Asphalt Concrete Recycling in Canada

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Asphalt recycling has become a key component of the Canadian paving industry, and it is critical that the appropriate technology is adopted to ensure that the desired pavement quality is achieved. The range of cold and hot asphalt recycling procedures is reviewed in terms of applicability, limitations, and practical experience, and an outline of suggested engineering specification and testing requirements is given. Production of high-quality recycled hot mix incorporating a high content of reclaimed asphalt pavement requires a consistent processed reclaimed asphalt, appropriate new asphalt cement properties, representative Marshall mix design, proper hot-mix plant operations, and quality control–quality assurance to conventional hot-mix requirements. For cold or hot in-place asphalt recycling, evaluation of the existing pavement for suitability and selection of appropriate procedures and materials is emphasized. Research needs such as fine manufactured sand for recycled hot-mix voids development, fatigue and rutting resistance performance of recycled mixes, and rejuvenators for in-place recycling are identified. Experience indicates that asphalt recycling is technically sound and economically favorable and that it clearly contributes to sustainable development by conserving materials, energy, and landfill.

Old asphalt generated during most pavement resurfacing and reconstruction projects can be economically recycled into good-quality asphalt materials while conserving aggregates and asphalt cement, eliminating disposal problems, reducing transportation requirements, and lowering fuel use. Methods and equipment for a range of cold and hot asphalt recycling processes—blended granular material, cold plant, full-depth cold processing, cold in-place train with emulsion, hot in-place surface, and hot-mix plant—are well developed and widely used across Canada, particularly for highway projects and in urban areas. However, old asphalt is still unfortunately being stockpiled or landfilled in many areas such as small, widespread, or rural sites where recycling is not yet developed, technically accepted, or economically attractive. This is also the case for old concrete, although the asphalt industry makes a significant contribution to materials, energy, and landfill conservation in some urban areas by recycling the concrete component of construction and demolition wastes into granular materials.

With increasing concern for sustainable development and emphasis on materials reduction, reuse, and recycling, it is critical that the full potential of cold and hot asphalt recycling is developed. Factors inhibiting more asphalt recycling such as agency conservatism, obsolete specifications, environmental constraints, and lack of technical guidance must continue to be overcome. It is considered that growing limitations on landfilling old asphalt, coupled with increased practical experience and the favorable economics of asphalt recycling, will provide the necessary impetus. The general contribution of old asphalt use, developed over the past 15 years, to wastes and by-products reuse and recycling in transportation construction will be outlined, and a description of the asphalt technology will follow.

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USE OF OLD ASPHALT

Old asphalt recycling ranked first in a recent survey on the use of wastes and by-products in transportation construction and an overall evaluation of material availability, technical suitability, favorable economics, and positive environmental impact (*1*, p. 31; *2*; *3*). For some urban areas, the extent of reclaimed asphalt pavement (RAP) use in hot-mix plants to produce recycled hot mix (RHM) approaches the rate of RAP generation—for instance, some 534,000 T of RAP was used in the greater Toronto area (GTA) in 1990 and an additional 788,000 T was stockpiled by the end of 1990 for subsequent recycling (*3*). This contribution to materials, energy, and landfill conservation through the cost-effective, technically sound use of RAP in RHM is even more impressive when considering the additional 1990 recycling of some 783,000 T of reclaimed concrete material (RCM) into granular base.

A wide range of cold and hot asphalt recycling processes are used across Canada, ranging from a focus on hot in-place surface recycling in British Columbia (more than 4 million m² tendered in 1991), to hot-mix batch, drum and drum-batch plant recycling in Ontario (estimated 1.3 million T of RAP in about 4 million T of RHM in 1991), to none in Newfoundland. A summary of the current provincial status of cold and hot asphalt recycling is presented in Table 1; this recycling information is not definitive or static, however, and further producer and user input is welcomed. Each of the available old asphalt recycling processes is described in following sections, along with the selection, design, and testing of asphalt technology involved. It will become apparent that a spectrum of cold and hot processes is available, from blended granular material through to recycled hot mix with high RAP content, so there is wide scope in selecting the optimal procedure for specific resurfacing and reconstruction projects (*6*).

BLENDED GRANULAR MATERIAL

The simplest use of old asphalt is the uniform blending of suitably processed RAP with conventional granular or crushed RCM, at a plant or in-place, for base, subbase, or shoulder applications. For instance, the use of processed RAP in blended granular material is approved by the Ontario Ministry of Transportation (MTO) (which currently limits RAP content

TABLE 1 Summary of Cold and Hot Recycling in Canada[a]

PROVINCE OR TERRITORY	TYPE OF RECYCLING					
	COLD (b)		HOT (c)			
	IN-PLACE	PLANT	IN-PLACE	PLANT	RAP PERCENT	EXPERIENCE YEARS
British Columbia	Y (d)	N	Y	Y	20 to 40	11
Alberta	NK	N	Y	Y	up to 40	9
Saskatchewan	Y	N	Y	Y	30 to 70	10
Manitoba	NK	NK	N	Y	30 to 50	3
Ontario	Y	Y	Y	Y	15 to 50	13
Quebec	Y	NK	Y	Y	15 to 30	13
PEI	Y	N	N	N (Trial)	NA	NA
New Brunswick	Y	N	N	Y	up to 45	10
Nova Scotia	Y	Y	N	Y	up to 35	6
Newfoundland	N	N	N	N	NA	NA
Yukon	N	N	N	Y	NK	NK
NWT	N	N	N	N	NA	NA

a. Summarized from Transportation Association of Canada Soils and Materials Committee information. Also includes specific city, commercial and demonstration uses. (Additional information to keep this asphalt recycling summary current would be appreciated.)

b. Cold in-place includes pulverizing. Cold plant includes any plant processing.

c. Hot in-place includes reform (heater-scarification), remix, repave and remix-repave [4]. Hot plant includes batch, drum and drum-batch [5]. RAP - reclaimed asphalt pavement.

d. Y - Yes, N - No, NK - Not Known and NA - not applicable.

to up to 30 percent with the blended granular material meeting other conventional granular material physical and gradation requirements) and several agencies in southern Ontario (which typically limit RAP content to up to 15 or 20 percent). MTO has found the engineering properties of blended granular material to be satisfactory and is evaluating RAP use of up to 40 percent in blended granular material (*7*). There is a significant decrease in the California bearing ratio (CBR) of blended granular material for a RAP content greater than about 20 percent, and care must be taken to avoid segregation and to obtain adequate blended granular material compaction, particularly to minimize potential traffic densification. Unfortunately, use of RAP in blended granular material does not take advantage of its asphalt cement content.

FULL-DEPTH COLD PROCESSING

Full-depth cold processing of old asphalt in-place involves pulverizing the existing pavement (typically up to about 100 mm asphalt concrete, surface treatment or mulch, over granular material base) to a maximum depth of 200 mm (*8*, p. 211). This in-place processing thoroughly mixes the individual pavement layers into a relatively homogeneous mixture (typically specified as −26.5 mm) that is then compacted as granular material base. Additional granular material can be added during processing if pavement strengthening is required. Full-depth cold processing allows the old asphalt to be used while reducing the potential for an old, cracked surface to reflect through the new surfacing. Although the aged asphalt cement is considered to play a minimal stabilizing role, with no additional pavement structural capacity beyond granular equivalency generally given for the compacted, pulverized material, practical experience indicates that some stabilizing is actually achieved. Full-depth cold processing is being used regularly in both highway and commercial pavement rehabilitation projects for which the existing pavement structure is adequate or nominal strengthening and reshaping are required.

Variations in the pulverizing equipment allow for the introduction of emulsion, calcium chloride, or another stabilizing agent during the pulverizing and mixing process to produce a stabilized base or shoulder. For increased productivity, uniformity of processing, and controlled emulsion addition, in-place cold recycling has evolved to a train operation.

COLD IN-PLACE TRAIN WITH EMULSION ADDITION

A typical cold in-place recycling train, as shown in Figure 1, consists of

- Cold milling machine (with water added as necessary for cooling and dust control) reclaiming the old asphalt pavement to a specified depth (generally 100 mm but up to 150 mm);
- Screening and sizing/crushing unit (−37.5 mm size often specified);
- Mixing unit for addition of polymer-modified high float emulsion (about 1.25 to 1.50 percent HF150P as determined by mix design) and water, if required;
- Reclaim/paver unit to place the recycled cold mix;
- Compaction and secondary compaction, if necessary, after curing.

FIGURE 1 Recycling of old asphalt pavement using cold in-place train with emulsion.

The mixing and placement units are combined in some trains using a Midland mix paver (*8*). Although the cured, compacted, recycled cold mix provides a satisfactory temporary driving surface, for long-term performance a hot-mix overlay (or suitable surface treatment for low-volume roads) is placed.

Table 2 gives a typical cold in-place asphalt recycling design procedure based on practical experience that essentially simulates the in-place process. The starting point of asphalt technology for most recycled asphalt mix designs is the characterization of representative samples of the base (millings for Table 2) of the old asphalt, including the recovered asphalt cement (Abson recovery procedure). The finishing point is the necessary quality control–quality assurance testing to ensure specification compliance. For the cold in-place train, this testing also involves determining when the hot-mix overlay can be placed.

TABLE 2 Typical Design Procedure for Cold In-Place Asphalt Recycling[a]

A.	DETERMINE PROPERTIES OF REPRESENTATIVE MILLINGS FOR EACH SECTION
1.	obtain representative samples of section (b) to be milled using a small grinding machine or coring
2.	determine moisture content, asphalt cement content and gradation of samples, including penetration (Abson recovery)
B.	PREPARE BRIQUETTES AT EMULSION ADDITIONS OF 0.5, 1.0, 1.5, 2.0 AND 2.5 PERCENT (c)
1.	batch five 1100 gm samples (b) for each emulsion addition level and place in 60°C oven for 2 hours
2.	add water to sample to estimated field moisture content and thoroughly mix, then add warm emulsion (60°C) and mix to check coating
3.	spread mixed sample in pan and allow to cure at 60°C for 1 hour to simulate time between paver laydown and initial compaction
4.	place cured sample in a regular Marshall compaction mold, rod and compact each face 50 blows
5.	cure sample overnight in mold at 60°C and then recompact each face 25 blows
6.	cure recompacted sample in mold on its side at 60°C for 24 hours prior to briquette extrusion, then allow to cool to room temperature before testing
C.	TEST BRIQUETTES FOR EACH EMULSION ADDITION LEVEL
1.	determine maximum theoretical density for mix from breaking up one briquette, and bulk relative density on remaining four briquettes, in order to determine air voids
2.	determine Marshall stability and flow for two briquettes at 22°C (room temperature) and two briquettes at 60°C
D.	SELECT OPTIMUM EMULSION CONTENT
1.	from plots of density, air voids, stability at 22°C and stability at 60°C against percent added emulsion, select optimum emulsion content to give: stability at 22°C of at least 8900 Newtons; stability at 60°C of at least 4500 Newtons; air voids in 8 to 12 percent range; and adequate coating.

a. Adapted from McAsphalt Engineering Services procedure based on State of Oregon experience.

b. The samples must be representative of the millings produced during recycling of the section.

c. Typically a polymer modified high-float emulsion such as HF150P.

The testing is generally done within 2 weeks, when the in-place moisture content of the recycled cold mix is 2 percent or less and 96 percent of the laboratory density has been achieved (which may require secondary compaction). Practical experience indicates that these two conditions have been met when intact cores can be recovered for testing.

As with all in-place asphalt recycling operations, it is critical that the pavement section is a suitable candidate in terms of pavement structural adequacy. It is simply not possible to complete a surface rehabilitation when the old asphalt pavement is in a failed condition requiring drainage improvements, significant strengthening, or even reconstruction. Candidates for in-place recycling will generally be in at least fair structural condition, with mainly surface deterioration.

However, the cold in-place train with an efficient depth capability of up to about 100 mm can generally handle a pavement section in poorer condition, with more cracking, than hot in-place surface recycling, provided that the pavement section will be structurally adequate when the recycling and overlay is completed along with other rehabilitation activities such as improved drainage. Pavement designers generally assign a higher structural strength to recycled cold mix than granular base (1.4 times granular base by MTO, for instance), but research is required on the structural characterization of recycled cold mix along with documentation of design and testing procedures.

PLANT COLD RECYCLING

Although not commonly done in Canada, processed RAP can be combined with an emulsified rejuvenator in a central mixing plant and then placed with a conventional paver much like the rear section of the cold in-place train. An in-place variation on this procedure used in Nova Scotia is to recycle the processed RAP as aggregate through a Midland mix paver with emulsion addition.

HOT IN-PLACE SURFACE RECYCLING

The use of hot in-place surface recycling has developed rapidly in Canada over the past 4 years from simple heater-scarification to the use of several heat reforming systems and special techniques, as shown in Figure 2, for heating/scarifying/rejuvenation/remixing up to a 50-mm depth of aged old asphalt to new hot-mix quality and placing of an integral hot-mix overlay in one pass (*4*, p. 258; *9,10*, p. 60; *11*, p. 75). Several recent Canadian Technical Asphalt Association papers (*4,9,10*) have described hot in-place recycling projects in Ontario, British Columbia, and Alberta and the asphalt technology involved. The typical steps in a hot in-place recycling project are summarized in Table 3, which provides a flow chart from pavement evaluation through quality control. Several key aspects of Table 3 should be noted:

- The section must have an adequate pavement structure;
- Surface treatments, rubberized materials, and so forth may preclude recycling the section; and
- The addition of a rejuvenator can significantly reduce in-place air voids.

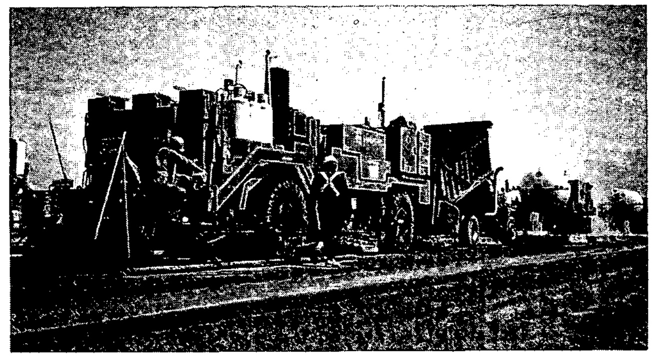

FIGURE 2 Hot in-place surface recycling of old asphalt pavement.

The wide availability of heat reforming systems in Canada, favorable economics involved, and documentation of the asphalt technology necessary to obtain the desired quality should foster the rapid growth of hot in-place recycling. However, two potentially limiting environmental factors require consideration and improvement: (a) there can be considerable gaseous emissions (blue smoke) at times from preheaters and reformers that must be controlled through equipment modifications or changes in operating procedures, and (b) the rejuvenators typically used must meet increasingly strict health and safety requirements.

HOT-MIX PLANT RECYCLING

Production

As indicated in Table 1, the use of processed RAP in batch, drum, and drum-batch hot-mix plants to produce RHM is the most common type of asphalt recycling across Canada and is now considered standard asphalt technology (*5,12*). Recycling is an important component of the hot-mix paving industry, and it is critical that the best available technology is followed to ensure that the desired RHM quality is economically achieved—that is, quality and physical characteristics at least equivalent to conventional hot-mix asphalt (HMA).

Although the RAP will probably come from a specific pavement for major highway projects, in urban areas the RAP (millings and full-depth pieces) from many projects is typically stockpiled for processing. The stockpiled RAP is then processed through a portable plant or integrated processing operation (Figure 3) that can handle both RAP and RCM. A typical RAP processing plant consists of a primary crusher, screening units, a secondary crusher, conveyors, and a stacker, with the crushing operation forming a closed loop to achieve the desired processed RAP gradation. It is important for use in RHM that the processed RAP is consistent, kept as coarse as possible and the fines (−75 μm) generation minimized, with process control monitoring (processed RAP moisture content, gradation, and asphalt cement content). Plant operations developed to produce consistent (homogeneous) processed RAP from various sources include

- Inspecting incoming RAP with rejection of contaminated loads (excess granular material, surface treatment, joint sealant, etc.);

TABLE 3 Typical Steps in Hot In-Place Asphalt Recycling Project[a]

A.	PRELIMINARY PAVEMENT EVALUATION FOR SECTION
1.	determine if pavement structure is adequate - a pavement with structural defects, beyond localized problems, will not be suitable
2.	check for presence of surface treatments, rubberized materials, etc. - may need to remove, if possible, or may not be suitable
3.	consider factors such as rutting (limits use) and utility covers (slows production significantly)
4.	if hot in-place recycling not applicable, develop alternative rehabilitation method(s)
B.	DETAILED PAVEMENT EVALUATION IF HOT IN-PLACE RECYCLING APPLICABLE
1.	determine the existing surface condition in terms of cracks (types and extent), transverse profile and longitudinal profile
2.	determine the properties of the existing asphalt concrete, to at least the proposed scarification depth, in terms of thickness, density, asphalt cement content, gradation, penetration/viscosity of recovered asphalt cement and air voids (b)
C.	SELECTION OF HOT IN-PLACE RECYCLING OPTION
1.	determine the appropriate option for the section (may be specified) i. reform - heating/scarifying/levelling/reprofiling/compacting (to improve the surface profile - heater/scarification) ii. remix - heating/scarifying/rejuvenating (and/or adding new hot mix)/mixing/levelling/reprofiling/compacting (to improve quality of old surface) iii. repave - heating/scarifying/levelling/laying new hot mix/ compacting (to improve surface profile and place hot -mix overlay in one pass) iv. remix-repave - combination of remix and repave options in one pass (to improve quality of old surface and place hot-mix overlay in one pass)
D.	SELECT REJUVENATOR AND/OR DESIGN NEW HOT MIX
1.	for remix option, select the rejuvenator (type and application rate) and/or design new hot mix
2.	for repave option, design the new hot-mix overlay
E.	COMPLETE PROJECT WITH APPROPRIATE QUALITY CONTROL
1.	quality control/quality assurance (QC/QA) similar to conventional hot mix with addition of scarification depth monitoring and more emphasis on recovered penetrations (Abson recovery).

a. Based on experience with the Taisei Heat Reforming Process [4,11].

b. As addition of a rejuvenator can significantly reduce recycled asphalt in-place air voids, it is critical that this aspect is considered at the design stage [4,11].

• Working and mixing the RAP several times during stockpiling, handling, crushing, storing, and feeding the hot-mix plant (use of a daily, mixed processed RAP working pile, for instance);

• Gentle RAP crushing to minimize the fracture of coarse aggregate and fines generation (*5*); and

FIGURE 3 Large RAP and old concrete processing operation; large RAP stockpile (*right*), large RCM stockpile (*background*), processed RAP screened to coarse and fine fractions (*foreground*), crushed RCM granular material (*left*).

• Splitting the processed RAP into a coarse and fine fraction (typically −9.5 mm).

Producing coarse- and fine-fraction processed RAP (Figure 3) permits more consistent cold feed to the hot-mix plant or higher recycling ratios using mainly the coarse fraction, which is lower in fines.

The processed RAP is combined with new aggregate and new asphalt cement (typically a higher penetration to soften the aged asphalt cement) in a batch plant (10 to 25 percent RAP, amount limited by ability to superheat aggregate), drum plant (30 to 70 percent RAP with a practical limit of 50 percent for gaseous emissions control), or newly developed drum-batch plant [Figure 4 (*13*)] to produce RHM. The production of good-quality RHM incorporating a high RAP content (40 percent and greater) requires

• An RHM Marshall mix design on representative materials;
• Consistent processed RAP;
• Selection of an appropriate new asphalt cement penetration/viscosity grade to ensure satisfactory in-place penetrations;
• Hot-mix plant production that limits moisture content, mixes uniformly, and meets environmental regulations; and

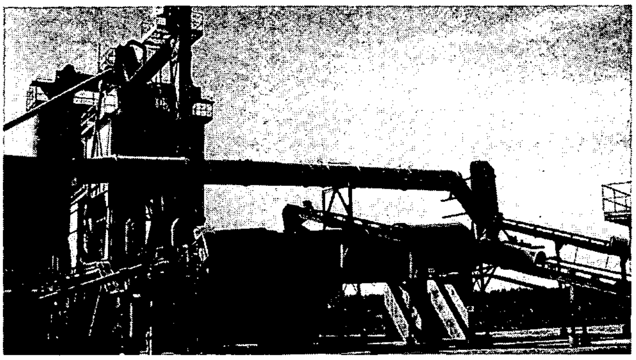

FIGURE 4 Combined hot-mix drum mixer and batch plant with RAP entry to mixing chamber behind burner.

• Producer quality control–agency quality assurance procedures (*5*).

For RHM with a very high content of processed RAP (or even 100 percent RAP use), special plants based on microwave technology to limit gaseous emissions (blue smoke) have been developed in the United States (*14*, p. 63), but there is some concern with the thermal efficiency. There is significant scope for the Canadian hot-mix industry to implement energy savings through plant insulation, covered RAP and aggregate stockpiles, covered cold feeds, and so on, as is conventional practice in Japan, for instance.

Quality and Specifications

Generally, the need for special aggregate characteristics in surface course mixes (good frictional properties, for instance) and high-stability binder course mixes (100 percent crushed aggregates, for instance) limits the major use of RHM to mixes for binder courses and surfaces with low traffic volumes. Regardless, abundant technical data are now available that indicate that properly specified and produced RHM is equivalent in quality and performance to conventional HMA (*15*, p. 78; *16*; *17*). For instance, a recent MTO specification compliance simulation summarized in Table 4 indicates that the RHM was very close to the conventional HMA and special surface course mixes for mean payment factor, or inversely mean payment reduction factor (*17*), which is similar to previous MTO experience (*5*). There is simply no justification in assuming that properly specified and produced RHM is inferior to HMA. Obviously, it is incumbent on the hot-mix industry to ensure that any remaining reputational problems with old asphalt recycling are overcome by placing only RHM of quality.

Although smaller agencies may be concerned with ways to provide for RAP use in a project, it can be done simply by referencing the RHM quality requirement to a conventional HMA. For instance, the Metro Toronto hot-mix specification states:

> The use of RAP (Reclaimed Asphalt Pavement) for the contract will only be permitted in HL 8 mix, with a replacement limit of 40% (recycling "ratio" limit of 40/60, RAP to new aggregate). Any RAP incorporated shall have the necessary gradation, physical properties and asphalt cement content consistency to result in an HL 8 (RAP) mix meeting all the requirements for HL 8 mix (*18*). [HL 8 is conventional binder course hot mix.]

Generally, the quality assurance testing for the RHM would be similar to that for HMA, but it involves more concern with recovered penetrations meeting HMA requirements (*18*).

TABLE 4 Comparison of Typical Specification Compliance for RHM and Conventional Hot Mixes[a]

MIX TYPE (b)		NUMBER OF LOTS (c)	MEAN PAYMENT FACTOR (d)
HL 3	Surface Course HMA	22	0.994
HL 4	Surface/Binder Course HMA	124	0.971
HL 8	Binder Course HMA	42	0.965
DFC	Dense Friction Course	23	0.984
OFC	Open Friction Course	14	0.984
RHM	Recycled Hot Mix	165	0.981

a. Adapted from Ontario Ministry of Transportation (MTO) data developed for a simulation of the impact of new End Result Specification (ERS) on the hot-mix industry [17].

b. These are typical mix types used by the MTO. HMA - hot-mix asphalt.

c. Total of 390 lots (2000 tonne lot - four 500 tonne sublots) from 1989 considered for asphalt cement content and gradation in terms of deviation from the job mix formula (JMF) and permissible range, the basis of the ERS.

d. A mean payment factor of 0.965, for instance, would be equivalent to a 'mean payment reduction' of 3.5 percent ((1.000 - 0.965) x 100).

Economics

The economics of RAP use in RHM are obviously favorable, given increasing interest by the hot-mix industry and transportation agencies. These economics can be shown for RHM incorporating various RAP percentages and typical material prices in the GTA in early 1991 (*3*):

	Material Typical Prices ($/T)
Hot mix aggregate at plant	11 (average for coarse aggregate, screenings, and asphalt sand)
Asphalt cement at plant	175
Processed RAP in stockpile	6 (to process and stockpile)

The assumptions for this cost analysis are as follows:

1. RHM to meet HL 8 (HMA binder course) specifications,
2. RAP contains 4.0 percent aged asphalt cement,
3. Production costs for RHM and HMA the same, and
4. RHM to contain 5.0 percent asphalt cement.

The materials costs for HMA and RHM are given in Table 5. From the table, the savings for 10, 20, and 40 percent RAP are 5.8, 11.6, and 23.2 percent, respectively. The actual savings in materials cost for RHM at a specific hot-mix plant, compared with the typical savings indicated, will also depend on factors such as cost recovery through dumping charges, processing plant capacity, RAP moisture content, and so forth. The potential savings with RHM use obviously increase with any increase in the price of new aggregates and particularly asphalt cement.

TABLE 5 Material Costs for HMA and RHM

Material	HL 8($)	RHM 10% RAP($)	RHM 20% RAP($)	RHM 40% RAP($)
RAP		0.57	1.15	2.32
New aggregates	10.45	9.44	8.43	6.37
New asphalt cement	8.75	8.08	7.40	6.06
Total materials cost	19.20	18.09	16.98	14.75
Saving in materials costs		1.11	2.22	4.45

RHM Mix Design

The general steps in a typical RHM design procedure, based on the Marshall method of hot-mix design (*19,20*), are summarized in Table 6. The new asphalt cement penetration/viscosity properties resulting in the RHM recovered penetration meeting specification can be selected using experience-based formulae (*19*), a matrix (Table 7, for instance), or a standard penetration/viscosity blending chart for two asphalt cements (Figure 2), noting that the penetrations and viscosities for blending chart use are those anticipated after mix production. As the processed RAP tends to be tightly graded with high fines content, it is often necessary to incorporate a clean, fine sand in order to develop adequate RHM voids in mineral aggregate (VMA). In summary, the key RHM mix design steps are (a) test representative materials, (b) select the softer asphalt cement, and (c) meet voids requirements.

Environmental Considerations

The positive environmental features of materials, energy, and landfill conservation associated with RAP use are clear, but there are two potential environmental constraints of concern: gaseous emissions (blue smoke) control during RHM production, and the potential leachability of RAP. With RAP incorporated up to 50 percent in RHM (typical current upward limit for provinces and states), there does not appear to be a blue smoke problem for hot-mix plants with appropriate heating and mixing systems and effective dust control systems (baghouses of the best available technology, for instance), and this should remain the case for new clean air programs. Technical data (21–23) indicate that RAP is a nonleachable material and should not be considered a waste. However, some Canadian agencies are still concerned with the RAP leachability issue, and it must be resolved along with other hot-mix industry concerns such as the use of solvents and the health and safety aspects of asphalt cement use.

Research and Development Needs

Several areas of asphalt technology need research and development to extend the use of RHM:

1. Effect on mix quality of incorporating a small RAP quantity (the New Jersey practice of 10 percent, for instance) in all hot mix types for binder and surface course applications,
2. Use of fine manufactured sand for RHM voids development,
3. Rutting resistance of RHM incorporating fine manufactured sand compared with high-stability hot mix, and
4. Overall physical characterization of RHM compared with HMA in terms of creep (rutting resistance), fatigue endurance, and durability.

At present, most agencies do not consider RHM for pavements requiring high rut resistance, even though RHM typically has a high stability. The use of fine manufactured sand in RHM may overcome any concerns about stability associated with the current use of fine, clean sand for voids development.

CONCLUSION

A significant increase in cold and hot asphalt recycling activities across Canada is anticipated because of today's emphasis on conserving materials, energy, and landfill. The equipment and technology for recycling asphalt is highly developed for a wide range of cold and hot in-place and plant processes. Agencies can specify, and the asphalt industry can supply, high-quality cold and hot recycled asphalt. It would be a shame if factors such as specifier conservatism or lack of technical guidance continue to limit asphalt recycling by some agencies when it is clear that asphalt recycling is technically sound and environmentally favorable and that it contributes to sustainable development.

TABLE 6 Typical Design Procedure for RHM[a]

A.	DETERMINE MATERIAL PROPERTIES AND PROPORTIONS
1.	obtain representative samples of RAP (b), new aggregates (b) and new asphalt cement selected (c)
2.	determine asphalt cement content of RAP, including penetration/ /viscosity (Abson recovery) (c)
3.	determine gradation of RAP aggregate, including bulk relative density
4.	determine gradation, percent crushed, bulk relative density and absorption of new aggregates (d)
5.	determine the desired percent retained 4.75 mm from proposed recycling ratio
6.	determine if a 'recycling' sand is necessary to develop voids mineral aggregate (VMA) and select as necessary (e)
7.	determine the total aggregate grading, check specification compliance and modify as necessary
B.	PREPARE MATERIALS FOR MARSHALL MIX DESIGN
1.	determine increments (range) of total asphalt cement content required to develop Marshall parameter plots
2.	select recommended grade or preferred penetration/viscosity of new (additional) asphalt cement (c)
3.	determine mass of RAP, new aggregates and new asphalt cement for each increment
C.	COMPLETE MARSHALL MIX DESIGN
1.	prepare Marshall briquettes incorporating RAP (f), new aggregates and new asphalt cement
2.	test Marshall briquettes - bulk relative density, maximum relative density, stability, flow, air voids, VMA and appearance
3.	report recommended RHM design
D.	QUALITY CONTROL/QUALITY ASSURANCE (QC/QA)
1.	similar to conventional hot mix with addition of monitoring RAP (moisture content, gradation and asphalt cement content) and more emphasis on recovered penetrations (Abson recovery).

a. Adapted from current Ontario Ministry of Transportation (MTO) procedures that incorporate the Asphalt Institute Marshall method of hot mix design [19,20].
b. All samples must be representative. Process control data should be used. RAP - reclaimed asphalt pavement.
c. The new asphalt cement selected must have penetration/viscosity properties resulting in the RHM recovered penetrations (Abson recovery) meeting specification [12,19].
d. For new aggregates that have not been used before, factors such as petrography and stripping resistance must be considered. This also applies to RAP aggregate, if aggregate related pavement distress involved.
e. In order to develop VMA, it is often necessary to incorporate a clean, fine sand.
f. The RAP must be carefully dried during testing (≈ 105°C) to avoid asphalt cement hardening, and then combined with suitably heated new aggregates to give an overall mixing temperature meeting the appropriate combined RAP asphalt cement and new asphalt cement mixing temperature viscosity.

TABLE 7 Approximate New Asphalt Cement Penetration Required for RHM Recovered Penetration of 60

RECYCLING RATIO RAP/NEW AGGREGATE	RAP (a) ASPHALT CEMENT PERCENT TOTAL MIX	NEW (b) ASPHALT CEMENT PERCENT TOTAL MIX	REQUIRED NEW (c) ASPHALT CEMENT PENETRATION
0/100	0.00	5.00	90
10/90	0.48	4.52	100
20/80	0.96	4.04	115
30/70	1.45	3.55	130
40/60	1.94	3.06	155
50/50	2.44	2.56	220

a. Assuming reclaimed asphalt pavement (RAP) asphalt cement content of 5.0 percent and recovered penetration of 30.

b. Assuming RHM design asphalt cement content of 5.0 percent.

c. Based on Thin Film Oven Testing (TFOT) and practical experience.

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