Binder performance and testing

GRIP ON BITUMEN: MAPPING THE CHANGES IN BITUMEN MARKET AND ITS IMPACT ON PERFORMANCE

Sayeda Nahar[1], *Wim Teugels*[2], *Alex van de Wall*[3], *Natascha Poeran*[4], *Inge van Vilsteren*[5]

[1]*TNO Technical Science, The Netherlands,* [2]*Nynas NV, Belgium,* [3]*KWS, The Netherlands,* [4]*Boskalis, The Netherlands,* [5]*Rijkswaterstaat, The Netherlands*

Abstract

Major road networks in the Netherlands are made of asphalt concrete. These roads enable our economic and social activities by facilitating the movement of goods and people. Development and maintenance of the road network, by keeping it operational is crucial to the growth and competitiveness of the economy. In order to maintain high quality of these roads, while striving towards a more sustainable, circular society requires a thorough understanding of both the performance of asphalt concrete and its constituents. Bitumen is known to be the most important component that influences the performance and durability of asphalt. Composition of bitumen can vary depending on nature and source of the crude oil and its refining process. In recent years, bitumen market has changed significantly in terms of its quality and consistency. One aspect of this change is the unavailability of certain crude oil sources, which introduces a change in choice of crude oil source and often mixture of crude oils from multiple sources. Another aspect is that the refineries are in transitions due to economic and regulatory reasons. As a result, there is an inconsistency in crude source and quality of bitumen in the market. This change can influence both short and longterm performance of bitumen and asphalt. To address timely topics and to promote asphalt related innovations, a collaboration platform between asphalt industry, road authority and knowledge institutes is introduced in 2018 in the Netherlands. The program is called Asphalt- Impulse. All stakeholders work together towards a common goal: “Doubling the lifetime of asphalt pavements, halving the scatter in lifetime, halving the CO2-footprint with the same or lower production cost”. One of the projects within Asphalt-Impulse is called “Grip on Bitumen”. The project aims at a better insight and understanding the influence of refining methods, crude oil sources: in this way to map potential sources of change in bitumen market. It also aims to define additional performance indicator for bitumen that can better predict the functional properties of

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

bitumen and asphalt. This paper summarizes the knowledge document developed within ‘Grip on bitumen’ and presents the aspects of bitumen manufacturing process, driving factors of the current change in bitumen market and its possible impact on asphalt and other industrial application.

1. INTRODUCTION

Changes in the refining industry have impact on the local bitumen market in the Netherlands. These changes have drawn considerable attention from bitumen consumers in terms of bitumen quality and consistency. These changes are taking place due to economic, regulatory reasons, unavailability of certain crude oil sources and are inevitable. The market is adapting resulting in a profound need to understand better the future of bitumen in terms of quality and performance in asphalt and other industrial applications.

Earlier, bitumen was locally produced through well defined refining processes, primarily by atmospheric distillation followed by a vacuum distillation. The bitumen obtained by such a process is known as straight run bitumen. Other refining processes, such as oxidation, solvent deasphalting and thermal cracking, have been used to further process vacuum residues into components used to blend different grades of bitumen. More recently, many refineries are further upgraded with additional process units, such as cokers and residue hydrotreaters, to enhance extraction of lighter components that have higher economic value reducing or completely removing vacuum residue from the refinery output. Ultimately, these developments have impact on bitumen- supply, manufacture and product properties in both physical properties as well as chemical/molecular composition and therefore likely to affect the performance as a binder.

In order to meet carbon emission targets, set by Dutch road authority and also globally, there is a growing need to assess the life-cycle impact of raw materials, i.e. bitumen. The trends in the market show emphasis towards more circular economy and use of less energy during asphalt production. As a result, recycling with higher allowable limit of recycled asphalt pavement (RAP) and horizontal recycling, (i.e. recycling RAP from surface course back to surface course) are foreseen in the future. Development of energy efficient asphalt technologies without compromising the performance properties is also anticipated in the near future. In all the above-mentioned cases, quality and performance of the binder will be more significant than that it used to be.

Recently, one of the most discussed topics in the refining industry is the IMO 2020 legislation introduced by International Maritime Organization (IMO). This act is to reduce global sulphur oxides (SOx) emissions from heavy fuel oil used in the ships from 3.5% to 0.50% m/m (mass by mass) and is implemented from 1st January 2020. Due to the mandated IMO 2020 regulation, refineries around the world are already updating their strategies. This will influence different aspects of refining process: from selection of crude oil feedstock to end product composition and properties. The bitumen market is expected to be affected in five areas: supply/demand, available product grades, quality, transportation (costs) and bitumen price marker.

Bitumen customers show an increasing concern regarding the performance of bitumen in terms of workability, product quality or consistency and short- and long-term durability of neat bitumen in asphalt and in other industrial applications. Specialty bituminous products, like polymer modified bitumen (PmB) and bituminous emulsions, are particularly susceptible to changes or fluctuations in bitumen chemistry. Under these circumstances, complying with current standard paving grade bitumen specifications may not be adequate to guarantee desired performance level of the bitumen in its end-application.

In new, innovative asphalt applications the current traditional specifications may not be adequate to cover the range of performance requirements. For example, what is the impact of using ‘only’ 60% fresh bitumen in pavements containing 40% RAP? Or, what specific additional requirements (longer life, higher traffic intensities) do asphalt materials need to have today and what could be the contribution of bitumen? Are there new requirements that need to be incorporated into specifications? In the Dutch national Asphalt Impulse initiative, the project ‘Grip on Bitumen’ is seeking to address some these questions and in particular establish ‘the impact of bitumen quality on asphalt mix quality’. The project objectives are;

(1) to obtain better insight into the base knowledge of developments of bituminous binders,
(2) establish bitumen properties (and their variation) relevant for asphalt properties.
(3) define a framework for assessing binders for specific asphalt application and
(4) share this knowledge between producers and users of bitumen.

In order address the first objective to begin to understand better the potential impact on bitumen quality and consistency, there is a need to develop improved understanding of the influence of the crude oil source and refinery processing on bitumen performance characteristics.

The improved understanding could help remove some of the concerns bitumen users have today, bridge the apparent knowledge gap and pave the way to update bitumen specifications in the future. This paper reviews bitumen manufacturing process, potential sources of the changes in the bitumen market and the possible impact on asphalt and other industrial application. As such, it summarises the knowledge gathered in this area to address the first of the four objectives and serves to provide a knowledge base to realise the other three project objectives.

2. WHAT IS BITUMEN AND HOW IS IT PRODUCED?

2.1. What is bitumen?

Bitumen is a dark brown to black cement-like residuum obtained from the distillation of crude oils. The distillation process always involves atmospheric distillation followed by vacuum distillation. The distillation residue may be further processed in order to obtain a material whose physical properties are suitable for commercial applications. In Europe bitumen is specified based on its physical properties as it is mostly used as an engineering material. The specification systems in Europe use harmonised test methods which vary by region and intended use and defined centrally by CEN.

2.2. How is bitumen produced?

Like almost all substances manufactured in (or imported into) Europe, bitumen is covered by REACH legislation. In Europe there are only four REACH registered refinery streams that are used in bitumen manufacturing (1) Asphalt, (2) Residue (petroleum), vacuum, (3) Asphalt, Oxidised and (4) Residue (petroleum), thermally cracked vacuum. The first three are most commonly used. There are a number of other refinery streams which have been (pre-) registered for use as bitumen component, such as various hydrotreated-, hydro-desulphurised or dewaxed vacuum residues. However, these registrations are inactive and not used in bitumen production today.

In practice, bitumen is primarily obtained in a refinery by vacuum distillation of carefully selected crude oil or blends of crude oil. Lighter, low molecular weight boiling point fractions from crude oil are separated resulting in a product with high boiling point, high molecular weight and very low volatility. Depending on the specific refinery asset configuration and location, refineries process different crude oil blends to manufacture the oil products needed by the market and select the most optimal mixture of crude oil types to match this market demand. On average, bitumen represents about 3% of the crude oil processed in refineries globally but this also includes refineries that choose not to produce bitumen.
Because petroleum distillation residuums are the starting materials for all bitumen production, the chemical and physical properties of the bitumen depend upon the properties of the crude oil from which the bitumen is manufactured. From commercially available assembly of crude oils or crude oil blends, only certain selections are suitable to produce bitumen. Commonly heavy (high density), sour (high sulphur) crude oils are used to produce bitumen of optimum quality [1-4, 9].

2.3. Straight-run process

In a simple refinery configuration, bitumen is produced using atmospheric followed by a successive vacuum distillation, which is known as straight-run bitumen. Depending on bitumen product requirements, vacuum residue can be used directly as bitumen, further processed, or used as a component of blended bitumen. To meet specifications, a minor adjustment to the physical properties (i.e. increasing hardness) of the residuum may be required. A mild air-blowing process, known as air rectification can be introduced to harden the bitumen. Air-rectified bitumens are used in paving and other applications like roofing and coating industries. Both straight run and air-rectified bitumen products conform to the same specification.

2.4. Further processes: Deasphalting, Oxidation, Thermal cracking, Hydrotreating/desulphurisation

A solubility-based separation unit; solvent deasphalting is used in some refineries for subsequent further upgrading of vacuum residues. The deasphalting process involves different solvents like propane, butane, isobutene, pentane, or supercritical solvent extraction to separate asphaltene-type fractions from the residue to produce lube oil base stocks. This process results in a harder bitumen grade than the original vacuum residue and can be blended with other bitumen components to produce required specified bitumen grades [1,4,9].

Another modification process of bitumen involves passing air through bitumen feedstock at elevated temperatures in order to significantly change the physical properties. Bitumen from such a process is known as oxidised or blown bitumen. Resulting product has an increase in softening point, decrease in penetration and an increase in viscosity which is required for some tailored industrial application [1, 2, 4].

Refineries are equipped with other upgrading units that include a thermal cracking process to further break down the long paraffinic side chains attached to aromatic rings and subsequently transform them to form shorter molecules. In this process, often referred to as visbreaking, the vacuum residue is treated at high temperature (440-500°C) and different process conditions depending on the properties of the feedstock, desired yield and end product requirements. Hydrotreating takes place when hydrogen is introduced into this specific process usually resulting in some desulphurisation. For bitumen production, after the process of thermal cracking the residue is introduced to vacuum distillation unit to remove the lighter distillates. The residual product obtained through these processes is often a hard, highly viscous material that can be blended with other softer low viscosity bitumen substances in the refinery to obtain a range of specific bitumen grades.

2.5. Production of range of bitumen grades by blending process

Consistency of the bitumen largely depends on the consistency of the composition of the crude oil feedstock and the manufacturing process. A range of bitumen grades can be obtained by blending bitumen streams of different viscosities. Bitumen with desired physical properties can be obtained by blending higher viscosity bitumen products or bitumen with lower viscosity products or bitumen in tailored proportions to satisfy final specification requirements. Different strategies are adapted for blending according to the capacity, convenience to storage and supply of bitumen. The process may take place at the refinery, terminals, or at a third-party facility for the convenience of transporting (i.e. by truck, rail, or barge) to the final locations.

At some third-party blenders, the blending components can be diverse and seems to be much less controlled than for bitumen substances even though this practice formally falls under separate regulation: the European Dangerous Preparation Directive [19]. For example, re-refined used engines oils (REOB or VTAE) are known to be blended to produce softer bitumen grades. The term REOB or VTAE refers to the residual distillation product from a vacuum tower produced during the re-refining process of used lubricating oil rather than refining crude oil. It is important to understand that this product is a bitumen preparation and compositionally different than bitumen substances coming from a vacuum tower of a crude oil refinery. The quality and chemical compatibility of the blend components are crucial to performance and durability of bitumen to its specific application areas [4].

3. INFLUENCE OF MANUFACTURING PROCESS INTO MOLECULAR MAKE-UP OF BITUMEN

3.1. Processes and resulting shift in chemical composition

At molecular level, bitumen is a mixture of thousands of dissimilar high boiling point hydrocarbons: aliphatic, aromatic and a mixture of both. It may also contain small amounts of hetero atoms like nitrogen (≤2%), oxygen (≤2%), sulphur (≤6%), and trace metals (i.e. nickel, vanadium and iron are the most abundant). Bitumen processed from certain crude oil feedstocks may contain wax of 2 to 5% by weight [5].

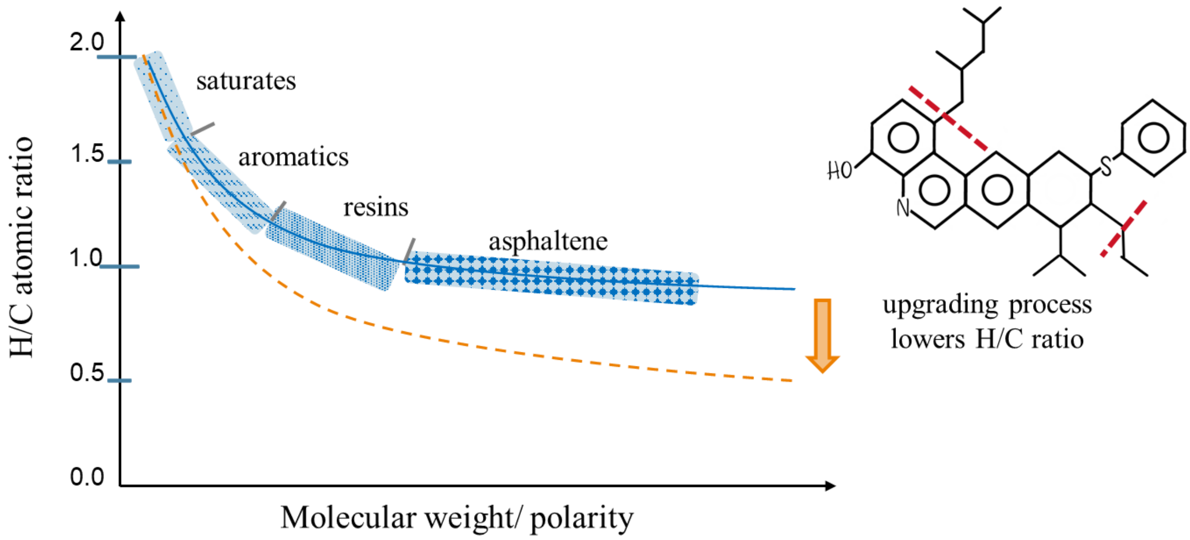

Figure 1: Schematic presentation of hydrogen to carbon atomic ratio of the fractions of molecular classes of bitumen and its possible shift due to change in molecular weight distribution.

To simplify the diversity of the chemical nature of bitumen, a pragmatic approach to define the chemical nature is to separate bitumen into some chemical fractions on the basis of differences in solubility. One of the most accepted separation techniques on the basis of solubility is SARA analysis. The fractions are commonly known as: saturates, aromatics, resins and asphaltenes (SARA) as shown in Figure 1. The molecular weight and the aromaticity of the fractions increase in the order saturates < aromatics < resins < asphaltenes [1,2,5]. SARA fractions are experimental boundaries of a continuous range of molecules; hence molecular properties can vary within a fraction. SARA fractionation can also be explained by hydrogen to carbon atomic ratio, that decreases with increasing molecular weight. Hence the H/C atomic ratio gradually decreases from saturates to asphaltenes [1, 2].

As described in section 2 bitumen manufacturing may involve multiple process units to produce different grades of bitumen. Different refining processes induce different physical change and/or (irreversible) chemical change in the refinery stream resulting in different end products.

Atmospheric and vacuum distillation are processes that separates molecules based on boiling point. Little to none chemical transformation takes place in this process. For (a blend of) crude oil(s) deeper distillation results in bitumen products with higher average molecular weight which have higher viscosity and are harder. Similarly, solvent deasphalting is a separation technique based on solubility where no molecular transformation takes place. The residue

output of this unit will have a higher viscosity than the input of this process unit resulting in a harder bitumen component.
The processes of oxidation and thermal cracking (with or without the presence of hydrogen) of vacuum residue do transform molecules resulting in a different chemical composition of the end products and different physical properties. During oxidation the primary process is carbon-carbon bond formation via oxidative condensation, increasing asphaltene content reducing aromatics resulting in a harder bitumen product much more elastic than visco-elastic in nature. Thermal (hydro)cracking process followed by a vacuum distillation to remove lighter low boiling point products results in cleavage of peripheral chains of aromatic compounds having side chains and opening of the naphthenic rings of naphthenic-aromatic compounds [2]. These chemical changes also alter the molecular weight distribution of the components, that can be realized from a possible downward shift of hydrogen to carbon atomic ratio of the molecular fractions as presented in Figure 1. Any change in chemical composition, will likely affect directly the physical properties (i.e. viscosity, stiffness and adhesion) of bitumen.

3.2. Relationship between crude oil composition and pavement performance.

There is a basic relationship in the asphalt supply chain which says that: Crude oil composition ↔ Asphalt binder composition ↔ Asphalt binder properties ↔ Mixture properties ↔ Pavement performance. Therefore, a lot of research has been made in order to better understand these key relationships. Rheological properties (DSR and BBR) are suggested as being the best tool to provide insight in the binder complexity [14] and from SAR-AD composition analysis, good correlations were found with several bitumen viscosity or rheological tests (including the viscoelastic behavior characterized by the R-parameter, crossover modulus, and penetration) [15].

Investigating the possible relationships between bitumen composition and performance is not new and a major research on this topic was also done during the US Strategic Highway Research Project which resulted in the Superpave Specifications. In order to predict the changes in fundamental engineering properties a series of physical as well as chemical test data must be known to model various properties.

A working model has been developed to provide this information (see figure 2). The model envisions aromatic, high molecular weight, core molecules dispersed in a medium of relatively, low-molecular weight molecules. The dispersed phase is viewed as being peptized by adsorbed aromatic molecules lower in molecular weight than the core materials and which are soluble in the dispersing medium. The core materials are considered as asphaltene micelles, the peptizing agents as resins and the dispersing medium as oils (maltenes). The hypothesis characterizes chemical composition by classifying asphalts into sol-like or gel-like categories. In the extreme case of the sol, no micellar structures would be present, and any such asphalt would be a true solution. All asphalts exhibit micellar structures to varying degrees [16, 17]. This model is still applied and provides often the basis for “engineered bitumen” concepts.

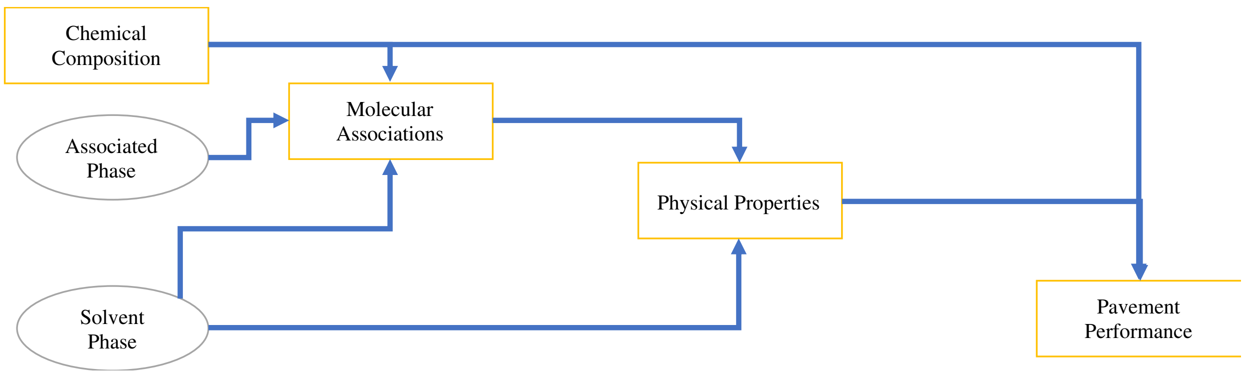

Figure 2: Chemistry Physical Property - Performance Relationships [16, 17].

This colloidal or micellar model has been revised since and nowadays SHRP suggests a “microstructural” model. In such model, bitumen is a single-phase, complex mixture of molecules with no micelles, no networks, and no floating “islands” of materials. However, while there are no true phases in asphalts, there is a mixture of molecules of widely varying polarity and molecular weight, and the materials in this mixture interact with one another to form “associations”. These associations form among the polar molecules in the asphalt, which create weak electrostatic bonds between the polar sites on the molecules. The molecular weight distribution and amount of non-polar materials affect the associations of the polar materials.
All these interactions between bitumen molecules are weak, and the bonds may be broken through the action of heat or shear forces. This concept of weak interactions between the molecules explains why bitumen behaves as a Newtonian fluid at elevated temperatures, and also explains why bitumen exhibits a constantly changing behavior. Due to the weak nature of the polar-polar bonds, the bonds are constantly being broken and reformed, each time in a unique way that never yields quite the same material.
In this model all molecules are mobile and only interact through dispersive, polar and hydrogen bonding interactions.

3.3. Phase behavior: a performance indicator?

Different bitumen manufactured to the same specification, such EN 12591, can a priori not be simply physically distinguished from one another using the standard test methods on which this specification is based. In other words, even though two bitumen meet the same EN 12591 specification, they can still be chemically and physically different when more advanced test methods are used.

Below the onset of melting temperature, distinct phase morphologies can emerge in bitumen. This evolves from differences in chemical composition and intermolecular interaction. Phase transition events at submicron level can be investigated by Atomic Force Microscopy (AFM). Microstructures investigated by AFM show evidence, in some cases, of a characteristic two-phase morphology where the domains may be co-association of microcrystalline wax and asphaltene type molecules which shows different stiffness and adhesion characteristics than rest of the matrix [3].

Figure 3 presents micrographs of some neat bitumen of penetration 70/100 obtained from three refineries. These refineries process different crude oil feedstocks and are also different in their configuration. Here, neat bitumen from refinery 1 and 3 show typical two-phase morphology: domains of characteristic properties that are dispersed in a matrix phase. Bitumen from refinery-2 is processed from a non-waxy crude and doesn't show any phase separation. Bitumen obtained from thermal cracking may introduce more polycondensed hydocarbons showing high carbon intensity and can result in a shift in mutual solubility of the generic fractions. This may lead to unexpected phase separation at micrometer scale due to difference in chemo-physical affinity. Such phase behavior could possibly fingerprint bitumen crude oil source and production process and reveal mutual compatibility at high precision.

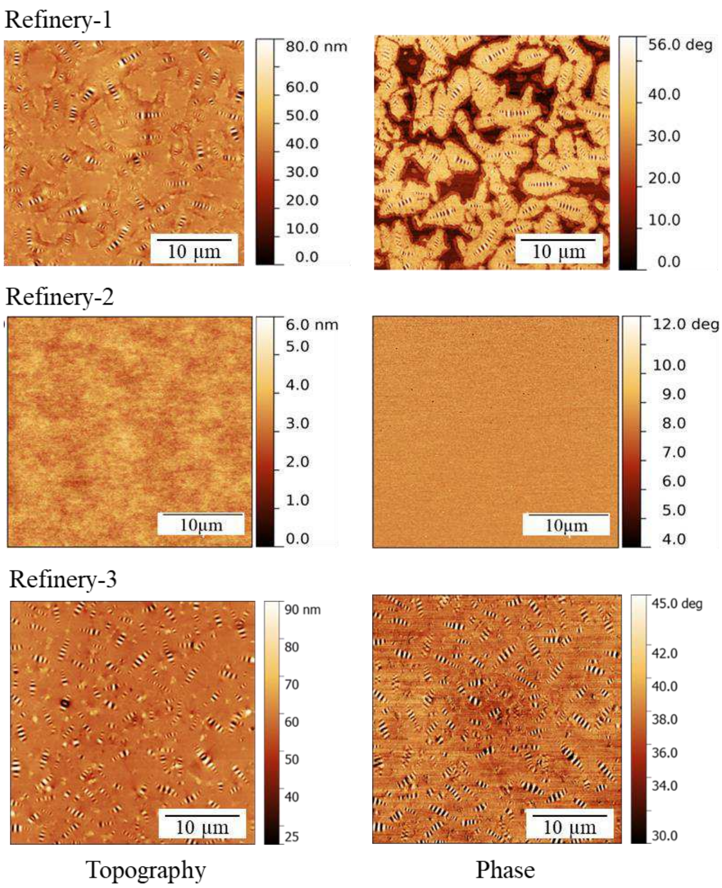

Figure 3: AFM micrographs (30×30 μm2 topography and phase images) of neat bitumen of the same penetration grade which are obtained from different 3 refineries that vary in crude oil feedstocks and production processes [3].

4. CHANGES IN REFINERIES AND MARKET DEMAND

Currently around 110 Million tonnes of bitumen are produced per year worldwide. The largest bitumen user is the asphalt sector, consuming 85% of the total production. The second largest application area is the roofing industry that uses approximately 10% and the remaining 5% use covers special industrial application areas. In Europe there is currently an annual demand of approximately 15 million tons of bitumen down 30% from 2008 demand. [10, with updated data for 2018]

Changes in legislation, policies and changes in oil products (mainly fuels) market demands has changed the European refinery landscape considerably. Additionally, global political factors affect the type of crude oils available for European refineries. Refineries will manufacture the products needed by the market and select the most optimal crude type to match supply possibilities and market demand. Over time, this can result in crude supply fluctuations (See figure 4).

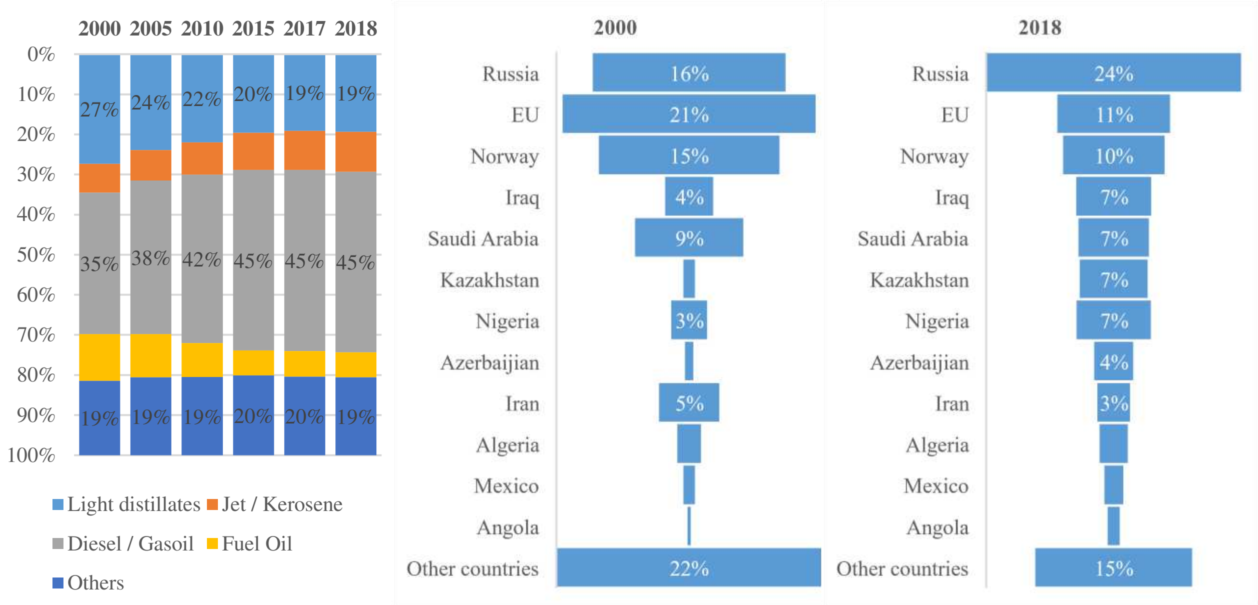

Figure 4: European product demand and crude oil processed from 2000 to 2018 [BP, Eurostat, OPEC]

The factors that drive the refinery transitions are the upgrading of refineries to meet new supply-demand situation, to accommodate flexibility in crude oil feedstock sourcing and also adapting with new legislation or policies.

4.1. Transitions in refineries

Refineries invest to adapt to a changing crude oil supply and market demand situations. Upgrading units are introduced in the refineries to process heavier, higher sulphur crudes which typically attract higher discounts than lighter and low sulphur, easily processable crudes. In this way, over the years, refineries are adapting to more complex configurations to process a wider variety of crudes aiming at desired product yields. In most refineries, bitumen is not the primary product and the choice of crude oil will not primarily be based on the bitumen production. However, when the refinery produces bitumen, this is not by accident: a conscientious choice is made. This choice comes with limitations to crude oil flexibility as the number of crude oils suitable for bitumen production is limited.

At the same time, recent refinery trends [13] show that more complex processes are becoming common allowing feedstocks of different composition and consistency to be handled through upgrading broadening crude oil sources. An individual refinery typically may process around 40 – 70 different types of crude oils.

In the past few decades, new technologies, including both carbon rejection methods and catalytic conversion methods, have emerged. A combination of carbon rejection and the addition of hydrogen (H_2) can be used to upgrade residuum fuels to make the low-sulphur gasoline and ultra-low-diesel (ULSD) fuels required by environmental regulations. Upgrading residual fuels uses either carbon rejection or H_2 addition, or a combination of the two. Traditional carbon rejection technologies include delayed coking, visbreaking, fluid coking, solvent deasphalting and residual fluid catalytic cracking [12]. Depending on the selected technique, a refinery has the possibility to upgrade and convert all vacuum residue in more marketable lighter products. With IMO 2020 ahead, several refineries have chosen to invest in upgrading to reduce the amount of heavy refinery products.

4.2. IMO 2020

The International Maritime Organization (IMO) has implemented a lower sulphur limit for marine fuels, commonly known as IMO2020, aiming to protect public health and the environment by reducing air pollution from marine fuels. This has a significant impact on both the shipping- and the refinery industry and it is also a key driver of refinery transitions. The IMO act first came into force in 2005, and since then, the limits on sulphur oxide emissions have been progressively tightened. From 1 January 2020, the limit of sulphur content in fuel oil used for ships is reduced from 3.5% to 0.50% w/w worldwide. The shipping industry can choose to use low sulphur fuels or invest and install scrubbers to clean up ship's exhaust gases. The refining industry is moving towards producing low/ultra-low sulphur fuels which affects the choice of crude oil processed and changes in refinery configuration.

In conventional refining practices, high sulphur fuel oils used to be a common outlet for sulphur. Due to the IMO 2020 legislation, refineries have had to make choices how to deal with the sulphur coming into the refinery via its crude oil. So, refiners with a large yield of high-sulphur residue will look to increase residue destruction and desulphurisation. This will have an impact on a range of products, including petroleum coke and bitumen. Upgrading will reduce bitumen supply, and there is a risk that bitumen-producing refineries could close as refiners move to lighter crude slates or install cokers and other upgrading capacity to produce lower-sulphur fuels and cut residue. This could lead to changes in bitumen grades or to supply tightness in some parts of the world during the peak paving season [8].

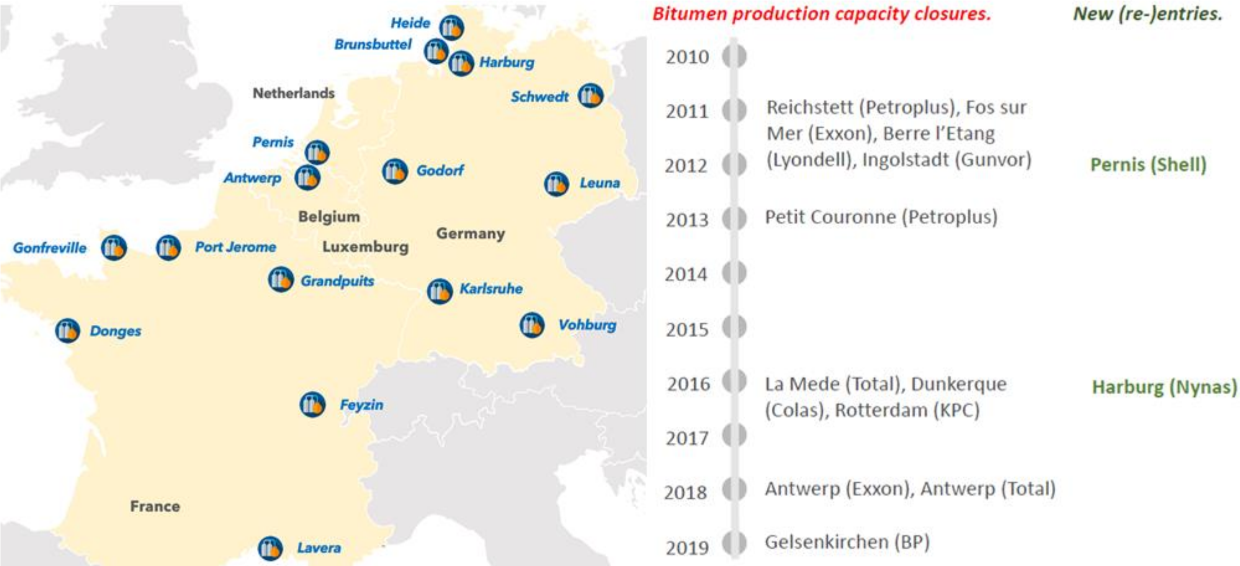

Figure 5: Changes in bitumen production capacity around the Netherlands in the past 10 years [info Nynas].

4.3. Closing of bitumen production

Since 2009, Europe has lost around 2.2 million barrel/day worth of crude oil refining capacity across the continent. During this time annual bitumen demand dropped 30% from approximately 22 million tons to 15 million tons. Despite efforts to diversify crude sourcing through upgrading production processes, maximizing yields and introducing flexibility, Europe is expected to see further refinery changes and/or closures. As a consequence of the total refining rationalisations driven mainly by fuel supply/demand various production sites have stopped bitumen production, forcing customers to source bitumen from a different supplier. For example, since 2009 bitumen imports to the Netherlands have shifted almost completely from Belgium to imports from Germany. Figure 5 summarizes the change of bitumen production sites around the Netherlands in the past 10 years [compiled by Nynas based on published information].

4.4. Asphalt production and recycling of asphalt

There is an increasing use of reclaimed asphalt pavement (RAP) materials in new hot mix asphalts (HMA) in Dutch and international practices. Focus of the asphalt industry is on innovations that includes high RAP content (~60%) in new mix design with more emphasis on life cycle aspects and environmental impact. Figure 6 presents an overview of new asphalt production and use of RAP in the Netherlands. In recent years, there is a significant increase in use of RAP in new HMA.

Another specific development in the field of asphalt recycling is 'horizontal recycling'; which means RAP available from top asphalt layer is recycled to the same layer in new construction. In Dutch practice, wearing courses of most highways is constructed using porous asphalt (i.e. single or two-layers). The top layer of a two-layer porous asphalt is commonly constructed using polymer modified bitumen. The challenge in the field of horizontal recycling would be to re-activate the aged (polymer modified) binder through replenishing its mechanical properties and to ensure a good blending between recycled and freshly added bitumen. All these innovations, practices and trends lead to more circular economy. In order to meet this sustainability ambition, quality of asphalt component is an important aspect. Current bitumen specifications cannot guarantee a fit-for-purpose behaviour in all (new) asphalt concrete applications and may need to include requirements on functional, durability properties at wide range of temperatures.

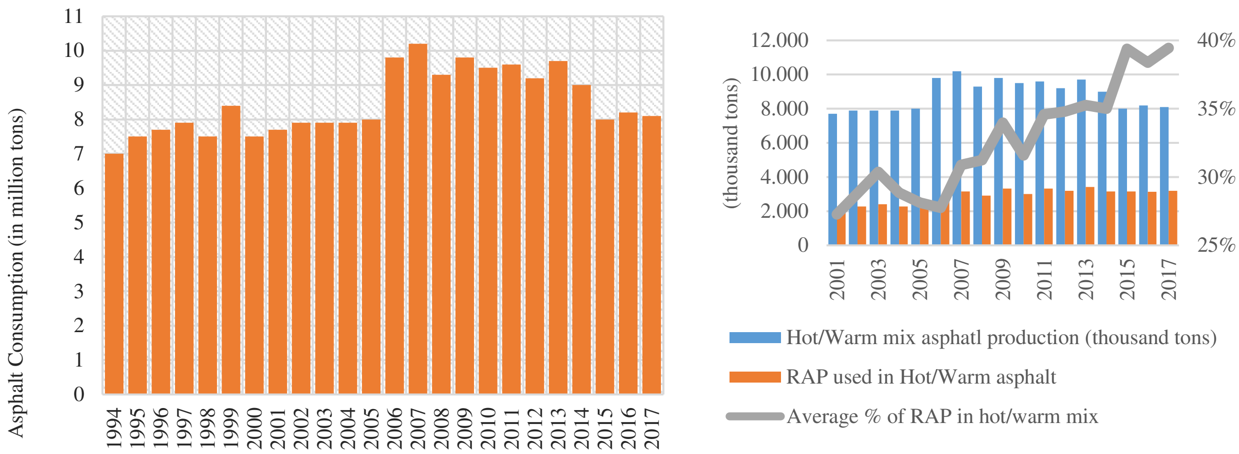

Figure 6: Asphalt consumption and recycling in the Netherlands. (adapted from Asphalt in figures 2017, EAPA) [6]

5. IMPACT OF CHANGES IN THE BITUMEN MARKET

The changes in refinery landscape, driven by changes in the global fuels market, and refinery closures in Europe create uncertainties with the users-consumers of bitumen. Uncertainties in the asphalt sector relate to cost, availability, quality or quality variations. Changes in the supply chain, appearance of non-refining suppliers and bitumen travelling further contribute to differences in perceived bitumen product quality even though the product meets standard bitumen specifications. Developments, innovations and trends in the asphalt market generate questions around the chemistry and durability of bitumen which go beyond traditional (physical) specifications.

The IMO 2020 regulation will have a noticeable impact on the overall supply side as well as on how many different bitumen products will be available. The cost of transportation and how bitumen is priced are other factors that are likely to be impacted. It is expected that more refiners change their set-up, either through a change in the type of crude oil that they process or by installation of upgrading units. This is especially true for those refiners that do not have a strong focus on the bitumen market. Overall, the European bitumen supply/demand will likely remain balanced after 2020 with as always, some regional and seasonal imbalances but indications are that these will reduce. Due to further residue upgrading, refineries will likely produce harder grades than in the past. Softer bitumen components may therefore be less widely available, and the chemistry of bitumen may become more diverse. This will affect available grades and quality. Consequently, a more intimate knowledge of bitumen becomes more important. The extra costs shipping companies will be incurring, either from using low-sulphur fuel oils or through installation of scrubbers will in turn result in increased transport costs for both crude oil and bitumen. Finally, when it comes to pricing, HSFO is expected to disappear as a price marker for bitumen as reduced traded HSFO volumes leads to severely increased volatility [11].

Bitumen specifications today are composed of test methods measuring traditional physical properties. For most unmodified, regular bitumen these are still valid when applied in standard applications. However, for more demanding applications further additional rheological characterization could help make a differentiation between bitumen from different sources or origin. This may facilitate the choice of the right bitumen for the application.

The consequence of all these changes is ultimately that the users and producers of bitumen need to jointly develop a better understanding of the impact of changes in production and application. The Asphalt Impulse initiative in the Netherlands intends to create such a platform for discussion with the project ‘Grip on Bitumen’ focusing on the relevance of bitumen quality on asphalt quality.

6. CONCLUSIONS AND OUTLOOK

The composition of bitumen can vary depending on the source of the crude oil feedstock and refining process used in its manufacture. In many refineries, a large selection of crude oils is processed, and bitumen manufacturing processes may differ per refinery. However, bitumen production always starts with atmospheric - followed by vacuum distillation. Normally this gives a vacuum residue that will meet a standard bitumen specification. Depending on refinery configuration and crude oil, the vacuum residue may be further processed and subsequently the physical and chemical properties will change further. These changes translate into changes of both bitumen physical properties and its chemistry. How the latter translate to performance aspects like long term durability is less well understood, Furthermore, the absence of a long-term ageing requirement in the current standard paving grade specification leaves room for concerns regarding the long-term durability performance of bitumen in certain applications.

The major change in marine fuel legislation, e.g. IMO 2020, impacts bitumen in different areas: supply/demand, available product grades, quality, transportation (costs) and bitumen price marker. The magnitude of the impact is difficult to quantify and, in some cases, even the direction of the impact is difficult to predict. For example, will the sulphur content in bitumen increase as this becomes a sulphur outlet for the refinery or will it go down as refineries start processing sweeter (lower sulphur) crudes and-or desulphurise refinery streams more?

The refinery landscape has restructured through refinery closures, rationalisations and reconfigurations with more changes expected to come. Suppliers that are not refiners have entered the supply chain. These changes bring with them a potential for greater variations in product consistency and quality. A pragmatic approach needs to be outlined to define performance related properties that can assess suitability of bitumen in asphalt and other industrial application. Next to product performance, health, safety and environmental related aspects of bitumen are prioritized in the production, supply and application chain.

Bitumen quality and consistency is influenced by these changes which is acknowledged by the bitumen suppliers. Nevertheless, suppliers state that these changes are inconsequential for meeting the requirements for current paving-grade or other industrial grade bitumen specifications. However, the asphalt sector now raises the question regarding current bitumen specifications whether they are still applicable to describe the bitumen quality and if it is fit for the future (applications). The whole sector should work together towards a pragmatic solution. Openness and an improved understanding of all the processes along the whole bitumen and asphalt supply chain could reduce the tension and create an opportunity for trust between producers and users of bitumen. Mapping changes in bitumen production and market, as summarised in this paper, hopefully lays the foundation to further explore bitumen properties relevant to asphalt properties and ultimately contribute to defining a new framework for assessing binders for specific asphalt applications that create long life durable asphalt pavements.

7. COPYRIGHT

The Authors declare that the paper is original and there is no conflict of interest in publishing this paper.

8. ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the team of “Grip on bitumen” for the fruitful discussion sessions and Asphalt-Impulse programme in the Netherlands.

9. REFERENCES

[1] G.V. Chilingarian, T.F. Yen, “Asphaltenes and Asphalts”, 1, 1994.

[2] A. Chakma, “Kinetics and Mechanisms of Asphaltene Cracking During Petroleum Recovery and Processing Operations”, Asphaltenes and Asphalts, 2, Edited by T. F. Yen ,G. V. Chilingarian, Chapter-6, 2000. https://doi.org/10.1016/S0376-7361(09)70277-8

[3] S. Nahar, “Phase Separation Characteristics of Bitumen and their Relation to Damage-Healing.”, PhD Thesis, 2016. https://doi.org/10.4233/uuid:670c70ff-f9f0-4cdb-aa4d-b661e7117354.

[4] Asphalt Institute, and European Bitumen Association, “The bitumen industry: a global perspective: production, chemistry use, specification and occupational exposure.”, 2015.

[5] J. Read, D. Whiteoak, “The Shell bitumen handbook”, 2003.

[6] EAPA, “Asphalt in figures, 2017”, European Asphalt Pavement Association.

[7] Sulphur 2020 – cutting sulphur oxide emissions, media centre- in focus, International Maritime Organization.

[8] Argus Media, “https://www.argusmedia.com/en/blog/2019/september/11/imo-2020-series-beyond-the-bottom-of-the-barrel”

[9] J.F. Le Page, S.G. Chatila, M. Davidson, “Resid and Heavy Oil Processing.”, Editions Technip, 1992

[10] W. Teugels, “Bitumen: A Specialty Product in Today’s Refining World.”, Impervius Conference, Baveno – Italy, 2019

[11] J. Weston, “Bitumen market outlook.”, Argus European Bitumen conference, Porto – Portugal, 2018

[12] R. Elshout, “Upgrading the bottom of the barrel.”, Hydrocarbon Processing, March 2018

[13] T. Janssens, T. Fitzgibbon, “The conundrum of new complex refinery investments.”, McKinsey & Company, September 2015

[14] JP. Planche, “Relationships between asphalt binder chemistry and physical properties: Why they are important and How to assess them?”, ISAP Conference, Brazil, 2018

[15] F. Delfosse, I. Drouadaine, S. Faucon-Dumont, S. Largeaud, B. Eckmann, JP. Planche, F. Turner, R. Glaser, "Impact of the bitumen quality on the asphalt mixes performances.", 6th Eurasphalt & Eurobitume Congress, Prague - Czech Republic, June 2016
[16] TW. Kennedy, RJ. Cominsky, "Hypothesis and Models Employed in the SHRP Asphalt Research Program.", Strategic Highway Research Program, Washington, 1990
[17] DR. Jones, TW. Kennedy, "The Asphalt Model: Results of the SHRP Asphalt Research Program.", SHRP A-001 Contract, Center for Transportation Research University of Texas
[18] G. White, "Changes in Australian paving-grade bitumen: are they real and what should Australia do about it?", 27th ARRB Conference – Linking people, places and opportunities, Melbourne, Victoria 2016
[19] Directive 1999/45/EC of the European Parliament and of the Council of 31 May 1999