Recycling of Asphalt Concrete-
Oregon's First Hot Mix Project

Interim Report
for
FHWA Demonstration Projects Division
Contract DOT-FH-15-220

by

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Disclaimer

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Acknowledgements

This asphalt concrete recycling project was constructed under the administrative supervision of John Sheldrake, Region Engineer and under the direct control of Loren Weber, Resident Engineer.

The project required assistance and cooperation from many offices and individuals. In particular, Ed Hall, Resident Engineer on the project from which the material was salvaged, was instrumental in arranging for salvaging and stockpiling the material. Also, the work done by the Materials Section under the direction of James E. Wilson, Materials Engineer and Glenn Boyle, Asphalt Mix Design Supervisor, was essential to the success of the project.

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Those named, and many others, contributed a great deal toward the accomplishment of this recycling project. Each person's contribution is sincerely appreciated.

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INTRODUCTION

The need to reduce fuel consumption and conserve natural resources have been items of ever-increasing importance during recent years. This report discusses a project in which almost 50,000 tons of asphalt concrete placed to carry detour traffic during a freeway reconstruction project were subsequently salvaged and recycled to overlay a section of State secondary highway. The material was stockpiled for about two years while plans for the pavement project were developed.

Assistance was provided by the Federal Highway Adminstration's Demonstration Projects Division to subsidize the cost of some of the recycled asphalt concrete and to cover costs of evaluation for the project. The work was included under Demonstration Project No. 39, "Recycling Asphalt Pavements".

HISTORY

During construction of the 13.5 mile, six lane, I-5 freeway project from Woodburn Interchange to Hayesville Interchange (north edge of Salem, Oregon), it was necessary to provide detour widening to handle the large volume of traffic while construction was in progress. The existing roadway was widened approximately 32 feet for the purpose of carrying traffic while two lanes of continuously reinforced concrete pavement were being constructed over the existing pavement. After the third CRCP lane was constructed, along with a 10 foot shoulder, approximately 8 feet of the widening extending beyond the final shoulder was removed as excess. The material removed was class "B" asphalt concrete averaging 5 inches in thickness. The removed asphalt concrete was stored at the St. Louis Angling Ponds, through agreements with, and the cooperation of, Marion County and the Oregon Department of Fish and Wildlife.

The project from which the salvaged asphalt concrete was removed was designed in 1972 and the contract awarded in March, 1973. At that time, salvaging the asphalt concrete for reuse was not considered economically practical. The original contract was written making the contractor responsible for disposal of the excess pavement that had to be removed. After the contract was awarded, the oil embargo of 1973 and the subsequent price increases altered the economic balance between wasting and salvaging the excess asphalt concrete and an interest in recycling the material developed.

From a casual conversation about what could be done with salvaged asphalt concrete, Milo (Mike) Barker commented on value of the material and suggested a possible use either as a base or wearing surface. At the time Mike was Equipment Shop Superintendent, but used to be a foreman on the State traveling paving crew and as such had reused salvaged asphalt concrete in small quantities for patching around maintenance yards. Ed Hall, Resident Engineer of the Woodburn Interchange-Hayesville Interchange project, carried the idea of salvaging the pavement into reality by contacts with the Construction Section and the Federal Highway Administration so an agreement could be made for the storage of the salvaged material for use on a future project. The amount of asphalt concrete removed from the Woodburn Interchange-Hayesville Interchange project was 46,100 tons that was salvageable. Many tons of asphalt concrete are removed statewide from State Highway Division projects each year. In the past, materials removed on construction projects have been disposed of by burying, since usually the removed asphalt is taken off the last part of the project, after embankments have already been made.

The energy crisis has created a serious impact, especially on the highway construction industry. Not only have asphaltic products been in short supply, but costs have increased dramatically with prices doubling during the last few years. Suitable aggregate sources are becoming difficult to obtain due to scarcity and environmental restrictions. Asphalt supplies are dwindling as the crude oil resources are depleted. Energy factors are also very high on the conservation list including the saving of gasoline, diesel oil, burner oil, and electricity required to mine, haul, crush, and process the aggregates for the asphalt concrete mixture. Ecological plusses in recycling pavement are gained by saving land that has to be distrubed to mine aggregates or waste salvaged materials.

Many other states have embarked on a recycle program in the last 2 or 3 years. Now, with the available material, the State of Oregon was able to begin its own program, through the cooperative effort of the Federal Highway Administration, Oregon State Highway Division, Contractor on the Woodburn-Hayesville project, Department of Fish and Wildlife, Department of Environmental Quality, and many others. The continued cooperation of these agencies was essential to make it work. The goal is that the knowledge and experience gained will benefit many other projects to come.

PROJECT DESCRIPTION & CONSTRUCTION PLAN

The project on which the salvaged asphalt concrete was placed extends from St. Paul (M.P. 28.33) and the West City Limits of Woodburn (M.P. 36.5) on the Hillsboro-Silverton Highway in Marion County, Oregon. The existing highway had an asphalt concrete surfacing varying between 20 and 24 feet in width with a predominate width of 22 feet. Eight cores taken on the project found wearing course thicknesses ranging from 3 inches to 5 inches and base thicknesses ranging from 0 to 7 inches. The average wearing course thickness was about 4.5 inches and the average base about 5 inches. The average daily traffic at milepost 31 is 1,000 and at milepost 36 it is 2,600. The existing shoulders were a clayey soil and had been widened using pit run gravel.

The reconstruction provides two 12 foot travel lanes having variable 1 to 2 foot paved shoulders on each side, making a 26 foot to 28 foot roadway. Except for the minor easing of several sharp curves, the overlay follows the existing vertical and horizontal alignment. The shoulder was cut vertically at the edge of the existing pavement to a 4 inch depth and to the desired width and backfilled with asphalt concrete. The recycled asphalt concrete was then used to construct a 6 inch overlay in two 3 inch lifts over the complete roadway. Placement and compaction were no different from methods utilized with new asphalt concrete.

During construction of the project, it was found that the addition of a higher percentage of new aggregate than had been planned was helpful in reducing stack emissions. Because of this, most of the project utilized 20 to 30 percent new aggregate blended with the recycled material. The result was approximately 4,800 tons of salvaged material remained in the stockpile at the completion of the original project. To utilize this material, the project was extended to include a 2.5 inch overlay over another 2.4 miles of the highway toward Hillsboro. The subsequent evaluation of the recycled pavement will include the section having the thinner 2.5 inch overlay.

PRELIMINARY INVESTIGATIONS

During the early stages of planning the project, preliminary testing indicated difficulty might be encountered in crushing the salvaged asphalt concrete. At room temperature, the mix clogged a small laboratory jaw crusher. After cooling and wetting, the material crushed satisfactorily.

In another crushing experiment at a commercial crusher using jaw, cone, and roll components, the material crushed very well without the addition of water or any new rock additive. In still another crushing experiment, approximately 25 cubic yards of the salvaged asphalt concrete was crushed at a commercial plant using a large jaw, 2 cones, and an impact crusher, with no difficulty when the ambient temperature was 50 degrees. To avoid clogging at the mouth of the jaws, it was apparent that the primary jaw crusher should be of sufficient size to accomodate large chunks of material.

The tentative crushing schedule of the contractor was for the middle of June. This anticipated the need for either watering down the stockpile or night crushing to provide a suitable temperature for crushing the fresh asphalt concrete. From extractions, the average asphalt recovery was 4.6 percent. The mix design on the original mixture was 5.3 percent average. Since the material was still very fresh and ductile, it tended to heal back together when stored at room temperature. This suggested the contractor might have difficulty if he elected to stockpile after crushing. Because the asphalt was still ductile, it was concluded a softening agent would not be necessary. This would eliminate one major problem with stack emissions.

EVALUATION PROCEDURE (WORK PLAN)

Prior to letting the contract, an accelerated testing program was undertaken to ensure all the knowledge available would be gained. To cover the several aspects of this project, a procedure was worked out to cover work to be done by the Resident Engineer, the Materials Laboratory, and others. This was done to get complete coverage of items without duplication or omissions. Following is a list of items the Resident Engineer was to be responsible for:

1. Obtain samples prior to crushing and after crushing and send to Lab one sample/2,000 ton minimum.
2. Obtain fuel use forms from Ed Johnsen. Evaluate and modify if needed to fit circumstances. Circulate to Construction, Materials,

Region, and Research for review. Distribute daily in early stages of project to these sections.

3. Review present crushing forms and revise as needed to show specific information for this project. To provide type of crusher, size, settings, rates, ampere hours on gauges, water added and aggregates added, if necessary.

4. Locate where Benkleman Beam tests are taken and record such that follow up tests may be made in exactly the same areas.

5. Establish pre-construction conference. Keep accurate records.

6. Maintain complete records of weather during crushing and paving. Information specified - rainfall (i.e., trace, light, moderate, heavy, and duration), temperature hourly. Maintain fuel use records, distribute forms daily in initial stages.

7. Record how stockpile material is handled. Methods and equipment used to handle salvaged material. Construction of new pile; equipment used. Equipment on pile, size of pile. Comments as to problems or advantages if any. Send samples to Lab for mix design.

8. Job mix control; asphalt extractions and gradation tests for contract compliance. Record belt scale readings hourly. For Laboratory evaluations, sample at one per 2,000 tons of mix. Record heat settings when samples taken.

9. Use nuclear density tests to establish roller patterns. Record mix temperatures, density, number of roller passes and type of roller in the field report form.

10. Samples of new mix are to be taken from roadway and carefully documented as to location. Submit reports daily in initial stages to Construction, Materials, Region, and Research.

11. Record temperatures of mix at plant and laydown. Obtain samples for moisture determination.

12. Document changes during construction. Amounts of asphalt and rock added, temperatures, time, purpose, and where placed. All information which may be of help for future evaluation of results.

13. Arrange to have cores taken for density. Laboratory will need one 4 inch and two 6 inch cores for evaluation of asphalt content, aggregate gradation, and mix evaluation. Also take 4 inch cores for each lift at 1/2 mile intervals similar to the usual practice for paving projects.

14. Arrange to have Benkleman Beam tests taken at completion of construction.

15. Upon completion of the project, prepare interim report within 60 days.

16. Assist Research in follow up data: Benkleman Beam tests, skid tests, surface condition appraisal, pavement mix properties, and ride score.

17. Maintain a complete photo log throughout the life of the project; stills, movie, video tape, photo car, and fly-over photos.

Following is a list of items the Materials Lab was to be responsible for:

1. Extract asphalt and find content, viscosity, and penetration from samples sent in from the field.

2. Mix design; determine percentage of new aggregate and asphalt to be added. Evaluate crushing characteristics, density, and air voids of compacted mix. Find stabilometer and cohesiometer values.

3. Prepare mix design early so additional aggregates (3/4"-#10) may be processed and quantity established.

4. Run tests on paving samples from the field.

5. Obtain moisture content from field submitted samples.

6. Evaluate asphalt content, aggregate gradation, and mix from field submitted cores.
7. Work with the Resident Engineer on preparation of the report.

Following is a list of items other people and units were to be responsible for:

1. Ed Johnsen (Cost Analyst) to instruct the Resident in use of the fuel use form and assist in modifications.
2. Chuck Reeves to supervise and circulate for review a new revised crusher form to Construction, Materials, Region, and Research.
3. Clarence Gregg to have ten or more Benkleman Beam readings taken prior to construction and periodically following construction.
4. Region Geologist to obtain future core samples during post construction evaluation at the same locations as the samples taken from the field at the time of construction.
5. Research Unit; editing and final preparation of interim report.
6. Research Unit to arrange for skid tests, surface condition appraisal, pavement mix properties and ride score with assistance from the Resident Engineer and others.

CHRONOLOGY OF CONSTRUCTION

The following sections of this report provide details of progress for each of the activities involved. The narrative is frequently abbreviated, being presented as entries from a diary. Since neither the Contractor nor the Highway Division had any previous experience with recycling asphalt concrete through a hot-mix process, many operations were experimental. The notations reflect the trial and error nature of the work and are included with the belief they will be helpful to others involved in recycling mixes having ductile asphalts.

CRUSHER

First day of crushing, June 30, 1977. A 988 rubber tired loader feeding crusher but not working well; it was unable to pick up a full bucket of material. Crusher components; a 20" x 36" jaw crusher, an impact crusher, and two 5' x 14' screen decks with 2" screen cloth. Jaw crusher set at 4" opening and the impact crusher at 950 rpm. After first sieve analysis, the jaw was opened to 5 inches. There were no problems in crushing the material other than large chunks would wedge into the jaw and ride up and down for a time before the chunk would catch and break. Crushing specifications were 100% of the material passing the 2" sieve, 50-90% passing the 3/4" sieve, and 0-15% passing the #10 sieve. Crushing was done within specifications except passing the #10 sieve; slightly too many fines. Crushing was done in dry warm weather, 90 F. There was some pile consolidation when left in the stockpile, especially in warm weather, but this easily came apart when picked up by the loader.

Second day of crushing, July 7, 1977. A 54" cone crusher was added in addition to the other crushing components, and this was set with an opening of 2-1/2". Also, the impact crusher was slowed down to 650 rpm to try and reduce the amount of material passing the #10 sieve.

Another 5' x 14' screen deck was added; one screen deck prior to entry into the cone with the material that passes the 2" screen going to the final belt and the rest of the material going into the cone. The second screen deck was mounted between the cone and the impact crushers with the material passing the screen going to the final belt and the oversize going to the impact crusher. The third screen deck was placed after the impact crusher; the material passing the 2" screen deck going to the final belt and the oversize going back through the impact crusher.

The crusher was fed by a D-8H Caterpillar crawler tractor with rippers for the rest of the crushing operation. The rippers were only used occasionally.

Third day of crushing, July 20, 1977. The dies on the jaw crusher were roughened up by welding beads. This helped very much to grip the larger asphalt concrete chunks and pull them into the jaw crusher. The jaw was opened to 6", the cone remained at 2-1/2" and the impact remained at 650 rpm. The crusher components remained at these settings for the rest of the crushing operation.

The crushing operation was geared to the paving plant rather than to stockpile the crushed material ahead. The crusher had no problem in crushing any of the asphalt concrete even in very hot weather (108 F). At warmer temperatures the material was a little "mushy", but did not stick to any of the crusher components. As a result of the crusher working with the plant rather than to stockpile, the potential of having the material reheal after crushing was avoided.

The crushing was done slightly out of specification limits on passing the #10 sieve, with an average of 16.2%, (from 67 field control tests). Very little of the fine material (material passing the #10 sieve) was manufactured in the crusher. There was a substantial amount of base aggregate in the stockpile that was picked up in the salvage of the asphaltic concrete. In addition to this, the grousers of the D-8H crawler tractor caused some further breakdown of the material, creating fines.

On the tenth day of crushing, July 29, 1977, an additional crawler tractor (D-6) was brought in to help push material to the jaw. This added tractor was used two hours per day.

PAVEMENT MIX SPECIFICATIONS

Recycled asphalt concrete pavement is a hot mixture of salvaged asphalt concrete pavement crushed to a maximum size of two inches, mixed with additional 3/4"-#10 aggregates and additional asphalt cement and plant mixed into a uniformly coated mass, hot laid on a prepared foundation and compacted to a specified density.

Proportions of Materials:

Component	Percent of total mix (by weight)
Recrushed asphalt concrete materials (2"-0)	78-100
Additional 3/4"-#10 aggregates	0-20
Additional asphalt cement	0-2

Mix Formula and Tolerances:

After the mix formula is determined as prescribed, the constituents of the mixture and the temperature of the mixture at the time it is placed in final position shall conform thereto within the following tolerances, but always within the range of specified proportions.

Constituent of Mixture	Tolerance (plus or minus to mix formula)
Recrushed asphalt concrete materials (2"-0)	4%
Additional 3/4"-#10 aggregates	4%
Additional asphalt cement	0.5%
Temperature of mixture at time it is placed in final position	20 F

Recrushed Asphalt Concrete Materials:

Sieve Size Passing	Recrushed asphalt concrete (2"-0) percentage by weight
2"	100
3/4"	50-90
#10	0-15

Added Aggregates:

Sieve Size Passing	Additional 3/4"-#10 aggregates (% by weight)
1"	100
3/4"	95-100
1/4"	25-50
#10	0-10
#200	0-4

These specifications and tolerances were adhered to as close as possible until it became apparent the addition of a greater percentage of new aggregate would be needed to reduce emissions from the stack. As an average, 24.8% new aggregate was added to the recrushed asphalt concrete material.

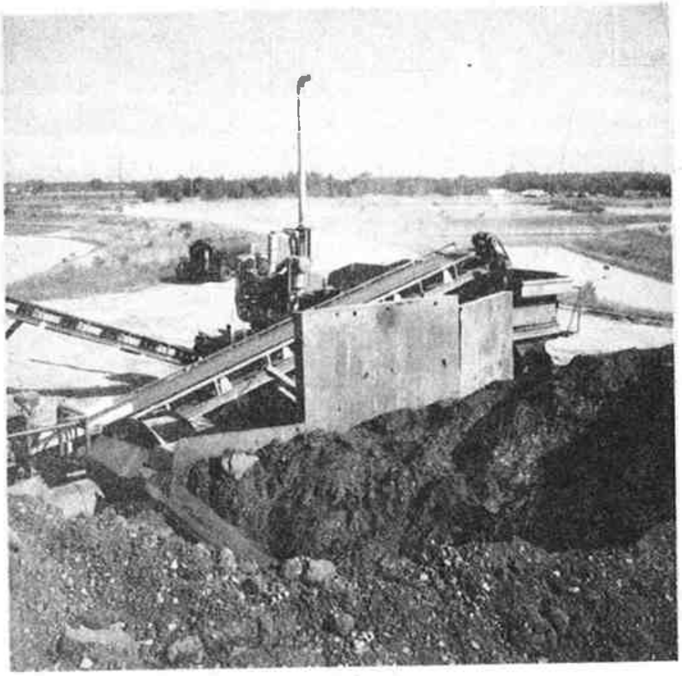
The following page shows some overall views of the crushing and screening equipment used on the project.

PAVING PLANT SUMMARY

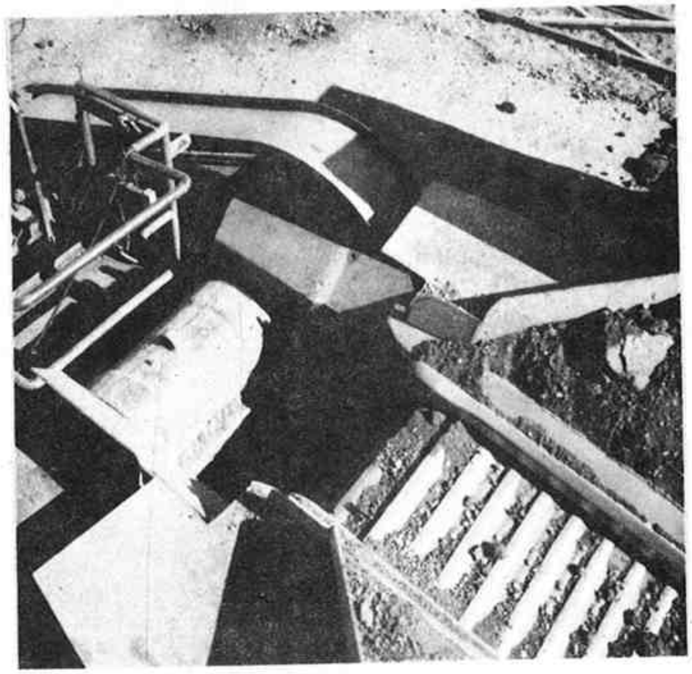
The paving plant used for the project was a newly designed and constructed dryer drum plant manufactured by the Boeing Construction Equipment Company. The contractor, Babler Brothers Inc., leased the plant and Boeing personnel assisted with its operation during the project. The plant is a Model 400 (400 tons per hour) having a conical, perforated plate heat shield between the burner and the paving mix in the drum. The heat shield made it possible to re-mix the salvaged asphalt concrete without burning the asphalt.

As with most new plants, adjustments and modifications were required to obtain satisfactory performance. Four days were required to obtain an opacity reading of less than 40 percent but, fortunately, the Oregon Department of Environmental Quality (DEQ) permit granted four days of unrestricted opacity to make necessary modifications in plant and procedure. Because of the importance of recycling and energy conservation, the DEQ permit allowed 40 percent opacity during the principal production period, double the normal requirement of 20 percent. The permit required that the plant be operated for at least two days within the 20 percent limitation.

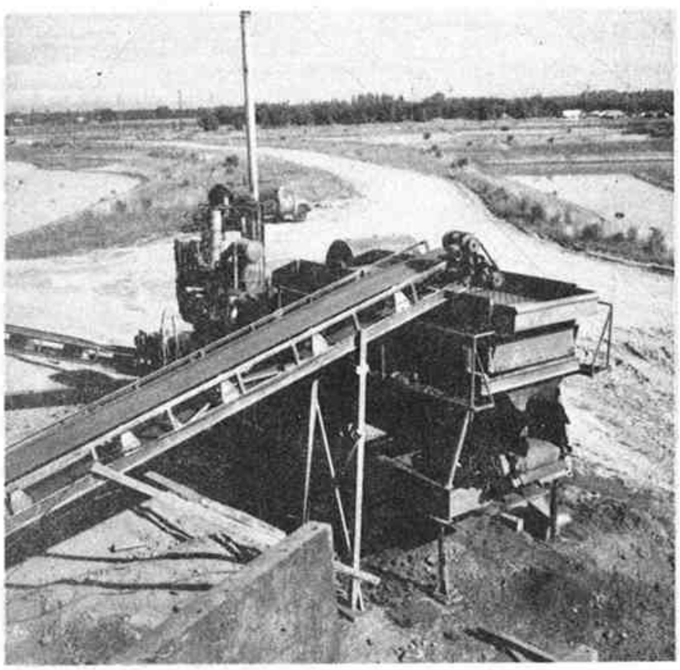
The first mix was made from the recrushed, salvaged asphalt concrete with neither aggregate nor asphalt added. The mix was not satisfactory because some of the particles were not coated. The rest of the mixes provided a satisfactory



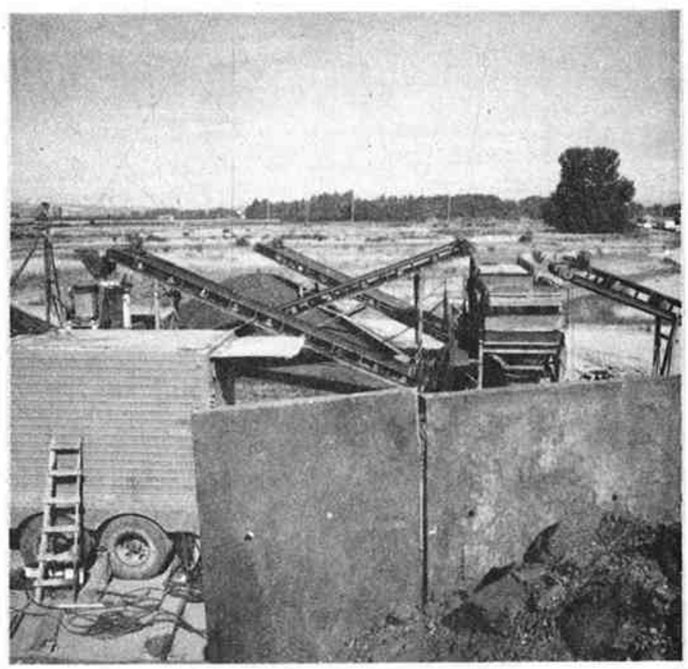
Feed into crusher



20"x36" Jaw crusher



Screen deck and 54" Cone crusher



Impact crusher, screen deck and final stockpile pavement, but emissions were outside of acceptable limits with some of them. Following is a list of the different mixes used:

	Aggregate Added		Asphalt Added	
	Percent	Gradation	Percent	Grade
1.	0	3/4"-#10	0	
2.	0	"	0.7	AR 2,000*
3.	20	"	1.7	"
4.	10	"	1.2	"
5.	15	"	1.5	"
6.	20	"	1.5	"
7.	30	"	2.1	"
8.	30	"	1.6	"
9.	20	"	1.3	"
10.	30	"	1.8	"
11.	30	"	1.6	"
12.	30	"	1.4	"
13.	20	"	1.2	"
14.	20	"	1.4	AR 2,000
15.	20	"	1.5	AR 1,000
16.	30	1/4"-#10	2.1	AR 2,000

* All asphalt from Shell Oil Company

By trying different combinations of mixes, adding different amounts of water, making modifications to the dryer drum and managing the stockpile of crushed asphaltic concrete, the Contractor was able to obtain opacities of less than 20 percent with a production rate of 250 tons per hour and mix temperature of 220 F. To maintain a reasonable production rate, it was found necessary to add 20 to 30 percent new aggregate and 1.5 to 1.8 percent additional asphalt. The plant was operated during the entire project without any pollution control devices.

The compaction was in some cases good even at low temperatures of the mix, but there were 21.8 percent failing compaction tests recorded (below 92 percent relative compaction). This was attributed primarily to the low mix temperatures. Only 13 percent of the compaction tests were below 91 percent relative density.

PAVING PLANT OPERATION

As the mixing operation got underway, two problems were immediately evident. The asphalt pump was designed for conventional mixes using 5 to 7 percent asphalt and our preliminary mix design was to use 0.3 to 1.0 percent added to the recycle mix. The speed of the pump was so slow at these rates as to cause "lagging" and not metering out the asphalt at a uniform rate. This was corrected by substituting a pump from a 200 ton per hour plant. The second problem involved the cold feed bins which, when filled with recrushed asphalt concrete, bridged over, causing clogging of the feed bins. This was corrected by the addition of vibrators to the sidewalls of the cold feed bins.

The cold feed bins had three equal compartments and a separate feed for each compartment. Two bins were filled with recrushed asphalt concrete and one bin was used for new 3/4"-#10 aggregate. A Ramsey belt scale weighed the new aggregate. This was the method of payment for the added aggregate and as a percentage check with the recrushed asphalt concrete.

A water spray bar was mounted over the conveyor leading to the drum dryer with pressure gauges so that water could be added in known percentages.

Another Ramsey belt scale was mounted on the final conveyor belt leading to the drum dryer. This weighed the total material, recrushed asphalt concrete and the new aggregate. By subtracting one belt scale reading from the other, the weight of recrushed material was found and, with it, the percent of new aggregate could be obtained.

The dryer drum plant used on this project was quite different from a conventional drum in that the burner was set back from the drum itself with a cylinder of stainless steel providing a heat passageway from the burner to the drum. This cylinder had air vents for proper air flow. Immediately at the head end of the drum was a metal cone with 1 inch holes for heat transfer. This shield allowed the heat but not the flame to enter into the drum. The asphalt feed was a spray bar inserted nine feet into the drum, beyond the heat shield. The spray bar was positioned longitudinally and was adjusted between 8 and 10 feet beyond the heat shield.

Fourteen feet from the rear of the drum was a steel baffle that covered all but 10 inches around the perimeter of the inside drum diameter. The baffle aided with dust control. The conveyor that feeds into the bottom of the drum was a high speed conveyor, designed to "throw" the material into the drum farther away from the heat, to prevent burning of the oil.

Following is a day-to-day account of the mixing operation.

First day of plant operation, July 20, 1977. No additives were combined with the recrushed asphalt concrete. The mix was heated to 210-220 F at the plant with a production rate of 235 tons per hour. Smoke was far in excess of standards. The mixture was not getting a good asphalt coating on all of the aggregate and the mixture appeared dull and "mealy". This was not an acceptable mixture.

Second day of plant operation, July 21, 1977. No aggregates were added but 0.7 percent asphalt cement (Shell AR2000) was added. Temperature of mix 220-235 F at the plant with a production rate of 275 tons per hour in the morning and 195 tons per hour in the afternoon. Smoke in excess of standards, (opacity 60-70%). A paving plant design problem became apparent on this day with the position of the discharge chute being too high on the dryer drum, at the 9 o'clock position. This created a build up of material in the drum. The problem was corrected by lowering the discharge chute to the 8 o'clock position. The bituminous mixture looked good and was within specifications except for being slightly high on material passing #200 sieve.

Third day of plant operation, July 22, 1977. Minor adjustments were made to the air damper and while keeping the mixture temperature at 210-220 F and the production rate at 230 tons per hour, the opacity readings lowered to 45 percent; still above the DEQ variance of 40 percent. Mixture used was 100 percent recrushed asphaltic concrete and 0.7 percent asphalt cement added. It is not uncommon for a brand new plant to require running several days to work out the "bugs".

Fourth day of plant operation, July 25, 1977. No adjustments or modifications were made. Opacity readings were very poor. In the afternoon a trial of hotter mix was attempted; 275 F at the plant, and opacity was 100 percent.

Fifth day of plant operation, July 26, 1977. There was a marked change in the stack opacity by adding 20 percent virgin 3/4"-#10 aggregate and additional asphalt cement. This day the plant was operated under the 40 percent opacity variance.

Sixth day of plant operation, July 27, 1977. Plant ran less than one hour before plugging up. At this time it was learned that the lifter buckets had been installed clear through to the very back end of the dryer drum and at this time the drum had to be cleaned out and the lifter buckets removed up to three feet away from the back end. This clogging caused a portion of the problem with the smoke emissions as material had built up on the back end of the drum and cooked. It continued to smoke until it was cleaned out.

Eighth day of plant operation, July 29, 1977. The burner was shifted slightly forward (1-1/2"). DEQ certified the plant was within the 40 percent opacity range, with an average reading of 33 percent.

Ninth day of plant operation, August 1, 1977. No problems with the plant. It was observed that smoke opacity readings are higher in the mornings when humidity is higher and lower as the humidity becomes lower in the afternoon.

Tenth day of plant operation, August 2, 1977. The percent of aggregate added and asphalt added was lowered to 15 percent and 1.5 percent; as a consequence, the smoke opacity readings went higher.

Eleventh day of plant operation, August 3, 1977. First day of placing recycle mixture through the paver. Previously it had been used for shoulder widening and had been placed with a motor grader. In the afternoon the mix temperature was raised to 275 F at the plant. The mix was very acceptable and handled very well, but the opacity was near 100 percent; another experiment tried and failed.

Twelfth day of plant operation, August 4, 1977. A modification was made to the asphalt feed. A spray bar was installed transversely to the feed belt at the belt entry into the drum. This was run approximately one hour and then changed back to the original position because the stack emissions were not acceptable. At the end of the shift an inspection plate was opened at the end of the drum dryer and there was a build up against the back wall of the drum.

Fourteenth day of plant operation, August 8, 1977. Again, a build up occurred due to an emergency shut down of the plant. A motor burned up on the conveyor feed into the dryer drum.

Fifteenth day of plant operation, August 9, 1977. Using a blend of Shell AR 1,000 and Shell AR 2,000 (more nearly equal to AR 1,300). Smoke quite heavy (outside variance limitations). A greater amount of aggregate was added to help control emissions. This brought the opacity readings down but still not as good as with a less amount of aggregate and an asphalt cement of AR 2,000 grade.

Sixteenth day of plant operation, August 10, 1977. Additional lifter buckets were removed from the end of the dryer drum to prevent build up. The addition of 1/4"-#10 aggregate in lieu of 3/4"-#10 aggregate was tried as an experiment. The Materials Lab determined this was of no particular value over the 3/4"-#10 aggregate. The purpose was to open the mix gradation to provide more voids to prevent asphalt flushing under traffic.

Seventeenth day of plant operation, August 11, 1977. Plant using a blend of 20 percent new aggregate added and 1.2 percent asphalt added in the morning; opacity readings were in the 40-50 percent range. In the afternoon, 30 percent aggregate and 1.8 percent asphalt was added and the opacity readings were in the 20 percent range.

Eighteenth day of plant operation, August 12, 1977. Opacities were nearly good enough to qualify for a 20 percent day using 30 percent aggregate added. Plant averaged 265 tons per hour.

Nineteenth day of plant operation, August 15, 1977. At the end of the shift the drum was checked for build up and there was a small amount of build up which may have been caused by an emergency shut down of the plant due to a malfunction. This was cleaned out and at this time a mechancial wiper was welded in to keep the back end of the drum from building up.

Twentieth day of plant operation, August 16, 1977. Plant was certified by DEQ as qualifying under 20 percent opacity today. No build up occurred in the dryer drum. Thirty percent new aggregate and 1.8 percent asphalt were added. Production averaged 238 tons per hour.

Twenty-first day of plant operation, August 17, 1977. As an experiment, tonnage was increased to 315 tons per hour, opacity readings averaged 37 percent for the day. Three hundred-fifteen tons per hour was the maximum the plant

plant could run at the percentage of new aggregates added without opening the feed gates wider and recalibrating the cold feed system.

Twenty-second day of plant operation, August 18, 1977. Opacity readings not very good today. Preliminary observations indicate there is a direct relation between opacity readings and high humidity and the amount of water added.

Twenty-third day of plant operation, August 19, 1977. Opacity averaged 24 percent for the day. Humidity was high and the water was reduced on the feed belt. This decrease in water added during a time of high humidity helped to reduce the opacity readings.

Twenty-fourth day of plant operation, August 22, 1977. As learned recently from preliminary observations and applied very effectively today, while the humidity was high in the morning hours the water added was 0.5 percent, and as the humidity decreased and the ambient temperature rose, the water added to the feed belt was raised to between 2 and 2-1/2 percent. Opacity readings averaged under 10 percent for the day.

Twenty-fifth through twenty-eighth day of plant operation, August 23 - August 29, 1977. Very good opacity readings again on these days, following procedures used on August 22.

Twenty-ninth day of plant operation, August 30, 1977. The percentage of virgin aggregate added was reduced to 20 percent today and the crusher is not working right with the plant. The crusher is going to crush the salvaged asphalt concrete remaining in the stockpile. These two factors combined to raise the opacity readings to an average of 30 percent for the day.

The rest of the plant operation was conducted without opacity readings from DEQ, but were done within the 40 percent daily average. There were a total of thirty-five days of plant operation. Three of these last few days were in a start-up and shut-down situation, paving road approaches and such. During these last few days, the plant operated with 20 percent aggregate added.

Information on the day-to-day operation of the plant, showing weather information, production rates, mix temperatures, rock and asphalt added, opacity readings, and some of the properties of the mix is shown in Appendix A.

PRELIMINARY CONCLUSIONS

Using fairly new asphalt concrete such as used on this project was, to say the least, very touchy, in that the mixing was unbalanced very easily. One problem may be discounted, and that was a design problem in the arrangement of the lifters in the back of the dryer drum. This has been corrected by removing the lifter buckets and installing a wiper arm to keep build up from occurring.

Following is a list of variables that observations indicate made large contributions to the smoke opacities, either to help eliminate or contribute to the smoke problem.

1. Mix temperature should be kept at less than 250 F (preferable 230-240 F).
2. Light oil (Shell AR 1,000) creates more smoke. Shell AR 2,000 was used the rest of the time.
3. The addition of 25 to 30 percent new aggregate reduced emissions.
4. Tonnage should be kept to no more than 260 tons per hour and probably a little less.

5. Good management of stockpile (ratio between coarse and fine recrushed asphaltic concrete) is necessary. A two pile split may be preferable, although only one pile was used on this project.
6. The correct amount of water added to the cold feed, using humidity as a guide, is very important to the opacity readings.
7. All steps where the heat of the mix can be conserved should be taken, such as covering the slat conveyor and tarping the hauling vehicles if the haul is any distance.

The following page shows pictures of some of the features of the Boeing Model 400 paving plant.

OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY SUMMARY

A variance to operate an asphalt concrete pavement recycling plant out of compliance with standard specifications was granted to the contractor of this project because technology had not been developed to operate a recycling plant using fresh asphalt concrete within the 20 percent opacity limitation. There were limitations set in the variance such as: (1) four days shall be allowed for adjustments and plant calibrations, during which visible emissions may exceed 40 percent opacity, (2) during at least two days, the plant shall be operated to restrict visible emissions to 20 percent opacity or less, (3) during the remaining portion of the project, visible emissions shall be restricted to 40 percent opacity or less, and (4) particulate emissions from stack testing should not exceed 0.04 grains per standard dry cubic foot and a mass rate of 40 pounds per hour. There were other limitations but these four were the major ones.