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Theoretical analysis of waste cooking oil rejuvenator in reclaimed asphalt for sustainable hot asphalt mix preparation at the Área Metropolitana de Bucaramanga

Danna Peñaloza [a], Danna Vásquez [a], Valentina Valdivieso [a], Yeison Jaramillo [a], Vladimir Plata [b] & Paalo Moreno [a]

[a] *Facultad de Ingeniería Civil, Universidad Santo Tomás de Colombia, Bucaramanga, Colombia. danna.penaloza@ustabuca.edu.co, danna.vasques@ustabuca.edu.co, valentina.valdivieso@ustabuca.edu.co, yeison.jaramillo@ustabuca.edu.co, paalo.moreno@ustabuca.edu.co, paaloandrea@gmail.com*
[b] *Departamento de Ciencias Básicas, Universidad Santo Tomás de Colombia, Bucaramanga, Colombia. vladimir.plata@ustabuca.edu.co*

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Abstract
Reusing reclaimed asphalt pavements (RAPs) provides economic, social, and environmental benefits. To improve the performance of these materials, rejuvenating agents such as waste cooking oil (WCO) have been implemented. The annual amounts of RAP and WCO available in the Área Metropolitana de Bucaramanga (AMB) were calculated to be 32 thousand and 22 thousand tons per year, respectively. Subsequently, international standards were reviewed and compared with Colombian regulations to establish a methodology to determine the appropriate percentage of WCO to add to RAP for hot asphalt mix preparation. The authors suggest investigating WCO levels from 3% to 6% and selecting the percentage that reestablishes the penetration grade (INV-E-706-13), softening point (INV-E-712-13), and viscosity (INV-E-717 -13) of asphalt binder. For hot asphalt mix preparation, the authors propose using the Marshall method and determining the appropriate percentage of asphalt according to stability and flow tests (INV-E-748-13), percent air voids (INV-E-736-13), and bulk density (INV-E-733-13).

Keywords: waste cooking oil; reclaimed asphalt pavement; asphalt rejuvenator; sustainable construction.

Análisis teórico del aceite residual de cocina como rejuvenecedor del asfalto recuperado para la preparación de mezclas asfálticas en caliente sostenibles en el Área Metropolitana de Bucaramanga

Resumen
Reutilizar pavimentos asfálticos recuperados (RAP) implica beneficios económicos, sociales y ambientales. Para mejorar el desempeño del material se ha implementado la utilización de agentes rejuvenecedores como el aceite residual de cocina (WCO). Se calculó la cantidad anual de RAP y WCO disponible en el Área Metropolitana de Bucaramanga (AMB) siendo 32 mil y 22 mil toneladas anuales respectivamente. Posteriormente se realizó una revisión de estándares internacionales que se compararon con la normativa colombiana para establecer la metodología para determinar el porcentaje apropiado del WCO en el RAP y para la preparación de mezclas asfálticas en caliente. Se sugiere experimentar rangos del 3%-6% de WCO y seleccionar el porcentaje que reestablezca la penetración (INV-E-706-13), punto de ablandamiento (INV-E-712-13) y viscosidad (INV-E-717-13). Para la preparación de la mezcla asfáltica en caliente se propone el método Marshall determinando el porcentaje adecuado de asfalto según los ensayos de estabilidad y flujo (INV-E-748-13), porcentaje de vacíos (INV-E-736-13) y densidad bulk (INV-E-733-13).

Palabras Clave: aceite residual de cocina; pavimento asfáltico recuperado; rejuvenecedor asfáltico; construcción sostenible.

1 Introduction

Asphalt mixtures are widely used as layers in pavements worldwide, and it is estimated that more than one billion tons of asphalt mix are produced annually to be used in pavements [1]. The ability of asphalt to endure the loads that it undergoes while guaranteeing durability and economy for contractors and safety and comfort for users makes it an ideal material

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for the construction industry. However, to produce large amounts of asphalt mix, it is necessary to use large amounts of virgin materials and energy, which consequently has a negative impact on the environment [2]. In recent years, the incorporation of recovered asphalt pavements (RAPs) for the design of asphalt mixtures has grown in response to these environmental considerations.

The incorporation of RAP into asphalt mixtures reduces production costs and the material's carbon footprint [2]. However, this practice could affect the physical and rheological properties of asphalt mixtures.

To solve this issue, the asphalt contained in RAP is subjected to a rejuvenation process using different agents, such as waste cooking oil (WCO). Although the total world production of WCOs is not known exactly, it is estimated that more than 16 million tons of WCO are produced annually by the largest generators (China, Malaysia, USA, Europe, Taiwan, Canada, and Japan). When this waste is released in aquatic environments, it has negative effects on marine life, increases the cost of drinking water purification, and reduces the useful life of pipes by causing obstructions [3].

Several authors have described the benefits of incorporating WCO in the design of asphalt mixtures, alluding to improvements in resistance to fatigue cracking, short-term aging (mixing and construction), and low-temperature cracking as well as an improvement in the material stability and resistance to humidity compared to asphalt mixtures with RAP contents that do not undergo a rejuvenation process. It should also be mentioned that WCO modifies the viscosity of asphalt [4-6].

Although the practice has been tested in different parts of the world, it is unknown whether it is feasible to implement it in the context of Área Metropolitana de Bucaramanga (AMB), Colombia.

However, a previous study conducted by one of the authors characterized the WCO produced in the AMB. In that study, samples of WCO were collected from several restaurants. Palmitic acid (C16:0) and oleic acid (C18:1) were the primary fatty acids of all the samples. Regarding the physicochemical properties, the acid value varied from 1 to 9 mg KOH/g (AOAC 940.28); the peroxide value was between 2 and 13 meq O2/kg (AOAC 965.33), and the dynamic viscosity at 40 ◦C varied from 34 to 73 cP. The high variability is due to the different frying conditions such as cooking temperature, time of use and length of reuse [7].

It is necessary to specify whether RAP and WCO are available in the city and quantities are sufficient for this application.

Along with the lack of this information, there is uncertainty regarding the methods and quantities of RAP and WCO to use in the mix design process. Additionally, it is unknown whether the tests proposed by local regulations comply with international standards for the performance of asphalt mixtures in laboratory measurements.

To address these concerns, a systematic review of the literature in databases was proposed to identify the availability of RAP and WCO within the AMB and establish the appropriate methodology for preparation of a hot mix asphalt incorporating rejuvenated RAP with WCO in the AMB.

2 Methodology

This research was developed through a search for information framed by explanatory, descriptive, analytical, and projective concepts. A theoretical analysis was carried out on the availability of RAP and WCO and their rejuvenating effect on the physical and chemical properties of the asphalt contained in RAP for the preparation of new hot mix asphalt in AMB.

2.1 RAP quantity determination in the AMB

To collect information about the quantity of RAP available within the AMB, the INVIAS projects database was used [8]; the search criteria were limited to the Santander department between 2015 and 2021, and then projects exclusively located inside the AMB were selected autonomously. This made it possible to identify road construction and rehabilitation projects in the area. All the road projects under consideration were assumed to involve road rehabilitation.

First, it was necessary to know the RAP volume. The length and width of the pavements in projects are reported in the INVIAS database. A thickness of 5 cm was chosen for the compacted asphalt layer, considering that the thickness of the tread layer varies in the 4-7.5 cm range [9]. Then, the mass calculation was performed assuming the pavement density to be 1.5 T/m^3 [10].

2.2 WCO quantity determination in the AMB

To collect information on the amount of WCO available within the AMB, local newspapers [11] and government documents [12] were used as sources of information.

The literature search made it possible to identify the WCO deposit points and the sectors involved, the number of liters that were produced annually, and the type of oil used since 2015.

2.3 Systematic literature review (SLR)

To collect pertinent and updated information regarding asphalt rejuvenation, a systematic review of the literature was carried out in an indexed database and another database belonging to a government entity to establish the current regulations.

The SLR was developed in two databases: SCOPUS and the INVIAS database.

In the SCOPUS database, the procedure followed was as follows:

1. The collection, characterization, and incorporation of RAP in the preparation of new asphalt mixtures along with the rejuvenating effect of WCO on the physical and chemical properties of the asphalt contained in RAP for the preparation of new hot asphalt mixtures were selected as keywords.
2. Irrelevant information was excluded by eliminating duplicate documents, examining the titles and abstracts, and establishing the period, study areas, and other details. Additionally, articles that did not consider aged asphalt, rejuvenation methods, or other types of rejuvenators were excluded, as were articles published before 2015.

3. A bibliometric analysis of articles was conducted by year of publication, country, institution, and type of document.

In the INVIAS database, the document search considered the following parameters:

1. Pavement state-required before recycling.
2. Procedure for pavement collection before recycling.
3. Storage and treatment of RAP after recycling.
4. Tests that are conducted on RAP to verify the state in which it is found and thus to determine the percentage can be included in accordance with the values recommended by INVIAS

The documents selected in this stage were the input for the development of stages 2.4 to 2.6

2.4 *Ways to collect, characterize and incorporate RAP in the preparation of new asphalt mixtures*

To tabulate the information regarding RAP collection, the following parameters were considered: the place of collection, collection method, dimensions of the RAP, and percentage of asphalt present in the RAP.

To tabulate the information regarding RAP characterization, the most used tests in the articles reviewed in the SLR were considered. Subsequently, these tests were compared with those carried out by INVIAS to find similarities with international standards.

Finally, to determine the appropriate methodologies for incorporation of RAP in new asphalt mixtures, the following parameters were analyzed in the documents selected in the SLR: percentage of RAP incorporated in the mixture, virgin particle size, adequate percentage of asphalt, and mixing temperature, type, and time.

2.5 *Ranges and appropriate methodology for WCO incorporation as a RAP rejuvenator*

Since selected SLR articles, the methods to incorporate WCO as a rejuvenator in RAP and the appropriate ranges of incorporation were determined. Additionally, the effect of the composition of WCO on the physical and chemical properties of asphalt contained in RAP was identified with respect to the composition of the asphalt, i.e., the SARA (saturated, aromatic, resins, asphalt) content.

Eventually, the appropriate methodology was proposed to find the suitable WCO percentage to restore the properties of asphalt present in the AMB RAP.

2.6 *Preparation of new hot asphalt mix incorporating RAP rejuvenated with WCO.*

According to the articles selected in the SLR, the appropriate methodology was established for preparing a new hot asphalt mix incorporating RAP rejuvenated with WCO. The percentage of rejuvenated RAP replacement was selected.

3 Results

The results obtained using the methodology described in the previous section are explained below.

3.1 *RAP quantity determination in AMB*

Table 1 shows the identification number and dimensions of each of the road rehabilitation projects within the AMB. In total, four projects were considered: Project 1 corresponds to the "Extension of the Eastern Parallel of the Floridablanca-Bucaramanga Highway (Tcc Molinos Section)", Project 2 corresponds to the "Girón - Floridablanca Ring Road Returns Project", Project 3 corresponds to the "Bucaramanga - Barrancabermeja - Yondó" road and Project 4 corresponds to the "Bucaramanga - Pamplona" road.

Projects 1 and 2 are completed, while projects 3 and 4 are under construction

According to the information provided, a RAP volume of approximately 21,000 m^3, equivalent to 32,000 tons of recycled asphalt pavement by 2021, could be reused in the preparation of new hot asphalt mixes.

3.2 *WCO quantity determination in the AMB*

Colombia is the largest producer of palm oil in America and the fourth-largest producer worldwide. This industry represents 7% of the country's agricultural gross domestic product (GDP) [13]. This is demonstrated in 464,000 hectares of oil palm planted [14], distributed in 21 departments and 161 municipalities, with the eastern part of the country leading the figures for crude palm oil production [13].

Regarding consumption, the National Federation of Oil Palm Growers (Fedepalma) reports that during the period from January to March 2021, the country consumed 310,000 tons of palm oil, and although imports of vegetable oil decreased, sales of national production increased by 12% during the same period [12].

Within the country, producers, marketers, and distributors must comply with the correct handling of this substance, working together with authorized managers and complying with resolution 316 of 2018 of the Ministry of Environment and Sustainable Development [15].

In the AMB, Grasecol (Grasas Ecológicas de Colombia S.A. S) is the only authorized manager. They are the first link in the WCO recycling chain in addition to commercially managing it to be transformed, a process that does not exist in Colombia [11].

To collect the WCO, the company works with different entities, such as restaurants, residential complexes, and six "clean points", where citizens can deposit their used oil if it meets the following standards: it is not contaminated with water or has a bad smell, and it is packaged in such a way that no spillage occurs [16].

From these strategies, according to the sources consulted in the AMB and GRASECOL, 21 thousand liters per month or 1890 tons per month of WCO are obtained (considering its density as 90,000 kg/m^3 [17]), which are collected by the entities that are part of this initiative.

The AMB has more than 22 thousand tons per year of WCO that can be implemented for the rejuvenation of RAP instead of being discarded.

Table 1.
Dimensions of the road rehabilitation projects located in the AMB

Projects	Length (m)	Width (m)	Thickness (m)	Reference
Project 1	2,000	7.0	0.05	[8]
Project 2	10,000	7.0	0.05	[8]
Project 3	12,400	10.3	0.05	[8]
Project 4	28,500	7.3	0.05	[8]

Source: Own elaboration

3.3 Systematic literature review (SRS)

The search was run using keywords and Boolean operators. Four search equations were used:

Equation 1: [RAP] AND [Recycled] AND [Asphalt] AND [Pavement]

Equation 2: [Rejuvenator OR Rejuvenation OR Recycling Agent OR Waste Oil] AND [Asphalt OR Bitumen OR Reclaimed Asphalt Pavement

Equation 3: [Implementing OR effects OR methods] AND [Waste Oils with Reclaimed Asphalt Pavement OR Waste cooking oil]

Equation 4: [Pavement OR Asphalt Pavement] [Rejuvenator OR Rejuvenation OR Bio-Oils OR Waste Oils OR Recycling Agent]

Table 2 shows the number of initial records, which is the initial amount of information found in the databases, and the number of final records, which is the number of documents that were used for the preparation of the article after conducting a review and excluding information not pertinent to the research topic.

These results were obtained by considering only documents relevant to engineering published between 2015 and 2021 and research articles, reviews, and conference papers in the final stage of publication written in English or Spanish.

The bibliometric analysis was carried out from the metrics obtained by SCOPUS. During the period 2018-2019, the publication of articles on this subject increased considerably. The leaders in this area are China and the United States.

The second part of the SLR was carried out through the INVIAS portal. Relevant standards were sought in the recycling, pretreatment, and incorporation of RAP in the manufacture of hot asphalt mix. In this way, the following titles of the standards were obtained.

3.4 Ways to collect, characterize and incorporate RAP in the preparation of new asphalt mixtures

This stage was carried out by the 11 documents obtained through the SLR in Eq. (1) mentioned in Table 2 and the standards presented in Table 3

The results for the collection, characterization, and incorporation of RAP are presented below:

The collection of RAP samples can be done by two methods: recycling in plants and milling.

In-plant recycling consists of obtaining samples collected from production leftovers or mixtures that are not used because they do not present the standard manufacturing conditions to be able to carry out their commercialization [18].

Table 2.
Results of the SRL in specialized databases

Search Equation	Number of Initial Records	Number of Final Records
Equation 1	97	11
Equation 2	14	1
Equation 3	170	5
Equation 4	142	13

Source: Own elaboration

Table 3.
Results of the SRL in the INVIAS database

Title	INVIAS	Reference
General provisions for the execution of priming, bonding, and curing irrigation, surface treatments, asphalt sand seals, asphalt grouts, hot and cold asphalt mixtures, and recycling of asphalt pavements	Artículo 400	[18]
Continuous Grade Hot Mix Asphalt (Asphalt Concrete)	Artículo 450	[18]
Asphalt pavement milling	Artículo 460	[18]
In-place hot recycling for asphalt pavement	Artículo 462	[18]
Penetration grade of bituminous materials	INV E-706	[19]
Asphalt viscosity determination using a rotational viscometer	INV E-717	[19]
Quantitative extraction of asphalt in pavement mixtures	INV E-732	[19]
Granulometric analysis of aggregates extracted from asphalt mixtures	INV E-782	[19]
Determination of the proportion and grade of recycling agent in asphalt concrete hot mixtures with recycled material	INV E-812	[19]

Source: Own elaboration

Milling refers to the process that occurs in a place with a milling machine, where the asphalt layer is lifted, and the grind size obtained does not exceed 1 inch or 2.54 cm in diameter [18].

Ten of the eleven articles reviewed had information about the methodology used to collect the RAP. In 3 investigations, plant recycling was used [20-22], and in the remaining 7, the milling technique was used [23-29].

According to INVIAS, the standard that describes the process of collecting and storing recycled material is INV E 462-13 [18]. This standard emphasizes that this material must be recycled through partial or total disintegration of asphalt layers according to the cutting depths indicated in the project documents or by the Controller. Additionally, it should be stored for the shortest time possible to prevent the material from absorbing an excessive amount of water.

Loading, transportation, and unloading of disaggregated material at collection sites are described by Articles 460-13. [18]

After collecting and storing RAP, it is necessary to characterize a sample to observe its initial state and verify whether it meets the minimum parameters required for reuse. The appropriate methodology for RAP characterization is presented below [18].

Out of the 11 documents in Eq. (1) of Table 2, 5 articles [22,26,28-30] presented tests for RAP characterization;

penetration grade, viscosity, asphalt quantitative extraction, Marshall test, and softening point test are the most used methods.

INVIAS establishes the following: asphalt quantitative extraction tests INV-E-732-13, aggregate granulometric analysis INV-E-782-13, penetration grade INV-E-706-13, recovered binder softening point INV-E-712 -13 and Marshall test INV-E-748-13 for RAP characterization [19].

A viscosity test is also suggested by INVIAS, but it should be applied only to recovered asphalt since it is necessary to know the asphalt binder state [19].

Similarity exists between the applied methodologies in the cases studied and the INVIAS standards since the tests applied are the same.

Finally, RAP incorporation in new asphalt mixture preparation considers parameters such as the RAP percentage, the particle size of virgin aggregate, adequate asphalt percentage for mixture balance, and mixture temperature. The SLR showed that according to country and local regulations, the RAP incorporation percentage varies.

Countries such as Japan have RAP percentage incorporations from 30% to 100%, with an average of 47% [31], whilst in Colombia, the maximum percentage allowed is 40% (INV E-812-13) [19]. This shows the possibility of increasing the percentage established by INVIAS standards in the coming years.

The procedure proposed by INVIAS for recycling and incorporating RAP is described in the INV E 812-13 standard [19].

3.5 Ranges and appropriate methodology for RAP rejuvenation

The SLR provided the following results:

First, three (3) methods were found for the incorporation of WCO as a rejuvenator of aged asphalt binder.

The first method is the mixing method, which is divided into two parts. It is first necessary to find the oil percentage that restores the properties of the asphalt recovered from the RAP. For this, extracted asphalt is mixed with a rejuvenator at different percentages under certain conditions of time, temperature, and mixing speed. Then, with the oil percentage that restores the properties, it is possible to prepare hot asphalt mix and mix RAP and WCO with aggregates and virgin asphalt [1, 32].

The second method is the spray method, which involves spraying a rejuvenator onto the surface of asphalt layers. This method can be used for preventive maintenance in the first 3-4 years of new pavement construction to delay or mitigate the appearance of cracks in the surface [1].

The third method is the encapsulation method in which thermally stable capsules are added and must be homogeneously dispersed in hot asphalt mixes before compaction when they break and release rejuvenator that can change the chemical structures of the cracks. The method is divided into three phases: first, the capsule is embedded in the asphalt mixtures and must withstand traffic loads; second, high traffic loads and asphalt aging force the capsule to crack; and third, The capsule releases rejuvenator due to increased pressure [1,32].

According to the 19 documents obtained from the search Eqs. (2) - (4) mentioned in Table 2, the most used method for incorporating the oil is the mixing method, which was mentioned in 11 of the articles [1,2,32-40]

Regarding the oil content range, the dose and type of rejuvenating agent must be adequate to produce an asphalt mixture. Some authors have confirmed that the dose of rejuvenator should be carefully selected considering the virgin binder properties and the RAP binder since their interaction influences the final performance of the asphalt mixture [1,2,41].

Adequate rejuvenator content should be calculated to recover the four basic properties of penetration grade, softening point, viscosity, and ductility, and simultaneously in this classification system, penetration grade, softening achieve the virgin binder performance grade (PG) [1].

Penetration grade, softening point, and ductility are empirically correlated with asphalt binder performance. Therefore, asphalt binders with high ductility and penetration grade values and low softening points are usually more appropriate for cold weather conditions, whereas asphalt binders with low penetration grade and ductility values and high softening points are appropriate for hot weather conditions [6].

Additionally, due to differences in the physical properties and chemical composition of rejuvenators, their effects on the properties of asphalt binders are variable.

According to the SLR, in general, adding WCO increases penetration grade and ductility values and decreases the softening point and viscosity. These changes are due to alteration of the asphalt chemical composition, i.e., reduction of the asphaltene/maltene proportion. This does not mean that the asphaltene/maltene composition is restored to its original value in the virgin asphalt state [1,4,5-6,34].

Table 4 reports the effect and the theoretical basis regarding the impact of WCO on RAP.

The WCO content is selected to reestablish the parameters analyzed at the virgin asphalt level mentioned in Table 4 and related to the asphalt binder state in RAP. It should be noted that the older the binder is, the higher the dose of rejuvenator necessary to recover the basic control properties [5].

Table 4.
WCO effects on aged asphalt

Property	Effect	Justification	Reference
Penetration Grade	Increases	WCO reduces the presence of asphaltenes and increases the number of maltenes	[1,4,5]
Softening Point	Decreases	The proportion of high molecular weight asphaltenes is decreased, resulting in a softer asphalt.	[1,4,5]
Ductility	Increases	WCO improves ductility, which directly impacts asphalt plasticity	[1,5]
Viscosity	Decreases	**Mixing temperatures and required compaction are reduced, improving asphalt workability**	[1,4,5]

Source: Own elaboration

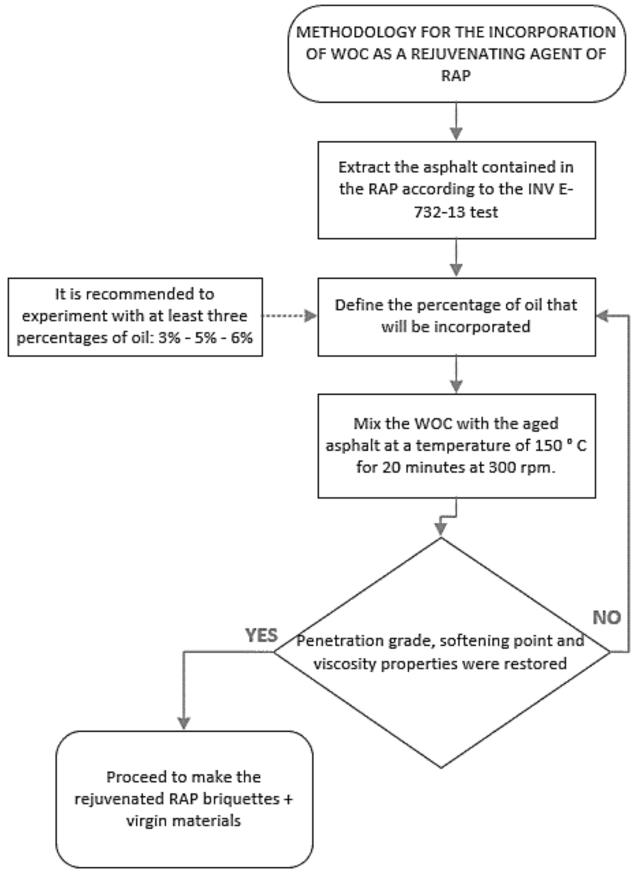

Figure 1. Procedure for RAP rejuvenation.
Source: Own elaboration

Table 5.
Adequate WCO percentage recommended by the literature

WCO range used	Reference
0% - ≤ 5%	[4,5,6,32-41,43]
>5% - ≤ 10%	[1,5,6,34,36-39,43,45]
>10% - ≤15%	[2,5,36,44,45]
>15% - ≤ 20%	[5,36,42,45]

Source: Own elaboration

As shown in Table 5, the most used WCO dose is equal to or less than 5% of the weight of the asphalt binder (14 articles), followed by doses between 5% and 10% (10 articles), between 10% and 15% (5 articles) and between 15% and 20% (4 articles). Therefore, the appropriate content of the incorporated rejuvenator could be in the range from 1% to 20% by weight of asphalt, more likely being below 10% nonetheless. Additionally, in several studies, more than one rejuvenator percentage was reported. Consequently, those references are repeated in the different ranges of WCO incorporation.

Apart from the WCO percentage, parameters such as mixing temperature, time, and speed are required to be properly selected for ensuring a total blending scenario between the aged binder and the WCO using low-cost equipment. Fig. 1 shows the proposed procedure for RAP rejuvenation.

3.6 Preparation of new hot asphalt mix incorporating RAP rejuvenated with WCO.

The literature indicates that there are two methods for incorporating rejuvenated RAP into hot asphalt mixtures.

The first method is the Supervave or Superior Performing Asphalt Pavements method described in AASHTO R 35. It is used at three (3) levels; as the mixing level increases, the complexity and reliability of the design increases [46].

The second is the Marshall method, which is only applicable to hot mix asphalt with aggregates smaller than 25 mm or one inch [46].

Of the 19 articles found in the SLR mentioned in Table 2 in the search Eqs. (2) – (4), 3 articles used the Superpave method [44-46], 6 articles used the Marshall method [2,4,34,38,41,45] and 10 articles did not perform paving as their approach was the asphalt-oil mixture.

In Colombia, INVIAS suggests the use of Marshall method, because this method was adapted in this research to incorporate RAP with WCO as a rejuvenator. The procedure is described below:

3.6.1 Asphalt mix selection.

In Colombia, hot asphalt mixtures (HMAs) are known as MDCs (Mezclas Densas en Caliente) and contain stone

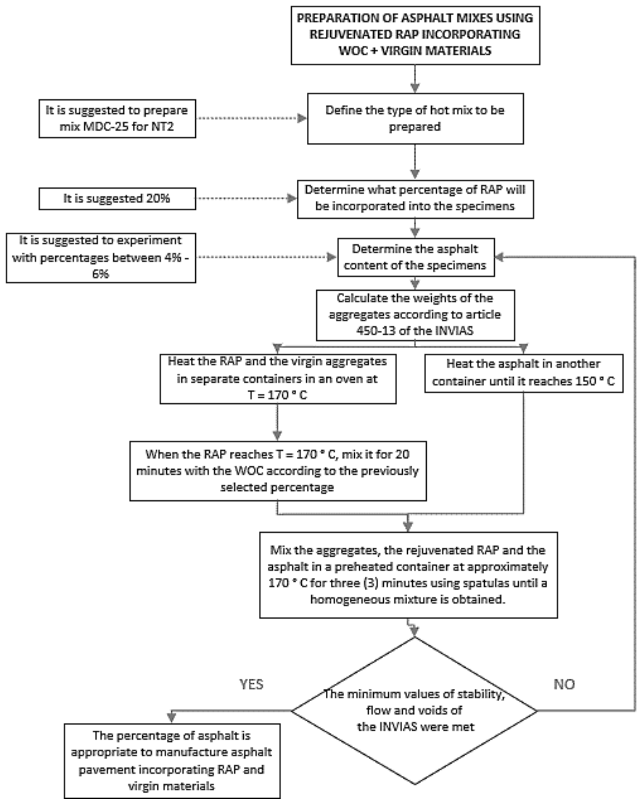

Figure 2. Methodology for the preparation of asphalt mix using virgin material and RAP.
Source: Own elaboration.

aggregates with well-graded granulometry and different sizes of solid particles (gravel, sand, fines, mineral filler) that are mixed with asphalt cement.

These are manufactured at temperatures between 140 °C and 180 °C and have a low percentage of air voids by volume (3% -9%).

For this investigation, a dense hot asphalt mix with continuous grading MDC-25 and a traffic level 2 (NT2) was established.

The stone aggregate used for producing hot asphalt mixes must satisfy the granulometry and quality requirements of coarse aggregate. The requirements are listed in table 450-6 of INVIAS 2013.

3.6.2 Preparation of asphalt hot asphalt mixture

To prepare asphalt specimens, the following aspects are considered: number of specimens, preparation of the aggregates, and percentages of RAP and virgin asphalt.

3.6.3 Mixture preparation

Marshall design mixes are prepared using a specific procedure to heat, mix and compact mixtures under certain conditions.

The proposed procedure to prepare hot asphalt mixtures is presented in Fig. 2 according to the review of 6 articles that proposed the Marshall method [2,4,34,38,41,45] and the INVIAS INV E-748-13 standard [19].

After preparing a homogeneous asphalt mixture, the Marshall test (INV E-748-13) is carried out, and the mixture is compacted into a mold by applying 75 blows with a Marshall or Proctor hammer on each face of the specimen.

3.6.4 Criteria and mechanical tests to determine the behavior of an asphalt mix

The decision whether a hot asphalt mixture is satisfactory with the obtained asphalt content is governed by the application of certain limiting criteria to the mixture test data. Mixture design criteria for the Marshall method with its respective INVIAS standard are described below in Table 6, which is an adaptation of a table in standard 450-10 INVIAS 2013

Table 6.
Values required for MDC according to INVIAS

Property	INV Standar	Traffic level NT2	Reference
Minimun stability value (N)	E-748	7,500	[19]
Flow range (mm)	E-748	2,0 a 4,0	[19]
Flow/stability (kN/mm)	E-748	3,0 a 5,0	[19]
Air voids	E-736	3% a 5%	[19]

Source: Own elaboration

After preparing an asphalt mix, the percent air void test must be performed before conducting the Marshall test using the Marshall apparatus. In addition to this test, a bulk specific gravity test and density test are performed.

4 Conclusions

High-temperature refining of bitumen not only consumes fuel oil, a nonrenewable resource, but also releases harmful gases into the atmosphere. Incorporating reclaimed asphalt pavement (RAP) reduces these effects as fewer virgin materials are needed. This alternative can be applied in the AMB because the municipality collects 32 thousand tons of RAP per year.

Furthermore, the negative impact of residual cooking oil (WCO) on natural and urban environments supports the reuse of this organic waste as a rejuvenator for recovered pavements; this is an attractive alternative that can be implemented in the region where there are 22 thousand tons per year of WCO.

The mixing method is recommended for RAP rejuvenation. It is necessary to find the percentage of oil that restores the penetration grade properties, softening point and viscosity of asphalt present in recycled asphalt pavement. To do this, asphalt must be extracted from RAP, and tests must be conducted on samples prepared with different levels of asphalt (3%-6% by weight) at a mixing temperature of 150°C for 20 minutes and a mixing speed of 300 rpm.

After determining the appropriate oil percentage, a hot asphalt mixture is prepared according to the Marshall test. Dense hot mixes incorporating 20% RAP and 4-6% asphalt is recommended to ensure that the required minimum values of stability and flow, percentage of voids and bulk specific density are met.

Through this theoretical analysis, an adequate methodology was established to prepare hot asphalt mixture incorporating RAP rejuvenated with WCO in the AMB. In this way, two types of waste materials, RAP and WCO, are used in a valuable application that contributes economic, environmental, and social advantages to the sustainable development of the AMB.

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D. Peñaloza, is a BSc. Eng in Civil Engineering in 2021 from the Universidad Santo Tomás, Bucaramanga, Colombia.
ORCID: 0000-0003-1321-5871

D.Vasquez, is a BSc. Eng in Civil Engineering in 2021 from the Universidad Santo Tomás, Bucaramanga, Colombia.
ORCID: 0000-0003-2476-5481

V. Valdivieso, is a BSc. Eng in Civil Engineering in 2021 from the Universidad Santo Tomás, Bucaramanga, Colombia.
ORCID: 0000-0002-5787-2921

Y. Jaramillo, is a BSc. Eng in Civil Engineering in 2021 from the Universidad Santo Tomás, Bucaramanga, Colombia.
ORCID: 0000-0001-6833-913X

V. Plata, is PhD in Chemical Engineering. He has ample experience developing basic and applied research projects for technological development and innovation. His interests have centered on the valorization of industrial and agro-industrial waste and the production, characterization, and enhancement of liquid biofuels, especially biodiesel. Recently, he started a new research line regarding the construction of sustainable pavements.
ORCID: 0000-0003-1725-0463

P. Moreno, is a PhD. In Chemical Engineer with more than ten years of experience in the formulation, execution, and evaluation of research projects with national and international entities. She is professor at the Civil Engineering Faculty at Universidad Santo Tomás, Colombia. In addition, she has experience developing sustainable building materials using agro-waste and recycled materials. Her accomplishments include the development of procedural innovations, consultancies in the construction industry, research articles, presentations at national and international conferences, and mentoring undergraduate students in different engineering fields.
ORCID: 0000-0002-5694-2510