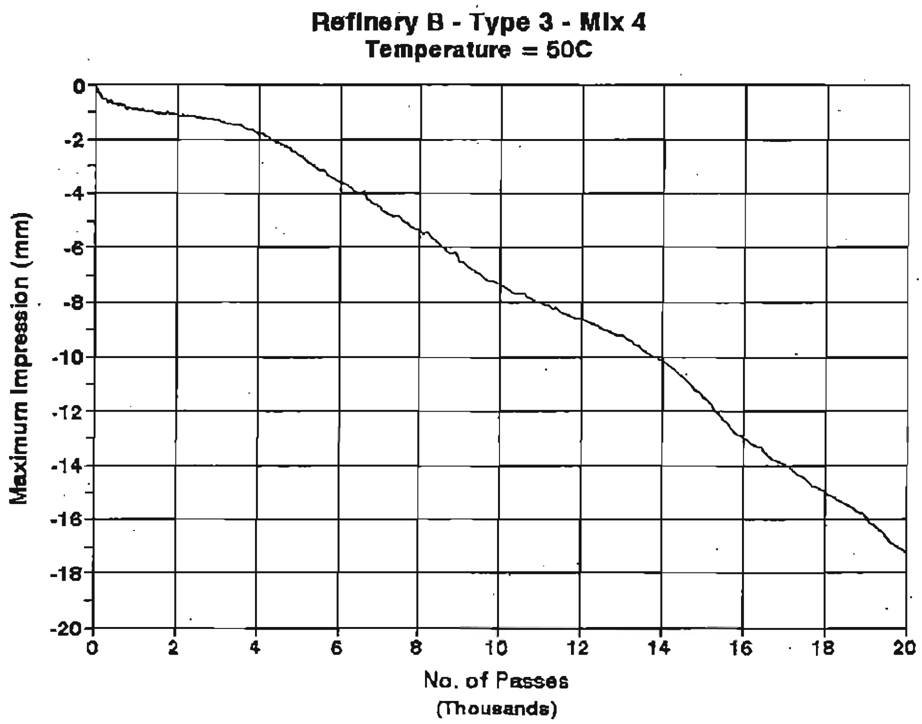


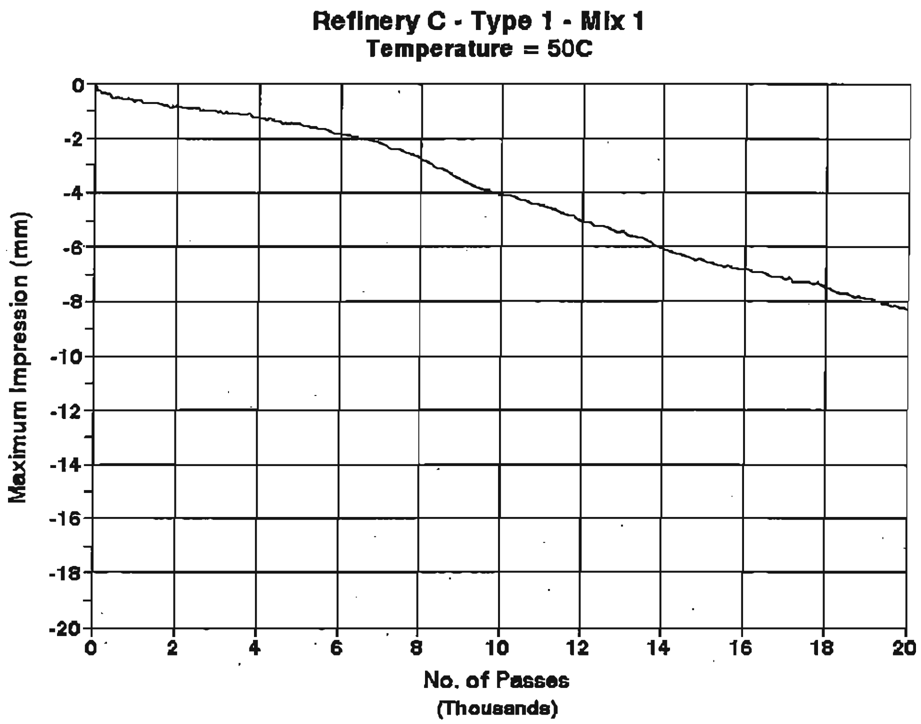
Refinery B - Type 3 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

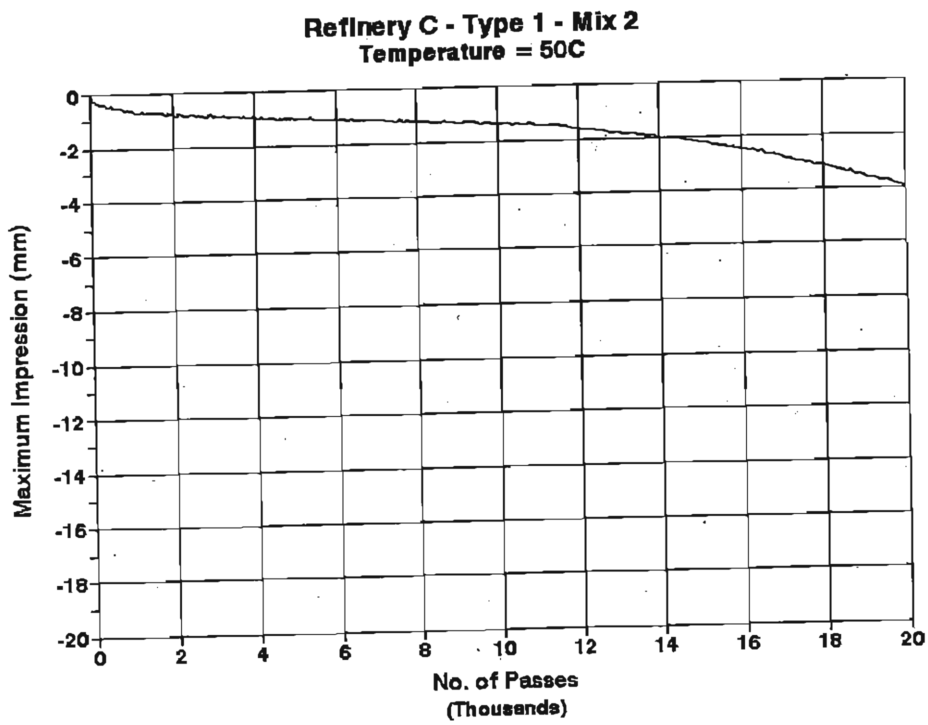



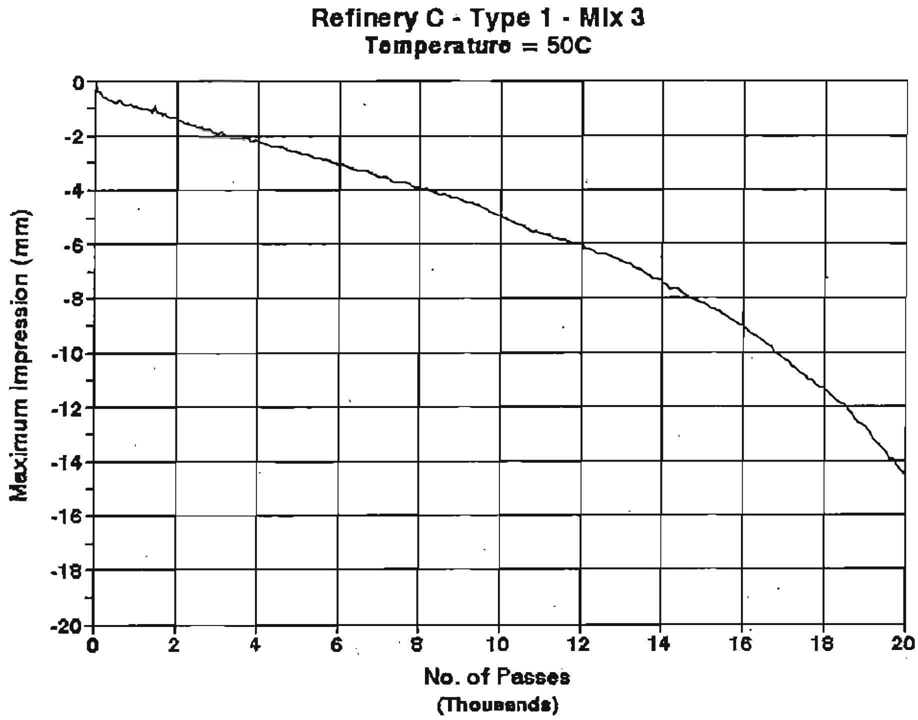
Refinery B - Type 3 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery B - Type 3 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

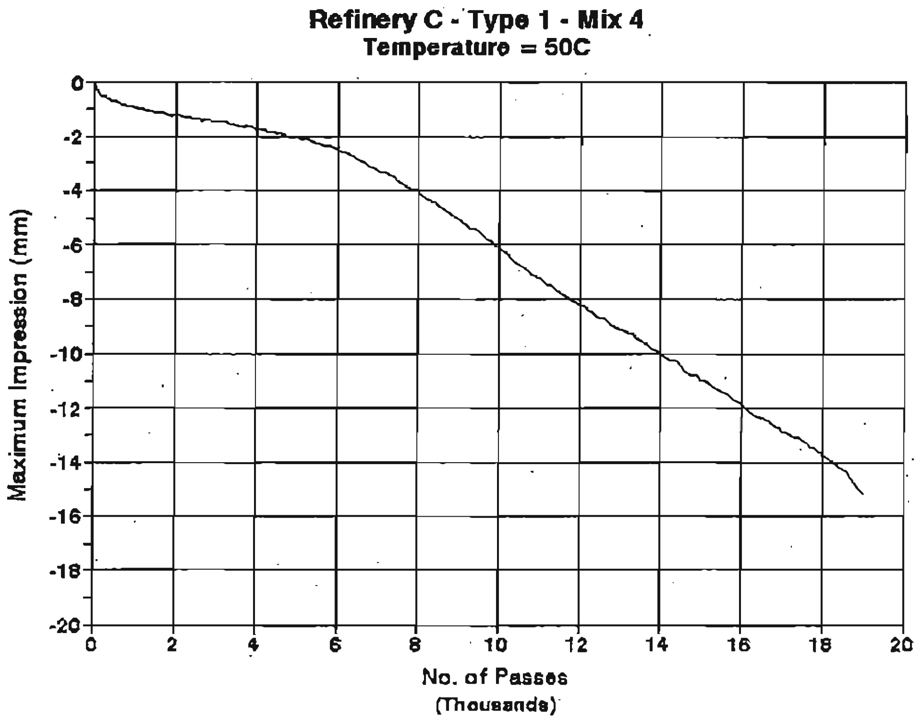

Refinery B - Type 3 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery C - Type 1 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

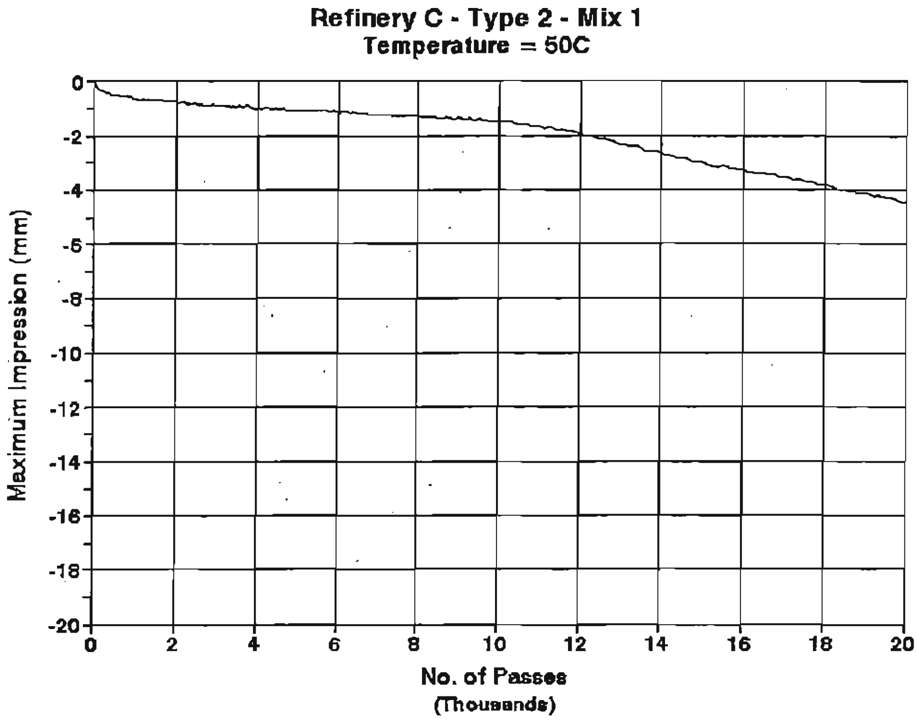

Refinery C - Type 1 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)



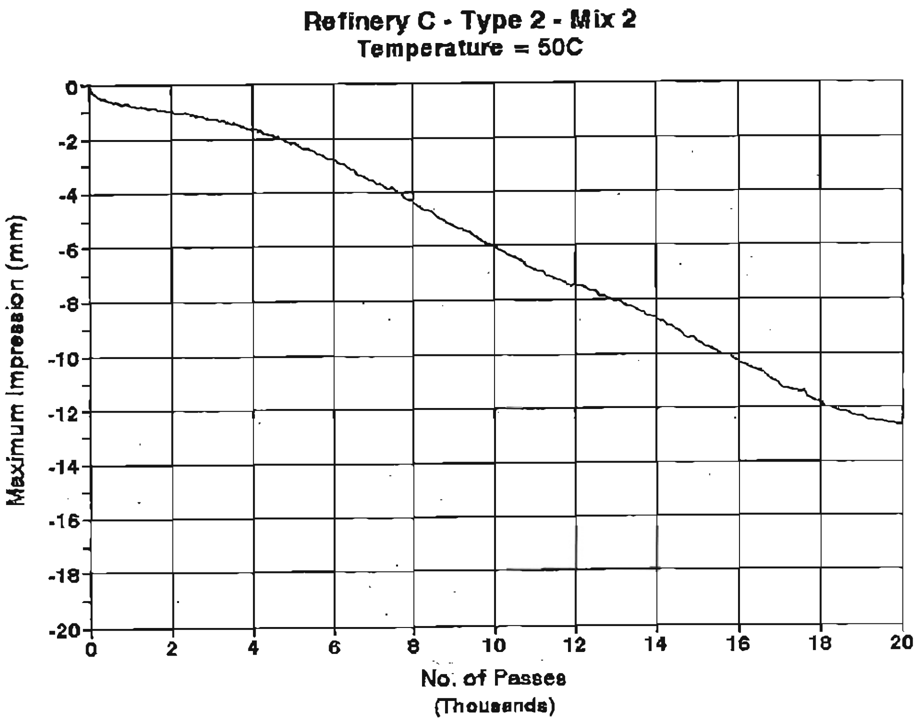
Refinery C - Type 1 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

Refinery C - Type 1 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

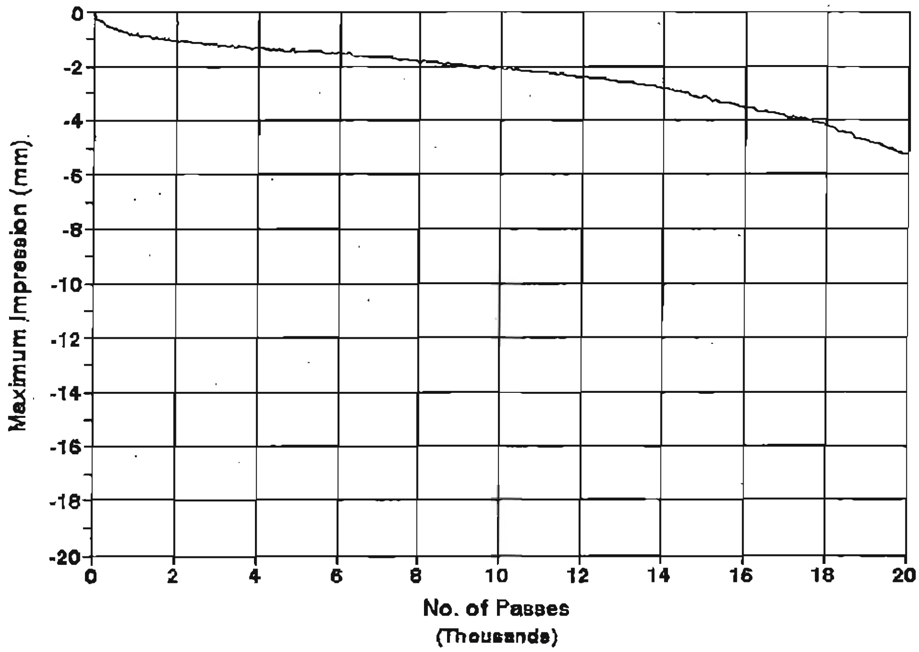


Refinery C - Type 2 - Mix 1
Temperature = 50C
Maximum Impression (mm)
No. of Passes
(Thousands)

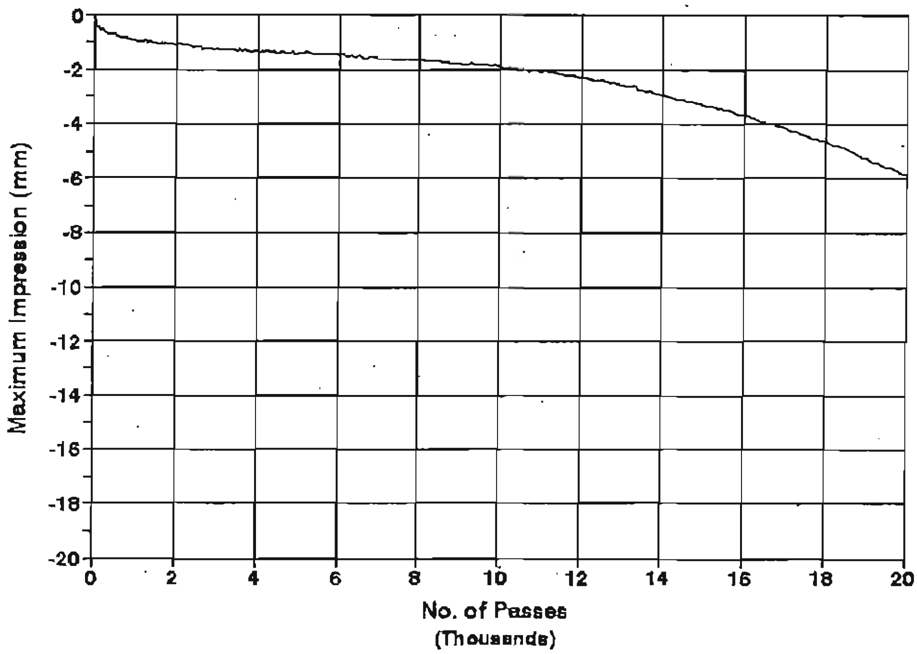



Refinery C - Type 2 - Mix 2
Temperature = 50C
Maximum Impression (mm)
No. of Passes
(Thousands)

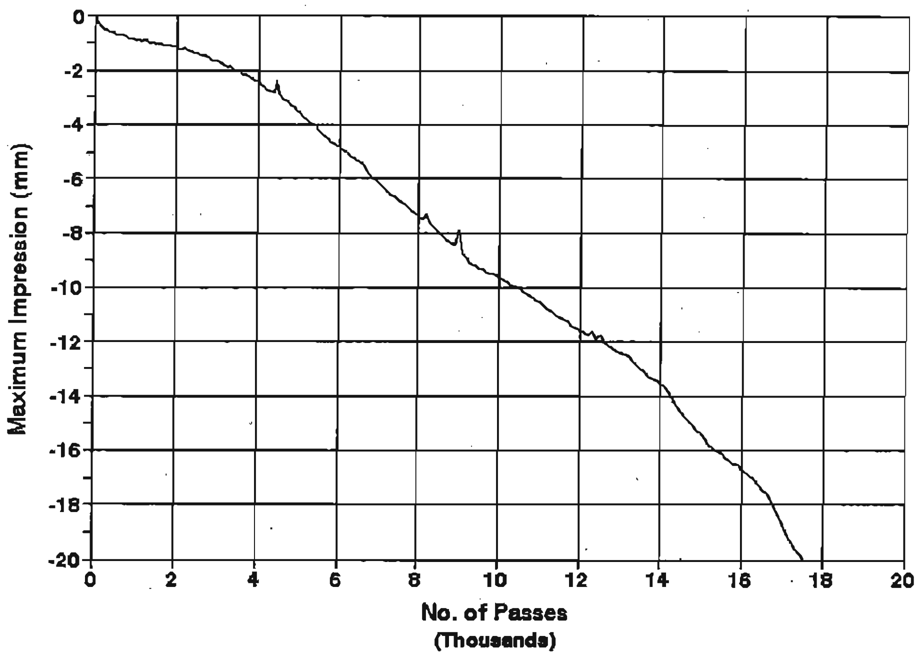
**Reflnery C - Type 2 - Mix 3**
**Temperature = 50C**



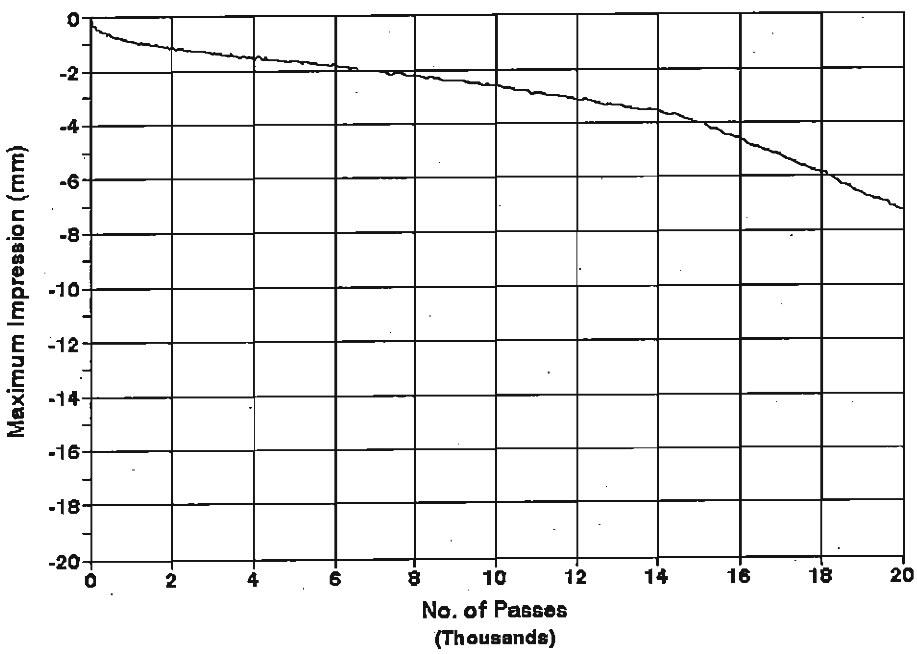

**Reflnery C - Type 2 - Mix 4**
**Temperature = 50C**

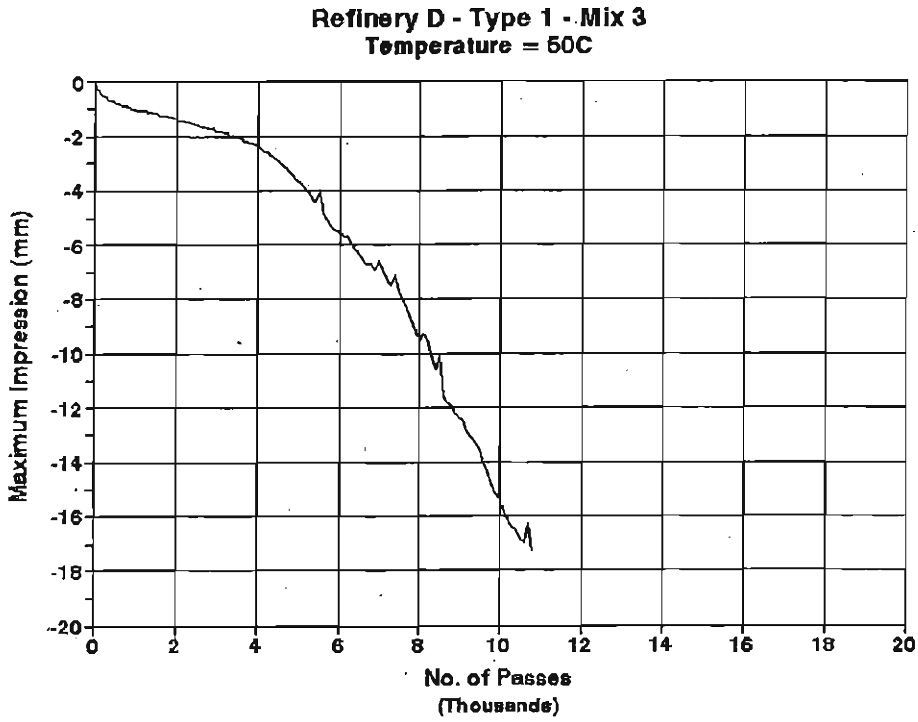


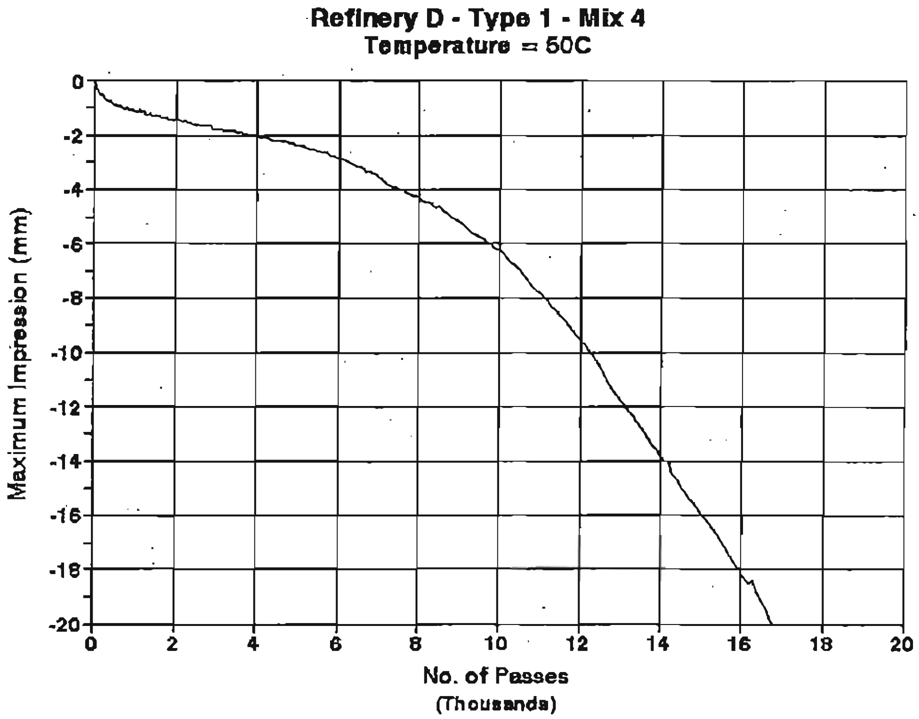
Refinery D - Type 1 - Mix 1
Temperature = 50C

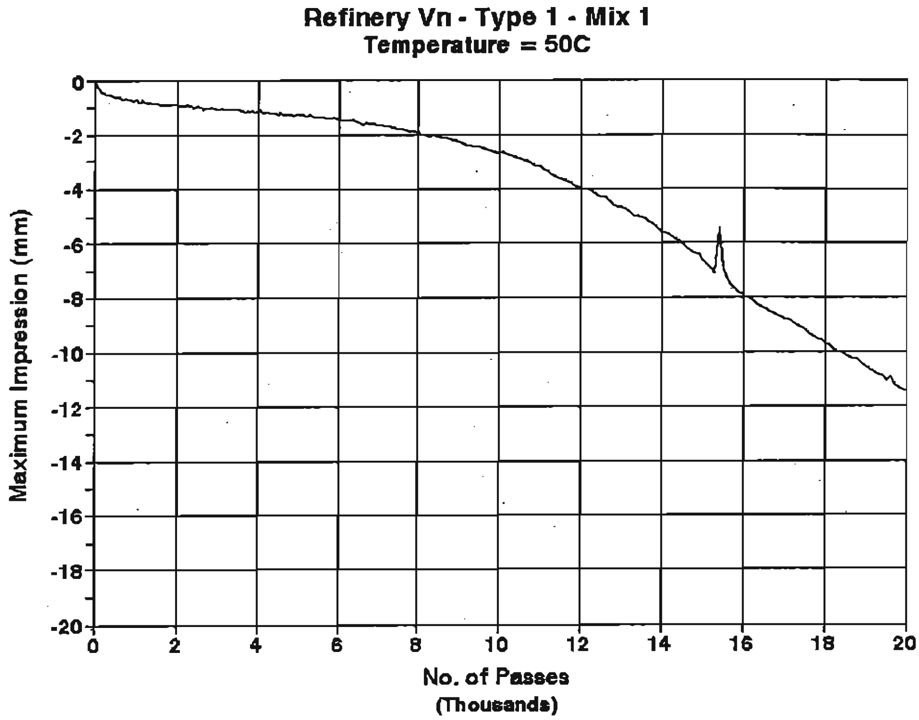


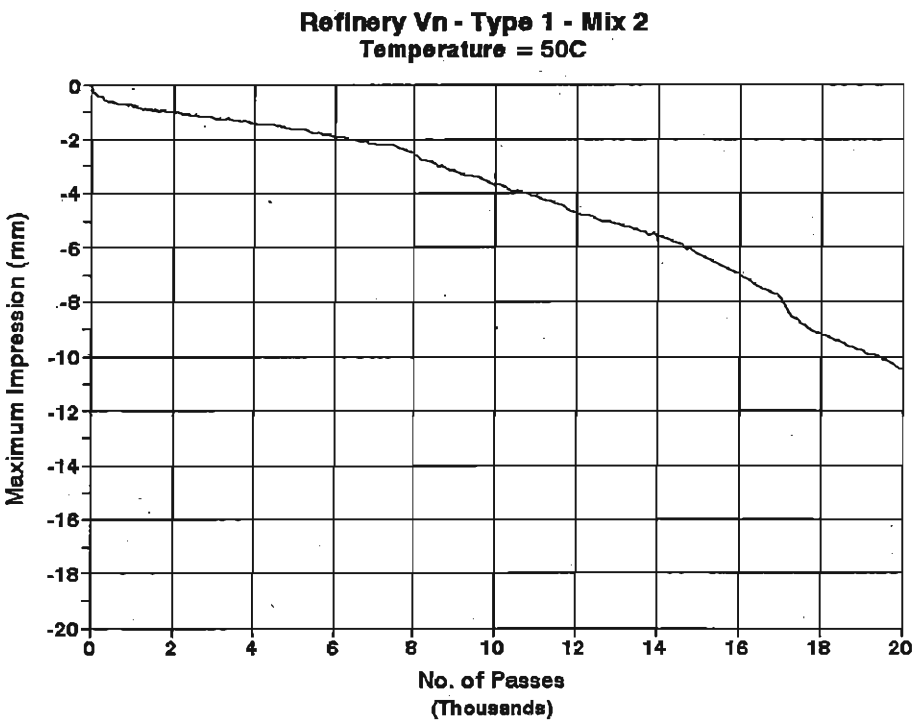

Refinery D - Type 1 - Mix 2
Temperature = 50C

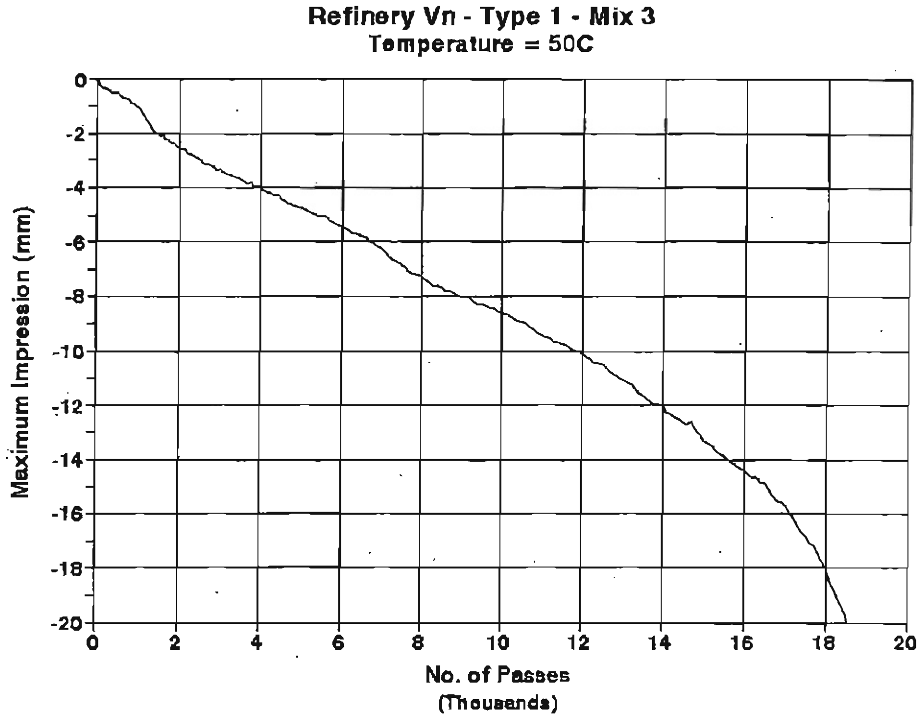


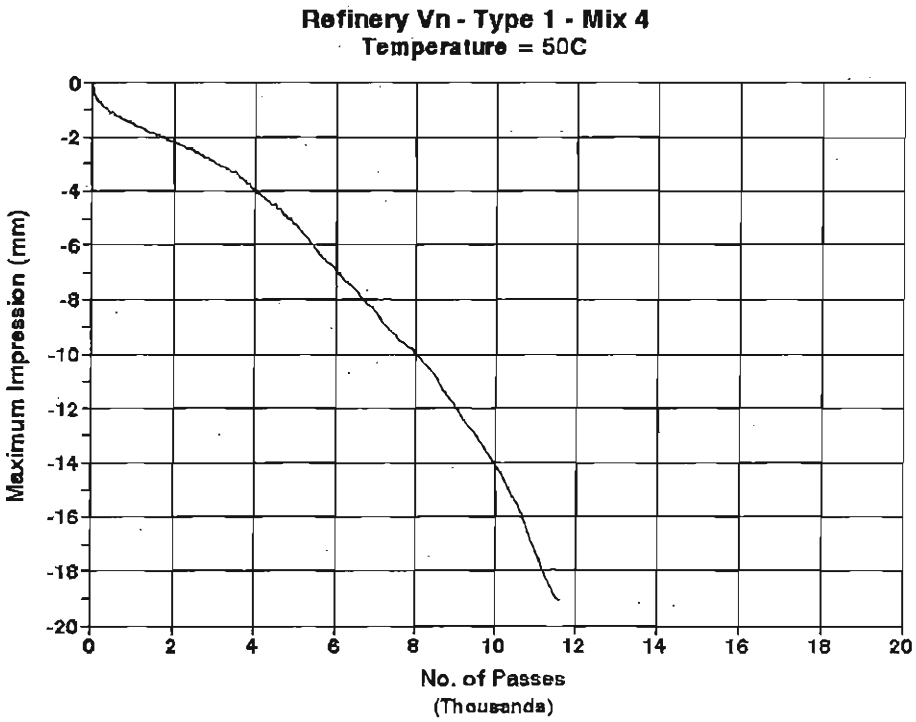

Refinery D - Type 1 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery D - Type 1 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery Vn - Type 1 - Mix 1
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery Vn - Type 1 - Mix 2
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery Vn - Type 1 - Mix 3
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Refinery Vn - Type 1 - Mix 4
Temperature = 50C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)