Innovative bitumen technology to reduce impact on air quality

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Abstract. With increasing environmental awareness, air quality is a topic of intense discussion and focus with many environment authorities/agencies setting targets aiming to improve air quality. Reducing the impact on air quality from road construction and maintenance activities plays a part in a holistic approach to improving air quality, particularly in the urban environment. This paper describes an innovative bitumen technology which can help reduce the impact on local air quality from bitumen and asphalt mixtures during asphalt manufacture and pavement installation. It presents laboratory experiments designed to replicate the end-to-end aspects of the bitumen supply chain; starting from refineries and storage depots to paving at road construction sites. The laboratory results have shown substantial reductions in a range of air quality indicators, such as SOx, NOx, particulate emissions, volatile organic content emission as well as in other potential nuisances such as H2S and odour. Full scale field evaluations carried out in major cities have reflected the results obtained in the laboratory and show a reduction in the emission of specific gases and particulates at various points of the asphalt preparation and pavement laying process. This bitumen technology plays a role as part of the holistic solution in improving air quality in the urban environment.

1. Introduction

‘Air quality’ refers to the condition of the air within our surroundings [1,2,3]. Good air quality is the degree to which the air is clean, clear and free from pollutants such as smoke, dust and smog among other gaseous impurities.

Air quality is determined by assessing a variety of indicators. An Air Quality Index (AQI) is a number used by many government agencies [1,2,3,4,5] to communicate to the public the current quality of the air or how the air quality might change in the future, a little like a weather forecast. Different jurisdictions [2,3,4,5] have their own air quality indices, corresponding to particular air quality standards, but all tend to follow similar principles.

It is known generally that there are a mixture of different compounds of gases i.e. nitrogen oxides, sulphur dioxide, carbon monoxide, particulates, volatile organic compounds (VOCs) etc. which can be released from bitumen and asphalt mixtures at elevated temperatures that may impact air quality in the immediate vicinity of an operating asphalt plant or during paving applications. Generally, the gases from bitumen and its application are normally present at low levels in outdoor air [6,7,8].
Specific gases and particulates from hot mix asphalt (HMA) plants which impact air quality are categorised under two types of emissions: ducted sources and fugitive sources.

The primary sources of specific gases and particulates associated with asphalt production are the dryers, hot bins, and mixers, which emit particulate matter and a variety of gaseous emissions during production [9,10,11,12,13].

Other sources of specific gases and particulates found at asphalt plants and paving applications are shown in figure 1.

**Figure 1.** Schematic diagram to indicate the locations to measure gases and particulates:
1: Hot liquid bitumen storage tanks.
2: 
- Asphalt storage silos which temporarily store the asphalt;
- Truck load-out operations, in which the loose asphalt mixture is loaded onto trucks for hauling to the job site;
- Hot oil heaters, which are used to heat the asphalt storage tanks;
- Yard emissions, which consist primarily of fugitive emissions
- Most of the other potential specific gases and particulates, such as the dust generated during the drying of aggregate, are captured by baghouse filters or similar controls and not released to the environment.
3: Asphalt in truck beds and the discharge of loose asphalt mixture from truck to paver tipper
4: Asphalt laying and compaction at paving sites.

There are also other sources comprising vehicular traffic generating CO, NO and fugitive dust on paved and unpaved roads while aggregate material handling, and other aggregate processing and drying operations.
Shell investigated the impact of its innovative bitumen technology which helps reduce emissions of specific gases and particulates from bitumen and asphalt mixtures during asphalt manufacture and pavement installation.

2. Materials and characterisation

Shell Bitumen FreshAir consists of an innovative active additive bitumen technology and was developed over a number of years. The mixture of inhibiting components of Shell Bitumen FreshAir act directly with selective compounds which are the source of gases, particulates and odour releasing molecules in bitumen.

2.1. Laboratory testing

Shell’s global R&D team conducted an extensive laboratory study which examined a range of twenty bitumens from different geographical regions spanning a wide range of grades from very hard (10/20 penetration grade) to very soft bitumens (160/220 penetration grade) from different refineries. The laboratory experiments were designed to simulate the end-to-end application from bitumen storage, transportation, asphalt mixing (and compaction) and early pavement life to investigate the impact of Shell Bitumen FreshAir in relation to different air quality indicators.

The studies included analysis of specific gases emitted from bitumen during bitumen storage at elevated temperatures (140°C and 180°C) for a one-month duration.

Specific gases and particulates were measured from asphalt mixing at multiple temperature 140°C, 160°C and 180°C, and early life of the pavement at room temperature and at 60°C.

Additionally, any potential impact upon bitumen properties and asphalt mixture performance as a result of the Shell Bitumen FreshAir addition was assessed.

2.2. Testing and Analysis

Various testing and analytical methods were used, developed or modified to measure the number of gases and particulates during the study to correspond to various stages of the bitumen supply chain and its application:

2.2.1. Bitumen testing. In the laboratory, to study the bitumen storage effect, bitumen was stored in an aluminium toothpaste tube and placed in a vertical static position in the oven at multiple temperatures over a period of time and specific gases (NO, NH₃, SO₂, CO) were measured in vapour space i.e. 30% headspace (the air left above the content in the closed aluminium toothpaste tube).

Gaseous emissions were measured using different Dräger sampling tubes and systems enabling the identification and measurement of different gases (NO, NH₃, SO₂, CO, NH₃). These tubes are glass vials filled with a chemical reagent that reacts to a specific chemical or family of chemicals. A calibrated 100 ml sample of air was drawn through the tube with a Draeger accuro® pump from the aluminium toothpaste tube. Multiple gaseous tubes with varying detection ranges were used.

Volatile organic content and semi-volatile organic content were measured using an analytical technique that combined separation properties by gas chromatography (GC) with the detection feature of Mass Spectrometry (MS) and Flame Ionization Detector (FID) to identify different substances within a test sample in the headspace i.e. the air left above the contents in a sealed container.

2.2.2. Asphalt preparation and testing. A 30 L asphalt mixer was used to study the emissions from hot asphalt mixtures. The measurements were carried out at three temperatures, viz. 140°C, 160°C and 180°C. These temperatures were selected to cover the normal range of temperatures for asphalt mixtures. For gases like NO₂, NH₃, CO, O₃ and the TVOC, PM₂.₅ and PM₁₀ it was not possible to directly measure the emissions since the detectors did not have a sampling pump to withdraw the air sample for analysis. To withdraw samples from the 30 L asphalt mixer the detectors were kept in an enclosure through which a continuous stream from the headspace in the mixer was withdrawn using an air pump, at a flow rate of 2.0 L/min. Specific gases (NO, NO₂, NH₃, SO₂) and particulate matter
(PM$_{2.5}$, PM$_{10}$) were measured in a 30 L mixing unit with special modification to the mixer in order to control the dilution of emissions while mixing in the mixing unit. The measurements were carried out at multiple mixing temperatures (140°C, 160°C and 180°C) over a period of 20 minutes of mixing.

Specific gases (NO, NO$_2$, NH$_3$, SO$_2$) and particulate matter (PM$_{2.5}$, PM$_{10}$) were monitored at room temperature and elevated temperatures on the prepared slab at 60°C. The asphalt slab was placed in a plastic enclosure containing both gaseous emission and PM detectors. The sample within the plastic enclosure as shown in figure 2 was then kept for monitoring in an environmental chamber for a duration of one month.

**Table 1.** Devices used to monitor specific gases and particulates in bitumen and asphalt while mixing and monitoring in environmental chamber

| Specific gases and particulates | Detector used                                      |
|--------------------------------|---------------------------------------------------|
| SO$_2$, NO, CO, NH$_3$ & H$_2$S in Bitumen | Dräger sampling tubes and system                   |
| VOC                            | Agilent GC/MS-FID                                  |
| SO$_2$                         | Honeywell, BW GasAlertMicro 5                      |
| NO$_2$                         | Honeywell, BW GasAlert NO$_2$ EXTREME              |
| NO                             | Honeywell, BW GasAlert NO EXTREME                  |
| NH$_3$                         | Honeywell, BW GasAlert NH$_3$ EXTREME              |
| PM$_{2.5}$ and PM$_{10}$       | TSI Inc. DustTrak DRX Aerosol Monitor 8534         |

**Figure 2.** Schematic of experimental setup used to measure the emissions from an installed asphalt pavement immediately after compaction

2.3. **Field Trials**

To validate the findings in the laboratory study, a number of externally monitored field trials were carried out to assess the efficacy of Shell Bitumen FreshAir during real life asphalt production and paving and to provide a statistical validation of the laboratory results.

To minimise field variations as much as possible all field measurements were monitored by an independent environmental consultancy specialising in dust and air quality monitoring and consultancy.

Trials were carried out using Shell Bitumen FreshAir in cities around the world – London (United Kingdom), Saraburi (Thailand), Lelystad (Netherlands), and Nantes (France). The results were analysed to better understand how this solution can help road industry work towards cleaner asphalt production and paving.
2.3.1. Field trials and measurements. The field trial assessments and monitoring guidelines were selected and modified from the US Environmental Protection Agency (US EPA), European Environmental Agency (EEA), and UK Environmental agency to suit the trials that were carried out.

The external agency’s equipment (calibrated and certified portable devices) and test methods selected were used at all trial sites to minimise experimental set up variations. The measurements were carried out both upwind and downwind of the various measurement locations. All weather conditions were recorded using a portable weather station for all the trials. The asphalt mixtures used at the different trials had different mixture designs, aggregates and contained varying quantities (0-40%) of recycled asphalt pavement (RAP).

At the asphalt plant: measurements were taken at the mixing unit and truck loading silos and at paving site measurements were taken during unloading of the asphalt mixture into the hopper of the paver, at the screed of the paver and behind the paver, during and post compaction. The results provided are an average of these measurements.

3. Results

The studies performed in the laboratory indicate that the amount of gaseous and particulates generated during the bitumen usage from end-to-end application varies, depending on the source of the bitumen, the grade of bitumen and the processes used to make the bitumen.

3.1. Effect of Shell Bitumen FreshAir on gaseous emissions from bitumen

The monitoring of Shell Bitumen FreshAir samples resulted in a reduction in the concentration of SO\(_2\) and H\(_2\)S measured in the headspace of the toothpaste tubes after 7 and 15 days storage at different temperatures (140°C - 180°C). The studies performed in the laboratory indicate that the amount of gases generated during the bitumen storage varies, depending on the source of the bitumen, the grade of bitumen and the processes used to make the bitumen. The data of the 20 bitumens tested was given to statistical analysis experts and the conclusions are provided in this paper. The reduction in the SO\(_2\) and H\(_2\)S concentrations average a reduction of 25% and were found to be independent of the application temperature (140°C - 180°C), see Tables 2 and 3.

Table 2. Effect of Shell Bitumen FreshAir on the concentration of SO\(_2\) in the headspace of the toothpaste tube – 95% confidence intervals

| Time of storage (days) | Mean reduction measured (%) | Lower bound of reduction measured (%) | Upper bound of reduction measured (%) |
|------------------------|-----------------------------|-------------------------------------|--------------------------------------|
| 7                      | 25.8                        | 11.1                                | 40.5                                 |
| 15                     | 26.9                        | 15.9                                | 37.9                                 |

Table 3. Effect of Shell Bitumen FreshAir on the concentration of H\(_2\)S in the headspace of the toothpaste tube – 95% confidence interval

| Time of storage (days) | Mean reduction measured (%) | Lower bound of reduction measured (%) | Upper bound of reduction measured (%) |
|------------------------|-----------------------------|-------------------------------------|--------------------------------------|
| 7                      | 26.9                        | 14.8                                | 39.0                                 |
| 15                     | 30.3                        | 21.4                                | 39.2                                 |

NH\(_3\), CO and NO were detected at very low levels for a few of the bitumens and some were below detection levels (BDL) during the measurements.
3.2. Effect of Shell Bitumen FreshAir on emissions from hot asphalt mixture during laboratory mixing

It was observed that NH$_3$, NO$_2$, CO and O$_3$ were not detected in significant concentrations in the 30 L mixer over a time of 20 minutes and at all temperatures tested. Air quality indicators, SO$_2$ and NO were detected in the 30 L mixer while mixing the asphalt mixture. Apart from this H$_2$S was also detected, and whilst this is important it is not an air quality indicator. Significant reductions were seen with respect to the concentrations of SO$_2$, NO and H$_2$S, irrespective of temperature. Without a rigorous statistical analysis of the results it could be said that the Shell Bitumen FreshAir resulted in a decrease in emissions during mixing compared with conventional bitumen, which could improve air quality indicators.

The analysis of the data with respect to SO$_2$ showed a minimum mean reduction of 62% and NO of 28%, see Table 4. The temperature of the asphalt mixture was seen to have no statistical influence on the reduction in SO$_2$ and NO observed.

Data collected on the PM$_{2.5}$ and PM$_{10}$ was not used as stable data could not be obtained, potentially as a consequence of the experimental design. It is recommended that field data be used to for any the effectiveness of Shell Bitumen FreshAir the reduction in PM$_{2.5}$ and PM$_{10}$ levels.

| Gaseous Emission | Mean reduction measured (%) | Lower bound of reduction measured (%) | Upper bound of reduction measured (%) |
|------------------|----------------------------|--------------------------------------|--------------------------------------|
| SO$_2$           | 90.0                       | 62.2                                 | 117.8                                |
| NO               | 57.5                       | 28.5                                 | 86.3                                 |

3.3. Effect of Shell Bitumen FreshAir on emissions from hot asphalt pavements and during early life

Measurements of the emissions from the hot asphalt slabs showed that the emissions, if any, were below the detection limit of the detectors used. The detectors used typically had a lower detection limit of 1 ppm. This would indicate that emissions, if any, were extremely small. Emissions from slabs when maintained at 60°C showed a similar trend, i.e. that emissions, if any, were too low to result in their detection during the course of the experiments.

After the first four asphalts were tested at all three mixing temperatures with no detection of emissions, further testing was discontinued.

3.4. Field Measurements

The reduction of specific gases and particulates are presented in table 5 which are given on an average basis over time, although minimum and maximum reductions were also recorded during the field measurements. The measurements were taken at multiple points at each paving site (unloading of asphalt mixture into paver hopper, at the screed, behind paver and before and post compaction. The results presented are an average of all measurement points and compared to conventional bitumen.

In the asphalt plant, during production i.e. near the mixing unit and during loading of loose asphalt mixture into trucks, Shell Bitumen FreshAir has shown, on average reduction of gases by 40% along with potential nuisance vapours such as H$_2$S and odour causing compounds associated with bitumen and asphalt mixtures.

In the field gaseous emissions (SO$_x$, NO, NO$_2$, VOC, CO) and PM were reduced on average by 40% compared to conventional bitumen during paving application. It was observed that the emissions reduce very quickly and disperse in the atmosphere within the first hour of paving application.

Field measurements for particulate matter in the Netherlands at the paving site were anomalous and need further research as well as in London where the measurements were impacted by contamination of some of the emissions (NO and VOC) at the paving site, during which different pavers, rollers/compacter were operated by the crew on conventional bitumen and Shell Bitumen FreshAir. During the field measurements there are many external factors which can impact the outcome of the results.
Table 5. Overall % reduction of specific gaseous and particulate emissions from field measurements

| Location          | SO$_2$ | NO  | NO$_2$ | CO  | VOC | PM$_{2.5}$ | PM$_{10}$ |
|-------------------|--------|-----|--------|-----|-----|-----------|-----------|
| Nantes, France    | -50    | -54 | -41    | -81 | -33 | -28       | -28       |
| London, UK        | -99    | 70  | -67    | -90 | 33  | -88       | -90       |
| Saraburi, Thailand| -19    | -84 | BDL*   | -67 | 33  | -47       | -56       |
| Lelystad, Netherland| -50  | -25 | BDL*   | -50 | -58 | NA        | NA        |

*BDL: Below Detection Level

4. Conclusions

The outcome of the laboratory findings corresponded well with field measurements outcomes in terms of measuring a reduction in specific gases and particulates when mixing and paving asphalt.

There is a significant, 40% on average, reduction between the concentrations of emissions in terms of SO$_2$, NO, NO$_2$, CO, PM and total volatile organic compounds measured from loose mixture (e.g., in a truck, when discharged into the paver hopper) and the road surface, immediately during and after compaction, when using Shell Bitumen FreshAir.

It was observed the emissions reduce very quickly and disperse in the atmosphere within the first hour of paving application.

With the field measurements, it is clear that considerable care needs to be taken to account for external parameters which have the propensity to alter the outcome of the field results e.g. type and kind of fuel used, paving equipment, handling of paving instruments, traffic, vehicle movement, location and surroundings of the paving application, weather, particularly wind, along with mixture designs, asphalt type and temperatures.

From laboratory data and field measurements, Shell Bitumen FreshAir showed significant reduction of specific gases (NO$_x$, SO$_x$, CO, VOC) and particulates as well as in other potential nuisance vapours such as H$_2$S and odour causing compounds associated with bitumen storage, transport, asphalt mixing and compaction.

Shell Bitumen FreshAir is an innovative bitumen technology which can help reduces the impact to local air quality from bitumen and asphalt mixtures during asphalt manufacture and pavement installation and plays a role as part of the holistic solution in improving air quality in the urban environment.

References

[1] World Health Organisation, http://www.who.int/airpollution/en/
[2] United States Environmental Protection Agency, https://www.epa.gov/environmental-topics/air-topics
[3] European Environment Agency, https://www.eea.europa.eu/themes/air
[4] Environment Agency, UK. https://www.gov.uk/government/organisations/environment-agency
[5] Environmental Protection Department, The Government of the Hongkong. https://www.epd.gov.hk/epd/english/environmentinhk/air/air_quality_objectives/air_quality_objectives.html
[6] Kuklinska K, Wolska L and Namiesnik J 2015 Air quality policy in the U.S. and the EU – a review Atmospheric Pollution Research 6 129-137
[7] United States Environmental Protection Agency 2002 National emission standards for hazardous air pollutants: Revision of source category list under Section 112 of the Clean Air Act Federal Register 67 6521–36 http://www.gpo.gov/fdsys/pkg/FR-2002-02-12/pdf/02-3348.pdf
[8] Jin Y, Andersson H and Zhang S 2016 Air pollution control policies in China: A retrospective and prospects Int. J Environ. Res. Public Health 13 1219
[9] Connolly U 2001 Clearing the air Hot Mix Asphalt Technology 6 21-2
http://www.flexiblepavements.org/sites/www.flexiblepavements.org/files/clean_air_2_pg_article.pdf

[10] United States Environmental Protection Agency 2000 Hot mix asphalt plants - emission assessment report EPA 454/R-00-019 https://www3.epa.gov/ttn/chief/ap42/ch11/related/ea-report.pdf

[11] United States Environmental Protection Agency 2004 Emission Factor Documentation for AP-42 Section 11.1 Hot Mix Asphalt Plants Final Report RTI Contract No. AGMT DTD 10/31/02

[12] AQEG 2005 Particulate matter in the UK: Summary Defra London https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/pm-summary.pdf

[13] Hodan W M and Barnard W R 2004 Evaluating the contribution of PM2.5 precursor gases and re-entrained road emissions to mobile source PM2.5 particulate matter emissions https://www3.epa.gov/ttnchie1/conference/ei13/mobile/hodan.pdf