Technical Note 183

Use of High Percentages of Reclaimed Asphalt Pavement (RAP) Material in Dense Graded Asphalt

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1 Introduction

The use of Reclaimed Asphalt Pavement (RAP) in asphalt has become standard practice in Australia and around the world. RAP is by far the most re-used construction waste material in asphalt manufacture. There are many benefits with incorporating RAP in asphalt. These benefits include:

- reduction in asphalt cost
- reduction consumption of natural resources (aggregate and binder)
- reduction material going to land fill, and
- good pavement performance (i.e. equivalent to asphalt that doesn't contain RAP).

During 2012 – 2016 Austroads undertook a project, TT1817 *Maximising the Use of Reclaimed Asphalt Pavement in Asphalt Mix Design*, to:

- evaluate the performance implications of including high percentages of RAP in asphalt mixes, and
- validate mix design procedures to mitigate negative impacts associated with the inclusion of high percentages of RAP.

This Technical Note builds on the outputs of Austroads project TT1817 and provides guidance to Prequalified Asphalt Contractors (PACs) on how they can demonstrate compliance with the binder blend viscosity requirements of MRTS30 *Asphalt Pavements* for higher RAP content mixes (i.e. mixes containing > 15% RAP and ≤ 40% RAP).

This Technical Note only addresses the issues associated with satisfying the binder blend viscosity and minimum effective binder volume requirements of MRTS30 *Asphalt Pavements*. It should be noted that designing an asphalt mix which contains RAP material involves a range of other considerations (e.g. meeting/complying with the aggregate gradation tolerances, practical limitations, etc.) which should be addressed separately by the Contractor.

2 Approval to incorporate ≤ 15% RAP into asphalt mixes

Transport and Main Roads allows the incorporation of ≤ 15% RAP into dense graded asphalt mixes without any requirements beyond what is described in MRTS30 *Asphalt Pavements*.

3 Approval to incorporate > 15% RAP into asphalt mixes

Transport and Main Roads allows the incorporation of > 15% RAP into dense graded asphalt mixes containing bitumen binders. Up to 20% may be incorporated into surfacing layers and up to 40% may be incorporated into intermediate, base and corrector courses.

However, prior to incorporating > 15% RAP into dense graded asphalt mixes on Transport and Main Roads projects, the Contractor must first seek approval from the department. The process for gaining approval involves an assessment of the following:

- Contractor's RAP Management (RMP) and Asphalt Quality Plans (AQP)
- capability of the Contractor to process RAP to homogeneous condition state prior to incorporation into asphalt, and
- capability of the Contractor to deliver asphalt conforming to the requirements of MRTS30 *Asphalt Pavements*, which is a reflection of the Contractor's RMP, AQP and plant.

These assessments are undertaken by the department's Asphalt Mix Design Registrar. Requests to operate at a higher RAP approval level must be submitted not less than 28 days prior to the commencement of Works to facilitate the timely assessment of the relevant information and inspections to be completed. Such requests must be submitted in writing with supporting information to the following email address asphaltmixdesign@tmr.qld.gov.au.

4 Binder blend viscosity requirements for Transport and Main Roads projects

4.1 General

For Transport and Main Roads projects, the viscosity of the binder blend can be managed in accordance with one of the following methods:

1. for up to 30% RAP, adjusting the virgin binder class in accordance with Table 4.2, or
2. for 16 % up to 40% RAP, varying the mix constituents to achieve a nominated binder viscosity based on RAP testing results. Namely:
   a. varying the binder class
   b. varying the percentage of RAP, or
   c. varying the percentage of rejuvenating agent.

The method to be used by a Contractor must be outlined in the Contractor's AQP and this section of the AQP requires approval by the department's Asphalt Mix Design Registrar prior to implementation on Transport and Main Roads projects.

4.2 Method 1 – adjusting the added binder class for up to 30% RAP

Table 4.2 can be used to adjust the added binder class for mixes containing RAP contents up to 30% (i.e. RAP Approval Levels 1, 2, 3, 1S and 2S). This table has been developed based on the results from RAP sourced by prequalified asphalt contractors in South East Queensland over a 12 month period in 2016/17. Table 4.2 can only be used to select the binder class where the RAP consists predominantly of profilings from old asphalt pavements with a binder content of 4.1 ± 0.5%. For other situations, Method 2 needs to be used to determine the binder class for mixes containing > 15% RAP.

Table 4.2 – Virgin binder class selection for mixes containing RAP

		Binder Class to be Used in Mix				
Course		**Base, Intermediate and Corrector**			**Surfacing**	
RAP Approval Level		**1**	**2**	**3**	**1S**	**2S**
Allowable Percentage of RAP in Mix (%)		0 – 15	13 – 22	23 – 30	0 – 15	13 – 20
Binder Content of RAP[1] (%)		Not applicable	4.1 ± 0.5%	4.1 ± 0.5%	Not applicable	4.1 ± 0.5%
Binder Class Specified	**C320**	C320	C240	C170	C320	C240
	C450	C450	C320	C240	C450	C320
	C600	C600	C450	C320	C600	C450
	M1000	M1000			M1000	
	PMB	PMB class specified			PMB class specified	

[1] For fractionated RAP, the weighted average binder content for the combined RAP should be used.

4.3 Method 2 – Varying the mix constituents to achieve a target binder blend viscosity for 16 % up to 40% RAP

4.3.1 General

This method is suitable for dense graded mixes containing 16 – 40% RAP. However, this method would typically be used where:

- the Contractor wishes to implement a higher than normal level of control of the binder blend viscosity
- the mix contains RAP that has unusual properties (e.g. very high or low binder content and/or very hard or soft bitumen), and/or
- the mix contains > 30% RAP.

4.3.2 Calculation of binder blend viscosity

4.3.2.1 General

In order for the viscosity of the binder blend to be managed in production, particularly those mixes that contain > 30% RAP, the binder viscosity and binder content of the RAP must first be determined.

Austroads test method AGPT/T193 is used for determining the viscosity of the binder blend. The process can be summarised into the following steps:

1. determine the binder content and viscosity of the RAP binder
2. determine the binder content for the asphalt mix
3. calculate the viscosity blending index (VBI_i) of all the blend components (i.e. RAP binder(s), virgin binder and rejuvenator) using Equation 1
4. calculate volume fraction of each binder blend component (x_i) using Equation 2 to 4
5. calculate viscosity blending index of the blend (VBI_β) using Equation 5

6. once the viscosity blending index of the binder blend is known, calculate the viscosity of the blend (μ) using Equation 6.

$$VBI_i = \frac{3 + \log\vartheta_i}{6 + \log\vartheta_i} \quad [1]$$

$$x_{\text{RAP binder(s)}} = \frac{\text{RAP content (\%)}}{100} \times \frac{\text{RAP binder content (\%)}}{\text{Asphalt mix binder content (\%)}} \quad [2]$$

$$x_{\text{rejuvenator}} = \text{Rejuvenator content (by mass of total binder \%)} \quad [3]$$

$$x_{\text{virgin binder}} + x_{\text{RAP binder(s)}} + x_{\text{rejuvenator}} = 1 \text{ or } 100\%$$
$$\Rightarrow x_{\text{virgin binder}} = 1 - (x_{\text{RAP binder(s)}} + x_{\text{rejuvenator}}) \quad [4]$$

$$VBI_\beta = \sum_{i=1}^{n} x_i . VBI_i \quad [5]$$

$$\mu = 10^{\left(\frac{3VBI_\beta}{1 - VBI_\beta} - 3\right)} \quad [6]$$

Where:

ϑ_i: Viscosity of the ith component (Pa.s)

VBI_i: Viscosity Blending Index of ith component

$x_{\text{RAP binder(s)}}$: RAP binder volume fraction (calculated separately for each RAP fraction, if two or more RAP fractions used, e.g. 10 mm and 14 mm)

$x_{\text{rejuvenator}}$: Rejuvenator oil volume fraction

$x_{\text{virgin binder}}$: Virgin binder volume fraction

VBI_β: Viscosity blending index of the blend

x_i: Volume fraction of the ith component

μ: Viscosity of the blend (Pa.s)

The following simplifying assumption is made when using the above equations:

- The difference between densities of the blend components can be ignored/neglected (i.e. it is acceptable to assume that the RAP binder(s), virgin binder and the rejuvenator oil/agent (if used) have the same densities).

The flowchart of the binder blend viscosity calculations is shown in Figure 4.3.2(a).

Figure 4.3.2(a) – Binder blend viscosity process flowchart

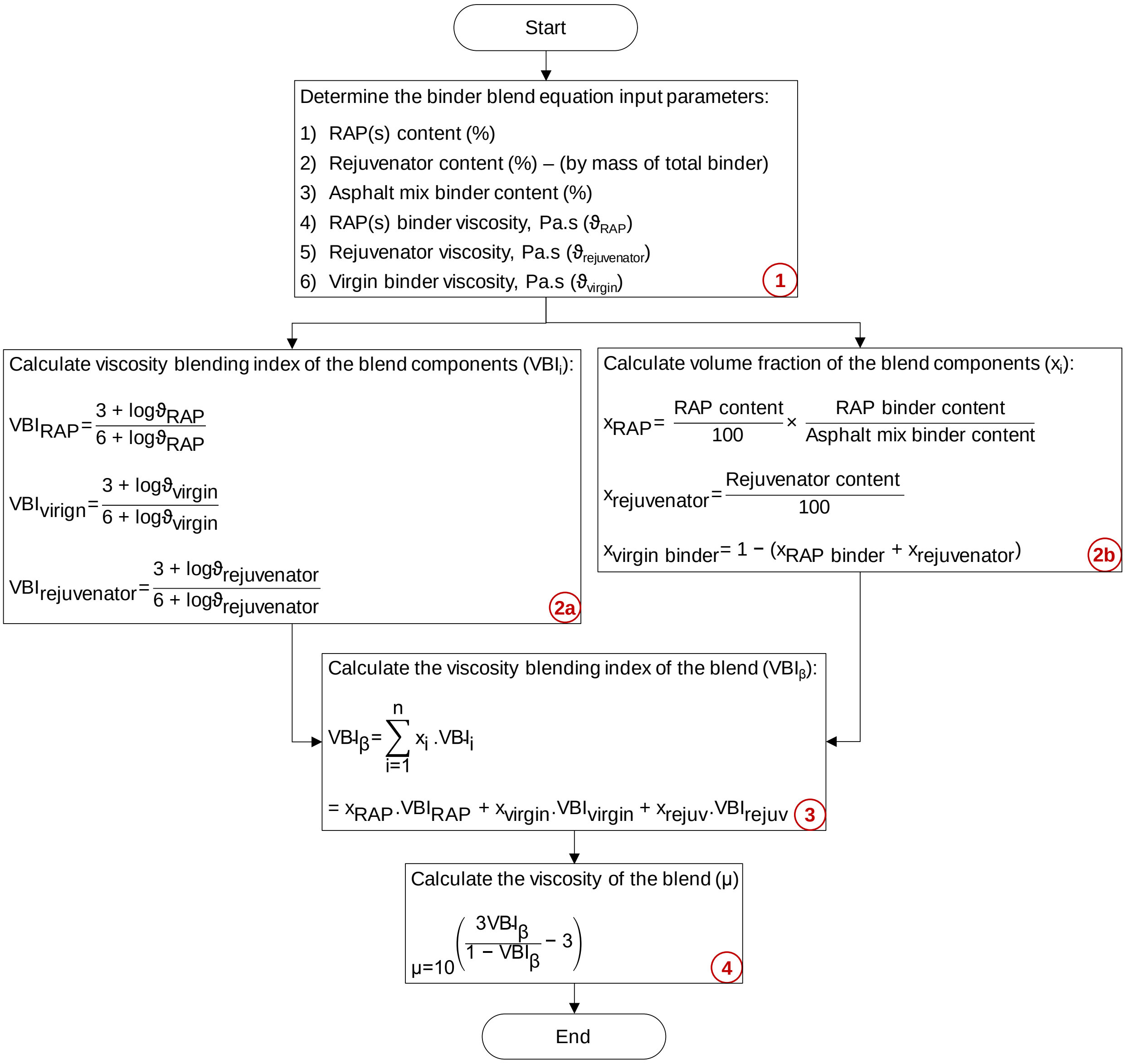
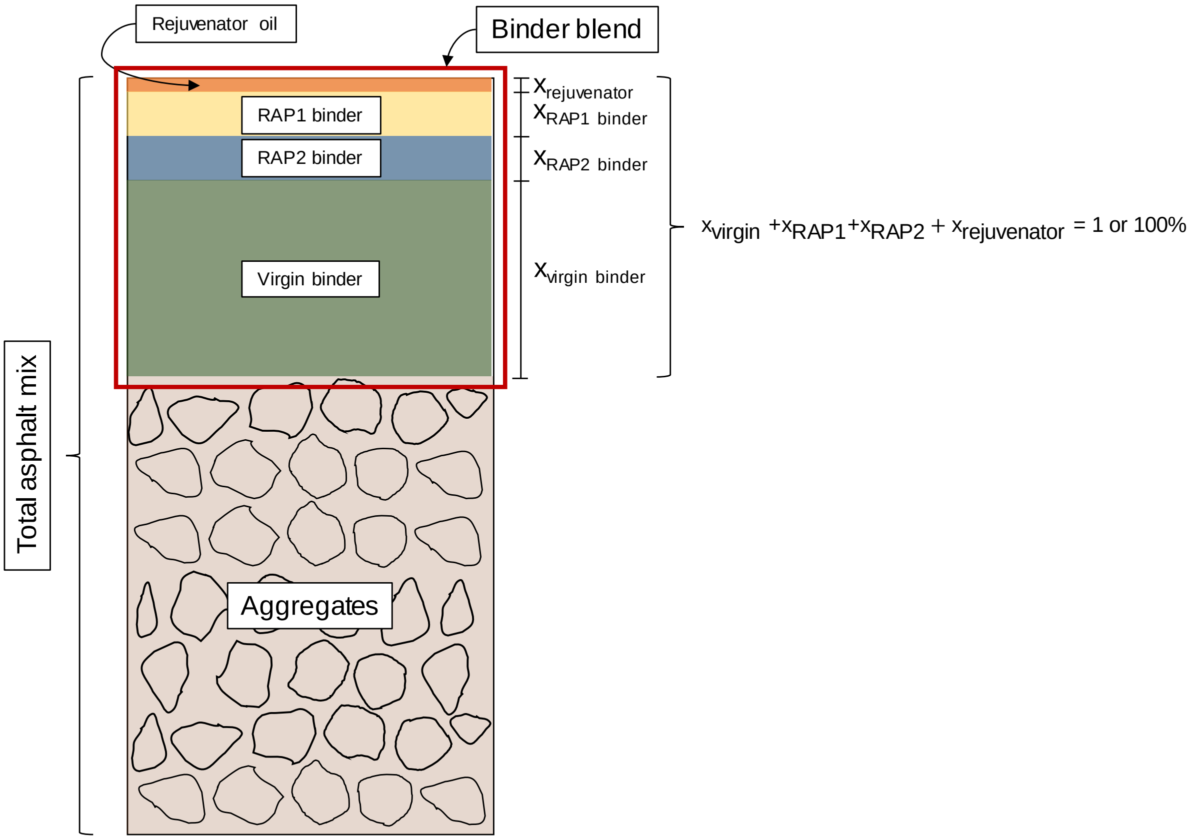


Figure 4.3.2(b) following is a schematic diagram of an asphalt mix containing RAP and rejuvenator oil. Figure 4.3.2(b) helps in better understanding the definition of the binder blend equation parameters such as the volume fraction of the blend components. Volume fractions are the contribution of each blend component to the total binder blend as illustrated in Figure 4.3.2(b).

Figure 4.3.2(b) – Binder blend components schematic diagram



4.3.2.2 Example of binder blend viscosity calculations

In this section, a practical example is provided to show the steps required to calculate the binder blend viscosity when two sources of RAP and a rejuvenator oil are added to an asphalt mix, where the target blend viscosity at 60ºC is 600 – 880 Pa.s (for C600 bitumen) as per Table 4.3.3(a). (Normally the process would be iterative. This example is simplified as only one iteration is needed/shown.)

Input Parameters:

- Total RAP content (by mass) in the asphalt mix: 30%
- RAP fraction 1 content in the asphalt mix: 20%
- RAP fraction 2 content in the asphalt mix: 10%
- RAP fraction 1 binder content (by mass): 4.4%
- RAP fraction 2 binder content (by mass): 2.8%
- Rejuvenating oil content (by mass of total binder): 3.6%
- Asphalt mix total binder content (by mass): 4.5%
- Virgin binder viscosity at 60ºC: 600 Pa.s (Class 600 bitumen)
- Rejuvenating oil viscosity at 60ºC: 0.02 Pa.s
- RAP fraction 1 binder viscosity at 60ºC: 19800 Pa.s
- RAP fraction 2 binder viscosity at 60ºC: 15700 Pa.s

Calculations:

1. The viscosity blending index of the blend components (virgin binder, RAP fractions 1 and 2 and rejuvenator agent in this example) are calculated by Equation 1.
2. Calculation of volume fraction of the blend components: volume fractions of each blend component are calculated through Equation 2 through to 4.
3. The viscosity blending index of the binder blend (VBI_β) can then be calculated using Equation 5.
4. Once VBI_β is obtained, the viscosity of the binder blend can be calculated by Equation 6.
5. Summary: adding 30% RAP in total (including 20% RAP #1 fraction and 10% RAP #2 fraction) to an asphalt mix with the given details (above) will result in a binder blend viscosity of 600 Pa.s.

$$VBI_{virgin\ binder} = \frac{3 + \log 600}{6 + \log 600} = 0.6582$$

$$VBI_{RAP1\ binder} = \frac{3 + \log 19800}{6 + \log 19800} = 0.7086$$

$$VBI_{RAP2\ binder} = \frac{3 + \log 15700}{6 + \log 15700} = 0.7058$$

$$VBI_{rejuvenator} = \frac{3 + \log 0.02}{6 + \log 0.02} = 0.3025$$

$$x_{RAP1} = \frac{20}{100} \times \frac{4.4}{4.5} = 0.1956$$

$$x_{RAP2} = \frac{10}{100} \times \frac{2.8}{4.5} = 0.0622$$

$$x_{rejuvenator} = \frac{3.6}{100} = 0.0360$$

$$x_{virgin} = 1 - (0.1956 + 0.0622 + 0.0360) = 0.7062$$

$$VBI_\beta = \sum_{i=1}^{n} x_i . VBI_i = 0.7062 \times 0.6582 + 0.1956 \times 0.7086 + 0.0622 \times 0.7058 + 0.0360 \times 0.3025$$

$$= 0.6582$$

$$\mu = 10^{\left(\frac{3VBI_\beta}{1 - VBI_\beta} - 3\right)} = 10^{\left(\frac{3 \times 0.6582}{1 - 0.6582} - 3\right)} = 600 \text{ Pa.s}$$

4.3.3 Target binder blend viscosity at 60ºC

Table 4.3.3(a) outlines the binder blend viscosity at 60ºC the Contractor must target in production. Achieving consistent compliance with this requirement will typically requirement adjustment to one of the following:

- binder class
- percentage of RAP, or
- percentage of rejuvenating oil.

Table 4.3.3(a) – Target viscosity at 60ºC for binder blend

Specified Binder Class	Target Binder Blend Viscosity at 60ºC (Pa.s)
C320	320 – 500
C450	430 – 640
C600	600 – 880

Calculations are made using:

- design (target) binder content for the mix
- percentage of rejuvenating oil to be used (where applicable)
- percentage of RAP(s) to be used in the mix, and
- binder content and binder viscosity at 60ºC results for the five most recent RAP stockpile results.

For example, calculations would need to be completed every time there is a new RAP stockpile to be used. Therefore, each stockpile must be tested for binder content and RAP binder viscosity at 60ºC prior to use.

Given that the bitumen viscosity at 60ºC for the virgin binder is typically not tested for each day's production, the virgin binder viscosity at 60ºC given in Table 4.3.3(b) is used for these calculations.

Table 4.3.3(b) – Assumed viscosity at 60ºC for the virgin binder

Binder Class	Viscosity at 60ºC (Pa.s)
C170	170
C240	240
C320	320
C450	430
C600	600

4.3.4 Examples

4.3.4.1 General

Examples of how the Contractor could demonstrate compliance with the binder blend viscosity at 60ºC requirements are outlined in the following sections.

The following assumptions are used for these example calculations:

- binder content of the mix is 4.5% by mass
- the specified binder class for the work is Class 600 bitumen
- binder class to be used in the mix (where rejuvenating oil is not used) is Class 320 bitumen
- target RAP content is 30% (consisting to 20% 'fine RAP' and 10% 'coarse RAP')
- viscosity at 60ºC of the rejuvenating agent is 0.02 Pa.s
- target rejuvenating oil content is 3.2% (by mass of the total binder) where a rejuvenating oil is used, and
- binder content and viscosity at 60ºC of RAP (over time) is listed in Table 4.3.4.1.

Table 4.3.4.1 – Properties of RAP used for example calculations

Fine RAP Stockpile			Coarse RAP Stockpile		
Stockpile Number	**Binder Content (%)**	**Binder Viscosity at 60ºC (Pa.s)**	**Stockpile Number**	**Binder Content (%)**	**Binder Viscosity at 60ºC (Pa.s)**
1F	4.4	19800	1C	2.8	15700
2F	4.5	29100	2C	2.6	25000
3F	4.8	15000	3C	3.2	9760
4F	4.6	27400	4C	2.7	35200
5F	4.1	21100	5C	2.5	15800
6F	4.6	19300	6C	2.5	23200
7F	4.5	13900	7C	2.6	15900
8F	4.2	20400	8C	2.5	14000
9F	4.4	11500	9C	2.7	18000
10F	4.1	25100	10C	2.8	12300
11F	4.6	23600	11C	3	14200
12F	4.7	13300	12C	2.8	18600

4.3.4.2 Checking compliance

Examples of how the Contractor could check compliance with the binder blend viscosity at 60ºC requirements are outlined in Appendix A.

5 Determination of effective binder volume for mixes containing RAP

The effective binder volume requirement for mixes containing RAP shall be determined using the Q311 and the percentage of absorbed binder is determined using the binder absorption/water absorption relationship referenced in Q311. The amount of binder absorption of RAP aggregate shall be assumed to be 0.4% by mass of aggregate.

Appendix A: Examples of Checking Compliance of the Viscosity of the Binder Blend using Method 2

Example 1 – Checking the added binder (virgin binder) class complies with the target binder blend viscosity range (C600 in this example)

Stockpile	Total RAP %	RAP proportions (%)		Rejuv.	Binder content (%)			Viscosity (θ_i Pa.s)				Volume fraction (x_i%)				Viscosity index (VBI_i)				VBI_β	Blend viscosity	
	(fine:coarse)	RAP 1	RAP 2	%	RAP 1	RAP 2	Asphalt mix	RAP 1	RAP 2	Virgin	Rejuv.	RAP 1	RAP 2	Virgin	Rejuv.	RAP 1	RAP 2	Virgin	Rejuv.		(600 - 880 Pa.s)	
																					Individual result	Average of the 5 most recent results
1	30 (2:1)	20.0	10.0		4.4	2.8	4.50	19800	15700	320		19.56	6.22	74.22		0.7086	0.7058	0.6473		0.6629	794	794
2	30 (2:1)	20.0	10.0		4.5	2.6	4.50	29100	25000	320		20.00	5.78	74.22		0.7133	0.7115	0.6473		0.6642	858	826
3	30 (2:1)	20.0	10.0		4.8	3.2	4.50	15000	9760	320		21.33	7.11	71.56		0.7052	0.6997	0.6473		0.6634	816	823
4	30 (2:1)	20.0	10.0		4.6	2.7	4.50	27400	35200	320		20.44	6.00	73.56		0.7126	0.7155	0.6473		0.6647	887	839
5	30 (2:1)	20.0	10.0		4.1	2.5	4.50	21100	15800	320		18.22	5.56	76.22		0.7094	0.7058	0.6473		0.6619	744	820
6	30 (2:1)	20.0	10.0		4.6	2.5	4.50	19300	23200	320		20.44	5.56	74.00		0.7083	0.7106	0.6473		0.6633	811	823
7	30 (2:1)	20.0	10.0		4.5	2.6	4.50	13900	15900	320		20.00	5.78	74.22		0.7042	0.7059	0.6473		0.6621	754	802
8	30 (2:1)	20.0	10.0		4.2	2.5	4.50	20400	14000	320		18.67	5.56	75.78		0.7090	0.7043	0.6473		0.6620	750	789
9	30 (2:1)	20.0	10.0		4.4	2.7	4.50	11500	18000	320		19.56	6.00	74.44		0.7018	0.7075	0.6473		0.6615	731	758
10	30 (2:1)	20.0	10.0		4.1	2.8	4.50	25100	12300	320		18.22	6.22	75.56		0.7115	0.7027	0.6473		0.6624	771	763
11	30 (2:1)	20.0	10.0		4.6	3.0	4.50	23600	14170	320		20.44	6.67	72.89		0.7108	0.7045	0.6473		0.6641	852	771
12	30 (2:1)	20.0	10.0		4.7	2.8	4.50	13300	18600	320		20.89	6.22	72.89		0.7037	0.7079	0.6473		0.6628	790	779

R_{ejuv}% is expressed as the percentage (by mass) of the total binder content

VBI_β: Blend viscosity index

Example 2 – Checking the rejuvenation oil content complies with the target binder blend viscosity range (C600 in this example)

Stockpile	Total RAP %	RAP proportions (%)		Rejuv.	Binder content (%)			Viscosity (θ_i Pa.s)				Volume fraction (x_i%)				Viscosity index (VBI_i)				VBI_β	Blend viscosity (600 - 880 Pa.s at 60°C)	
	(fine:coarse)	RAP 1	RAP 2	%	RAP 1	RAP 2	Asphalt mix	RAP 1	RAP 2	Virgin	Rejuv.	RAP 1	RAP 2	Virgin	Rejuv.	RAP 1	RAP 2	Virgin	Rejuv.		Individual result	Average of the 5 most recent results
1	30 (2:1)	20.0	10.0	3.2	4.4	2.8	4.50	19800	15700	600	0.02	19.56	6.22	71.02	3.20	0.7086	0.7058	0.6582	0.3025	0.6597	653	653
2	30 (2:1)	20.0	10.0	3.2	4.5	2.6	4.50	29100	25000	600	0.02	20.00	5.78	71.02	3.20	0.7133	0.7115	0.6582	0.3025	0.6609	705	679
3	30 (2:1)	20.0	10.0	3.2	4.8	3.2	4.50	15000	9760	600	0.02	21.33	7.11	68.36	3.20	0.7052	0.6997	0.6582	0.3025	0.6598	659	672
4	30 (2:1)	20.0	10.0	3.2	4.6	2.7	4.50	27400	35200	600	0.02	20.44	6.00	70.36	3.20	0.7126	0.7155	0.6582	0.3025	0.6614	725	685
5	30 (2:1)	20.0	10.0	3.2	4.1	2.5	4.50	21100	15800	600	0.02	18.22	5.56	73.02	3.20	0.7094	0.7058	0.6582	0.3025	0.6588	621	673
6	30 (2:1)	20.0	10.0	3.2	4.6	2.5	4.50	19300	23200	600	0.02	20.44	5.56	70.80	3.20	0.7083	0.7106	0.6582	0.3025	0.6600	666	675
7	30 (2:1)	20.0	10.0	3.2	4.5	2.6	4.50	13900	15900	600	0.02	20.00	5.78	71.02	3.20	0.7042	0.7059	0.6582	0.3025	0.6588	621	658
8	30 (2:1)	20.0	10.0	3.2	4.2	2.5	4.50	20400	14000	600	0.02	18.67	5.56	72.58	3.20	0.7090	0.7043	0.6582	0.3025	0.6589	624	651
9	30 (2:1)	20.0	10.0	3.2	4.4	2.7	4.50	11500	18000	600	0.02	19.56	6.00	71.24	3.20	0.7018	0.7075	0.6582	0.3025	0.6583	603	627
10	30 (2:1)	20.0	10.0	3.2	4.1	2.8	4.50	25100	12300	600	0.02	18.22	6.22	72.36	3.20	0.7115	0.7027	0.6582	0.3025	0.6593	640	631
11	30 (2:1)	20.0	10.0	3.2	4.6	3.0	4.50	23600	14170	600	0.02	20.44	6.67	69.69	3.20	0.7108	0.7045	0.6582	0.3025	0.6607	694	636
12	30 (2:1)	20.0	10.0	3.2	4.7	2.8	4.50	13300	18600	600	0.02	20.89	6.22	69.69	3.20	0.7037	0.7079	0.6582	0.3025	0.6594	644	641

R_{ejuv}% is expressed as the percentage (by mass) of the total binder content

VBI_β: Blend viscosity index