

## RURAL HOT MIX RECYCLING

Robert A. Welke, P.E.  
Michigan Department of Transportation

Hot recycling is the transporting of salvaged existing asphalt pavement from its original location to a central asphalt plant site for processing. Rural roadways that are recycled may present different problems and needs than urban projects. Generally, with the type of asphalt pavement encountered in rural projects, technologists need to consider the variability of the salvaged material that is designed into a recycled mixture. During the past four years much has been done to develop recycled asphalt mix design procedures. These procedures are being time tested and will, by the nature of the technology, be revised continuously. Rural roads that are recycled may, due to their length and lower traffic volumes, dictate lower unit cost designs. Recently developed equipment allows the removal of the total existing pavement or variable thicknesses of the upper pavement surface for recycling. The Michigan Department of Transportation has hot recycled several rural roadway projects during the past three years. Two typical rural recycling projects—one using drum mix recycling, the other using batch plant recycling—are discussed, and information and data on cost and energy conservation are presented.

Most Michigan trunkline flexible pavements are asphaltic concrete, constructed of high quality aggregates. Due to heavy traffic volumes with a large percentage commercial on the rural roads it is necessary to design all pavement sections for a high level of serviceability. To provide the public with the best possible roadway surfaces, it is apparent that we must develop an alternate to overlaying of existing pavements. This alternate is asphalt recycling.

The time of going to the 'back forty' and opening up a gravel pit is over in many parts of the country. Zoning laws and land use controls have made the availability of low cost aggregates a thing of the past. In Michigan it is not uncommon to haul high quality aggregates more than 161 km (100 miles) from their source to an asphalt plant site. It is apparent that we must conserve this natural resource if we are going to control product cost.

During 1979, the cost of asphalt cement increased 35 percent. The National Asphalt Paving Association has forecast that asphalt and fuel oil costs will increase 46 percent during 1980. Presently, about 45 percent of our asphalt comes from imported crude oil. With world political conditions as unreliable as they are, we may see higher-than-forecast asphalt prices or a reduction in supply of asphalt material.

Decreasing natural resources and large increased costs of asphalt have not diminished the need to maintain and improve our asphalt pavements. Both public and private organizations are feeling the pinch of ever increasing costs of asphalt paving and the continued need to extend or improve existing asphalt surfaces.

The Michigan Department of Transportation has 4,802 km (2,984 miles) of flexible pavement roads and 6,524 km (4,054 miles) of asphalt overlayed rigid pavement on the state trunkline system. In addition, most of the 128,748 km (80,000 miles) of the county road systems are asphalt. With the large increase in construction costs during the past few years it is difficult to keep up with the needs. Asphalt recycling has become a method that has the most potential to improve asphalt pavements while controlling costs and reducing energy requirements.

It is said that necessity is the mother of invention. Although asphalt recycling has been around for many years, very little was done to foster it until after the 1973 oil embargo. In Michigan we started cold in-place recycling of existing asphalt pavements in 1970. But the interest and monies for this work did not increase until 1974. Since that time, we have cold recycled several hundred lane-kilometers of asphalt pavement and hot mix recycled over 362,874 metric tons (400,000 tons) of salvaged asphalt.

From an engineering point of view, we are at the advent of considering asphalt recycling as a standard practice. In fact, in the Michigan Department of Transportation, most projects that are scheduled for resurfacing are evaluated for possible recycling. We have 20 projects scheduled for hot recycling and several for cold recycling this year.

It has been common practice in the past to pile layer upon layer of new asphalt mix on pavements that were distressed. This would improve the pavement structure and ride, but would not eliminate the reflective cracking problem, in which cracks in the old surface reappear or 'reflect' in the new layer. In a few years the resurfacing was in the same condition as the original asphalt pavement. Many times resurfacing will not solve the problem, but only add to it. Recycling of existing asphalt allows for the breaking up of the cracked pavement,

thus reducing the potential of reflective cracking in the new surface.

It is apparent that besides conserving energy, materials, and lowering construction costs, recycling can improve the pavement structure. It also can extend pavement longevity. We have enough experience to determine that asphalt is truly recyclable and at a cost that is less than 100 percent virgin mixes. Early test results have indicated that the aging or hardening of the asphalt binder in hot recycled mixtures is slowed in relation to conventional mixes. If this is true, the service life of a recycled pavement may be longer.

During the past several years much has been done to develop recycled asphalt mix design procedures. These procedures are being time-tested and will, by the nature of the technology, be revised continuously. We have developed computer programs for recycled asphalt mix designs to aid the practitioner in handling the increased number of variables encountered.

### Project Design

#### Project History

After a potential project has been chosen, it is important to review the past construction records. It is essential to know the history of construction, what materials were used, and the cross-section. If the roadway has a widely varied history and was constructed in a patchwork manner, it might be best not to consider it for recycling. Uniformity of materials and cross-section make for a more uniform recycled mix. Also, by checking past construction records one can possibly determine if tars or extensive amounts of liquid asphalts were used. If these materials are present in large amounts, again it may be best not to hot recycle because of potential air quality problems.

#### Coring

Coring the existing roadway is the next process. A certain number of cores are needed in order to obtain material for testing. Usually 10 to 20 cores are sufficient.

#### Sample Aggregate Base

When cold milling the existing pavement it is our experience that approximately 1.3 cm (1/2 in.) of aggregate base will be included with the salvaged pavement. A sample of the aggregate base is needed to determine if there are any large stones present (greater than 3.2 cm or 1-1/4 in.). If large stones are present this could cause paving problems. Crushing, scalping to remove oversize material, or not considering the project for hot recycling are the solutions if large stones are present. Also, if the pavement is directly on clay, it will cause the problem of having clay balls in the recycled mix. The only solution is to cold mill partial depth or not recycle.

#### Measure Thickness of Cores

This is valuable information for cold milling contractors and for design of the recycled mixture. Often the existing pavement will consist of various thicknesses of wearing, leveling, and base courses that have different properties and each requires consideration.

### Extraction and Abson Recovery

The next process is to run an extraction analysis of the existing pavement. This will give vital information concerning gradation and asphalt content.

The Abson Recovery process will give information as to the hardness of the existing asphalt binder. The first step is to take the effluent from the extraction and centrifuge out the fine dust particles. The presence of dust will make the asphalt cement appear harder than it really is. The next step is to distill off the solvent (usually tri-chlorethylene). The last step is to run a penetration of the salvaged asphalt cement at 25 C (75 F).

#### Tabulate Results

Once the results are known, they should be tabulated, averaged, and the standard deviation calculated for all sieves, the asphalt content, and the recovered penetration.

#### Mix Design

In order to design any bituminous mixture it is important to know the location, the environment, and the needs. Traffic volumes and loading, the climate, and the supporting base materials are the most important factors; however, there may be other considerations unique to a particular highway.

#### Rejuvenate Old Asphalt

In order to produce a suitable recycled mix it is paramount to have the asphalt binder at the proper consistency. We at MDOT have developed a chart (Fig. 1) which aids in making the proper decision as to what type and how much rejuvenating material is needed. Note the left and right y-axes. The left y-axis represents the viscosity of the material at 25 C (77 F) and the right y-axis represents penetration at 25 C (77 F). There is a very strong correlation between viscosity and penetration, thus, corresponding values can be substituted freely.

The first thing one does when using this chart is to shade-in the area of desired consistency of the resultant recycled mixture. In this case we are designing the recycled mix to be similar to a new 85-100 penetration grade asphalt mixture. Next the recovered penetration (or viscosity) of the reclaimed pavement is plotted (38 in this case) on the left y-axis. On the right y-axis the penetration (or viscosity) of the rejuvenating agent is plotted (in this case a 250 penetration asphalt cement). Next the two points are connected by a line and where the line intersects the shaded area is the desired blending index in percent (42 to 48).

From knowing the desired blending index one can use this value to compute the percent of salvaged material to be used in the recycled mixture. The percent salvaged material to be used is as follows:

$$S = 100 - \frac{AC \times BI}{AD}$$

Where:

S = salvaged material, percent  
 AC = asphalt content of salvaged material, percent  
 BI = blending index, percent  
 AD = asphalt demand of recycled mix, percent

Example:

AC = 5.2, BI = 55, AD = 5.8

$$S = 100 - \frac{5.2 \times 55}{5.8} = 100 - 49.4 = 50.6 \text{ percent}$$

Thus, for this example a 50 percent salvaged - 50 percent virgin mixture would be desirable. If one wanted to go to a higher percentage of salvaged material (lower blending index) then a softer rejuvenating material would be needed.

#### Gradation Analysis

The next design process is to analyze the gradation of the reclaimed material and decide what the gradation of the new aggregate should be. From our experience, cold milling does not significantly change the gradation of the reclaimed pavement except for the 0.075 mm (No. 200) sieve. It generally raises the material passing the 0.075 mm (No. 200) sieve by approximately 3 percent.

#### Sample Stockpiles

At this time it is assumed that the contract has been let, cold planing has started, and the sources of virgin aggregates are available. Thus, a representative sample of each can be obtained for mix design.

#### Extraction and Abson Recovery

Again, an extraction must be run--this time on the cold milled material. The increase in passing 0.075 mm (P200) should be noted along with the reduction in the asphalt content because of inclusion of the aggregate base.

From the Abson process, the recovered penetration of the cold milled material should match closely with the values from the cores.

#### Marshall Mix Design

Conventional Marshall Mix Design procedures and design criteria are sufficient. The aggregates and reclaimed pavement are heated to 140 C (285 F) and are mixed and compacted. It should be noted that the stabilities of recycled mixes are quite high because the milling process creates more crushed material.

#### Drum Mix Recycling Project

##### Construction

The Michigan Department of Transportation completed its first asphalt hot mix recycling test section in 1977. Based on the experience gained from this project and information from recycling projects around the country, it was decided to construct two large rural hot mix recycling projects in 1978. By specification, one project would

be recycled by the drum mix method and the other the heat-transfer method requiring a batch plant.

The location of the 11.6-km (7.2 mile) recycled portion of this project was on M 57 between M 66 and Berridge Rd in Montcalm County, east of Greenville. The work consisted of removal and reduction of the existing 6.7-m (22 ft) bituminous pavement (two 3.7-m, or 12-ft lanes and a 0.9-m, or 3-ft paved shoulder) at 179 kg/m<sup>2</sup> (330 lb/sq yd). Also included in another portion of the project was a conventional bituminous resurfacing.

#### Test Results

Large variations in the asphalt content and gradation test results are undesirable when producing a high quality bituminous paving material. However, it was anticipated, even before the project had started, that there would be more fluctuations in the test results than found in conventional mixes. The reason for this was the added variable of the salvaged material. Any of the following factors can cause this added variability:

- 1) variability in original bituminous mix,
- 2) variable thickness of different courses (wearing, leveling, or binder),
- 3) different construction histories (e.g., one area has had a resurfacing with a different composition of mix while another area has not),
- 4) fluctuations in depth of aggregate base removed with the bituminous pavement.

Existing bituminous pavements that have wide variances in any of the first three factors should not be considered for hot mix recycling for producing a wearing course. M 57 was chosen as a suitable project for a recycled wearing course because of its uniformity. Except for a 0.8-km (1/2 mile) section that received a 5-cm (2 in.) resurfacing, the material was uniform throughout the 11.6-km (7.2 mile) project. Factor number four was considered to be the most significant on this project for producing variability in the salvaged material.

As mentioned previously, approximately 1.3 cm (1/2 in.) of aggregate base was removed along with the existing pavement in order to assure a good bond for the recycled mix. The following table shows the asphalt content of the salvaged material when various depths of aggregate base are included (assuming a 4.8 percent asphalt content in salvaged mat and a 7.6-cm (3 in.) pavement thickness).

Quantity of Aggregate Base Salvaged, cm	Asphalt Content, percent
0	4.80
0.6 (1/4 in.)	4.43
1.3 (1/2 in.)	4.11
1.9 (3/4 in.)	3.84
2.5 (1 in.)	3.60

Thus, one can see that a minor fluctuation in the cold milling operation can cause a substantial fluctuation in the asphalt content in the salvaged material.

The average asphalt content for the entire project was 5.06 percent for the plant and 4.99 percent for the laboratory. At the beginning of the job, 5.4 percent was the target; however, the amount of material passing the 0.075-mm (No. 200) sieve was significantly higher in the actual mix than in the mix design. The reason the passing 0.075 mm (P200) was higher and the combined asphalt content lower

in the mix design was because more of the aggregate base was removed than had been expected. The laboratory averaged 6.78 percent passing 0.075 mm (P200); plant values are often inaccurate due to less sophisticated equipment. The mix design was based on 5.8 percent passing 0.075 mm (P200). A mix design rule of thumb is that for an increase of 1 percent in the material passing the 0.075-mm sieve (P200), the asphalt content should drop 0.3 percent.

Cores were taken from the newly compacted pavement and the air voids were found to be 3.6 percent at 5.2 percent asphalt cement. Air voids will become less with time as traffic further compacts the pavement. Experience has shown that 3.0 percent is the desired air voids after traffic has had a chance to compact the pavement. However, 3.6 percent air voids for newly compacted pavement is low; thus, asphalt content around 5 percent did not seem excessively low. Appearance of the mix was good; however, the percentage of new asphalt added was increased (0.1 percent) to 2.8 percent for a 60-40 percent salvaged-virgin mix in order to keep the combined asphalt content from dropping too low. For a 70-30 mix, 2.3 percent asphalt cement was added; for an 80-20 mix, 1.9 percent asphalt was added; and for a 90-10 mix, 1.3 percent asphalt cement was added. The combined asphalt content was approximately 5 percent for all mixes.

In order to analyze the variability found in the control charts, a comparison with conventional mix variability is necessary. Standard deviation is used as the indicator of variability. Table I compares the variabilities for 10 end product (conventional wearing courses) projects done over the past three years in Michigan with the variabilities within the M 57 project.

Standard deviations of asphalt contents were higher for the recycled project than for conventional mixes. This was expected due to the added variability of the salvaged asphalt cement. Although variability is higher it is believed that the effects on the wearing course will be insignificant. It should also be noted that a contributing factor to the 0.37 plant asphalt standard deviation was the presence of moisture. Drum mix plants do not fully dry the aggregate, and moisture in the mix appears to be asphalt cement in plant extraction results. Although moisture corrections were used on this project, the added variable undoubtedly increased the standard deviation for the plant results.

In analyzing the variability of the aggregate gradations, it must be remembered that a change in the mix proportion of salvaged and virgin materials caused a small change in the percent passing the various sieves, thus increasing total job variability. Even so, for the 0.075-mm (No. 200) and 0.6-mm (No. 30) sieves the standard deviation was slightly lower than average, and for the 2.36-mm (No. 8) and 9.5-mm (3/8 in.) sieves it was slightly higher. It was somewhat unexpected that the variability for the aggregate gradations proved to be comparable to that of a conventional mix. It is felt that the reason for this was the fact that the aggregate base, the salvaged material, and the virgin material all have similar gradations.

Recovered penetrations (indicator of viscosity) of recycled asphalt cement from laboratory extractions varied depending upon the percentage of salvaged and virgin used (Table II).

TABLE I

Asphalt Content and Gradation Analysis	Standard Deviations For 10 Projects			Standard Deviation For M 57 Recycle
	Avg.	High	Low	
Plant asphalt content	0.20	0.29	0.14	0.37
Lab asphalt content	0.21	0.30	0.12	0.29
Plant passing 0.075 mm (P200)	0.69	0.96	0.38	0.52
Lab passing 0.075 mm (P200)	0.76	1.14	0.31	0.51
Plant passing 0.6 mm (P30)	2.1	4.3	0.9	1.9
Lab passing 0.6 mm (P30)	2.2	3.1	1.1	1.6
Plant passing 2.36 mm (P8)	2.3	3.7	1.6	3.1
Lab passing 2.36 mm (P8)	2.3	2.9	1.3	2.7
Plant passing 9.5 mm (P3/8)	2.3	3.0	1.8	3.3
Lab passing 9.5 mm (P3/8)	2.6	4.3	1.7	3.0

It should be noted that all the variability of test results is not caused by variation in the mix, but also by sampling and testing errors. Although it is being studied at present, we are not able to separate the mix variation from sampling and testing errors. Thus, overall variability of test results is the only available indicator of mix variation.

As expected the higher the percentage of salvaged material used, the lower the recovered penetration (the higher the viscosity). Recovered penetrations in the 50's would be comparable to a typical recovery of a new 85-100 penetration grade pavement where values in the 70's would represent a new 120-150 pavement. Thus, the 80-20 and 70-30

TABLE II

Recovered Penetration	Original Pavement From Cores	Recycled Mix, Salvaged Virgin, percent			
		90-10	80-20	70-30	60-40
Average	38.4	41.7	53.9	55.0	68.2
High	45	45	83	59	83
Low	28	36	42	48	55
No. of Samples	7	4	11	11	9

mixes would seem to be similar to a new 120-150 mix. Analysis of the old pavement showed an average recovery of 38 which indicates that the original asphalt cement still had some life in it. Recovered penetrations below 25 are thought to be indicators of a crack susceptible material. It is common to find badly cracked areas with recovered penetrations in the teens. Although recovered penetrations are not a fail-safe method of predicting cracking susceptibility, they are an indicator. Thus it is felt that 200-250 penetration grade asphalt sufficiently rejuvenated the old asphalt cement to the viscosity of a new cement, except for the 90-10 mix.

There is a widely accepted theory that some of the old hardened asphalt that was absorbed into the aggregate does not become part of the effective asphalt in a recycled mix. Thus, the recovered penetrations in a recycled mix are lower and are not true indicators as to the hardness of the effective asphalt cement. It is felt that a recycled mix may have a greater service life than the recovered penetrations indicate.

Moistures in the mix and stockpiles were monitored. Moisture in the virgin stockpile averaged 2.5 percent on a dry basis, and 2.0 percent in the salvaged pile. Anywhere from 1 to 3 percent water was added on the cold feed belt; however, this moisture had no chance to be absorbed into the stone and evaporated quickly upon entering the drum. Moisture in the mix varied with temperature. At 132 C (270 F), 0.05 percent was in the mix, and at 116 C (240 F), 0.15 percent moisture was measured.

Approximately two months after construction, wet friction coefficients of the pavement were measured at 64 km/hr (40 mph) in accordance with ASTM E274. The average value was 0.54 with a high of 0.57 and a low of 0.49. The statewide average friction coefficient for initial construction is 0.51.

#### Air Quality

Particulate emissions were measured by Department personnel in order to determine if the plant complied with Federal and Michigan standards. Federal standards require that particulate matter shall not exceed 0.04 gr/DSCF (grams per dry standard cubic foot) and the plume shall not exceed 20 percent opacity. Michigan standards require 48 gm/1000<sup>3</sup> (0.30 lb/1,000 cu ft) of gas, approximately equivalent to 0.15 gr/DSCF, and the plume shall not exceed 20 percent opacity.

Table III shows the particulate emissions measured for this project.

only. At 80-20 a light blue smoke appeared and at 90-10 it became heavy.

#### Energy-Resource Savings

It is calculated that 719,228 l (190,000 gal) of asphalt cement and 14,152 metric tons (15,600 tons) of aggregate were recycled on this project. Use of the drum mixer and low mix temperatures saved an estimated 75,708 l (20,000 gal) of dryer fuel oil. It is also calculated that approximately 4,808 metric tons (5,300 tons) of shoulder material were saved (because removal of old pavement the top 7.6 cm (3 in.) of shoulder material was not paved over but bladed over to the new edge of pavement). Quantities are not known, but it is felt that a considerable amount of fuel was saved by recycling the aggregate from the existing roadway. New aggregate had to be hauled 24 km (15 miles) one way to the plant site where the salvaged material haul was from 0 to 9.7 km (6 miles).

#### Costs

The bid prices for the various items of work were as follows:

Remove, transport, and crush bituminous pavement (4 in. or less)	\$ 1.79/m <sup>2</sup> (\$1.50/sq yd)
Remove, transport, and crush bituminous pavement (more than 4 in.)	\$ 2.09/m <sup>2</sup> (\$1.75/sq yd)
Aggregate 20AA	\$ 4.96/metric ton (\$4.50/ton)
Asphalt cement	\$104.72/metric ton (\$95.00/ton)
Recycling bituminous material	\$ 7.94/metric ton (\$7.20/ton)

The final quantities varied somewhat from the estimated quantities. Overall, it cost \$18.43/metric ton (\$16.72/ton) for the entire recycling process. This compares very favorably to the 4.12 wearing course price of \$22.27/metric ton (\$20.20/ton) and leveling course price of \$20.89/metric ton (\$18.95/ton) for work elsewhere on the project.

The cost for 90-10 ratios of salvaged-virgin was not significantly different from the cost of a 60-40 ratio \$18.42 versus 18.46/metric ton, respectively (\$16.71 versus \$16.75/ton). The cost of rotomilling on this project was relatively high, \$9.71/metric ton (\$8.81/ton) of salvaged material.

TABLE III

<u>Date of Sample</u>	<u>Mix Ratio Salvaged-Virgin</u>	<u>Particulate Emissions gr/DSCF (EPA Method 5)</u>
August 1, 1978	80-20	0.20
August 3, 1978 - #1	90-10	0.21
August 3, 1978 - #2	90-10	0.20
August 4, 1978	80-20	0.19
August 10, 1978 - #1	70-30	0.11
August 10, 1978 - #2	60-40	0.09

All six tests were above the 0.04 Federal requirement but two of the six were below the 0.15 Michigan requirement.

There was no one available trained in measuring opacity; however, at 60-40 salvaged-virgin and 70-30, the plume of the stack appeared as steam

On the I 94 project, the rotomilling cost was \$7.28/metric ton (\$6.60/ton); however, the average thickness of the pavement was greater (15.2 cm, or 6 in. versus 7.6 cm, or 3 in.). As mentioned previously, approximately 4,808 metric tons (5,300 tons) of shoulder material was saved. At



\$3.86/metric ton (\$3.50/ton) this would amount to a savings of approximately \$18,500.

#### Batch Plant Recycling Project

Because of the interest in investigating the feasibility of heat transfer type hot mix recycling methods, the Michigan Department of Transportation let a project in June 1978 for hot mix recycling using a batch plant. The Department felt that the experience gained in trying this concept, along with the above drum mix recycling project, would help develop the expertise needed to further the art of hot mix recycling.

With the excellent results obtained on the Maplewood, Minnesota batch plant recycling project (1), Michigan felt it was feasible to let a similar recycling job. A 4-km (2.5 mile) section of eastbound I 94 in Berrien County (LaPorte Rd to US 12) was selected because of the excessive fatigue cracking in the existing pavement. Another reason for selecting this project was that this area of the state has a very limited supply of new aggregates which made the recycling more feasible and somewhat more economical. With these two conditions, the recycling offered the best viable design for this section of I 94 with an ADT of 19,000. The other option of resurfacing with 5 to 7.6 cm (2 to 3 in.) of bituminous concrete would have extended the pavement life only a few years before the cracking in the existing surface would have reflected and resulted in the same condition that was faced at the onset.

A design was selected using a 50-50 blend of reclaimed versus virgin material. Because of the feeling of Department personnel that the existing aggregate base was contributing to the pavement failure, it was decided to utilize this aggregate for the virgin portion of the recycled mixture. The existing pavement consisted of a 12.7 cm (5 in.) thickness, composed of binder, leveling, and wearing courses. The plans called for removing the existing pavement and reducing it to 95 percent passing the 50-mm (2 in.) sieve by either rotary reduction or plant crushing. The virgin portion was obtained from removing 15.2 cm (6 in.) of the existing aggregate base course.

The recycled mix was to be placed 25.4 cm (10 in.) thick in a minimum of three lifts and resurfaced with 70.5 kg/m<sup>2</sup> (130 lb/sq yd) of bituminous concrete leveling course 25A, 65.1 kg/m<sup>2</sup> (120 lb/sq yd) of bituminous concrete wearing course Type C, and 54.3 kg/m<sup>2</sup> (100 lb/sq yd) of Open Graded Asphalt Friction Course. The Department opted for the more conservative approach using the recycled base course on the first project because of the high traffic volumes (ADT of 19,000 and the measured percent commercial of 24 percent).

#### Construction

The recycling contract was awarded to Rieth-Riley Construction Co., of Battle Creek, Michigan. They moved their 2,948-kg (6,500 lb) H & B portable batch plant to a site adjacent to the project. For this project, the Department allowed the contractor use of limited access right-of-way, permitting him to go through openings in the right-of-way fence. Rieth-Riley used this option and located their plant on the north end of the project with access to the freeway. The existing 12.7-cm (5 in.) pavement was removed with single pass of a CMI rotomill. The rotomilling in a single-pass operation was quite surprising considering our experience on

previous freeway recycling that required two passes of the machine for similar pavement thickness. The single pass gave us a very uniformly graded material which alleviated any separate stockpiling or blending of the reclaimed pavement. There was also some concern of possible problems that could be encountered because of the various aggregates used in the original construction and the later widening and resurfacing. The original pavement and the widening used natural aggregates, but the resurfacing utilized blast furnace slag in the wearing course. The possible problem of variations in the asphalt content of the different pavement layers were eliminated with the single-pass operation of the rotomill. The contractor used a CMI Trimmer to remove the existing aggregate base. The 15.2-cm (6 in.) base was easily removed in a single pass and transported to the plant site.

The recycling process consisted of drying the aggregate base and superheating it to a temperature of 316 to 343 C (600 to 650 F) so that when the ambient temperature reclaimed pavement is added in the 50-50 blend, the resultant temperature of the recycled mixture is in the range of 93 to 138 C (200 to 280 F). The only modification needed on the existing plant was to devise a method for feeding the reclaimed pavement to the weigh hopper. Rieth-Riley elected to feed the reclaimed material by means of a conveyor belt to an opening in the weigh hopper. The belt was controlled by an interlocking system tied to the plant scales and controls which ensured the uniform proportioning.

A recommendation also stated in the special provision was that the contractor cover the stockpile of reclaimed bituminous material to minimize variations in the moisture content. The reduction in the moisture content in the reclaimed material results in a fuel savings with the lowered required new aggregate temperatures. Rieth-Riley not only tarped the salvaged stockpile, they elected to also tarp the virgin material so that more complete fuel savings could be realized.

The recycled mixture consisted of 49 percent reclaimed pavement, 48.8 percent virgin aggregate, and 2.2 percent 200-250 penetration grade asphalt cement. The contractor superheated the virgin aggregate (salvaged existing aggregate base) to 316 C (600 F) and deposited it in the hot bins without any oversize screening or sizing of the aggregate. The superheated aggregate was then fed into the weigh hopper where the reclaimed material was added to begin the heat transfer process. The next step was depositing the combined aggregate and reclaimed in the pugmill and mixing for an actual dry mix time of 10 seconds. The 'actual mix time' means a 10-second mixing period after the aggregate and reclaimed material are completely charged into the pugmill.

After the dry mixing period, the asphalt cement was added and mixed for a period of 30 seconds and then transferred to a 90.7 metric ton (100 ton) surge bin for the completion of the heat transfer prior to hauling to the paving site. The recycled mix was then placed and compacted with conventional paving equipment. A mix temperature of 127 C (260 F) was selected, and since density was successfully obtained, and a mixture that proved workable resulted, that temperature was used for the entire project.

Later, during the construction, the proportions were changed to increase the reclaimed aggregate to 55 percent. Even with the increased proportion, there was no apparent problem encountered in producing an acceptable mixture. Although there were neither stack emissions nor opacity tests conducted, the stack never showed any visibly

excessive pollution. On all future recycling projects, the Department is requiring the contractor to provide the necessary scaffolding for the monitoring of the stack emissions.

#### Test Results

Marshall stabilities of 9,146N and 10,885N (2,056 and 2,447 lb) flows of 12.5 and 13.5, and V.M.A. of 15.1 is well within the range of acceptable results for high traffic volume pavement. The air voids of 2.2 percent are a little lower than ideal, but considering that the recycled base would be covered with leveling, wearing, and open graded surfaces, it was quite acceptable. If the recycled material was intended as a wearing course, the selection of the virgin material would have become more critical. We would have selected an aggregate that would result in 3 to 5 percent air voids in the surface course of the recycled.

#### Energy Resource Savings and Cost

We realized complete resource savings on using the existing pavement and aggregate base for our recycled mix. There was no need to use new aggregate in the recycled base, which in this area of the state is quite desirable because of the absence of quality aggregates. There was also a savings of asphalt cement with the reduction of 2.5 percent when compared with a conventional base course using all virgin aggregate. On this project approximately 31,298 metric tons (34,500 tons) of new aggregate and 772,224 l (204,000 gal) of asphalt cement were saved. The removed bituminous surfaces equate to 15,703 metric tons (17,310 tons) and the removed aggregate base equals 9,182 metric tons (10,121 tons); therefore, the costs of removing the materials would be \$7.28 and 2.98/metric ton, respectively (\$6.60 and 2.70/ton), based on removal contract prices of \$1.79/m<sup>2</sup> for 12.7-cm (\$1.50/sq yd for 5 in.) bituminous surface and \$0.74 for removing 15.2 cm (6 in.) of aggregate material.

The following is the determination of the cost per ton of recycling the mixture:

Salvaged bituminous	
\$ 7.28/metric ton x 0.50 x 0.978 =	
\$ 3.56 (\$ 3.23/ton)	
Salvaged aggregate	
\$ 2.98/metric ton x 0.50 x 0.978 =	
\$ 1.46 (\$ 1.30/ton)	
Asphalt cement	
\$104.72/metric ton x 0.022 =	
\$ 2.30 (\$ 2.09/ton)	
Recycling	
\$ 9.16/metric ton =	
\$ 9.16 (\$ 8.31/ton)	
<u>Total per metric ton =</u>	
\$16.48 (\$14.93/ton)	

This compares with the approximately \$17.64/metric ton (\$16.00/ton) that new bituminous base would have cost.

Since 1978, when these two large rural hot mix recycling projects were completed the Department has constructed several more asphalt recycling projects. Using the experience gained from the early projects the Department has generally reduced the salvage to virgin aggregate ratios to a nominal 50-50 percent. This change was dictated by the need to reduce the possibility of stack emissions to within allowable limits and provide sufficient new

high penetration asphalt to flux the existing binder in the salvaged material.

During 1979, 18.2 km (11.3 miles) of eastbound I 94 was recycled similar to the project completed in 1978. The later project was constructed with 25.4 cm (10 in.) of recycled asphalt material and 2.5 cm (1 in.) of Open Graded Asphalt Friction Course. The 100 percent virgin leveling and wearing courses were eliminated. This reduction in pavement thickness and costs was prompted by the demonstrated high quality of asphalt recycled mixtures and our confidence in using the material for wearing courses.

#### References

1. "State-of-the-Art: Hot Recycling," National Asphalt Paving Association, May 1977.

Figure 1. Rejuvenating material chart.

