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HOT IN-PLACE RECYCLING OF ASPHALT PAVEMENTS

by

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This report contains the results of a literature search concerning hot in-place asphalt pavement recycling. Current methods and procedures for hot in-place recycling were reviewed and the advantages and disadvantages of each presented.

Four construction sites were visited. Each site used a different procedure to recycle the pavement. These procedures along with the equipment used are discussed in regard to selecting a recycling method, material controls, and available cost data.

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PREFACE

This study was conducted by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), during the period November 1988 through September 1989. The investigation was sponsored by the US Army Engineering and Housing Support Center. Mr. K. Gregg was the Technical Monitor.

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL); Mr. H. H. Ulery, Jr., Chief, Pavement Systems Division (PSD), GL; and Dr. R. S. Rollings, Chief, Materials Research and Construction Technology Branch, PSD, GL; Messrs. J. E. Shoenberger, T. W. Vollor, PSD, GL; A. D. Roberts, J. Danczyk, and G. E. Dill, Information Technology Laboratory (ITL), provided field survey support. This report was prepared by Messrs. Shoenberger and Vollor.

The Commander and Director of WES is COL Larry B. Fulton, EN. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons per square yard	4.5273	cubic decimetres per square metre
inches	2.54	centimetres
pounds per cubic foot	16.01846	kilograms per cubic metre
tons (mass) per square foot	9,764.856	kilograms per square metre

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

HOT IN-PLACE RECYCLING OF ASPHALT PAVEMENTS

PART I: INTRODUCTION

Background

1. The recycling of existing asphalt concrete pavement structures continues to gain wider usage. The incentives for recycling include not only conserving material resources to lessen possible ecological damages but also include reducing construction costs. Recycling reduces the amount of raw materials required by reusing existing pavement materials for construction. This reduction in the amount of raw materials required will include asphalt cement which will help to reduce our dependence on foreign sources of crude oil (Whitney 1980).

2. The pavement users (those who traffic the pavement) benefit with the hot in-place recycling process because traffic disruptions are kept to a minimum. The hot in-place recycling process provides a method of having a distressed pavement surface in front of the recycling train and a rehabilitated pavement surface appear from behind the recycling train ready for compaction and then traffic.

3. Hot in-place recycling (HIPR) is a process of correcting the surface distresses in asphalt pavement by heating the pavement surface and correcting the distress while the pavement is hot. The types of distresses that can be treated by this process include rutting, corrugations, thermal or age cracking, and slippery or low friction pavements. HIPR began in the 1930's with the first heater-planer machines (Dinnen 1981; Servas 1981; Epps 1980). The equipment used for this type of recycling has been improved with the addition of capabilities such as scarifying, mixing, and the addition of rejuvenators and new asphalt mix. The oil embargo of 1973 provided an increased interest in this and all types of recycling (Jimenez 1980). Currently, HIPR involves the heating of the in-place pavement followed by scarifying or milling of the heated pavement to loosen the asphalt concrete material and rejuvenating the loosened asphalt concrete material before placement and compaction. HIPR processes can currently treat the pavement to a depth of from 3/4 to 3 in.

depending on the type of procedure used. The HIPR process should be limited to pavements with satisfactory load carrying capacity.

Objective

4. The objective of this study was to evaluate the various types of HIPR methods currently in use in the United States. The evaluation entailed determining the advantages and disadvantages of the equipment and techniques of each HIPR method investigated.

Scope

5. To satisfy the objective, the following items were accomplished:

a. A literature search was conducted to obtain current information concerning HIPR.

b. Four construction sites, each using different equipment and procedures, were visited to observe the various HIPR methods at work. The sites and procedures were as follows:

Site	Method	Procedure
1. Marshall, TX	Single-pass	Wirtgen (remix)
2. Trinity, TX	Single-pass	Cutler (remix)
3. Richmond, VA	Multiple-pass	National Asphalt Heat Treating (heater-scarifier)
4. Grand Prairie, TX	Multiple-pass	Dustrol (heater-scarifier)

c. Details concerning the pavement conditions prior to recycling and the reasons for using this type of recycling were obtained.

d. An evaluation, using data supplied by the contractors, was made of the various equipment used to control the asphalt mixture properties and the type and amount of quality control testing required for HIPR.

e. Cost data were obtained from the contractors on each recycling method evaluated.

PART II: METHODS OF HOT IN-PLACE RECYCLING

General

6. HIPR can currently be divided into either single or multiple pass methods ("Hot In-Place Recycling," 1988; "Guideline Specification for Hot In-Place Recycling," 1988). These methods vary widely in the amount and complexity of the construction equipment. The operations common to most HIPR methods on asphalt pavement are heating, scarifying (planing, scarifying, or milling), rejuvenating, mixing, and compacting the recycled mixture. In the single-pass method the recycled pavement along with any additives or new asphalt mix is placed together in one operation and compacted. In the multiple-pass method the recycled pavement is placed as an intermediate course and compacted. A wearing surface is placed later in a separate operation. The individual methods are discussed below.

Single-Pass Recycling

7. Single-pass recycling was developed in Europe and has only started to gain wide usage in the United States during the 1980's ("The Truth about Remixing Asphalt," 1987). The single-pass method will involve either one of two procedures outlined in Figure 1. The first procedure called remix ("Guideline Specification for Hot In-Place Recycling," 1988) involves the combining of a new asphalt mixture with the reclaimed (scarified or hot-milled) asphalt mixture prior to placement on the pavement surface. The second procedure called repave (Whitney 1988) involves overlaying the recycled material with new asphalt mix prior to rolling or cooling of the recycled material. The single-pass method usually involves several pieces of equipment including heaters, scarifiers, hot milling heads, spray bars, or pavers in various combinations or as separate pieces of equipment.

8. The single-pass recycling method usually involves larger and more complex pieces of equipment than are used in the multiple-pass procedure. However, the single-pass methods usually have better control and greater flexibility in processing the recycled asphalt mixture.

Method	Process Listed in Sequence							
					Placing Recycled Mix		Placing New Mix	
	Heating	Planing/Scarifying	Milling	Adding Rejuvenator	Intermed Course	Surface Course	Surface Course	Compact
Single Pass								
Remix	1	2	2	3	4	4		5
Repave	1	2	2	3	4		5	6
Multiple Pass	1	2	2	3	4		6	5,7

Figure 1. Hot in-place recycling method sequence

Multiple-Pass Recycling

9. With the multiple-pass recycling technique, the recycled material and the wearing surface are applied in separate operations (Figure 1). The recycled material is used only as an intermediate or leveling course; whereas, a new asphalt mixture is used as the wearing course. The multiple-pass method usually involves the less complicated equipment of the two methods. The original heater-planer equipment fits into this type of method. The multiple-pass method involves the use of equipment that heats the pavement, scarifies or mills the heated asphalt material, adds rejuvenator as required, and places the recycled asphalt material. This normally involves several separate pieces of equipment including heaters, scarifiers, hot milling machines, and pavers. The recycled material is then compacted before cooling and is used as an intermediate or leveling pavement course.

10. A bituminous wearing surface is later applied to the recycled surface within a predetermined period of time. The bituminous surfacing is required to protect the recycled surface from the effects of traffic.

General

11. The majority of information available from a long-term performance point of view is on multiple-pass methods (heater-scarifying, heater-planning) recycling. These types of recycling have been in use for the longest period of time. The single-pass methods (remix, repave) have not been in use as long and there is less long-term performance information available. Therefore, the majority of literature available deals with multiple-pass methods of recycling and their performance.

PART III: LITERATURE SURVEY

Method Selection Considerations

12. HIPR can be classified into one of four possible procedures: reshaping, regripping, repaving, or remixing (Gerardu and Hendricks, 1985). The reshaping procedure can consist of two practices. The first is heating and rolling of the pavement. This practice is no longer used due to the damage it causes to the asphalt cement (hardening) of the pavement. The second practice involves using the heater-planer to remove asphalt material to reduce dead weight from bridge decks or to achieve underpass clearance. This practice is also seldom used since the advent of cold milling machines which has advantages in economics and control. Regripping is the heating and sometimes planing of the pavement prior to the spreading and rolling of precoated aggregates on the pavement ("Guideline Specification for Hot In-Place Recycling," 1988; Burton, 1979). This procedure is also seldom used, again because of possible damage to the asphalt cement by overheating during the heating process. Repaving involves heater-scarifying/hot-milling with the addition of a surface treatment or overlay of the recycled surface. Remixing involves heater-scarifying/hot-milling with new asphalt mixture added to the reclaimed material. Currently, most of the HIPR falls under the last two procedures with either single or multiple pass procedures.

Construction Equipment

13. HIPR can involve many different processes and procedures; however, as a minimum it will include the in-place heating and loosening of the asphalt pavement to an average depth of 3/4 in. or the diameter of the maximum size aggregate. Improvements to the equipment and procedures used for HIPR have had a great influence on its expanding use.

14. The equipment available for HIPR is constantly changing and being redesigned. Equipment manufacturers are developing new procedures and techniques and modifying existing equipment to improve the product produced by HIPR. Companies are being formed around particular methods or equipment and

in many instances, this particular HIPR procedure is available from only that one particular company.

Pavement Heating

15. Heating units have improved over the years both in response to environmental considerations and to an increased knowledge of the harmful effects of the heating process on the asphalt pavement. The environmental considerations addressed include the development of cleaner burning, more efficient heaters, and improved methods of applying and using the heat produced. The first heating units utilized a direct flame to heat the asphalt cement in the pavement resulting in overheating, burning, and oxidation of the asphalt pavement (Scrimsher 1981; Lawing 1976). In 1973, a new type of heater was introduced which used indirect (radiant) heating to eliminate the application of the flame directly on the pavement ("Guideline Specifications for Hot In-Place Recycling" 1988). Most heaters currently use indirect heating and propane gas as fuel.

16. There have been some attempts at using microwaves as a method for heating the pavement. Microwaves offer promise as a method to deliver heat energy to the interior of the pavement without passing it through the surface as heat. This would help to eliminate the problems of smoke, fumes, scorching, and air pollution. Microwaves heat the pavement by the aggregate's absorbtion of the microwave; energy which heats the aggregate and in turn heats the asphalt coating it (Smith 1986). Microwave machines require a large generator which must be towed or carried along to provide the required electrical energy. The prototype machines built to date combine the microwave energy with the hot exhaust gases of the electrical generator as it is towed in front. One problem facing the use of microwave heating is that the heating tends to extend down to 8 in. or more, although only 2-4 in. are required (Smith 1986). One method proposed to control the depth of heating involves the placement of a special fabric and tack/seal coat during the initial construction of the pavement. The fabric and tack/seal coats are used to concentrate the microwaves at the surface and, thereby, to improve the efficiency of the heater. The proposed method would require planning to restore the pavement using the microwave heating process during the initial construction or

overlay; thereby, eliminating all existing asphalt pavements from this recycling process.

Unbounding Pavement

17. The first process that evolved for HIPR was the heater-planer. In this process, after heating, the pavement was then removed by planing or scraping the heated asphalt material from the pavement. Heater-planing was used to correct surface defects such as ruts and corrugations. It was also used to remove the existing pavement for overpass clearance or to reduce the dead load on bridges. The material that was removed could be reused as a black base or as quality fill material (Shook and Shannon 1987). Eventually, scarifying teeth or tines replaced the planers and, this, along with better heating, allowed for deeper in-place recycling. Currently, these scarifiers are either spring loaded or mounted on breakaway holders to help prevent breakage of the teeth and aggregate in the pavement. Nonrigid or spring-loaded mounting is also helpful in allowing the scarifier to run over road obstacles such as manhole covers or concrete patches. The scarifying teeth are normally arranged in two or three rows to achieve complete coverage. The latest development in loosening the heated pavement is the use of a hot milling head to mill to the depth heated. The hot milling head allows for a more precise depth of cut than with the scarifying teeth. It also provides a means for removing the milled material from the pavement surface to allow for further treatment or better mixing before replacement. Another recent development has been equipment that will allow for the addition of new asphalt concrete mix to the recycled mixture to improve quality. Equipment is also available that can add new asphalt mix to the existing material or place it on top of this material without mixing.

Placement

18. The majority of HIPR processes currently in use have a screed at the end of their material handling operations to place the recycled material back on the pavement. These screeds range from those with no automatic controls (grade, slope, or depth) to those that are as completely automated as screeds on conventional paving machines. For screeds with no automatic

controls, the depth of placement is normally controlled by taking depth measurements by hand and manually adjusting the screed. The screeds with automatic controls operate like those of a conventional paver. Many of the automatic screeds are equipped with vibrators to achieve some initial compaction. Several single-pass machines are equipped with two screeds, one trailing the other and both individually fed, allowing multiple lifts to be placed in a single pass.

Rejuvenation

19. A spray bar for the addition of a rejuvenator will be found somewhere within the recycling equipment train. The rejuvenator should be added by a method where it can be uniformly distributed throughout the recycled mixture. Different equipment manufacturers currently add the rejuvenator anywhere between the scarification/hot-milling and the compaction of the recycled pavement. In addition to the spray bar, a storage tank for the rejuvenator and required connections will also form part of the required equipment.

Surface Defects

20. HIPR is a surface recycling method and the depth of rehabilitation is limited to the depth that it is scarified or milled. Therefore, it cannot correct pavement defects that extend deeper than the depth of recycling (Burton 1979; Shook and Shannon 1987). The depth of scarification will normally be 1/4 to 1/2 in. deeper than the final depth of pavement treated (Peters 1980). The following is a partial listing of surface defects which can be corrected by hot in-place recycling:

- a. Low skid resistance.
- b. Rutting.
- c. Corrugation.
- d. Raveling.
- e. Polished aggregate.
- f. Minor bleeding.
- g. Cracking (to the depth scarified or hot milled).
- h. Riding quality (smoothness).

Disadvantages

21. HIPR should be used only to repair pavements with surface distress and not those with base or subbase distress. Uneven surfaces can be corrected by this process; however, there are limits to this capability. Uneven surfaces will cause uneven heating and this may require the use of several passes of the equipment to achieve the desired results (Gerardu and Hendricks 1985; Scrimsher 1986). The surface finish of an HIPR pavement varies more than a conventional pavement and the low speed ride is not as smooth (Cooper and Young 1982). Obstacles in the road such as manholes and other stationary structures will require some handwork (Grau 1977). These HIPR pavements will tend to ravel if not covered with a surface treatment or overlay (Grau 1977). Pavements that are bleeding or flushing asphalt cement should not be selected for HIPR (Dikha and Fung 1981). Reflective cracking caused by joints in underlying PCC pavements are not effectively delayed by HIPR (Ganuhg 1987). Local asphalt suppliers may be hesitant to supply asphalt mix for HIPR operations because the use of in-place recycling will decrease the amount of asphalt mix that they would sell without recycling, thereby decreasing sales.

Advantages

22. The HIPR method can decrease the amount of reflective cracking except where the cracking is caused by structural failure (Grau 1977). The amount of decrease in reflective cracking is dependent on the type of crack that is reflecting through. The top portion of the crack is eliminated by the HIPR process and, where the crack is larger at the surface than at the milled/scarified depth, the crack will probably reflect through slower than if the surface was just overlayed with asphalt concrete.

23. Materials and fuel are saved by HIPR versus an overlay of the same thickness. Paving materials are reused and there is a minimum transportation of materials to and from the construction site. Another benefit of the HIPR is that good bond is achieved between asphalt layers where the repaving process is used in a single-pass procedure (Burton 1979; Scrimsher 1981). Also, this process improves the surface texture, riding quality, and other surface characteristics, eliminating much of the need for leveling courses and providing reduced traffic disruptions (Burton 1979; Cooper and Young 1982). The

exception to this is a heater-planer operation which can leave a rough surface.

Material Additives

24. Asphalt additives such as soft asphalt cements, emulsions, or rejuvenators in the recycled mixture have been used for many years. These additives are intended to enliven or soften the asphalt binder and return it to its original properties. Rejuvenators are various proprietary products which are designed to soften asphalt cement. The amount of softening is controlled by the amount of rejuvenator added to the mix. Rejuvenators are currently used almost exclusively for HIPR. Where a remixing process is involved, the new mix could be made with a softer asphalt. This mix is then combined with the recycled mix to arrive at a suitable asphalt blend. This procedure would result in a recycled mixture with a combined asphalt cement meeting the required material properties for penetration and viscosity. Additives have been applied at various stages during the recycling process--ranging from prior to the heating process to application after the recycled mix has been placed. Regardless of when or where the additives are applied, a spray application of any type of rejuvenating additive should be heated to avoid cooling the hot mixture.

Specifications

25. Specifications used for HIPR have normally been very general in requirements due to the various recycling procedures available and the varying pavement conditions encountered. The greatest difference between hot in-place recycled and virgin mix specifications has been the lack of control over the final properties of the mix. The normal method of using Marshall mix properties to control the paving mixture is not currently used in HIPR. This lack of control extends to the compaction of the HIPR mixture where the compaction often takes place without a field density requirement. HIPR specifications currently require pretesting the existing pavement for the amount of rejuvenator required to produce a recycled mixture with an asphalt binder meeting certain penetration and/or viscosity requirements. The majority of HIPR specifications also requires that the field density be a certain percentage of the theoretical maximum density of the recycled mixture. The use of density and

void criteria requirements is critical to assure that a satisfactory pavement is obtained (Ingberg 1980).

Costs

26. Cost comparisons between HIPR and conventional overlays placed at different times and locations are not valid because of market variables. The more accurate comparisons are those that compare the costs within a particular area or location for the same construction season. Cost comparisons between HIPR and conventional overlays should not be based solely on the cost per inch of depth of each type of pavement. Additional costs for the conventional overlay should include crack repair, resetting of manhole covers and curbs, and any additional work caused by raising the pavement surface level. Also, the cost of a milling operation should be included if milling is used to correct surface elevation deficiencies. The literature suggests that the cost of HIPR 1 in. of existing asphalt concrete pavement is approximately one-third less than the cost of a 1-in. overlay when all factors are considered (Epps 1980; Scrimsher 1981). Additional cost savings are realized in many instances by not having to close the roads during construction.

27. The cost for HIPR increases as the degree of sophistication of the equipment and techniques increases. Heater-planning and heater scarifying are the least costly forms of hot in-place recycling. The repaving and remixing procedures generally require more complicated equipment than heater-planer/scarifier procedures and tend to be more costly. This higher cost is rewarded by an increase in the depth of pavement treated and a higher degree of control over the final asphalt mixture.

PART IV: FIELD INVESTIGATIONS

Marshall, Texas

Pavement condition prior to recycling

28. The HIPR was used on I-20 near Marshall, Texas. The portion of I-20 under construction included both the East and West lanes starting at the Louisiana-Texas border extending 40 miles west toward Dallas, Texas.

29. The pavement being recycled varied in age from 4 to 7 years. Overall, the pavement was in good condition; however, the pavement was beginning to show signs of distress, including minor raveling in various locations and isolated rutting and bleeding along several stretches of the roadway. Other than these visual observations, no other reasons were given for the rehabilitation work. Texas state inspectors controlled the mix proportions.

Recycling procedure

30. The HIPR process used on I-20 was the Wirtgen recycling procedure (Figure 2). This procedure is a single-pass method that involves a train of equipment which heats and hot mills the old pavement, combines it with new asphalt concrete mix, and places the combined material in one pass (Photo 1). The train included two separate butane preheaters (Photo 2) and a hot milling and placement machine referred to as the Wirtgen Remixer (Photo 3). The remixer was also capable of adding additional heat to the old pavement surface before removing it with a hot milling drum (Photo 4). After milling, the material was windrowed and passed into a pugmill for mixing. The remixer has a front hopper to receive new asphalt pavement mix, which was then transported back through the machine. New asphalt concrete pavement mix was added to the recycled material and combined at the pugmill to improve the properties of the recycled mix or to add new material to compensate for grade deficiencies. After mixing in the pugmill, the recycled asphalt mixture was placed on the roadway. A steel-wheeled and rubber-tired roller were used to compact the newly placed recycled hot mix.

31. The use of separate preheaters allows for the gradual buildup of heat within the pavement, allowing for a deeper penetration of the heat. This procedure of applying the heat allowed deeper heating without any visual signs of burning the surface asphalt of the old pavement (Photo 5). The heaters used radiant heat having no direct flame in contact with the old pavement.

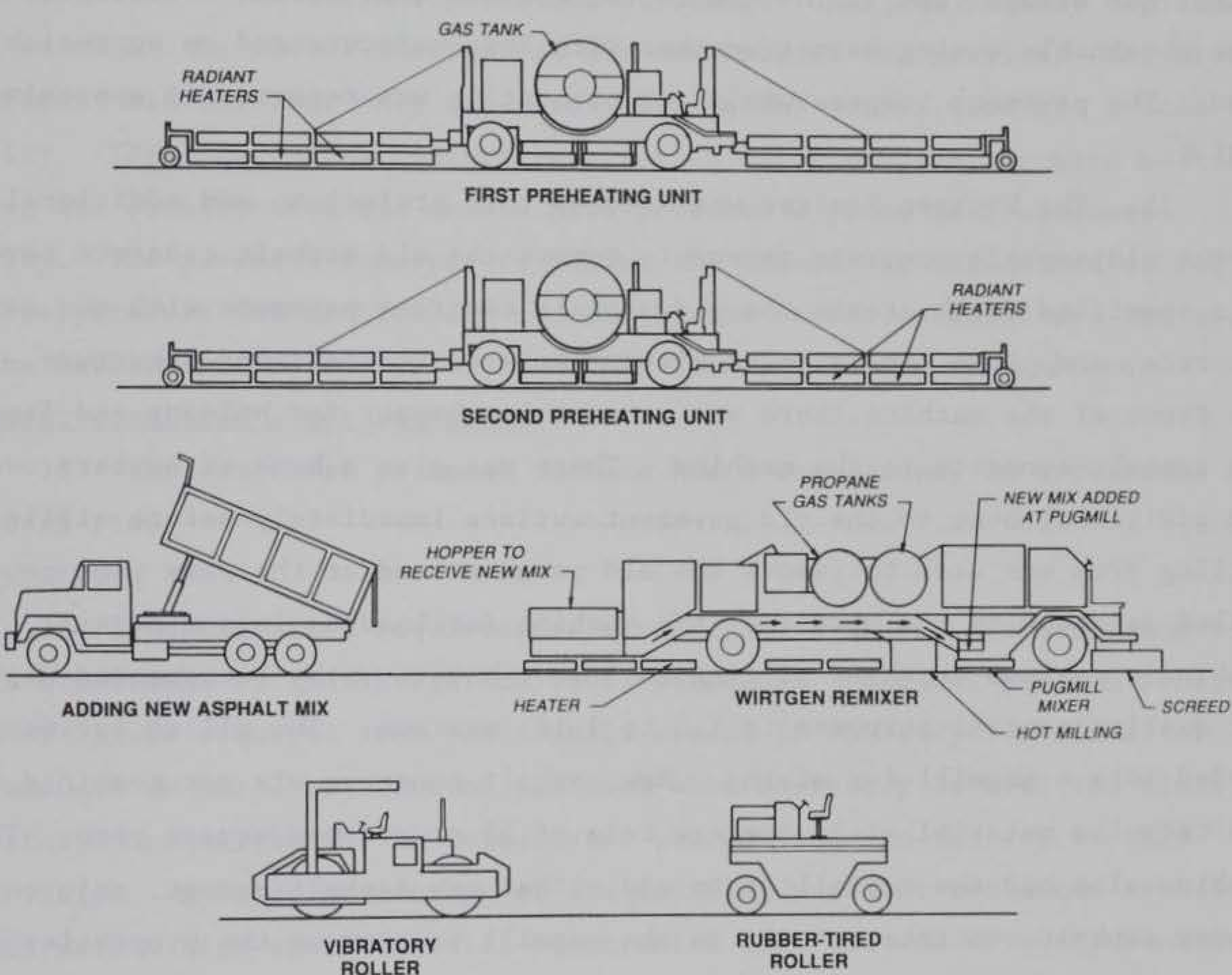

Figure 2. Writgen (remix) recycling process

The use of radiant heat reportedly reduces the damage to the old asphalt cement and reduces pollution caused by burning the asphalt cement. Two preheaters were used on this project because remixer personnel found that production rates were increased with no significant increase in construction cost. The atmospheric temperature during the visit ranged from 60° F to 70° F and there was a steady breeze. On the day of the observed recycling, the existing pavement surface was damp due to rain the previous night. These wet conditions in the morning slowed the forward speed of the paving train to 6 to 8 feet per minute (fpm). The contractor claimed that speeds of 12 to 15 fpm were obtainable during warmer weather with less moisture and no appreciable wind. The pavement temperature after preheating was reported at approximately 300° F.

32. The Wirtgen Remixer was used on this project to add additional heat to the old asphalt concrete pavement, remove the old asphalt concrete pavement to a specified depth, remix the old asphalt concrete pavement with new asphalt concrete, and place the recycled mixture back on the pavement structure. At the front of the machine there was a receiving hopper for holding and feeding new asphalt concrete to the machine. There was also a bank of heaters used to add additional heat to the old pavement surface immediately before milling. A milling drum was used to remove the old pavement and at the same time move the milled pavement to the middle of the machine for loading into a pugmill. The machine's maximum depth of milling is 3 in.; however, the recommended depth for quality control purposes is 1.5 to 2 in. maximum. The milled pavement was loaded into a pugmill for mixing. New asphalt concrete mix was combined with the recycled material at an average rate of 55 pounds per square yard. The machine also had the capability to add either new asphalt cement, rejuvenator, or new asphalt concrete hot mix to the pugmill to improve the properties of the old pavement or supply additional material to correct grades as desired. A heating unit located behind the milling drum is used to heat the milled surface to improve the bond between the milled surface and the newly placed recycled hot mix. The combined hot recycled mixture was placed with a screed at the rear of the remixer machine. The remixer was equipped with two screeds, one behind the other. This configuration of the two screeds gives the machine the capability of placing the recycled hot mix using the front screed and placing a new hot mix on top of the recycled mix using the rear

screed. When using this capability of the machine, the new hot mix is dumped in the loading hopper and is fed directly to the rear screed for placing, by-passing the pugmill.

33. A 10-ton steel-wheeled vibrator roller was used as the break down roller following the remixer (Photo 6). A small rubber-tired roller followed the break down rolling (Photo 7). Although density requirements were given to be 92 to 98 percent of laboratory density, no samples were observed being taken for laboratory compaction during the approximately 6.5 hr at the construction site. The field superintendent thought that the highway department took cores at the end of the day but did not know of the results. The highway department did say that only mat cores were taken; joints were not tested for density. The longitudinal joints constructed using the remixer were heated during the construction and should have produced a joint with adequate density. The pavement temperature behind the screed was maintained at 240° F. This temperature was continually checked by the screed operator and the speed of the machine was varied in order to maintain the 240° F temperature.

Pavement condition after recycling

34. The completed pavement surface had a consistency in appearance and a smooth ride.

Observations

35. Specification requirements were reported during conversations with Texas Department of Transportation (DOT) personnel. A final minimum penetration of 35 was required from the asphalt cement in the recycled mix after placement. An ARA-1 rejuvenator was used when necessary to meet the final penetration requirements. A rejuvenator was not used on the day of this observation. A large percentage of the existing pavement contained asphalt cement with a high enough initial penetration that the use of a rejuvenator was unnecessary. The top 1-1/2 in. of the existing pavement was hot milled and combined with enough new material (approximately 55 lb per square yard) to give a total lift thickness of 2 in. of recycled hot mix.

36. Pavement samples were obtained at different locations to give an indication of the penetration changes in the asphalt cement due to the heating process. A sample was obtained in front of the screed to represent the hot recycled mix. The samples obtained during the heating of the pavement were taken by using a shovel to dig into the heated pavement. The shovel did not readily penetrate the pavement, which resulted in a sample from the surface

and not the full depth of the pavement being recycled. However, penetration tests were conducted and the results are shown in Table 1.

Table 1

Penetration of Recovered Asphalt Cement

After First Heating	After Second Heating	Final Hot Recycled Mix
30	28	32

Very little change was noted in the penetration results. Additional testing with representative sampling techniques would be needed to make any conclusions. Variation in the results obtained from the recycled mix at this site should be larger than that expected from a new mix because the amount of new mix added varied due to the requirement to maintain grade.

Trinity, Texas

Pavement condition prior to recycling

37. The HIPR occurred on State Highway No. 20, just north of Trinity, Texas. The project included approximately 8 miles of the 24-ft wide, two-lane road.

38. The pavement being recycled had a seal coat overlaying an asphalt concrete mix, constructed with an iron ore aggregate. The pavement exhibited minor rutting and some minor cracking due to aging. There were isolated instances of alligator cracking which indicated base failures in those areas. Prior to recycling, the seal coat was milled off, exposing the surface of the underlying dense mix (Photo 8). The virgin material added during the recycling was intended to replace the volume of material removed by the cold milling of the seal coat.

Recycling procedure

39. The recycling procedure used in the construction was called the Cutler Remixing procedure (Figure 3).* This procedure involves the use of four separate pieces of equipment to heat, hot-mill, scarify, mix the recycled

* Cutler has another procedure not used on this construction project that they call Repaving, where new mix is not combined with the recycled material but is placed over the recycled material in a separate operation.

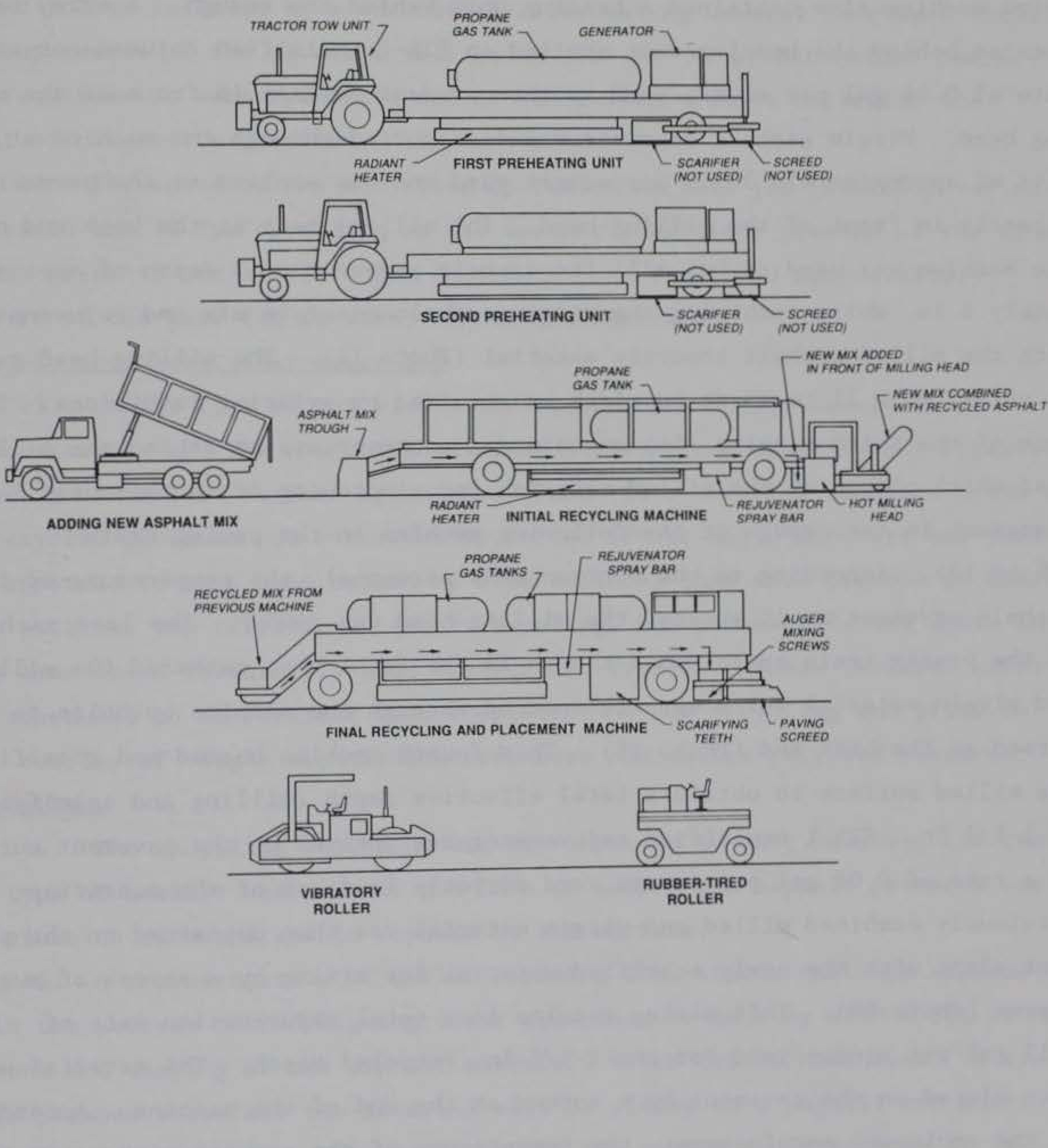

Figure 3. Cutler (remix) recycling process

asphalt concrete with new asphalt concrete material, and place the combined material. The recycling train includes two separate tractor-towed preheating units which are used to heat the asphalt surface. A pavement temperature of approximately 280° F was desired after heating by the second heating unit (Photo 9). These preheating units had the capability of scarifying and spraying rejuvenator, neither of which was used on this job. The third machine had a trough on the front of it to receive new asphalt concrete (Photo 10). The third machine also contained a heating unit behind the trough. A spray bar located behind the heating unit applied an ETR-1 emulsified rejuvenator at the rate of 0.06 gal per square yard to the pavement surface in front of the milling head. Virgin asphalt concrete was transported through the machine at the rate of approximately 30 lb per square yard and was applied to the pavement directly in front of the milling head. The milling heat at the back end of the machine was used to hot mill the asphalt pavement to a depth of approximately 1 in. while combining the virgin asphalt concrete mix and rejuvenator with the milled asphalt concrete material (Photo 11). The milling head could be varied from 11 to 13 ft in width as required by existing conditions. The back of the third machine also contained a conveyer system behind the milling head which picked up the milled material for windrowing or in this case for placement in the trough of the following machine in the paving train (Photo 12). According to the contractor's personnel, the temperature of the asphalt pavement as it entered the milling head was 240° F. The last machine in the paving train contained a trough in the front that gathered the milled and virgin material which was transported through the machine by belts to the screed at the back end (Photo 13). This fourth machine heated and scarified the milled surface to obtain a total effective depth (milling and scarifying) of 1-1/2 in. ETR-1 emulsified rejuvenator was sprayed on the pavement surface at a rate of 0.06 gal per square yard directly in front of the scarifier. The previously combined milled and virgin material was then deposited on the pavement along with the newly scarified material for mixing by a series of auger screws (Photo 14). This mixing results in a total rejuvenation rate of 0.12 gal per square yard for the 1-1/2-in. recycled depth. The material was then placed on the pavement by a screed at the end of the machine. According to the equipment manufacturer, the temperature of the asphalt mixture at the screed varied between 200° and 218° F, which met the minimum requirement of 200° F but was below the 245° to 250° F the contractor would have desired.

40. The heaters used on all four machines used burners to heat refractory tiles to incandescence, and these radiated the heat to the pavement surface. These radiant heaters use propane gas as fuel. This type of heat is preferred over direct flame, because it prevents the flames from directly reaching and burning the asphalt pavement. Burning and overheating of the pavement can still occur unless proper procedures are followed.

41. The recycled material was then compacted by a vibratory steel-wheeled roller followed by a pneumatic roller making several coverages until the temperature of the pavement fell below 170° F. No predetermined compaction requirements were specified and no tests were used to determine the amount of compaction obtained.

42. The speed of the recycling operation on this job generally varied between 10 and 12 fpm depending on the weather conditions present at the time. The day prior to our arrival, the contractor had completed approximately 6,000 ft of one lane (12 ft wide) of the road surface.

Pavement conditions after recycling

43. At the time of our visit, the project was approximately three-quarters complete. The completed pavement surface rode smoothly but appeared to have a nonuniform surface appearance (Photo 15). Several isolated areas of the recycled pavement had structurally failed (Photo 16). However, the failures appeared to have been caused by base failures that were present in these areas prior to the recycling. After recycling, the pavement failed again in these same areas immediately upon exposure to traffic. These isolated areas were scheduled to be repaired upon completion of the recycling and prior to 1-in. overlay of virgin asphalt concrete over the entire recycled pavement.

Observations

44. The recycling equipment was not observed in use; however, the indirect type of heaters used should not burn or scorch the asphalt pavement surface since no direct flame is exposed to the surface.

45. A representative of Cutler Repaving Inc. stated that his company was in the process of redesigning their equipment to do away with a lot of the movement and dumping of the asphalt material, which causes heat loss. A system is planned where all the material will be placed in a pugmill and mixed along with a rejuvenator. The remainder of the system would stay as it is. He stated that the redesign may end up being very similar to the Wirtgen method of mixing.

Richmond, Virginia

Pavement condition prior to recycling

46. This project involved HIPR on several residential streets in Richmond, Virginia. The pavements recycled varied in width and included both two-lane and four-lane streets.

47. The roads being repaired were considered structurally sound with only small isolated areas with base failures (Photo 17). The road contained thermal or age cracks and some rutting in the wheel paths. The contractor claimed that his equipment could relevel pavements with ruts up to 2 in. deep.

Construction procedure

48. The process used was the basic heater-scarifying process with the addition of a rejuvenator to improve the properties of the asphalt cement in the mix (Figure 4). The process uses two vehicles, both of which are pulled by a truck-tractor. Both vehicles use steel wheels behind the heating units to avoid damage to the tires from the heated pavement. These are replaced with pneumatic tires for long range transportation. The vehicles also have movable metal deflection shields behind each heater to direct hot air away from vegetation as needed (Photo 18). Both vehicles are remote controlled from a station located on the side of each vehicle. An operator who walks alongside controls vehicle speed, direction, and the operation of the heaters located on each vehicle (Photo 19). The heating units are a refractory type that use propane fuel (Photo 20). The first vehicle only preheats the pavement; whereas, the second vehicle heats and scarifies, levels, screeds, and rejuvenates the pavement. The scarifying teeth are spring-loaded and "give" when a solid obstacle is encountered (Photo 21). The springs also help prevent any fracturing of the aggregate during scarification. The scarifying teeth are set to penetrate a minimum of 1-1/4 in. to obtain an effective overall depth of 1 in. Reversible augers are located ahead of the screed to redistribute the scarified hot material as required (Photo 22). Depth and crown are controlled by an operator at the rear of the machine; there is no automatic control capability. After screeding, an enclosed spraybar applies 0.1 gal of Reclamite per square yard to the surface of the recycled pavement (Photo 23). The rejuvenator is not mixed with the recycled mixture; it is only sprayed on the surface.

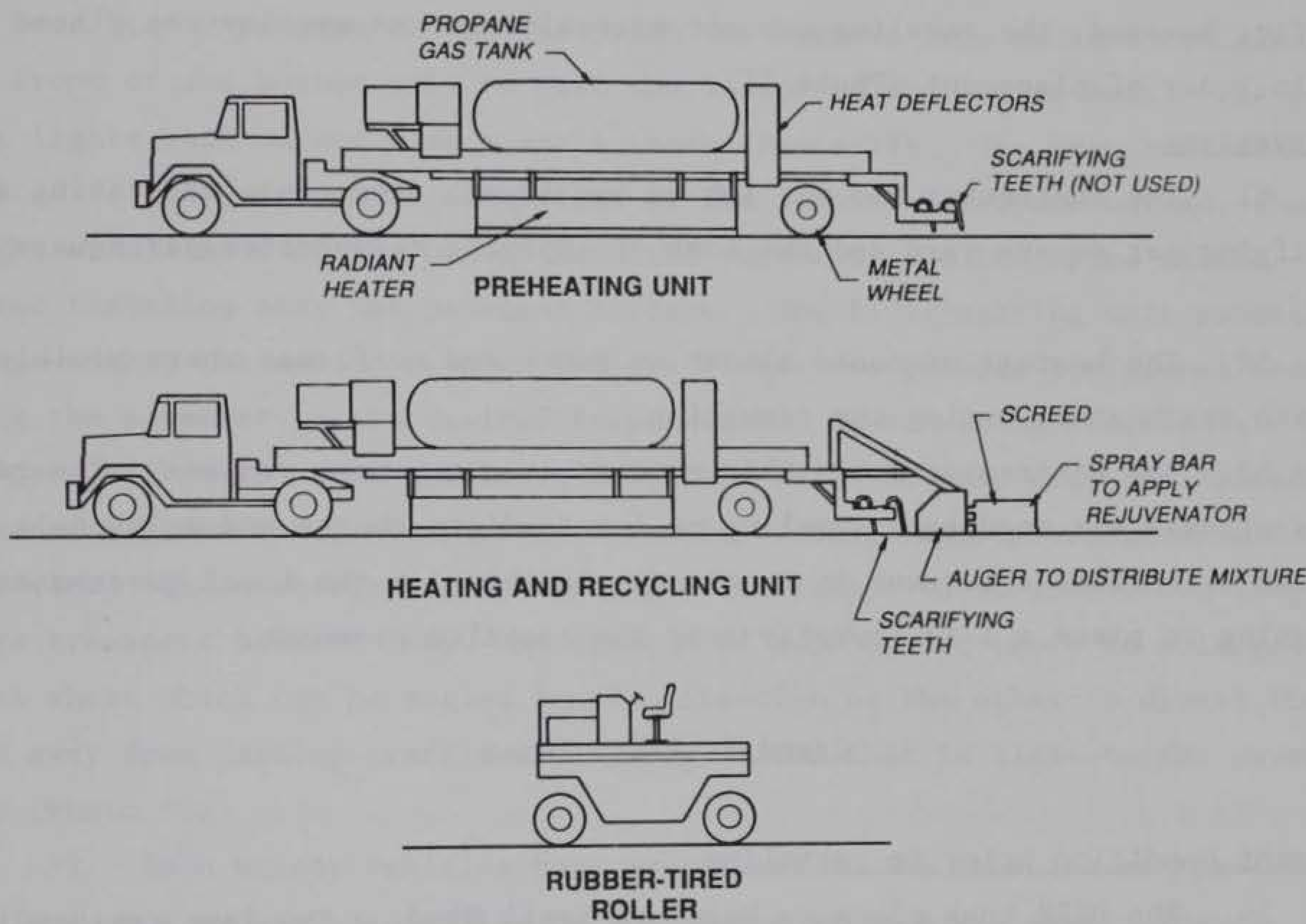

Figure 4. Natural asphalt heat treating recycling process

49. The compaction of the recycled pavement was accomplished with one or two coverages of a rubber-tired roller (Photo 24). There was no field testing of the recycled mixture. There were also no compaction requirements for the mixture. The only requirement was to make several passes with the rubber-tired roller. The road surface was opened to traffic immediately upon completion of the rolling. The contractor attempted to keep a forward speed of 17 fpm for the recycling operation to obtain the best results.

Pavement condition after recycling

50. The recycled pavement showed some tendency to ravel when exposed to traffic; however, the raveling was not excessive and an overlay was planed within 1 day of placement (Photo 25).

Observations

51. The contractor bid the job on two items: the cost for heating and scarifying per square yard and the cost of applying rejuvenator per square yard.

52. The heaters produced almost no smoke and no flames where visible beneath the heaters during the recycling.

53. The contractor sells this process as a two-pass process. The recycling process was used as a leveling or intermediate course and an asphalt overlay or surface treatment is required. On this job the local government was going to place a 1-in. overlay over the recycled pavement.

Grand Prairie, Texas

Pavement condition prior to recycling

54. The HIPR took place on Warriors Trail Road, a two-lane residential street, in Grand Prairie, Texas.

55. There were concrete curb and gutters along the entire length of the road with a few side roads that were paved with Portland Cement Concrete. Prior to the recycling operation, the existing asphalt pavement was cold milled to a depth of approximately 1 in. at each gutter and feathered out to nothing over a width of about 6 ft. (Photo 26). The road appeared to be structurally sound with a minimum of rutting or other surface distresses. A few isolated asphalt patches were observed in the surface. The road did contain many narrow fatigue or temperature cracks over the entire surface (Photo 27).

Construction procedure

56. A heater-scarifying process was used on the pavement with the addition of a rejuvenator to improve the properties of the asphalt cement in the mix (Figure 5). This was followed by an immediate overlay of the recycled mix with a hot virgin asphalt mix.

57. The recycling process consists of a preheater (Photo 28) and an additional heater following on a similar vehicle. Each vehicle is pulled by a truck-tractor and run by remote control with the operator walking alongside the vehicle and controlling both the truck-tractor and the heater. The heaters used liquid propane as the fuel with the burners located in a row along the front of the burner unit to heat the inside of the heater unit. The operator lights each burner with a small torch (Photo 29). The amount of heat applied to the pavement is controlled by the amount of propane burned, the height or distance of the heater from the pavement, and the speed of the heater traveling over the pavement surface. The first heating unit preheats the pavement; the second machine follows closely to provide additional heat to bring the pavement to the desired temperature. Each heating vehicle is equipped with metal rear wheels to allow the units to pass over the heated pavement. These metal wheels are steerable to facilitate movement around obstacles. These wheels can be exchanged for rubber-tired wheels for long range transport between jobs. At the end of each heater there is a large metal sheet which can be angled in one direction or the other to direct the heat away from passing traffic or any vegetation that is close to the pavement edge (Photo 30).

58. Both heater vehicles have scarifiers on the back end of the machines, but only the scarifier on the second machine was used. The scarifiers are composed of double rows of scarifying teeth that are offset from each other to allow scarifying of the entire surface. The scarifiers are spring loaded to prevent breakage of either the teeth or the aggregate in the pavement as it is scarified (Photo 30). The depth of scarifying varied from 3/4-1 in. with the final depth of recycling required to be a minimum of 3/4 in.

59. The third and final piece of equipment in the recycling train was a machine that sprayed a rejuvenator on the recycled material and then mixed, smoothed, and screed the mixture (Photo 31). This equipment was similar in appearance to an asphalt paver with a large metal storage tank for the

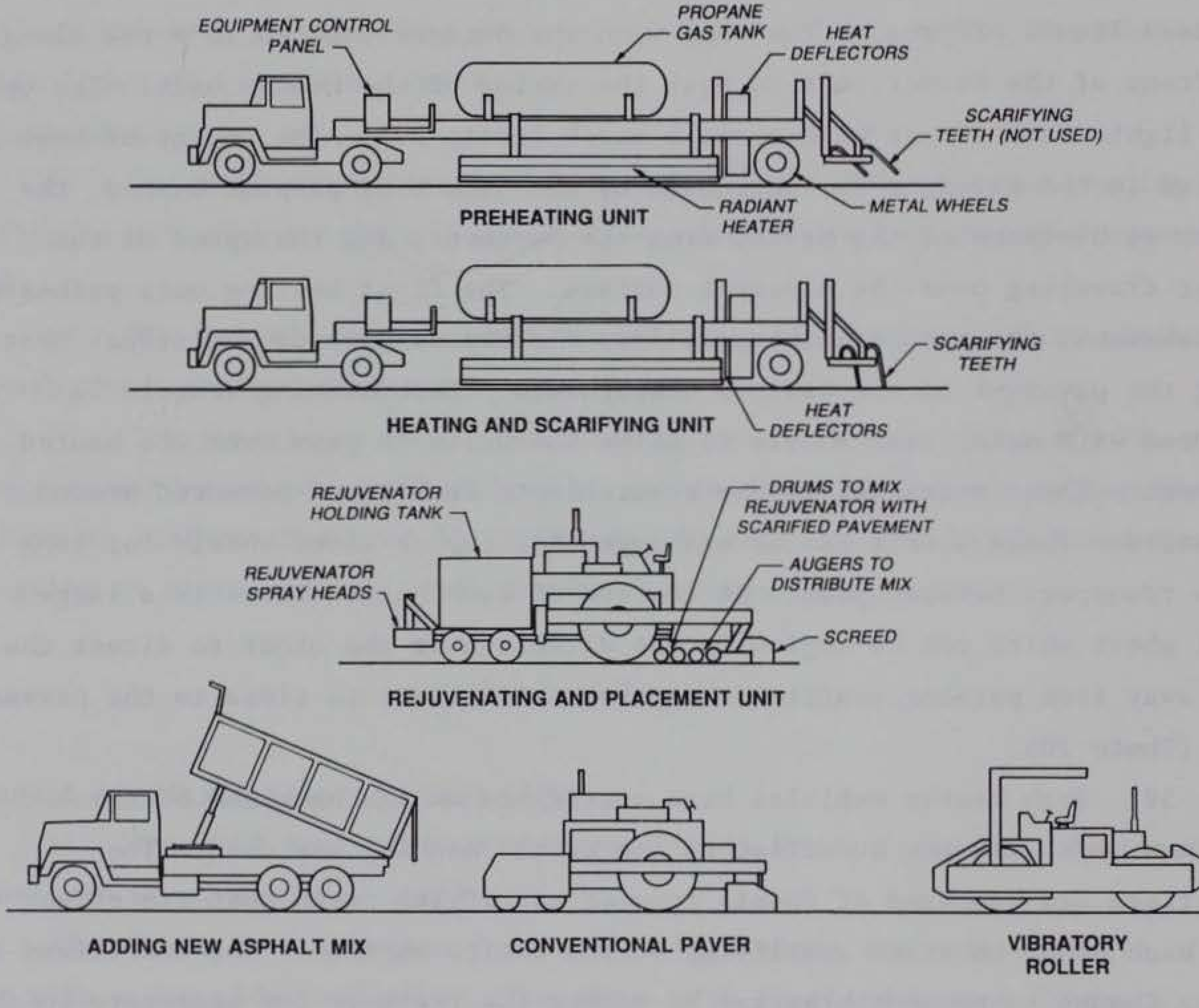

Figure 5. Dustrol recycling process

rejuvenator where the hopper would be on a standard asphalt paver. The rejuvenator is applied at the front of this machine by revolving spray heads. The application rate is tied to the forward movement of the machine (Photo 32). The machine has rubber-tired wheels for increased maneuverability. The paver had a vibrating floating screed to level and initially compact the pavement surface as the recycled mixture is placed. The depth and crown of the screed surface are controlled by the operator. No automatic control is available. A row of augers is located directly in front of the screed to redistribute and smooth the recycled mixture as required (Photo 33). In front of this auger is a set of metal drums with rows of teeth similar to those found on a cold milling machine. The milling heads revolve opposite from the direction of travel and are intended to throw the recycled mixture up onto itself to mix in the rejuvenator. These two separate drums, one in front of the other along with the extendable ends on the screed, allow the vehicle to handle paving widths up to 16 ft (Photo 34). The width of the pavement lane being recycled at the time it was viewed was approximately 13 ft.

60. The rejuvenator used was Reclamite. It was applied at 0.1 gal per square yard. The amount of rejuvenator applied was varied depending on the appearance of the pavement surface. Areas that appeared dry or old would receive rejuvenator, but if the pavement surface appeared new or rich in asphalt cement, little or no rejuvenator was added.

61. The placement of a 1-in. thick overlay of asphalt mix followed directly behind the recycling train (Photo 35). The new mix was placed on the uncompacted hot recycled mix and then compacted. There was no separate compaction of the recycled mix. There was no testing of the recycled mix prior to overlay.

Pavement condition after recycling

62. Assessment of the pavement condition after recycling was difficult because of the immediate overlay with new hot mix. Photo 36 shows the condition of the recycled pavement prior to the placement of the overlay. The scarifying process did not appear to break or damage the aggregate in the recycled pavement.

Observations

63. The speed with which the recycling train moved on this project was approximately 38 fpm. This was slower than the contractor's claimed optimum speed of approximately 45 fpm for these particular pavement conditions. The

recycling operation was slowed by the specification requirement that they not get further ahead of the following paving machine than required for the haul trucks operation.

64. On several occasions, a large amount of flame appeared beneath the heater units directly on the asphalt pavement. This sometimes caused smoke and gave a scorched appearance to the pavement. This effect could have been caused by the need for the contractor to slow his forward progress and wait for the paving machine. Also, there were periodic gusts of wind which would require more heat.

65. The HIPR mixture was not tested to meet any preset material requirements. A 1-in. overlay was placed integrally with the recycled mixture. The recycling contractor advised immediate overlay or some type of surface treatment within a short period of time after recycling.

PART V: RESULTS OF FIELD INVESTIGATIONS

General

66. The following paragraphs present the results obtained from observations made on four HIPR projects. The construction sites visited all used different procedures for recycling and used different manufacturer's equipment. The recycling operations at Marshall, Texas, and Trinity, Texas, were single-pass methods of HIPR; whereas, the recycling at Richmond, Virginia, and Grand Prairie, Texas, were multiple-pass methods of HIPR.

Recycling Selection Criteria

67. The original selection of a particular type of recycling method did not appear to be based on any experience or research into the benefits or advantages of one type of recycling process over another. The decision of the local authorities to use a particular HIPR procedure was based, in many instances, on contractors convincing local personnel to try their method of recycling. Success with a particular method has led some local and state agencies to specify the same methods over and over again instead of evaluating all possible procedures and selecting the best for their particular needs.

68. The recycling procedure selected can be greatly influenced by the local asphalt mix producers. The use of HIPR by specialty contractors could be viewed by local asphalt concrete producers and contractors as a loss of overlay work for them. Accordingly, they can quote prices to the specialty contractors in such a way as to discourage the use of single-pass recycling methods. Heater-scarifying and remix procedures that require separate new asphalt overlays of the recycled pavement can avoid these possible marketplace problems.

Recycling Procedures

69. The four different procedures for HIPR observed are not the only types available. There are several other methods and recycling equipment which were not observed in this study. Manufacturers and contractors are constantly adjusting and rearranging their equipment and techniques in order

to increase production or improve the product. The majorities of manufacturers and contractors contacted in this study have either recently made or plan to make changes in their equipment or procedures. The equipment or procedures currently available may not be available 10 years from now as manufacturers and contractors attempt to make improvements to their recycling process.

70. One thing common to all HIPR methods is the use of a rejuvenator to help restore desired material properties to the asphalt mixture. The methods encountered in adding the rejuvenator to the mixture ranged from spraying it on the surface to mixing it with the recycled material in a pug mill.

Material Property Controls

71. The amount of control of the properties of the recycled asphalt mixture varies with the method of recycling. HIPR methods with remix capabilities provide the best opportunity to adjust the recycled mix properties as required. None of the recycling methods observed were capable of providing the degree of control normally associated with central plant hot mix asphalt paving for either virgin or recycled mixes.

72. The amount of testing performed on the HIPR material varied with the organization contracting the work. Most of the construction projects had conducted some initial testing of the existing pavement for the penetration and viscosity of the asphalt cement prior to the start of work. Several projects used experience gained from previous work on similar types of pavement instead of additional testing. One remix project had an ongoing testing program of the pavement's density; however, the results were not being relayed to the field personnel to let them know if they were obtaining the required density. None of the projects observed involved monitoring the properties of the recycled mixture to assure that it met any predetermined material criteria. The amount of rejuvenator added was usually based on some preconstruction testing or, in some instances, previous experience with this type and age of asphalt pavement. No testing took place during construction to confirm these original findings.

Cost Data

73. Table 2 lists the bid prices for each of the hot in-place recycling projects visited. Direct comparisons are difficult as a project involves different equipment and in most cases different procedures. The location of the project will have an effect on the cost. Costs are effected by the availability of local contractors experienced with hot in-place recycling and the local availability of quality materials. Costs can be higher for any additional materials required in areas where a local asphalt mix supplier is not actively involved with the job. The local asphalt mix suppliers may consider this process as direct competition for them and as reducing the amount of work available in the future.

Table 2

Hot In-Place Recycling Costs per 1-in. Depth*

Location and Type	Pavement Thickness Recycled in.	Pavement Thickness Added Approximate in.	Recycled Material $/sq yd	Rejuvenator $/sq yd	New Mix $/sq yd
Marshall, Texas Remix method	1-1/2	1/2	1.25	0.13**	35.00
Trinity, Texas Remix method	1-1/2	1/4	1.22	0.28	30.00
Richmond, Virginia Heater-Scarify	1	N/A	0.75	0.25	N/A
Grand Prairie, Texas Heater-Scarify	3/4	N/A	0.70	0.11	N/A

* Cost comparisons are not possible due to variations in procedures used and size of the job.

** Rejuvenator was only applied in selected areas as required by existing pavement conditions.

PART VI: CONCLUSIONS

General

74. Hot in-place recycling can be an effective method of pavement repair when utilized on pavements that contain surface distress without structural distress.

75. Recent improvements in the radiant heaters, used by several manufacturers, which reduce pavement damage by preventing overheating and burning, have greatly reduced smoke and odor emissions but have not eliminated them. Emissions can be especially high on surfaces which have a significant amount of joint or crack sealer material near the pavement surface.

76. None of the recycling methods currently in use are designed to provide for corrections in grade. They can smooth out some surface irregularities such as minor rutting or corrugations.

Multiple-pass recycling

77. The heater-scarifying procedure can provide an acceptable intermediate or leveling course but is not acceptable as a surface course. The contractors involved in the two heater-scarifier projects visited recognize this and recommend an overlay of all heater-scarified pavements.

78. The heater-scarifying procedure can be effective in residential areas. Manholes and other utilities are easier to deal with using this procedure than with the single-pass methods which usually employ milling heads which have to be raised over obstructions. Scarifying teeth are usually spring loaded and pass more easily over obstacles.

Single-pass recycling

79. RIPR can be the most cost effective where the recycling alleviates the need to rework curb and gutter, manholes and other utilities, and drainage systems. The remix recycling is the type of procedure usually employed in these conditions.

80. Caution should be employed when using the remixing processes to obtain a wearing surface. The quality and durability of this surface versus a virgin mix is not well documented. Information from various manufacturers and construction jobs visited indicates that there is a built-in variation in the mix being placed since additional amounts of new mix added are only averages, with the exact amount varying with surface smoothness and other surface variations.

81. The repave procedure should provide a surface course equal to that produced by conventional overlays. The process will probably be cost effective only in limited circumstances such as locations where it is used in conjunction with other procedures. Placement of an overlay by a conventional paver should be more economical than passing a virgin mixture through a recycling train for placement over the recycled asphalt concrete. The advantage advanced by equipment manufacturers, that of providing a greater bond between the surface course and the underlying pavement, is not considered necessary for most construction.

82. The quality control procedures for the remixing process should be improved before it is considered for use as a high quality pavement. This can be accomplished only by making improvements in the recycling equipment, where the amount of new material combined with the recyclable asphalt pavement remains constant. The proportions of the mixture must be consistent and meet specified requirements with testing on a prearranged schedule to verify this.

PART VII: RECOMMENDATIONS

83. The remix system of recycling should have more control of the mixture properties than is currently being performed. In order to use this procedure as a surface course on pavements with no additional overlay, improved methods for controlling the final asphalt mixture properties must be developed.

84. The technology of HIPR is currently more applicable to road and street applications than to airfield applications. This recycling process is not able to satisfy the stringent mixture property requirements normally associated with airfield pavements.

85. The HIPR processes are constantly changing and could prove to be an economical method of rehabilitation of pavements. At present, no procedure is available to provide a recycled mixture suitable for use as a surface course. With advancing technology, the quality required may be obtained and, therefore, HIPR should be monitored.

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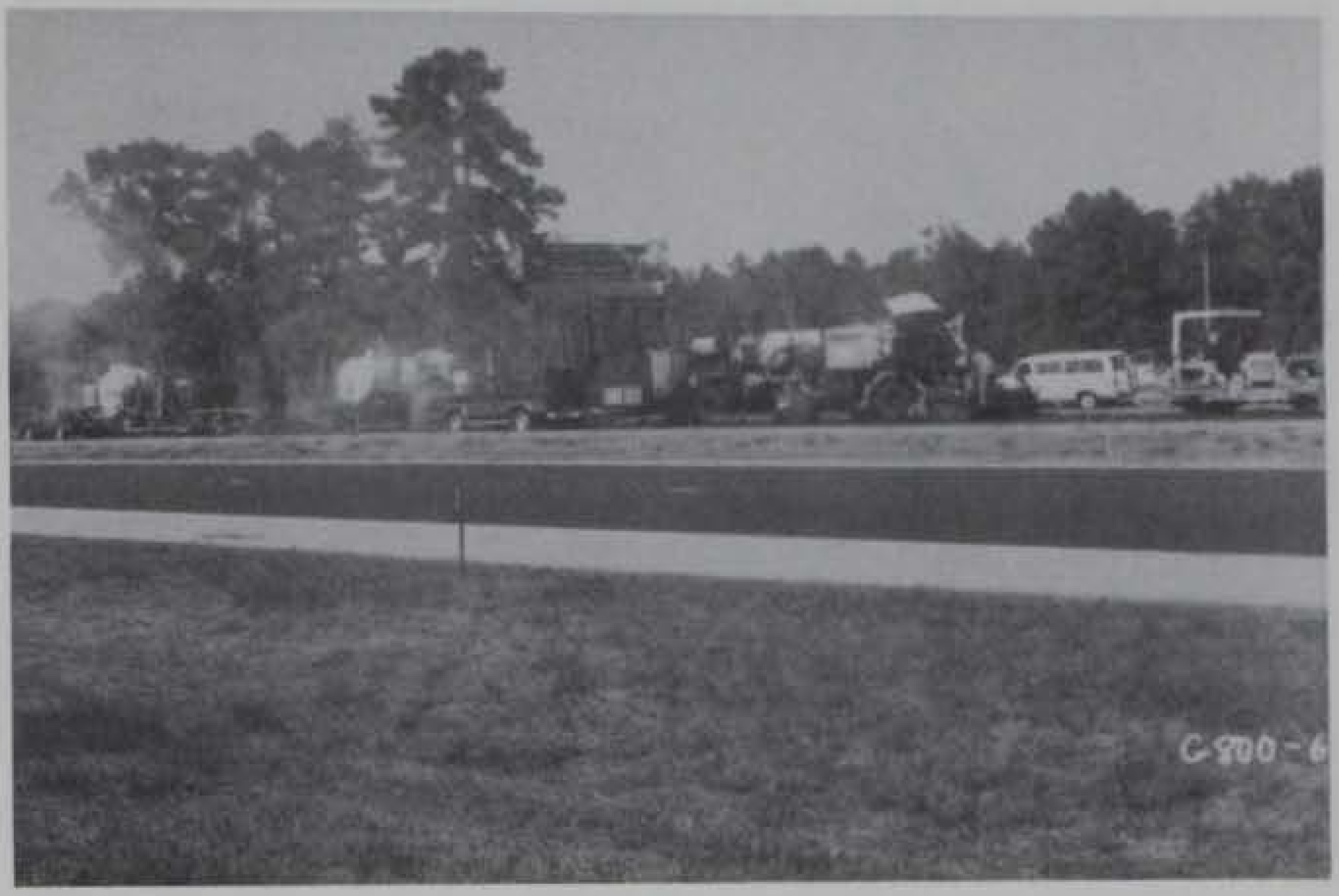

Photo 1. Wirtgen Recycling Process

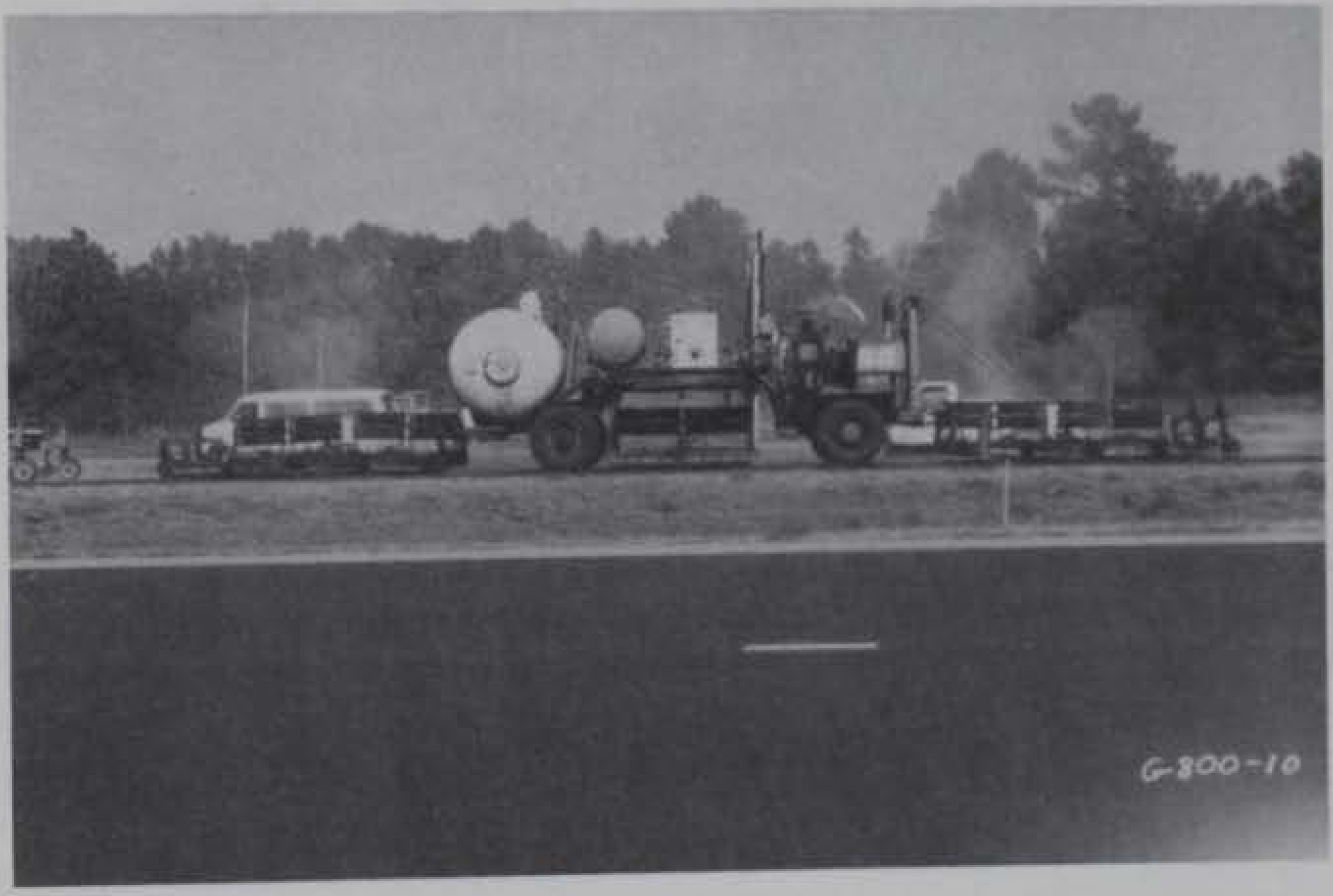

Photo 2. Liquid Propane Gas Fired Radiant Preheater Unit

Photo 3. Wirtgen Remixer

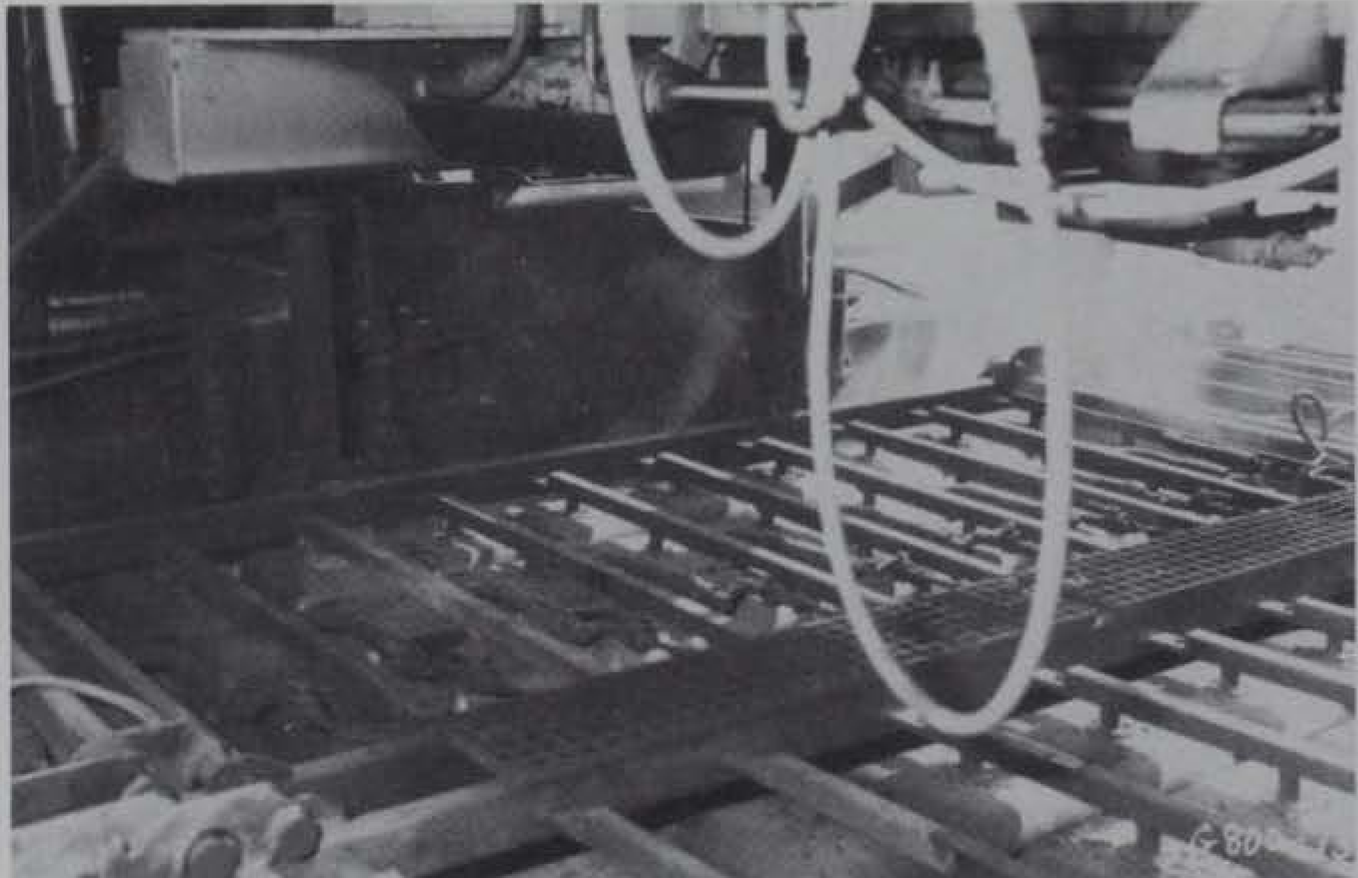

Photo 4. Pug mill for mixing asphalt mixture, located behind heating sections

Photo 5. Heated pavement behind second preheater

Photo 6. Vibratory roller compacting recycled pavement

Photo 7. Rubber-tired (pneumatic) roller compacting recycled pavement

Photo 8. Initial pavement surface on the right with seal coat removed and recycled pavement surface on the left side

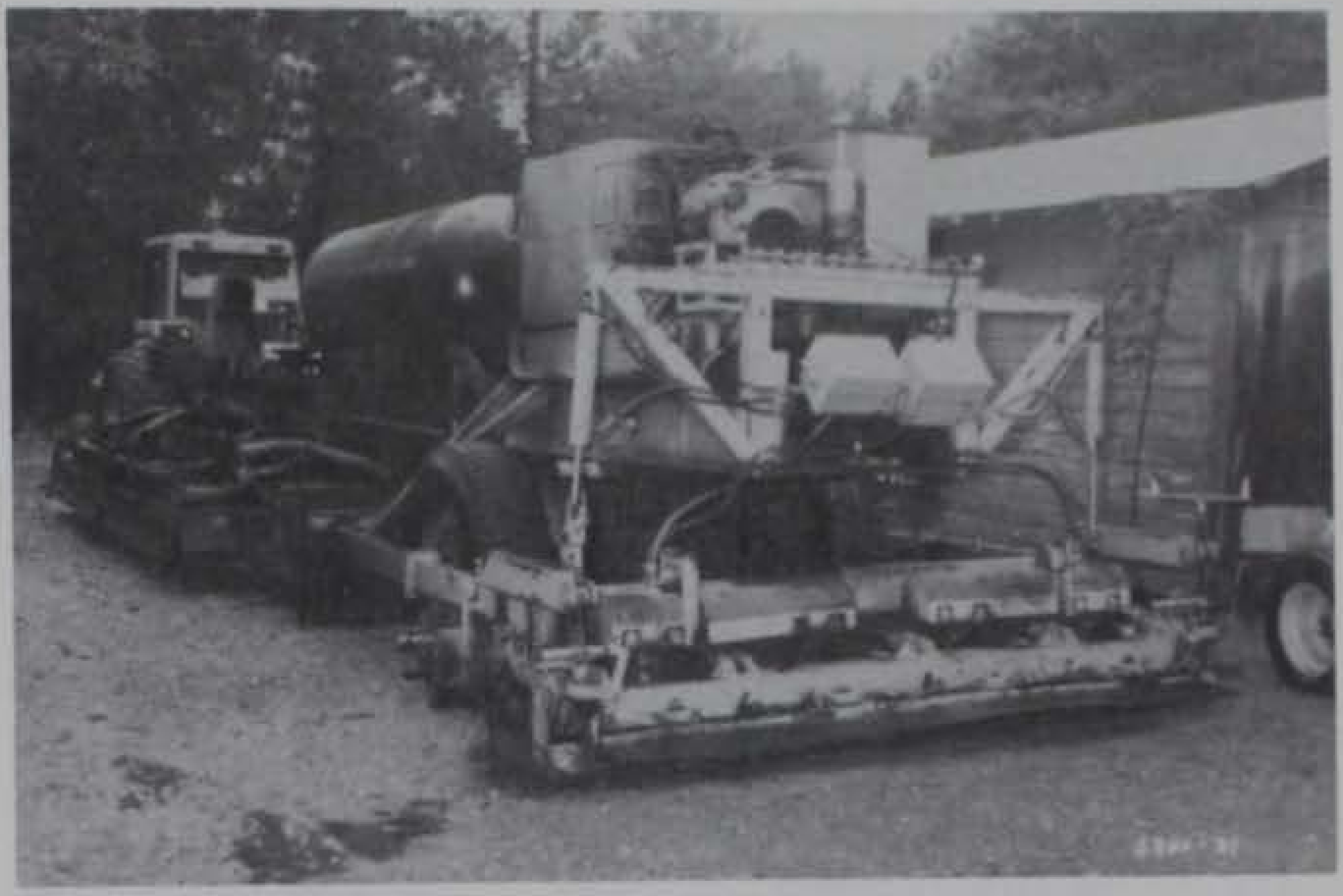

Photo 9. Tractor-towed preheating unit

Photo 10. Third machine in recycling train with front trough for new mix, heating section, and milling head at the rear

Photo 11. Milling head

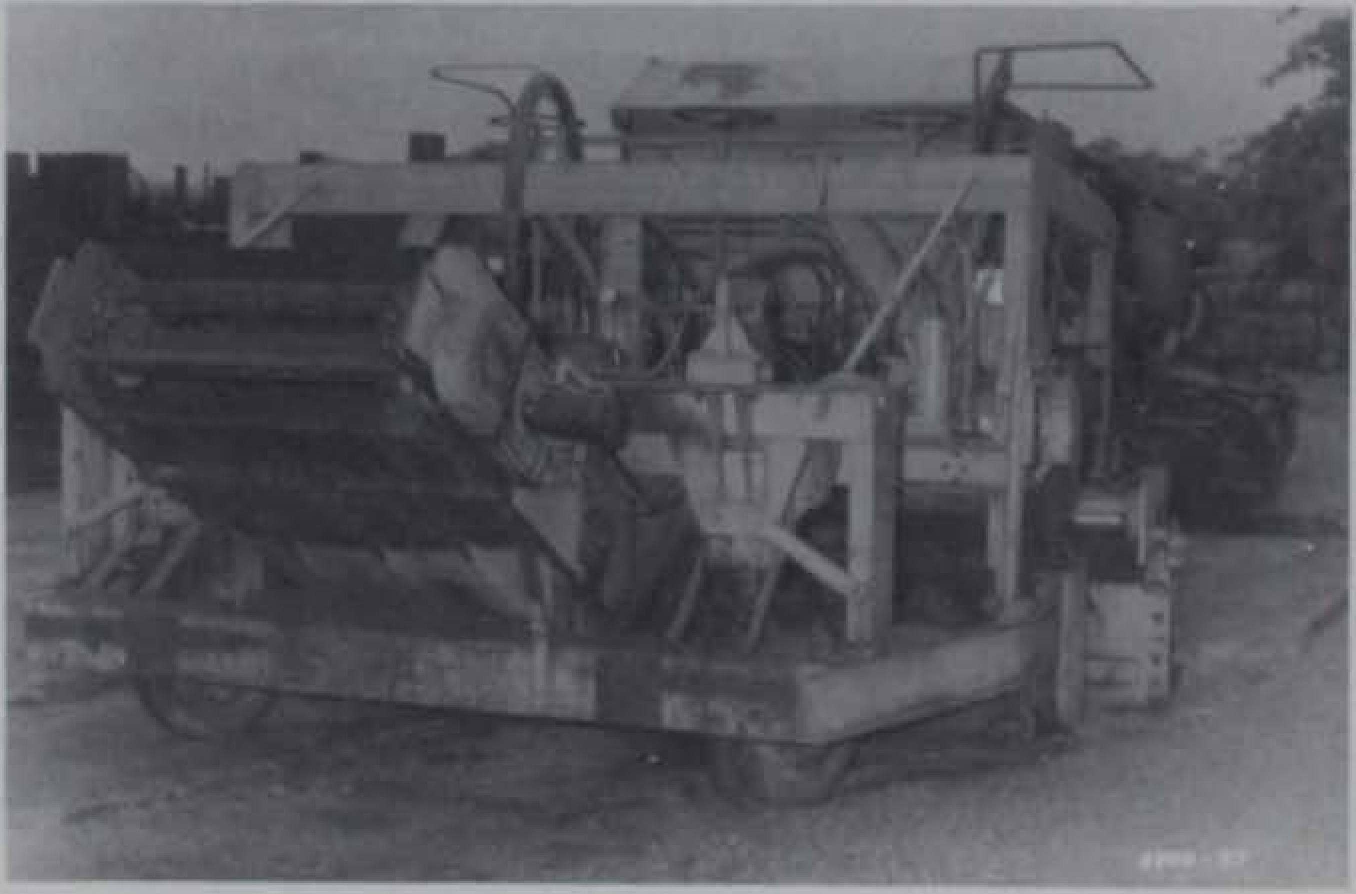

Photo 12. Conveyer behind milling head on third machine

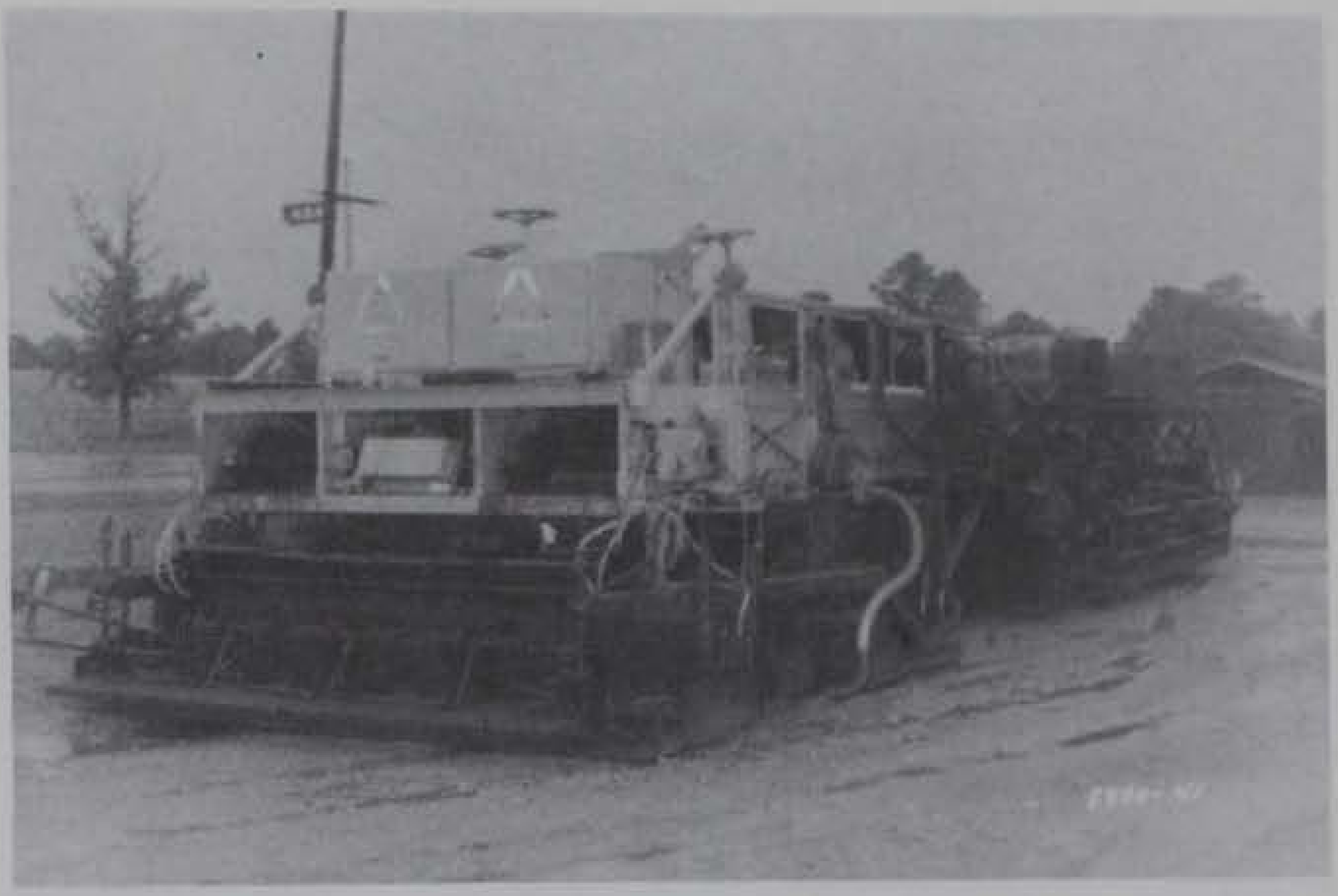

Photo 13. Last machine in recycling train with conveyor system through the machine to carry asphalt mixture to paving screen

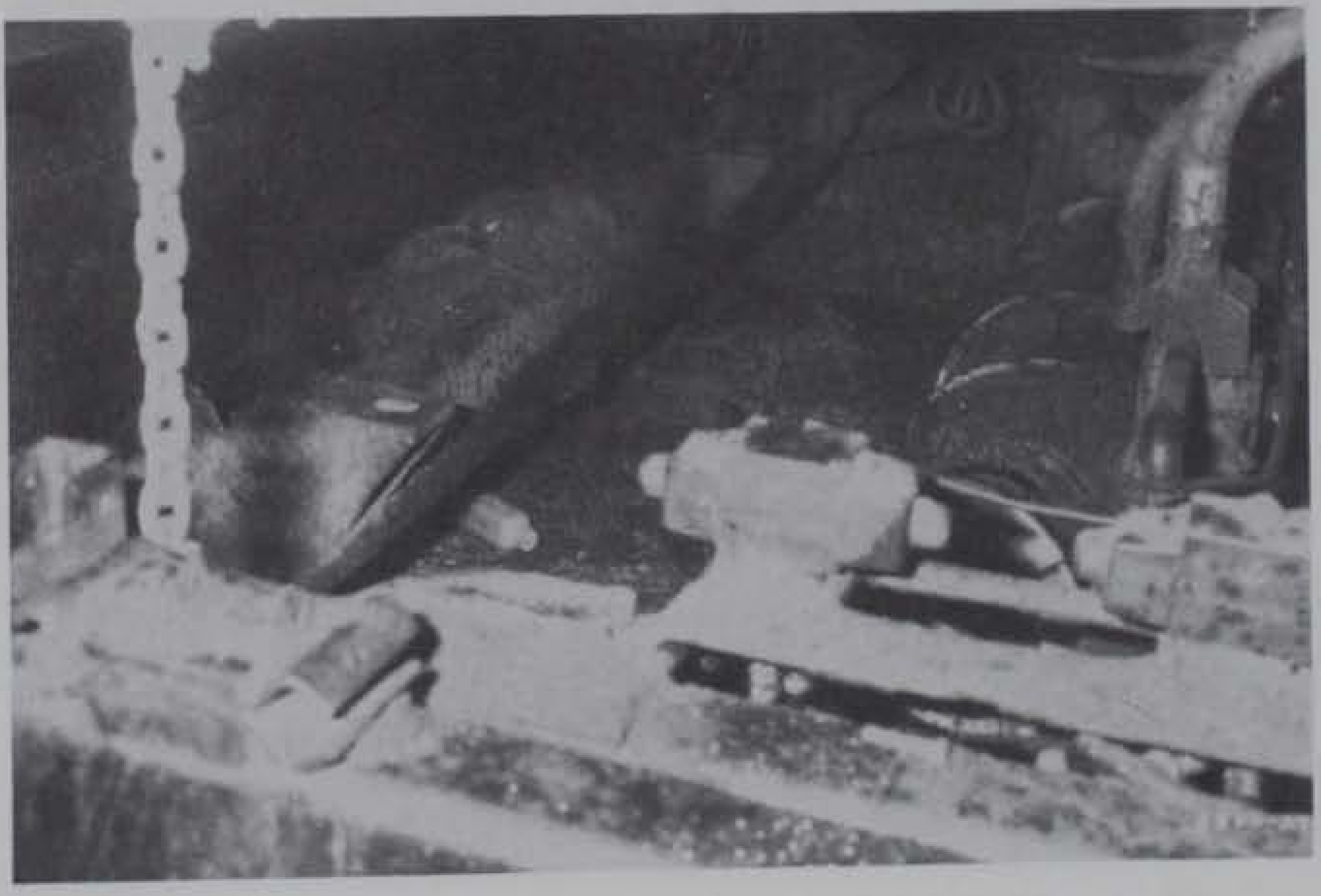

Photo 14. Augers for mixing and spreading recycled mix

Photo 15. Completed recycled pavement surface

Photo 16. Isolated base course failures reflected through the recycled surface upon exposure to traffic

Photo 17. Road to be recycled, isolated base failures along pavement edge

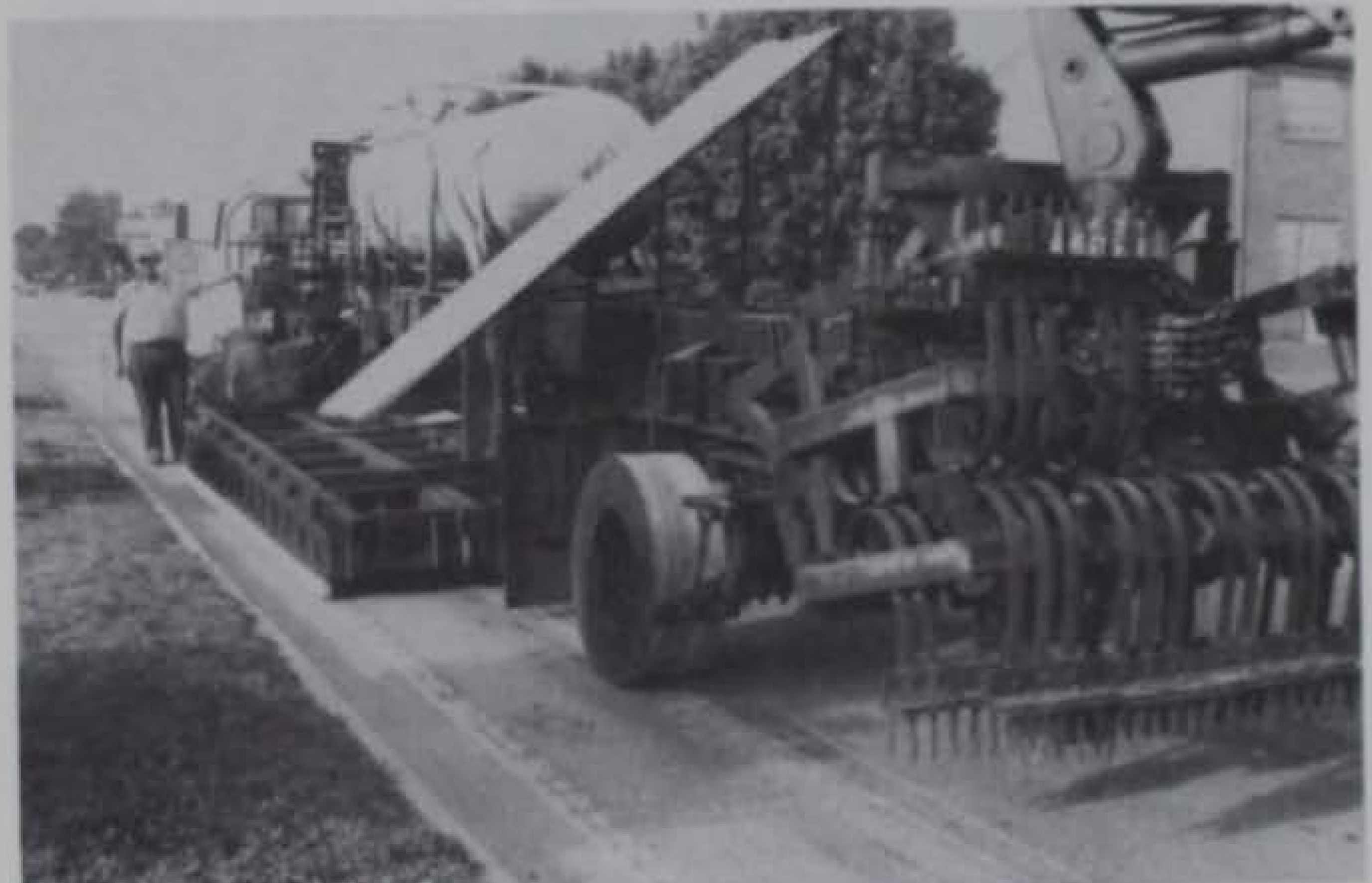

Photo 18. Preheater with deflection shield behind heater to deflect heat as required

Photo 19. Remotely controlled heater/
scarifying vehicles

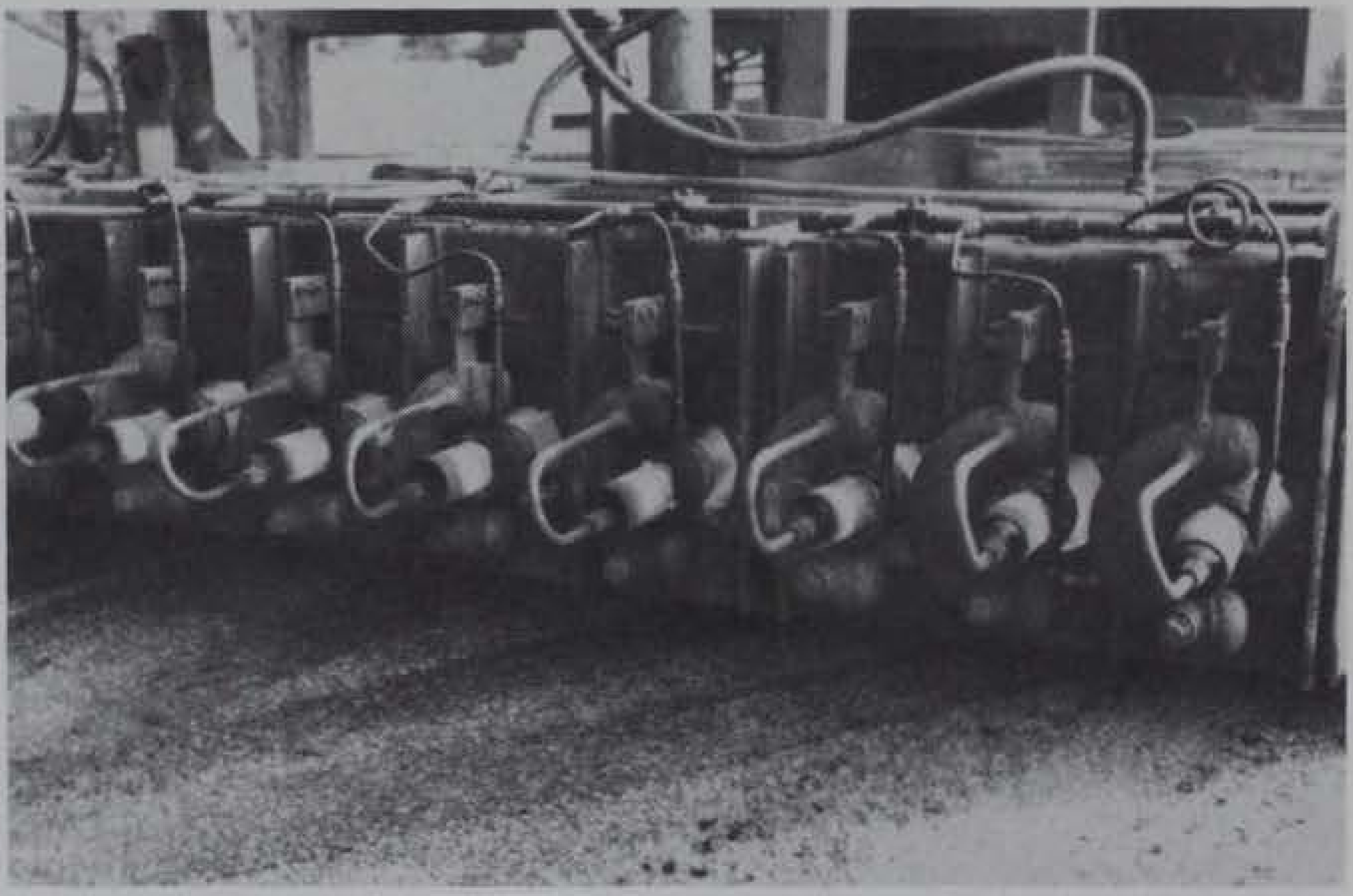

Photo 20. Burners at the head of the heater unit

Photo 21. Spring-mounted scarifying teeth

Photo 22. Reversible augers to redistribute mixture in front of screed

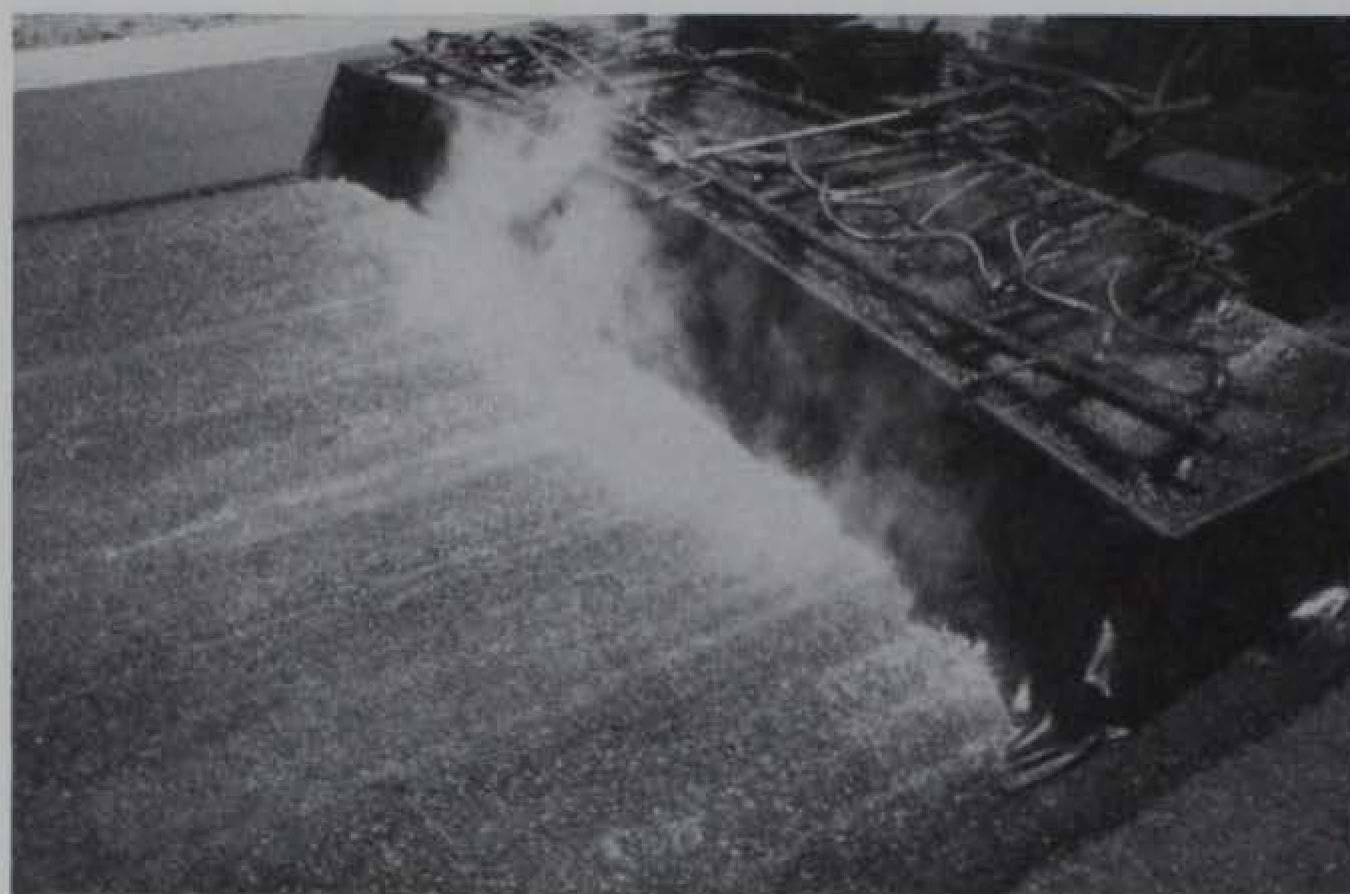

Photo 23. Spray bar applying rejuvenator

Photo 24. Compacting with a rubber-tired roller

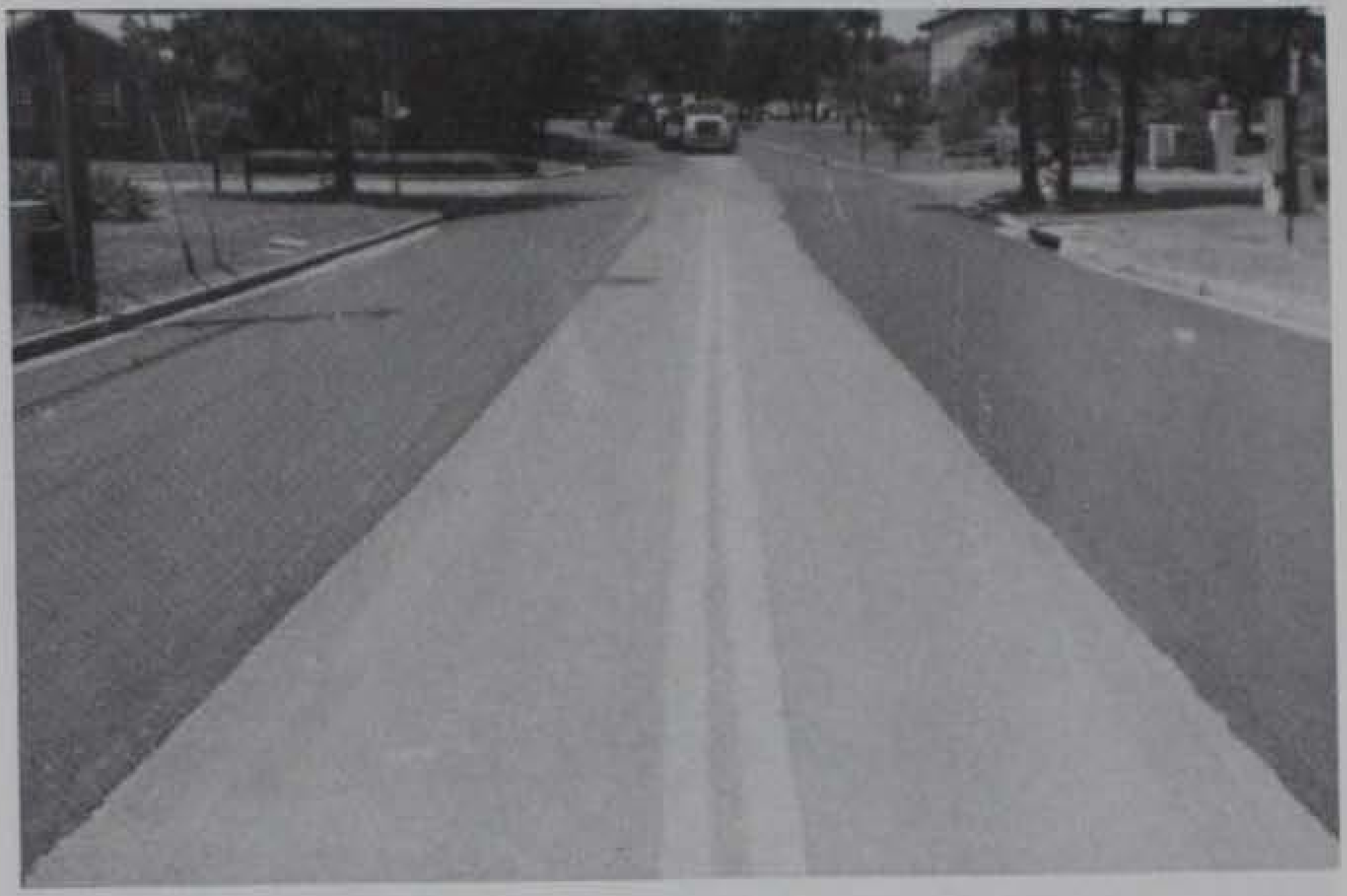

Photo 25. Completed recycled surfaces on either side of the street

Photo 26. Existing road, prior to recycling, road edges milled for final surface to match existing gutters

Photo 27. Fatigue temperature cracks in road surface

Photo 28. Preheater unit

Photo 29. Lighting individual burner units

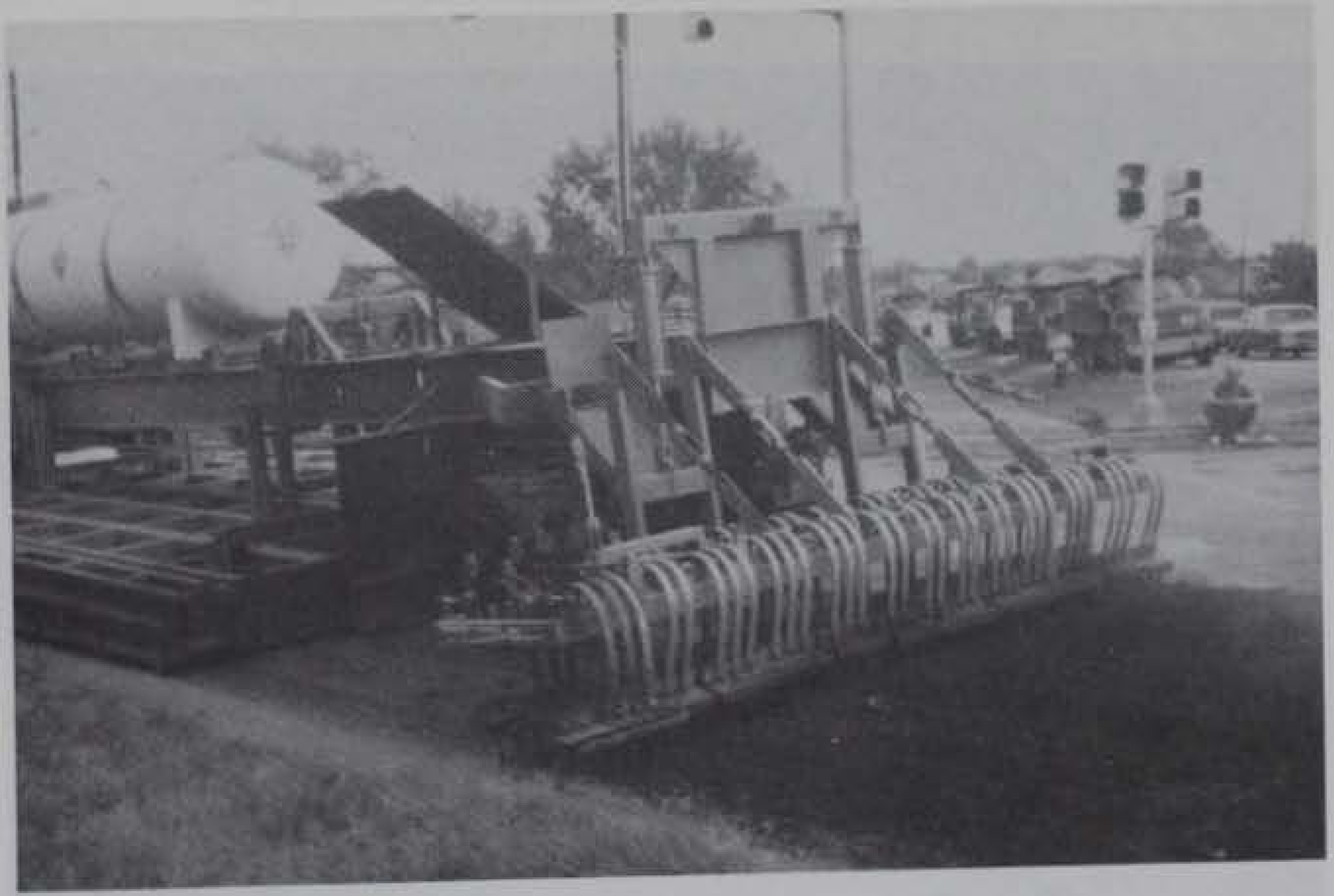

Photo 30. Heat deflection shield, directly behind heater and ahead of steel wheels; also not spring loaded scarifier

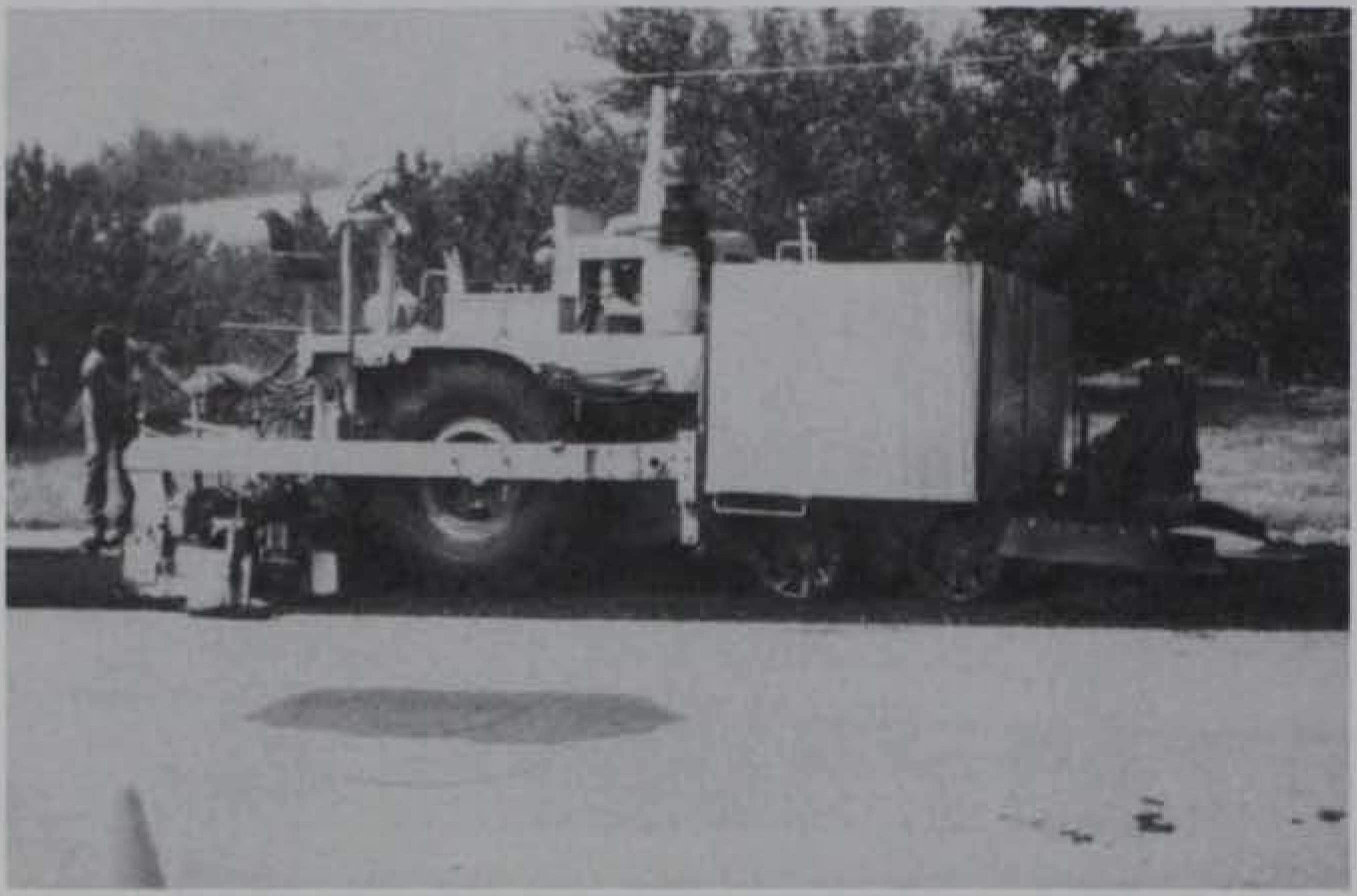

Photo 31. Third machine in recycling train to apply rejuvenator and screed mix

Photo 32. Spray bar for applying rejuvenator

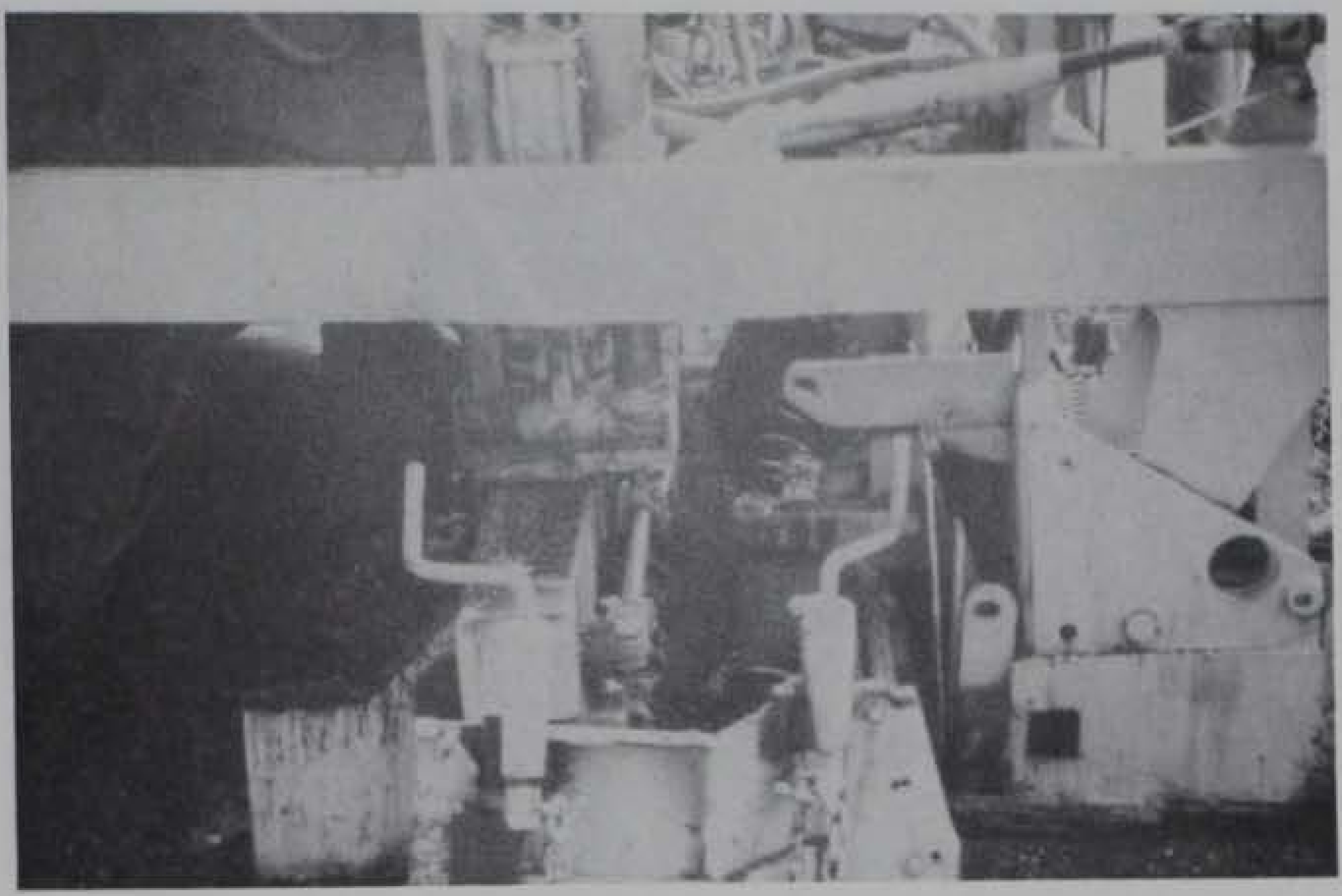

Photo 33. Double row of adjustable width augers for spreading recycled mix

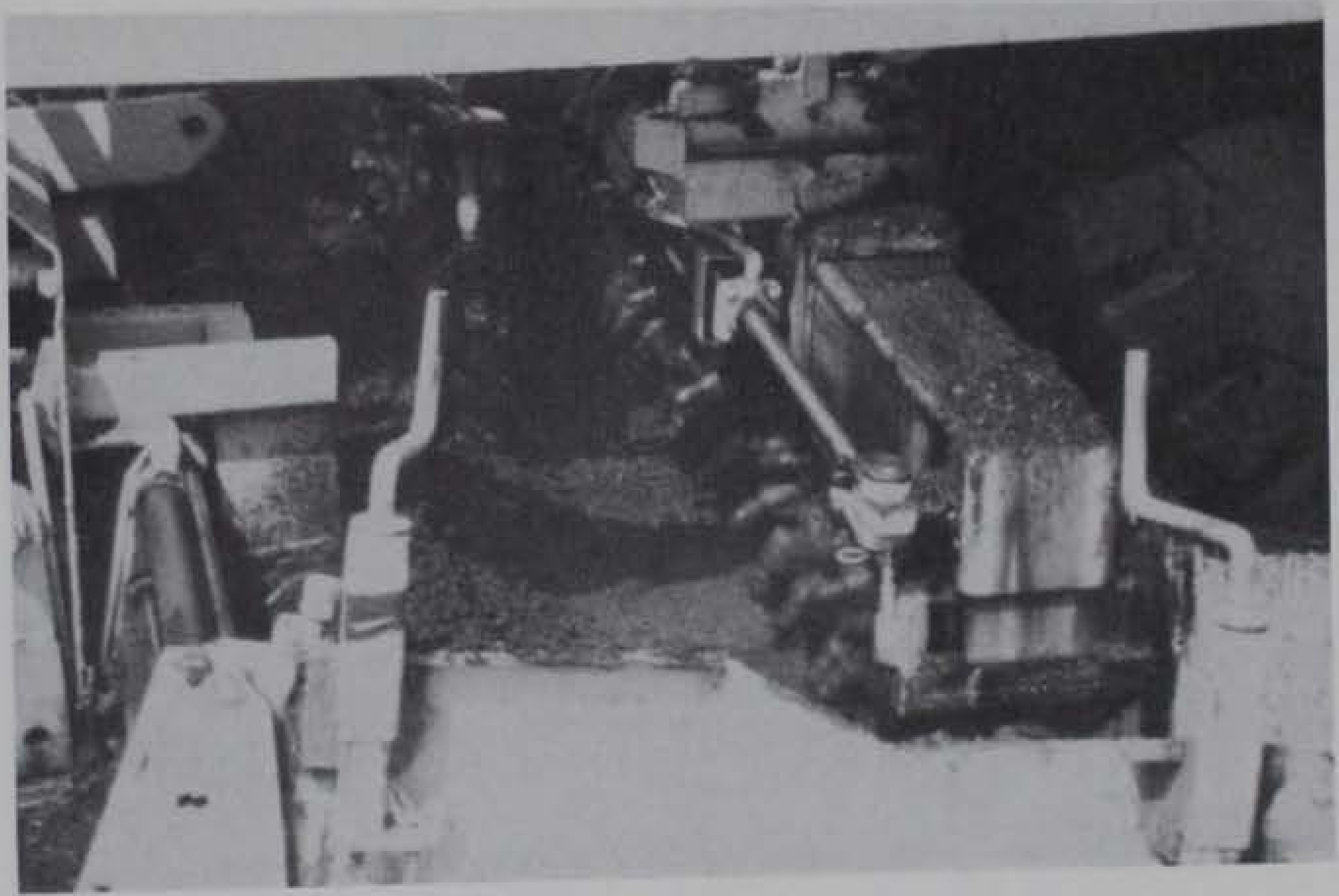

Photo 34. Double row of drums with teeth for mixing rejuvenator with scarified pavement

Photo 35. Placing overlay on recycled pavement

Photo 36. Recycled pavement surface prior to overlay