

Environmental Study of the Release of BTEX from Asphalt Modified with Used Motor Oil and Crumb Rubber Modifier

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Abstract

The need to be more environmentally conscious has recently shifted toward the forefront of society. With this new focus on environmentally responsible behavior comes the practice of using recycled materials in construction when possible. Therefore it is necessary to carefully evaluate the safety of any recycled materials being used in pavement materials. Under this study, a reference of testing is presented and implemented to test leachate of samples of two different asphalt binder types containing used motor oil (UMO) and/or crumb rubber modifier (CRM) for the presence of benzene, toluene, ethylbenzene, and xylenes (BTEX). Alongside batch leaching tests, air testing was also conducted. Air testing was carried out for select samples to evaluate BTEX content of air above the interactions between the asphalt binder and UMO. Air testing was also completed for asphalt binders interacted with both UMO and CRM. It was found that asphalt binders containing UMO have the potential to leach benzene at concentrations above the national drinking water limits. Results also show that interaction temperature, interaction time, and binder grade affect the amount of BTEX leached from modified asphalt binder. It was also found that binders modified with both CRM and UMO released less BTEX to both leachate and the air at the end of interaction time, meaning it is likely that CRM retains BTEX and prevents it from being released into the environment when used in conjunction with UMO.

Keywords: Used motor oil; Crumb rubber modifier; Benzene; Toluene; Ethylbenzene; Xylene; Batch Leaching; Air testing

Abbreviations:

UMO: Used Motor Oil; CRM: Crumb Rubber Modifier; BTEX: Benzene, Toluene, Ethylbenzene and Xylene; PAH: Polynuclear Aromatic Hydrocarbons; VOC: Volatile Organic Compounds; RAP: Reclaimed Asphalt Pavement

Introduction

In recent years, attention has been brought to the need to preserve the environment and its resources for future generations. This can be achieved through the utilization of waste materials, in addition to limiting the use of virgin products. However, one of the drawbacks that arise from the utilization of waste products is the fact that there is no control over the constituents of such products. This leads to the inability to forecast the environmental and safety aspects that result from utilizing such products as raw materials for other industries. Used motor oil (UMO) and crumb rubber modifier (CRM) are both waste materials that can be implemented in the paving industry. Although both materials have been investigated separately, up to this point no research has been dedicated to investigating the combined effect of such binder modifiers on the environment.

An asphalt pavement can have recycled materials within it that have to be taken into consideration when trying to account for all environmental outputs. CRM is an example of a recycled material that is incorporated into asphalt pavement. CRM is made from recycled tires, which in some cases contain carbon black and some oils.

Research by Thayumanavan et al. states that the NCHRP evaluation methodology developed in project 25-9 is to help transportation agencies make prudent decisions about the reuse of waste materials and by-products in highway construction. Both scrap tires and reclaimed asphalt pavement (RAP) were tested in this evaluation, and the primary objective was to assess the potential impact on surface water and groundwater of constituents released from these materials. Other materials that were tested include coal fly ash, bottom ash, blast furnace slags, and foundry sand [1].

Results of screening tests showed that crumb rubber does have toxicity impact. Crumb rubber was also shown to contain potential organic toxicants. Most concern for these toxic organics can be eased by the volatilization that is likely to occur in most scenarios. Testing needs to be done on rejuvenated mixes that contain crumb rubber despite the likely occurrence of volatilization. These screening tests have shown the potential danger of crumb rubber, and therefore it needs to be evaluated in all potential uses for it [1].

Dedene et al. explored the usability of UMO in the rejuvenation of RAP and found that it might serve as a rejuvenator; however the environmental aspect of utilizing UMO pavements was not investigated [2]. In work by Villanueva et al., the authors confirmed that the addition of UMO to asphalt enhances the low temperature behavior of asphalt [3].

In the work by Duhalt, the author indicates that UMO contains high concentrations of polynuclear aromatic hydrocarbons (PAH), such as benzo[a]pyrene, which are carcinogenic compounds. These PAH accumulate in motor oil during engine operation. The PAH content of used motor oil can be 670 times greater than that of new

motor oil. In addition, the lubrication additives present in the oils are, in some cases, pollutants [4].

Jia et al.[5] investigated the utilization of UMO in asphalt and concluded that the inclusion of UMO in asphalt binder should generally be avoided due to some critical negative effects on the performance of asphalt binder. Jia et al. also stated that if the inclusion of UMO becomes necessary for any reason, the amount should be strictly limited. The authors found that the inclusion of UMO in asphalt binder generally reduced the high temperature grade of the binder by 6°C on average at 5% oil concentration and 12°C at 10% oil content, depending on binder type.

Hidayah et al. [6] investigated the addition of UMO to RAP. They stated that the appropriate amount of UMO depends on the constituent of aged mixture material. The addition of UMO to RAP offered stiffness reduction and therefore improved resistance to cracking.

In the work of Hesp et al., the authors indicated that physical hardening and losses in strain tolerance due to the presence of UMO in asphalt are largely to blame for observed premature and excessive failures in pavement [7].

In another work by Hesp et al. [8] the authors indicated that Paraffins in UMO sludge precipitate asphaltenes from the base asphalt cement. This premature precipitation leads to increased pavement hardening. In addition, Paraffins in UMO sludge promote additional physical hardening to asphalt during cold storage.

Dedene [9] stated that UMO has the ability to counteract the stiffening from incorporating RAP into pavement and restore the performance grade (PG) to that of virgin binder. UMO is also capable of restoring maltenes to rubber asphalt binder (RAB), which will improve the structure of the asphalt binder. Mixture testing with RAP and UMO was shown to soften the asphalt specimens, both by increasing the amount of rutting and lowering the samples indirect tensile strength.

Benzene, toluene, ethylbenzene, and the ortho, para, and meta xylenes, are the four Alkyl Benzene volatile organic compounds (VOC) that represent common constituents of petroleum fuels. In gasoline, for example, these compounds may contain approximately 2% ethylbenzene, 5% Benzene, and 11-12% Toluene and Xylenes depending on the formulation. The term BTEX is commonly used by the petroleum industry in measuring the quality of fuels as it represents the sum of the concentrations of these four compounds. EPA and state agencies have adapted this parameter for use by to serve as a measure of effluent quality of these contaminants in water and to serve as an “indicator” parameter representing the wide variety of compounds found in petroleum products [10].

Several factors determine whether harmful health effects will occur or not, as well as the type and severity of such health effects after exposure to BTEX. The amount of BTEX to which a person is exposed and the length of time of the exposure, as well as which BTEX compound a person is exposed to, are all factors included. Of the four BTEX compounds, benzene is the most toxic [11].

As an example, the result of exposure to very high concentrations of benzene in air (10,000,000 ppb and above) can cause death [12]. Lower levels (700,000 – 3,000,000 ppb) can cause drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness [11].

The public water systems have supplied U.S. EPA established permissible levels for chemical contaminants in drinking water. These levels are called maximum contaminant levels (MCLs). The US EPA uses a number of conservative assumptions to derive these MCLs, thereby ensuring adequate protection of the public. In the case of known or suspected carcinogens, such as benzene, the MCL is calculated based on assumption that the average adult weighs 154 lbs and drinks approximately 2 quarts of water per day over a lifetime (70 years). The MCL is set so that a lifetime exposure to the contaminant at the MCL concentration would result in no more than 1 to 100 (depending on the chemical) excess cases of cancer per million people exposed [13].

Materials and Methods

Used motor oil

Ten samples of UMO were collected from auto shops, labeled with numbers for reference, and analyzed for BTEX content according to the procedure utilized by Wang et al. in EPA report 600/R-03/072 [14]. This procedure involves diluting the UMO in pentane and analyzing with gas chromatography-mass spectrometry (GC/MS). All samples were kept in sealed containers from the time of sampling to the time of analysis. All samples were initially analyzed within seven days of being obtained. Sample 6 was chosen to be used in all interactions as a binder modifier. Repeated analysis of the BTEX content of sample 6 was continued over an extended period of time in order to determine the effect of time on BTEX content of UMO. In particular, this was investigated to determine how much, if any loss of BTEX compounds occurs in short term sealed storage of UMO. Sample 6 contained the most benzene, while also having relatively high concentrations of toluene, ethylbenzene, and xylenes. It was therefore chosen for use in asphalt applications as a worst-case scenario.

Asphalt interactions

Asphalt interactions were conducted using either PG 64-22 or PG 52-34 asphalt binder in combination with UMO ranging from 0% to 9% by final weight of modified binder as well as CRM ranging from 0% to 20% of initial binder weight. The CRM was prepared from a mixed source of scrap tires using the cryogenic method with a particle size controlled to be smaller than mesh #30 and larger than mesh #40, according to US standard system. The interaction was conducted in a 1 gallon can and a heating mantle (Glos-col 100B – 618) connected to a bench type controller was utilized. A long temperature probe (TJC 36 – 12”) was used to control the interaction temperature. A high shear mixer (HSM-100LM-2) was used to mix the binder, UMO, and CRM. All interactions were conducted under a nitrogen blanket to prevent aging of the material. Interactions for which air samples were taken from the enclosed area above the modified binder were enclosed in an airtight fashion using a thermal plastic bag, thermal rubber, and thermal caulking. Table 1 illustrates the list of interaction conditions utilized in this research. In Table 1, only one source of UMO (sample 6) was used for consistency, as will be explained in the BTEX content of UMO section. A specific coding for the samples was adopted in the current work, starting with the asphalt type, HU-52 or HU-64, then followed by the interaction temperature, interaction speed, with additional information about additives and time following.

Binder	Interaction Temperature (°C)	Interaction Speed (Hz)	% UMO	UMO Source	% CRM	CRM Source
PG 64-22	160	30	0	-	0	-
PG 52-34	160	30	0	-	0	-
PG 64-22	190	30	0	-	0	-
PG 52-34	190	30	0	-	0	-
PG 64-22	160	30	3	Sample 6	0	-
PG 52-34	160	30	3		0	-
PG 64-22	160	30	3		10	CRM 30-40
PG 64-22	190	30	3		0	-
PG 52-34	190	30	3		0	-
PG 64-22	190	30	3		10	CRM 30-40
PG 64-22	160	30	9		0	-
PG 52-34	160	30	9		0	-
PG 64-22	160	30	9		20	CRM 30-40
PG 64-22	190	30	9		0	-
PG 52-34	190	30	9		0	-
PG 64-22	220	30	9		0	-

Table 1: List of Interaction Conditions.

Dynamic mechanical analysis

A dynamic shear rheometer (DSR) was used for dynamic mechanical analysis of modified asphalt. All tests were conducted at 64°C and 10 rad/sec. Samples were tested on 25 mm parallel plates with 2 mm gap for samples containing CRM, or a 1 mm gap for binder containing UMO and unmodified binder. The utilization of a 2 mm gap to test crumb rubber modified asphalt (CRMA) by a DSR was carried out by various researchers [15].

Flash Point of asphalt binder containing UMO

Flash point tests were conducted on binders modified with high percentages of UMO to ensure safety. Both PG 52-34 and PG 64-22 binders containing 15% UMO by final weight were evaluated, along with a control PG 52-34 binder sample. Flash point tests were conducted courtesy of the North Dakota Department of Transportation (NDDOT).

Leaching procedure

Leaching tests were carried out according to the NCHRP 24-hour batch leaching test as described in NCHRP report 25-9 [16-20]. A sample size of 100 grams of solid material (95% glass beads, 5% binder consisting of various UMO percentages by weight) and 400 mL of deionized (DI) water was employed. Glass beads were used to simulate aggregate without affecting sample composition. They effectively increase surface area of the asphalt binder in samples while not interacting with the binder. Samples were prepared at times of 2, 30,

and 120 minutes into the interaction process. After the 24-hour leaching process, pentane extraction was used to extract any BTEX present in a sample of the leachate. The process of mixing a leachate sample with saturated salt solution as well as n-pentane showed to have very good extraction efficiency. The pentane was then carefully removed and analyzed for BTEX content using GC/MS. Five BTEX standards were analyzed in conjunction with each set of samples to ensure accuracy and reduce variability of results and interpretation.

Air testing

Air testing was performed utilizing the National Institute for Occupational Safety and Health (NIOSH) 1501 method [21]. In this method, a solid sorbent tube (coconut shell charcoal, 100mg/50mg) is attached to an air pump with a 0.2 L/min. flow rate. The asphalt interaction was completely enclosed and airtight when air sampling was conducted. Samples were taken from 2 minutes to 30 minutes and from 30 minutes to 120 minutes into the interaction time. This configuration results in sampling times of 28 minutes and 90 minutes respectively. Samples were not taken from 0 to 2 minutes because the resulting sample volume would not be sufficient. The carrier gas for the sampling was nitrogen. As soon as the sorbent tubes were collected, they were covered tightly at both ends and stored at -10°C until they were analyzed.

Results

Dynamic mechanical analysis

Figure 1 illustrates the rheological properties of the binders modified with only UMO, only CRM, and UMO together with CRM. As can be seen in Figure 1, the addition of 9% UMO resulted in severe deterioration of both the complex modulus (G^*) and phase angle (δ). On the other hand, the utilization of 20% CRM resulted in major enhancement in both the G^* and δ . Unfortunately, these enhancements occur at the expense of the workability of the modified binder as a result of absorption of low molecular weight aromatics by the CRM and the decrease in the CRM interparticle distance [22]. The addition of 9% UMO with 20% CRM resulted in enhancement in both the G^* and δ . It is expected that this combination will not significantly deteriorate the workability as the UMO will compensate for the light aromatics absorbed from asphalt in the CRM.

BTEX content of UMO

Table 2 shows results for the concentration of BTEX in all UMO samples collected and analyzed. Concentrations of each constituent of BTEX are shown in $\mu\text{g/g}$. It was found that within the time frame research was conducted; the BTEX content of sample 6 remained constant over time. Sample 6 was used for all interactions and testing in this research.

The fact that the BTEX content stayed constant over time in the UMO leads to concerns about if, when, and where BTEX could potentially exit UMO and enter the environment. This reaffirms that if UMO is used as an additive to asphalt binder, testing needs to be conducted to ensure BTEX does not enter the environment in a harmful manner.

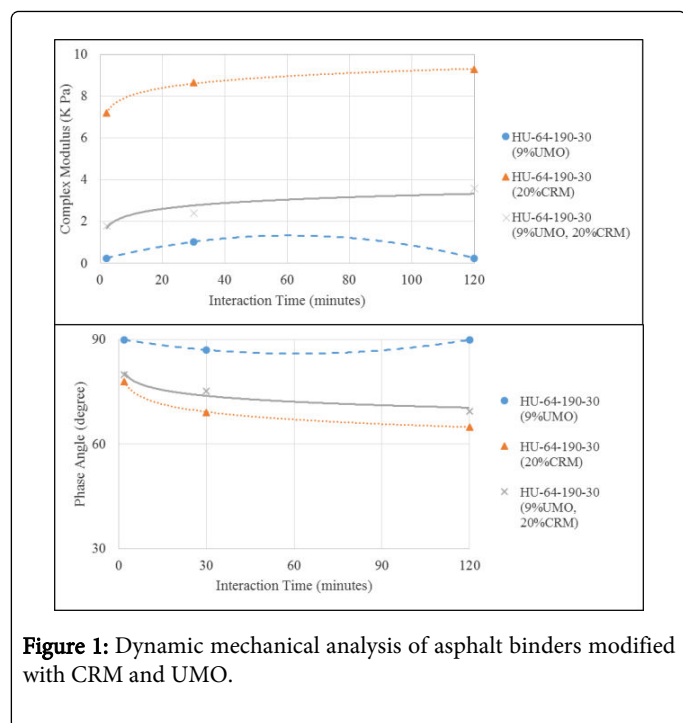


Figure 1: Dynamic mechanical analysis of asphalt binders modified with CRM and UMO.

Sample	Concentration of BTEX Components in UMO (µg/g)				
	Benzene	Toluene	Ethylbenzene	Xylene - p,m	Xylene - o
1	0	0	0	0	0
2	0	337.2	0	312.7	341.4
3	0	217	90.8	378.6	424.4
4	0	291.5	167.2	437.9	288.7
5	0	317.4	110.2	364.1	291.9
6	124	783	211.1	513.9	474.3
7	0	0	0	34.1	0
8	0	65.8	0	97.5	140.1
9	0	204.3	54.3	215.1	196.6
10	75.4	679.3	233.9	603.8	591.8

Table 2: BTEX Concentration in UMO.

Concerning sample source, it is noteworthy that UMO taken from semi-trucks (sample 1 and sample 7) contained almost no BTEX. This is likely due to the diesel fuel semi-trucks use and the fact that it burns cleaner than standard unleaded gasoline. The UMO sample with the next lowest BTEX content (sample 8) was known to have originally been fully synthetic oil. These results could indicate that synthetic oil has less of a tendency to absorb and retain BTEX while in use. In turn this could mean that used fully synthetic motor oil has a much lower BTEX content than most standard UMO.

Flash point results

Flash point tests were conducted by the NDDOT, and results are shown in Table 3. The addition of UMO does decrease the flash point of asphalt binders. Adding 15% UMO to PG 52-34 binder decreased the flash point from 278°C to an average of 245°C. While this decrease is substantial, it is still considered to be safe, and passes the Superpave specification of being greater than or equal to 230°C. Practical UMO percentages applied in pavement applications would likely be much less than 15%, so in general, the addition of UMO to asphalt binder should not be a safety concern with regards to flash point.

Binder Grade	UMO % by Weight	Flash Point (°C)
PG 52-34	0	278
PG 52-34	15	242
PG 52-34	15	248
PG 64-22	15	252

Table 3: Flash Point of Binders Containing UMO.

Batch leaching results

For reference and clarity, Table 4 and Table 5 displays all batch leaching values used in this report. It also displays BTEX content in leachate of control interactions that contain no UMO. This means that the unmodified asphalt binders tested do not readily leach BTEX. The time in Table 4 references the number of minutes from the start of the interaction to the time that the binder sample was taken. It is noteworthy that four control interactions were conducted and tested for PG 52-34 and PG 64-22 binders at temperatures of 160°C and 190°C. Results for all sampling times of all control interactions resulted in leachate BTEX concentrations of 0 mg/L. Results show that many leachate samples contain benzene at levels above the national drinking water standard of 0.005 ppm [23].

Time (mins)	BTEX Content of Leachate (mg/L)								
	Benzene			Toluene			Ethylbenzene		
	0	30	120	0	30	120	0	30	120
I	0	0	0	0	0	0	0	0	0
II	0	0	0	0	0	0	0	0	0
III	0	0	0	0	0	0	0	0	0
IV	0	0	0	0	0	0	0	0	0
V	0.05	0	0	0.156	0.104	0.032	0.028	0.015	0
VI	0.036	0	0	0.121	0.015	0.012	0	0	0
VIII	0.045	0	0	0.152	0.03	0.025	0.01	0	0
IX	0.014	0	0	0.062	0.038	0.024	0	0	0
X	0.012	0	0	0.074	0.025	0.014	0	0	0
XI	0.041	0	0	0.185	0.118	0.061	0.012	0	0
XII	0.023	0	0	0.13	0.075	0.063	0	0	0
XIII	0	0	0	0.067	0.039	0.012	0	0	0

XIV	0	0	0	0.073	0.051	0.038	0	0	0
XV	0	0	0	0.048	0.031	0.021	0	0	0
XVI	0	0	0	0.051	0.05	0.071	0	0	0
XVII	0	0	0	0.08	0.065	0.022	0	0	0

Table 4: Quantitative Results of BTEX Content in Leachate for benzene, toluene and ethylbenzene. (I. PG 64-22 at 160°C; II. PG 64-22 at 190°C; III. PG 52-34 at 160°C; IV. PG 52-34 at 190°C; V. PG 64-22 at 160°C (9% UMO); VI. PG 64-22 at 190°C (9% UMO); VII. PG 64-22 at 220°C (9% UMO); VIII. PG 64-22 at 160°C (3% UMO); IX. PG 64-22 at 190°C (3% UMO); X. PG 52-34 at 160°C (9% UMO); XI. PG 52-34 at 190°C (9% UMO); XII. PG 52-34 at 160°C (3% UMO); XIII. PG 52-34 at 190°C (3% UMO); XIV. PG 64-22 at 190°C (10% CRM, 3% UMO); XV. PG 64-22 at 160°C (10% CRM, 3% UMO); XVI. PG 64-22 at 160°C (10% CRM, 3% UMO); XVII. PG 64-22 at 160°C (20% CRM, 9% UMO))

Time (mins)	BTEX Content of Leachate (mg/L)					
	Xylene - p,m			Xylene - o		
	0	30	120	0	30	120
I	0	0	0	0	0	0
II	0	0	0	0	0	0
III	0	0	0	0	0	0
IV	0	0	0	0	0	0
V	0.182	0	0	0.109	0.131	0
VI	0.072	0	0	0.005	0	0
VIII	0.033	0	0	0.032	0	0
IX	0.049	0	0	0.016	0	0
X	0.021	0	0	0.015	0	0
XI	0.029	0	0	0.05	0.026	0
XII	0.02	0	0	0.023	0	0
XIII	0.013	0	0	0	0	0
XIV	0.014	0	0	0	0	0
XV	0.01	0	0	0	0	0
XVI	0	0	0	0	0	0
XVII	0.079	0	0	0.03	0	0

Table 5: Quantitative Results of BTEX Content in Leachate for xylene-p,m and xylene-o. (I. PG 64-22 at 160°C; II. PG 64-22 at 190°C; III. PG 52-34 at 160°C; IV. PG 52-34 at 190°C; V. PG 64-22 at 160°C (9% UMO); VI. PG 64-22 at 190°C (9% UMO); VII. PG 64-22 at 220°C (9% UMO); VIII. PG 64-22 at 160°C (3% UMO); IX. PG 64-22 at 190°C (3% UMO); X. PG 52-34 at 160°C (9% UMO); XI. PG 52-34 at 190°C (9% UMO); XII. PG 52-34 at 160°C (3% UMO); XIII. PG 52-34 at 190°C (3% UMO); XIV. PG 64-22 at 190°C (10% CRM, 3% UMO); XV. PG 64-22 at 160°C (10% CRM, 3% UMO); XVI. PG 64-22 at 160°C (10% CRM, 3% UMO); XVII. PG 64-22 at 160°C (20% CRM, 9% UMO))

Impact of interaction time on toluene content of leachate

While several components of BTEX did in fact leach from the modified binders tested, toluene is chosen as an indicator due to consistent results being found for it. Toluene was also consistently the most abundant component of BTEX found in leachate samples. Figure 2 shows the toluene content of leachate of binders containing UMO over interaction time. This data was taken from a wide variety of interaction conditions, and despite differences in UMO content, temperature, binder type, and CRM content, a negative trend is still present. In general, the total toluene content of these binders was between 0.05 and 0.15 mg/L for samples taken 2 minutes into the interaction. This concentration drops considerably for samples taken 30 minutes into the interaction, and drops even further for samples taken 120 minutes into the interaction. This clearly indicates that the longer the binder is heated in the interaction process, the less BTEX it contains.

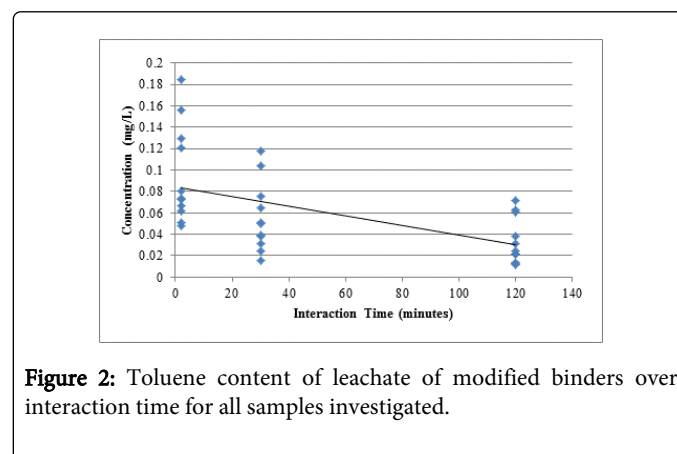


Figure 2: Toluene content of leachate of modified binders over interaction time for all samples investigated.

Impact of UMO content on BTEX content of leachate

As illustrated in Table 4, results clearly show that as the percentage of UMO added to asphalt binder increased, the concentration of BTEX in the leachate also increased. This is expected, as it is logical that if there is more BTEX present in a sample, then more BTEX will be leached from that sample.

Impact of interaction temperature on toluene content of leachate

Generally, as interaction temperature increased, toluene content in leachate decreased. Figure 3 shows this general trend by illustrating the drop in toluene content of leachate when increasing the interaction temperature from 160°C to 190°C. The data shown represents interactions containing 9% UMO and 0% CRM for both binder types.

The effect of interaction temperature on toluene content of leachate is perhaps more dramatically noticed when combined with changes in binder grade as discussed in the next section.

Impact of binder grade on toluene content of leachate

As illustrated in Figure 4, a marked difference in the toluene content of the leachate of the two binder types can be observed here. The PG 52-34 binder shows a much greater propensity to leach toluene than the PG 64-22 binder. This difference is especially noticeable over interaction time. This could be related to the higher

amount of low molecular weight aromatics present in the lower grade asphalt, which might decrease the ability of the asphalt to integrate the soft UMO and thus lead to such behavior as compared to harder asphalt.

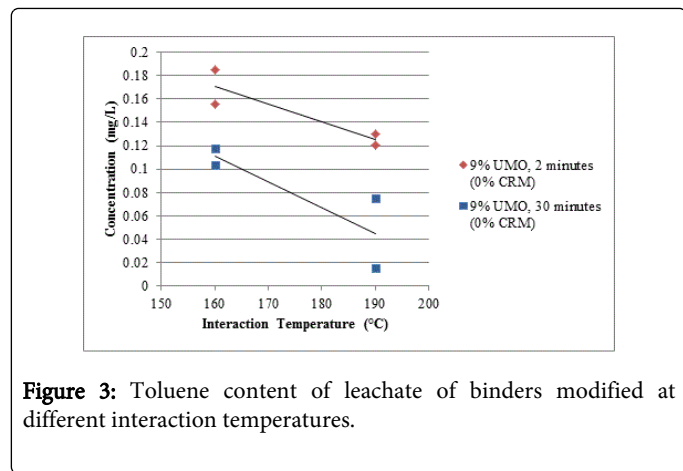


Figure 3: Toluene content of leachate of binders modified at different interaction temperatures.

Figure 4 also shows the relationship of decreasing toluene content of leachate over interaction time while also illustrating the difference between binder grades.

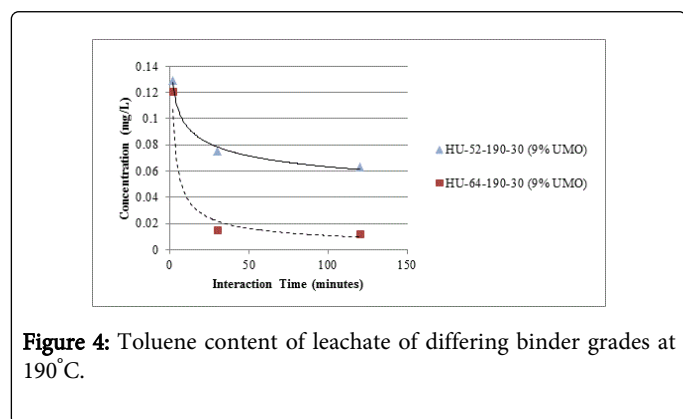


Figure 4: Toluene content of leachate of differing binder grades at 190°C.

Impact of CRM content on toluene content of leachate

It appears that it is possible that CRM affects the toluene content of leachate. Figure 5 shows leachate results comparing two interactions that are identical except for the CRM content. The most consistent and notable trend is observed in samples taken 2 minutes into the interaction process. For these 2 minute samples, the toluene content of leachate of binders containing both CRM and UMO is lower than that for those containing only UMO. This could mean that the CRM is absorbing and holding on to some of the UMO initially and causing a decrease in the toluene content of leachate. On the other hand, it could mean that the CRM is causing more BTEX to be released into the air. These possibilities can be further investigated through air testing.

BTEX content of air samples

Figure 6 illustrates the BTEX content comparison for the HU-64 asphalt samples interacted with 9% UMO with or without 20% CRM. It can be seen that after 30 minutes of interaction time the sample containing 20% CRM released higher amounts of benzene than the sample with no CRM.

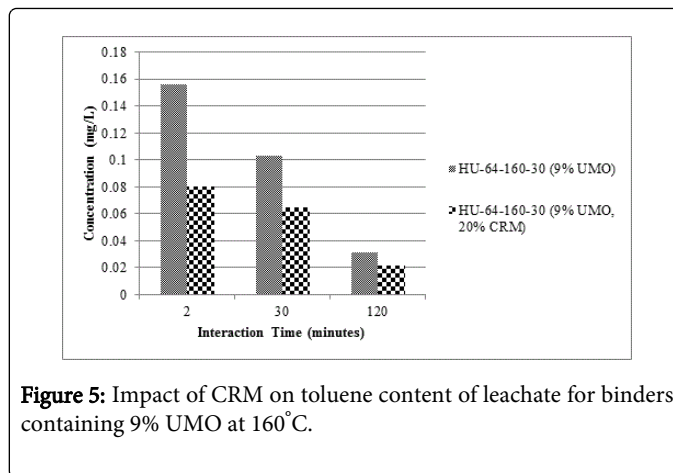


Figure 5: Impact of CRM on toluene content of leachate for binders containing 9% UMO at 160°C.

On the other hand, after 120 minutes of interaction time, almost no benzene was released from both samples investigated. For the toluene concentration in the air, the samples collected after 30 minutes of interaction time showed the same trend of higher concentration of toluene in the one having CRM over the one lacking it, where the toluene concentration was almost 250 ppm in the sample containing CRM, while it was about 190 ppm for the sample with no CRM. Opposite results can be seen for the samples collected after 120 minutes of interaction time, where the toluene concentration with slightly less for the sample containing CRM in comparison to the sample without CRM. A different trend can be seen for the ethylbenzene concentration in air for the samples with and without CRM after 30 minutes of interaction time. The concentration of ethylbenzene was about 80 ppm for the sample without CRM, while it was around 65 ppm for the samples with CRM. The same trend continues for the samples collected after 120 minutes of interaction time, but with lower concentrations. The same trend seen for ethylbenzene concentrations continues for the total xylene concentration in both the samples containing and lacking CRM, but with higher concentrations. It should be noted that xylene was the most released component of the four volatiles. After 30 minutes of interaction time, the concentration of the xylene for the sample without CRM was about 360 ppm, while it was about 240 ppm for the sample containing CRM. After 120 minutes of interaction time, the xylene concentration was almost identical for the samples with or without CRM, having a value of about 120 ppm.

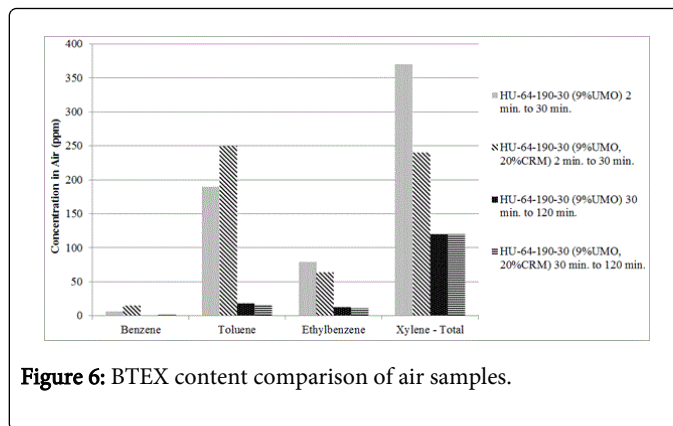


Figure 6: BTEX content comparison of air samples.

Relationship between leaching and air testing

Figure 7 shows that with increased interaction time, both the BTEX content of leachate and the BTEX content of air samples have decreasing trends.

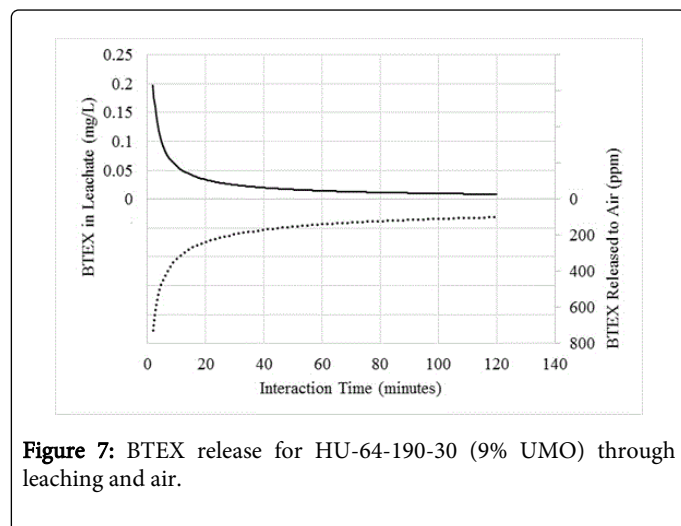


Figure 7: BTEX release for HU-64-190-30 (9% UMO) through leaching and air.

The amount of BTEX being released to the air is much greater than the amount of BTEX found in leachate. At high temperature over time, the BTEX is released into the air and becomes less present in the modified binder, therefore reducing the amount of BTEX available for leaching, and in turn reducing the BTEX content of leachate.

Conclusions

This research confirms that UMO content of modified asphalt binder clearly affects the BTEX content of leachate of that modified binder. As the UMO content of asphalt binder increases, the BTEX content of the leachate of that binder also increases. This is logical because as the BTEX that is available to be leached increases, the BTEX that is leached should tend to increase as well.

There is a marked difference in the leaching of BTEX over interaction time between 160°C and 190°C interactions. BTEX remains present in the binder (and in turn shows up in the leachate) further into the interaction at lower temperature. The interactions run at higher temperatures result in more BTEX exiting the binder and therefore not being present in the leachate.

Based on testing results for the interaction conditions in this research, binder type by itself affects BTEX content of leachate. In general, greater concentrations of BTEX are leached out of UMO modified PG 52-34 binder than are leached out of UMO modified PG 64-22 binder.

Binder type over time may affect BTEX content over time. This means temperature alone may not be the only prevailing force over time, and there may be interaction between binder grade and time that has an effect on the BTEX content of leachate. This could very well have something to do with the molecular structure and bonds of the two binder grades that were used in interactions. A trend has been observed, but additional investigation that is beyond the scope of this research may be required to determine the exact cause of this trend.

Binders containing both CRM and UMO appear to have a lower propensity to leach BTEX from samples taken at 2 minutes of

interaction time than binders containing UMO alone at the same percentage. The CRM may initially be absorbing UMO and slowly releasing it over time at high interaction temperatures, but more testing is required to determine if this is the case.

There is a steep degradation of BTEX as indicated by leachate analysis over interaction time. Degradation of BTEX as indicated by leachate analysis over interaction time tends to occur at an increased rate for modified PG 64-22 binder when compared to modified PG 52-34 binder.

If UMO is employed in any pavement application, it is recommended that the UMO be fully tested for harmful contaminants first. Two of the ten UMO sources obtained in this research contained benzene. If UMO is employed in any pavement applications whatsoever, testing should be conducted to determine if it contains any benzene. The concentration of benzene in leachate of some binders containing 3% UMO was above national drinking water limits as well as North Dakota general water quality standards. The concentration of benzene in leachate of many binders tested containing 9% UMO was also above both national drinking water limits and North Dakota general water quality standards.

With regards to toluene aside from benzene, it is best to err on the side of caution and use a maximum UMO content of about 9% of the total binder weight. This conclusion is based on the UMO sampled in this study that contained the highest concentration of toluene. If a UMO source with an equivalently high concentration of toluene (783 µg/g) is employed at a level of 9% by weight of the total binder, leachate levels will remain below current limits for toluene content.

Generally, as interaction temperature increased, toluene content in leachate decreased. This could be related to the increase of release of toluene to the air with the increase of interaction temperature.

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