Asphalt Technology for Hot In-Place Surface Recycling

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The heat reforming process for hot, in-place rehabilitation of deteriorated asphalt pavements consists of a heating system (up to three liquid propane gas infrared preheaters), which can effectively heat to a depth of 50 mm, and a reforming system (reform, remix, and repave options), which can readily improve the pavement quality through rejuvenation or place a new surface course, from very thin to 50 mm in thickness, in one pass. The main asphalt technology aspects of the heat reforming process can be summarized as determining the overall suitability of the aged, cracked, and rutted pavement for processing (must be structurally adequate for instance); testing the existing pavement to determine the necessary rejuvenator application rate (asphalt cement content, recovered penetration/viscosity, etc.); and monitoring the quality of the in-place, hot recycled mix and any new mix during and after processing, including surface tolerance. No problems have been encountered in meeting softening specifications for aged pavements. The heat reforming process has also been extended to effectively treat asphalt pavements with problems such as severe flushing and low in situ air voids. The key requirements for cost-effective, technically sound, hot, in-place rehabilitation are described through heat reforming process project experience and the associated asphalt technology.

The objective of in-place, hot asphalt pavement surface recycling (hot, in-place surface recycling) is to restore the existing aged, cracked, worn or rutted surface course to the same quality as a new hot-mix overlay (*1–4*) in a cost-effective manner. Pavements generally suitable for such hot, in-place recycling have adequate structural performance (no structural defects beyond localized areas that can be repaired) without prior treatments (surface treatment, rubberized asphalt, epoxy patching, etc.) that may preclude recycling, unless removed first (by milling for instance). Over the past 10 years, mainly as a result of surface rehabilitation equipment and technology developments in Europe and Japan, the process has evolved from simple heater scarification to hot, in-place surface recycling with rejuvenation, and new hot-mix overlay placement in one pass, capabilities. The focus of this paper is the heat reforming process (HRP-5, capable of heater scarification, addition of new material and rejuvenator, remixing, and simultaneously placing a new overlay; and HRP-6, same as HRP-5 but without integral overlay capability) for hot, in-place surface rehabilitation (reform, remix, and repave options), based on experience gained with North American highway and airport projects since 1987 (*5*). The key requirements for successful hot, in-place rehabilitation, including remediation of problems such as severe flushing, are described through direct project experience and the associated asphalt technology.

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HEAT REFORMING PROCESS

The heat reforming process [HRP-5 and HRP-6 (there are several comparable systems)], as shown in operation (HRP-5) and schematically in Figure 1, typically consists of a liquid propane gas (LPG) infrared heating system (up to three preheaters with up to 5.58 million kcal/hr total heating capacity) that can effectively heat to a depth of 50 mm and a reforming system that can apply additional heat (up to 616,000 kcal/hr),

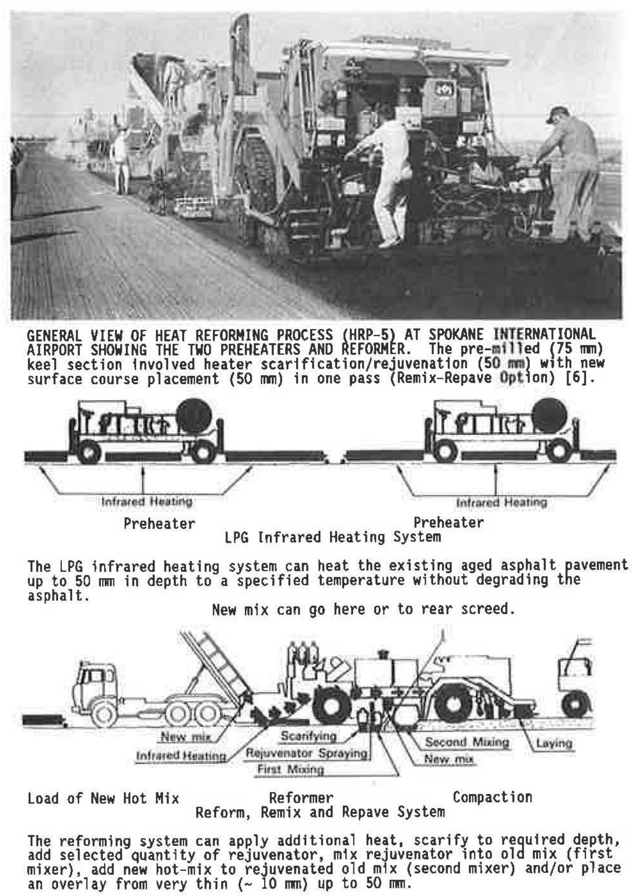

FIGURE 1 Equipment involved in heat reforming process (HRP-5) for one pass, hot, in-place asphalt pavement surface rehabilitation (*2*).

add rejuvenator, mix rejuvenator into the old mix, add new mix, and place a new hot-mix overlay [from very thin (about 10 mm) to 50 mm in thickness] in one pass. This overlay is well bonded to, and acts monolithically with, the rejuvenated old mix, as compared with conventional overlays. These components, and related features, are also shown in Figures 2 and 3. There are four basic heat reforming process options, as described in more detail in following sections;

- Reform option—heating, scarification, levelling, reprofiling, and compaction;
- Remix option—heating, scarification, rejuvenator, mixing (and/or new hot mix/mixing), levelling, reprofiling, and compaction;
- Repave option—heating, scarification, levelling, laying new hot mix, reprofiling, and compaction; and
- Remix-repave option—heating, scarification, rejuvenator, mixing, levelling, laying new hot mix, reprofiling, and compaction.

Because the reform and remix options do not involve the one pass laying of a new hot-mix overlay, a smaller simpler heat reforming process (HRP-6) without overlay capability has also been developed, as shown on highway and airport projects in Figures 4 and 5 (*9*, *10*). To minimize the number of stops for LPG tank refilling, preheaters with a full shift LPG tank capacity are now being used, as shown for the preheaters in Figure 4.

PROJECT STEPS AND ASSOCIATED ASPHALT TECHNOLOGY

The steps in a typical heat reforming process project and the important related asphalt technology aspects are given in a series of tables covering general steps (Table 1), preliminary pavement evaluation and applicability of the process (Table 2), detailed pavement evaluation (Table 3), selection of option (Table 4), and quality control (Table 5) (*1–4*). It is important that the procedures given in Table 1, from preliminary pavement evaluation through completion of the heat reforming project, be followed step by step, with reference to the

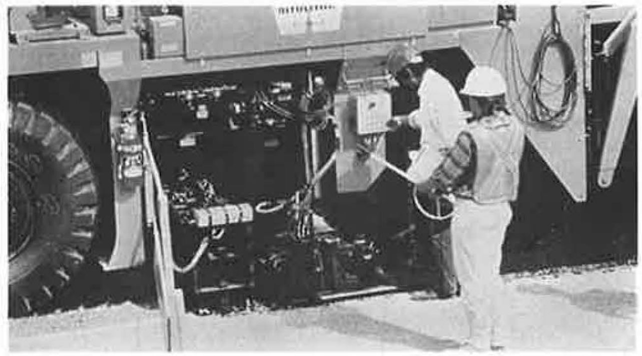

FIGURE 3 Reformer with rejuvenator tank and metering (top); scarifier, rejuvenator sprays, first mixer, controls, and second mixer (from left to right between the wheels). The first mixer blends the rejuvenator into the old mix and can also mill to ensure the required depth of scarification.

FIGURE 4 Heat reforming process (HRP-6) on British Columbia Highway 1 near Langley (40 mm without rejuvenation, reform option) (*8*).

FIGURE 2 Heat reforming process (HRP-5) on Ontario Highway 5/24, showing reformer (40 mm with rejuvenation, remix option) (*7*).

FIGURE 5 Heat reforming process (HRP-6) on Runway 15-33 at Prince George Airport (50 mm with rejuvenation, remix option) (*9,10*).

TABLE 1 GENERAL STEPS IN A HEAT REFORMING PROCESS PROJECT (2)

STEP	FURTHER DETAILS	COMMENTS
1. Preliminary Pavement Evaluation	Table 2	Mainly to determine if pavement structure is adequate.
2. Applicability ↓ Yes	Table 2	If Heat Reforming Process not applicable, develop alternative rehabilitation/ reconstruction method(s).
3. Detailed Pavement Evaluation	Table 3	Mainly quality and properties of existing pavement surface course.
4. Selection of Heat Reforming Process Option	Table 4	Reform, Remix, Repave or Remix-Repave.
5.a. Remix - Select Rejuvenator (Type and Application Rate), and/ or Design New Hot Mix. b. Repave - Design New Hot-Mix Overlay.	Figure 6	Major asphalt technology aspects in conjunction with Step 3.
6. Completion of Heat Reforming Process Project	Table 5	Quality control important.

Note: It is assumed that the appropriate specification preparation, tendering, quality control, etc. have been incorporated in the steps, as required.

supplementary information in Tables 2 to 5 as necessary. For instance, the preliminary pavement evaluation (Step 1, Table 1) must be of sufficient scope (Table 2) for the agency to be able to make a decision on the applicability of the heat reforming process (Step 2, Table 1) on the basis of pavement structure adequacy, any potential problems with prior treatments, and cost relative to other possible pavement rehabilitation strategies (milling and hot-mix plant recycling for instance). Any special features, such as severe flushing, can also be considered at this time. If the heat reforming process is applicable, then the detailed pavement evaluation information (Step 3, Table 1), developed as outlined in Table 3, is required for the selection of the heat reforming process option (Step 4, Table 1), and so on. Where there appear to be other appropriate rehabilitation strategies available, agencies sometimes tender the heat reforming process option selected along with alternatives such as milling/hot-mix plant recycling/conventional overlay in order to obtain the most cost-effective approach. In addition to the asphalt technology aspects determined by the detailed pavement evaluation (Table 3) and quality control requirements (Table 5), it is necessary to establish the rejuvenator type and application rate for the project. This is generally made the responsibility of the contractor, along with any necessary hot mix designs, if end result specifications have been adopted. It is also necessary to establish the desired recycled mix average and minimum temperatures required at the bottom of the scarified depth for proper placement and scarification, respectively.

Laboratory evaluations have been completed on Shell RJO Rejuvenator (RR), Witco Cyclogen L Rejuvenator (RC), and Sunoco Sundex 790 Rejuvenator (RS) (*11,12*) that have shown RR to meet standard recycling agent requirements (ASTM D 4552 for instance) and to be cost-effective. Supportive field experience with the RR rejuvenator was obtained in 1987 in Ontario (*5,7*). The Abson method for recovery of asphalt cement (ASTM D 1856) requires considerable technician skill and experience to obtain reliable recovered penetration/viscosity data. For this reason, the proposed ASTM rotavapor approach (*13*) is being evaluated because it can be automated and has shown reasonable laboratory and interlaboratory accuracy. The selection of RR rejuvenator quantity for softening aged asphalt cements, based on laboratory testing of both

TABLE 2 PRELIMINARY PAVEMENT EVALUATION—ADEQUACY OF EXISTING PAVEMENT STRUCTURE (*1,2*)

ITEM	DETAILS	REASON
1. Inventory Information	• class of pavement • pavement structure(a) • pavement history • traffic volume	• work schedule • applicability of Heat Reforming Process • supplements detailed valuation • work schedule
2. Pavement Structure	• structural defects (types and extent)(a) • non-structural defects (types and extent) • localized structural defects	• applicability of heat reforming process • selection of heat Reforming Process Option • need for preliminary localized repairs
3. Prior Treatments (See Inventory Also)	• any special treatments or materials (surface treatment, rubberized asphalt, road markings, fabrics, epoxy, patching, etc.)	• need for removal (cold milling for instance), if possible, before Heat Reforming Process
4. Geometry and Profile	• width, alignment and gradient(a) • surface profile (extensive rutting and wear)(b)	• applicability of Heat Reforming Process • need for preliminary treatment (cold milling for instance) if possible, before Heat Reforming Process
5. Miscellaneous	• manholes, catch-basins, utility covers, etc. • adjacent (close) plants, trees, flammables, etc.	• work schedule, protection and potential flammable gas counter-measures • work schedule and protective action as necessary

Notes: a. In general, a pavement with structural defects (i.e. lack of structural capacity and/or inadequate base, beyond localized defects that can be readily repaired) will not be a suitable candidate for the Heat Reforming Process. Pavements with non-structural surface defects (rutting, wearing, cracking, aging, poor frictional characteristics, etc.) are suitable candidates for the Heat Reforming Process.

b. Pavement width, alignment and/or gradient improvement requirements, or excessive rutting and wear (greater than about 50 mm), may preclude the Heat Reforming Process.

recovered and artifically aged asphalt cements (*11,12*), is shown in Figure 6 along with an example of its use in terms of penetration improvement. By using Figure 6, the RR rejuvenator application rate can be developed for any penetration or kinematic viscosity requirements. A similar approach can, of course, be used for the RC and RS rejuvenators. RR rejuvenator application temperature data (desirable viscosity) have also been developed. It is generally advised that the lowest suitable RR rejuvenator application temperature be used, typically about 70°C to 80°C, to avoid any misting (fugitive emissions) during incorporation and mixing.

The average recycled mix temperature required for satisfactory compaction is in the 105°C to 115°C range at the breakdown roller, depending on specific site and ambient conditions. Generally, no problems have been experienced with achieving specified compaction levels, particularly when the repave option is involved. For the scarification of the old asphalt concrete to be effective and efficient, specific project experience has shown that it is desirable for the minimum "bottom" temperature to be the softening point temperature for the project recovered asphalt cement before rejuvenation (T. Nishikawa, personal communication, Sept. 1988). Approximate penetration, softening point, and absolute viscosity data are given in Table 6 that can be used to select this desirable minimum temperature.

PERFORMANCE

Some specific project experience can be used to outline how well "projected" softening of aged asphalt, from the Figure 6 data, was achieved in the field. It is also of interest to know how much damage LPG infrared heating does to an existing pavement, which of course requires data from projects where rejuvenation was not involved. For a British Columbia reform option project (*8*), the before heat reforming process (HRP-6) data were an average penetration of 63 dmm, average kinematic viscosity (135°C) of 328 mm²/s, and average absolute viscosity (60°C) of 212 Pa.s, compared with after reforming data of an average penetration of 59 dmm, average kinematic viscosity (135°C) of 299 mm²/s, and average absolute viscosity (60°C) of 247 Pa.s (i.e., within the accuracy of testing, there was little damage to the pavement) (A MacNeil, personal communication, Sept. 1988).

For a 1987 heat reforming process (HRP-5) project in Ontario (Figure 2) with the reform option and significant quality

TABLE 3 DETAILED PAVEMENT EVALUATION—PROPERTIES OF EXISTING SURFACE TO BE CONSIDERED IN DETERMINING SUITABILITY FOR HEAT REFORMING PROCESS (1,2)

ITEM	DETAILS	TYPE OF SURFACE DEFECT(a) WEAR	RUTTING	CRACKING	FRICTION
1. Surface Condition	• cracks (types and extent)	N	N	M	N
	transverse profile	M	M	N	R
	• longitudinal profile	R	R	N	N
2. Existing Asphalt Concrete(b) (Usually surface course, but must be at least to proposed scarification depth.)	• thickness	M	M	M	M
	• asphalt cement content (for scarification depth)	M	M	M	M
	• gradation (for scarification depth)	M	M	M	M
	• density	M	M	M	M
	• air voids	M	M	M	M
	• penetration/viscosity of recovered asphalt cement (for scarification depth)	M	R	M	N

M - Mandatory R - Recommended N - Not Necessary

Notes: a. Information to be representative of the pavement section involved, with special areas (spray patching for instance) and localized structural distress areas noted.

b. Typically based on a coring program. Cores to be representative of pavement section involved, with additional cores taken as necessary for special areas.

control testing, the RR Rejuvenator application rate was set (0.40 l/m^2) to achieve a recovered average penetration of about 55 dmm, somewhat above the low end of the ministry (MTC, now MTO) specified range of 50 to 80 dmm. The aged asphalt cement had an average initial penetration before the reform option of 34 dmm, and the average recovered penetration after the reform option was 54 dmm, close to the "softening" level anticipated (7). [The parallel ministry testing indicated that a somewhat lower softening level of 44 dmm was achieved, but their data (not ASTM D 1856 method) includes tests on control sections without rejuvenator application (D. Lynch, personal communication, Nov. 1987)]. The compaction level achieved (> 98 percent) was satisfactory and the Marshall compliance testing was favorable, with the exception of somewhat low air voids. When a rejuvenating agent is added to an old mix, the effective binder content in the recycled mix increases by about 7 to 10 percent, resulting in lower air voids. It is necessary that this impact on field air voids be checked and options such as the addition of an underasphalted new hot mix or hot sand be considered, as proven effective on a number of remix option projects. Regardless, from both an economic and overall recycled mix quality viewpoint, the rejuvenator addition rate should be set as low as possible.

An obvious question at this point is the cost of the heat reforming process options compared with conventional hot-mix paving technology. Data on alternative bids, where equivalent quality and pavement modifications have been required, show the heat reforming process to be 10 to 20 percent lower in cost. As the actual beneficial depth of heater scarification extends below the specified nominal depth (i.e., have elevated temperature, with some closing of cracks below scarification depth, for instance), the actual cost-effectiveness is probably better than this level. In addiiton, specific site conditions, and particularly ambient conditions (prefer hot, calm days for hot in-place recycling) influence the project costs. For instance, under good operating conditions, the HRP-5 in the remix (50 mm)-repave (50 mm) option can achieve up to 1000 m^2/hr. With street work that involves utility covers or poor ambient conditions, or both, this production rate can drop to less than 500 m^2/hr. Regardless, in comparing the costs of alternatives, it is important that the quality and pavement modification requirements (i.e., end results) be equivalent. In addition, the heat reforming process has the public attractions of much reduced traffic impact during construction and the recycling of pavement materials.

PROBLEM PAVEMENTS

Projects recently completed demonstrated methods by which the heat reforming process technology can be used to address localized asphalt pavement problems such as flushing/bleeding, low in situ air voids, and so forth.

TABLE 4 HEAT REFORMING PROCESS OPTIONS (*2,3*)

PURPOSE(a)	OPTION	PROCESS
1. To improve the profile of surface course deformed by rutting or wearing, but in comparatively unaged condition with minor cracking (no rejuvenator required)(b).	Reform HRP-5 or HRP-6	Heating - Scarification - Levelling - Reprofiling(c) - Compaction(d)
2. To improve the quality of old, cracked, aged surface course by the addition of rejuvenator and/or new hot mix(e).	Remix	Heating - Scarification - Rejuvenator - Mixing and/or New Hot Mix - Mixing - Levelling - Reprofiling - Compaction
3. To improve the profile of surface course severely deformed by rutting or wearing, with new hot-mix overlay placed in one pass. To improve frictional characteristics. To provide some pavement strengthening.	Repave	Heating - Scarification - Levelling - Laying New Hot Mix(f) - Reprofiling - Compaction
4. Combination of remix and repave purposes.	Remix-Repave	Heating - Scarification - Rejuvenator - Mixing - Levelling - Laying New Hot Mix - Reprofiling - Compaction

Notes: a. Prime purpose given in each case.

b. Often used prior to hot mix resurfacing (heater scarification).

c. Standard screed and screed controls.

d. Standard compaction equipment and procedures.

e. The composition, gradation and/or asphalt cement content of the new hot mix can be adjusted to improve the quality of the old mix.

f. Standard augers and auger controls.

Severe Flushing/Bleeding

Variable, moderate to severe flushing/bleeding of wheelpath areas (and associated wheelpath rutting) developed on several relatively high traffic rural roads in southwestern Ontario shortly after MC800 hot mix binder course had been placed on the existing roadways (*14*). The flushing/bleeding problems were attributed to moisture in the mix that caused both poor coating of the coarse aggregate and excessive fluids (moisture and/or somewhat high MC800–asphalt cement/cutback–content).

The recommended remedial action consisted of spreading 12 to 19 mm of hot (about 180°C) asphalt sand (natural fine aggregate) on top of the bleeding areas. This operation was followed by thorough in-place remixing of this hot asphalt sand with the top 25 mm or so of MC800 binder course, then relaying (HRP) and compacting to give a satisfactory improved MC800 binder course driving surface for subsequent hot mix surface course placement. The rehabilitated MC800 binder course was left under traffic for about 6 weeks, with no evidence of the previous flushing, even in localized areas where the previous bleeding had been severe. A conventional hot mix overlay was subsequently placed without any problems but was designed to have air voids near the agency upper limit of 5 percent to reduce any future flushing potential.

Low In Situ Air Voids

Pavement cores indicated that an approximately 30-year-old existing surface course asphalt concrete was quite variable (extensive hot mix patches of varying age and thickness, original old surface course, and spray patching), with low air voids (SSD) of about 2.5 percent. Project specifications required that recovered penetration for the new mix be between 50 and 80 dmm, with the existing recovered penetration about 29 to 35 dmm (requiring RR rejuvenating agent dosage levels of 0.46 l/m^2 and 0.31 l/m^2 to raise the penetration of the original pavement and patch areas, respectively, to the specified minimum of 50 dmm).

To mitigate potential problems with flushing due to excessive liquid content (existing asphalt cement plus rejuvenator) and low in situ and mix air voids, a thin (5-mm) layer of hot (about 180°C) manufactured sand (100 percent crushed fine aggregate) was applied using a chip spreader between the first

TABLE 5 QUALITY CONTROL FOR HEAT REFORMING PROCESS[a] (1,2)

ITEM	RECOMMENDED METHOD(b)
1. Width	• same as for conventional paving
2. Depth of Scarification	• for HRP (depth set) - measure depth from existing surface adjacent to second mixer • for others - circular ring method
3. Rejuvenator Application Rate (if any)	• calculate from quantity used (litres)
4. Rejuvenator Quality (if any)	• same as for conventional paving (specifications and (ASTM D 4552 [11])
5. New Mix Addition Rate (if any)	• calculate from quantity used (tonnes)
6. Thickness of New Hot Mix Overlay (if any)	• calculate from quantity used (tonnes)
7. Temperature at Breakdown Rolling	• monitor at mid-point of re-profiled depth
8. Temperature of New Hot Mix (if any)	• same as for conventional paving
9. Asphalt Cement Content, Gradation and Marshall Compliance of New Mix (if any)	• same as for conventional paving
10. Compaction	• same as for conventional paving as usual (nuclear density for establishing rolling pattern, cores for acceptance) - important to compare to relevant re-compacted density
11. Surface Tolerance	• same as for conventional paving
12. Penetration/Viscosity of Recycled Mix	• same as for conventional paving

Notes: a. As the Heat Reforming Process is largely based on conventional hot mix paving technology, it is only necessary to supplement the usual quality control requirements. The quality control items and frequency of testing should be established at the level necessary to ensure specification compliance.

b. All testing should be done on random, representative samples, by qualified technicians in a certified laboratory.

and second preheaters (Figure 7) and was thoroughly mixed by the reformer with 40 mm of hot recycled mix (plus added rejuvenator), relaid, and compacted. The manufactured sand increased the air voids in the recycled mix sufficiently that the rejuvenating agent could be added at the prescribed dosage, and no flushing was observed in the new mat during compaction and after 1 year. In addition, the thin layer of hot sand acted as an ablation layer, absorbing any excess asphalt cement at the surface of the existing mix and preventing direct application of heat to any spray patch areas. The use of a third preheater and ablation layer has proven to be the most effective means of eliminating "blue smoke" problems.

USE OF SUPPLEMENTARY MATERIALS

Other supplementary materials can be applied in conjunction with the heat reforming process to improve the properties of the existing asphalt pavements. Among these is OR-60, which is a special oil absorbent aggregate (*16*; T. Nishikawa, personal communication, Nov. 1989) that has been used in Japan and will be tried in North America in the near future.

OR-60 is an artificial aggregate graded between 5 mm and 0.5 mm that, when added to mixes susceptible to plastic deformation rutting, acts as an inorganic oil absorbent hardener. OR-60 prevents plastic flow of asphalt concrete during hot weather by absorbing the lighter oil fraction of the asphalt cement. The OR-60 can be uniformly spread in a thin layer directly on the asphalt pavement to be heat reformed or directly incorporated through the HRP. At a typical application rate of 6 percent by mass of asphalt pavement to be treated, the OR-60 causes about 0.3 percent reduction in the asphalt cement content of the mix. It is anticipated that OR-60 will be used during 1992 for HRP projects in the Toronto area.

CONCLUDING COMMENTS

To take advantage of the demonstrated quality (Figure 8) achieved with the heat reforming process (HRP-5, HRP-6, and similar equivalent systems), it is necessary for project

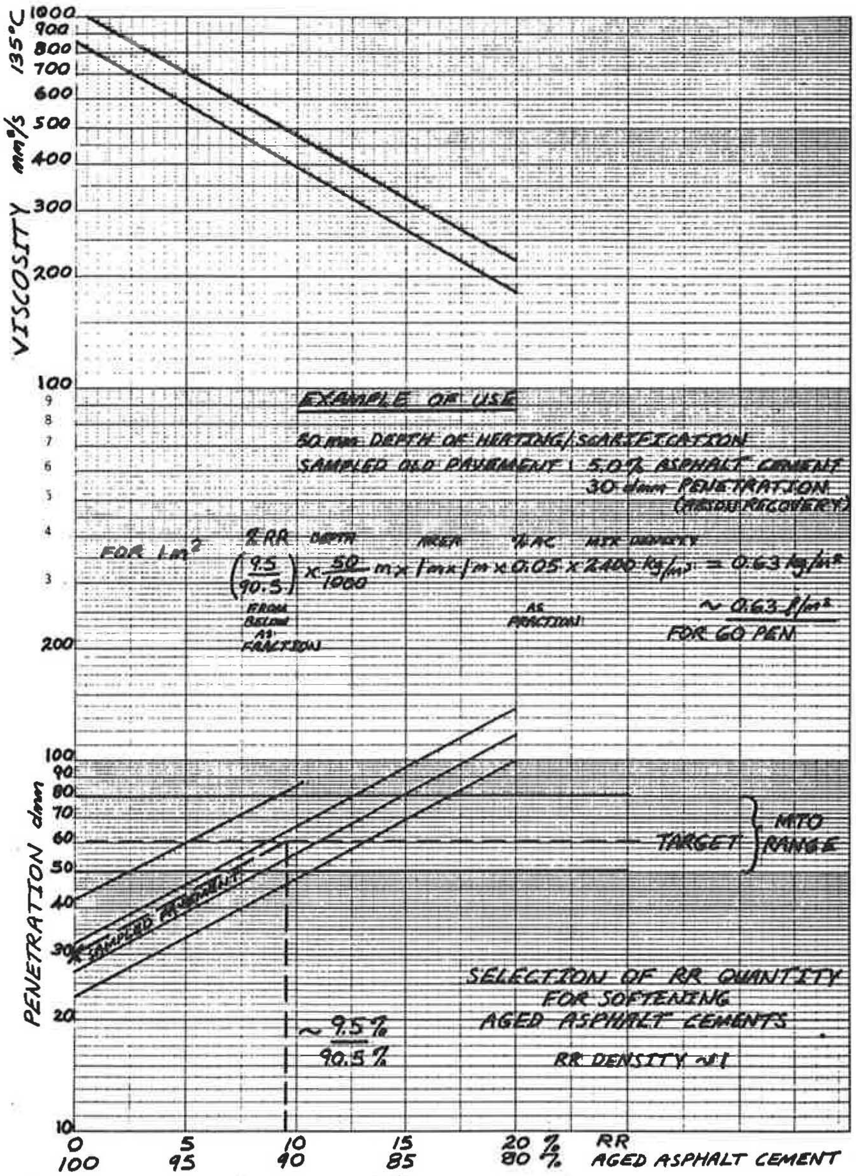

FIGURE 6 Selection of RR rejuvenator for softening aged asphalt cements (*11,12*).

specifications to reflect the equipment requirements in terms of LPG infrared preheaters (to minimize damage of existing pavement); scarifying unit (to ensure that specified scarification depth is achieved); rejuvenator addition (to have application rate properly interlocked to rate of reformer travel); first mixer to incorporate rejuvenator into scarified old mix (to both ensure thorough mixing and establish the depth of processing, typically through incorporating milling teeth); second mixer (to further mix the rejuvenated material and to allow the new hot mix addition to correct deficiencies in the old pavement such as air voids and stability); proper first and main screeds (to ensure the necessary distribution of material and laying quality, main screed typically state of the art with automatic grade and slope controls); and proper machine and mix instrumentation (to expedite quality control checks—infrared thermometers, depth sensors, rejuvenator temperature control, rejuvenator application meter, etc.). Because there are several qualified contractors and suppliers of suitable heat reforming process equipment, it should be no problem for North American agencies to obtain quality hot, in-place asphalt pavement rehabilitation.

Heat reforming process asphalt technology extensions include the addition of asphalt absorbing aggregate (OR-60) and the use of hot sand to remediate severe flushing/bleeding problems. It is anticipated that the growth of the heat reforming process in North America will result in future reports

TABLE 6 APPROXIMATE PENETRATION, SOFTENING POINT, AND ABSOLUTE VISCOSITY RELATIONSHIPS[a] (T. Nishikawa, personal communication, Sept. 1988)

Penetration(b) dmm	Softening Point(d) °C	Absolute Viscosity(c) Pa.s
5	84	690,000
10	74	140,000
15	69	57,000
20	64	29,000
25	61	18,000
30	59	12,000
35	57	8,400
40	55	6,100
45	53	4,800
50	51	3,700
55	50	3,000
60	49	2,400

Notes: a. From empirical relationships developed from extensive test data on recovered asphalt cements.

b. The softening point penetration relationship is approximate.

c. The softening point absolute viscosity relationship is fairly 'accurate'.

d. The minimum 'bottom' temperature for scarification should be the softening point temperature for the penetration/absolute viscosity of the project recovered asphalt cement before rejuvenation.

FIGURE 7 Hot manufactured sand being applied approximately 5 mm thick using a chip spreader between the first and second preheater (*15*).

FIGURE 8 Typical rural heat reforming (HRP-5) pavement surface (John Emery Geotechnical Engineering, Limited).

on both asphalt technology improvements and continuing equipment developments for cost-effective, technically sound, in-place, hot asphalt pavement rehabilitation and remediation.

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