Binder performance and testing

# IMO and the Effect on Bitumen Quality

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## Abstract

The ultimate effect of the implementation of new IMO 2020 regulations on the use of fuel oil contain sulphur on the quality of bitumen is currently unknow. However, some interesting factors may be deduced from historical data and comments on the sulphur content of bitumens and the discussions be held at various industry meetings/conferences on this subject. IMO (International Maritime Organization) has been introducing rules to lower the use of high sulphur fuel oils (bunker fuel) over the past years. Data on sulphur in bitumen has been collected since the beginning of use in the late 1800's/early 1900's [1], even with a specification limit on sulphur content in one agency for a period of time in the first half of the twentieth century (introduced in 1915) [2]. This was contested in 1940 with the detailed review of physical and chemical properties developed by Lewis and Welborn [3]. Many heavy oils that have been used for good quality asphalt binders have had sulphur contents that tend to be towards the higher part of the range of in asphalt. As the market dynamics change refiners will face challenges regarding use of sour crudes and this will inevitability effect the asphalt binder supply. This paper presents some discussion of changes ongoing in the industry with refiners preparing for the IMO changes. The effects of sulphur on bitumen properties are discussed and the possible implementations to the asphalt industry.

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## 1.Introduction

The regulations, referenced typically as IMO 2020 limit the air pollution from shipping. These regulations have changed the global limit for Sulphur content of ships' fuel oil from 3.50% m/m (mass by mass) to the new global limit of 0.50% m/m. These limits have evolved over the past eight years to reduce the amount of pollution in the maritime industry as follows:

- 4.50% m/m prior to 1 January 2012;
- 3.50% m/m on and after 1 January 2012; and
- 0.50% m/m on and after 1 January 2020.

IMO has been working to reduce harmful impacts of shipping on the environment since the 1960s.

## 2. Sulphur in crude oil

A common method for describing crude oils is to consider them as either sour or sweet according to Sulphur content. Major locations where sweet crude is found include the Appalachian Basin in Eastern North America, Western Texas, the Bakken Formation of North Dakota and Saskatchewan, the North Sea of Europe, North Africa, Australia, and the Far East including Indonesia. Sour crude is more common in the Gulf of Mexico, Mexico, South America, Urals and Canada. Examples are shown in Figure 1.

Due to geographic variation of sweet and sour crude supply the effect of IMO 2020 will not be uniform in all areas. It is expected that geographical areas with more complex refinaries, designed specifically for sour crudes will see a lower impact compared to other regions. Sweet crude is easier to refine and safer to extract and transport than sour crude.

Sour crude can produce high quantities of hydrogen sulphide which can pose serious health problems or even be fatal. Hydrogen sulphide is famous for its "rotten egg" smell, which is only noticed at low concentrations. At moderate concentrations, hydrogen sulphide can cause respiratory and nerve damage. At high concentrations, it is instantly fatal. Refinery types will cope with different sulphur regulations depending upon the sophistication of the refinery.

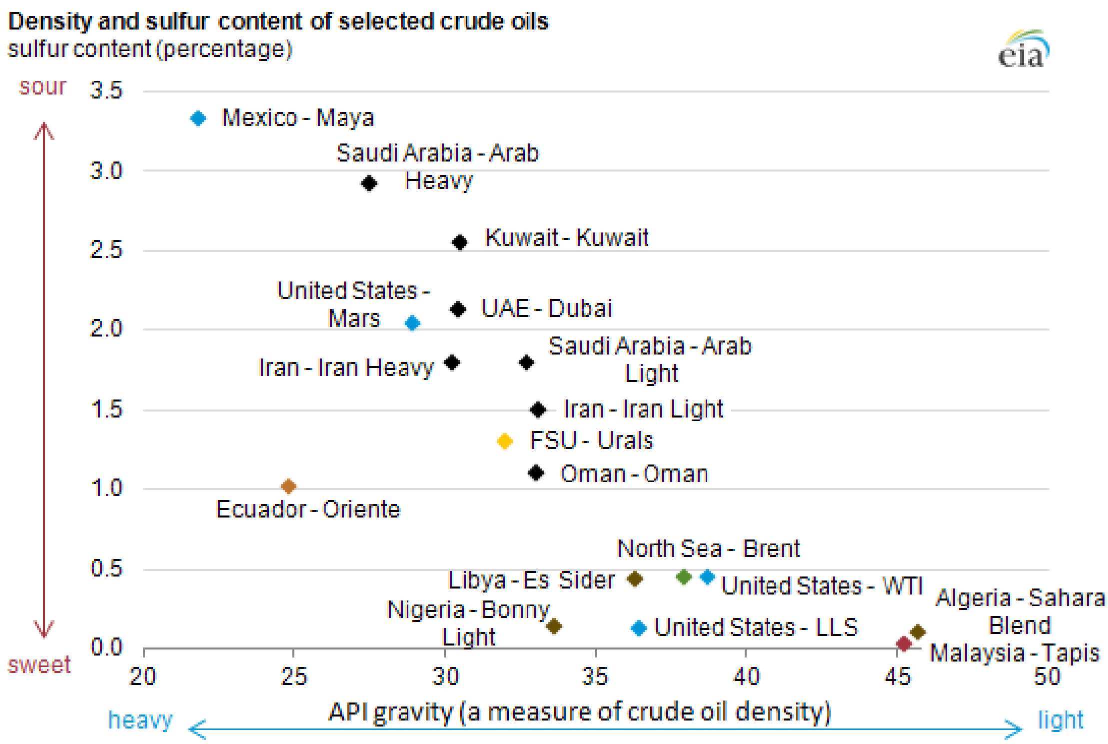


**Figure 1: Density and sulphur contents (%) of selected crude oils after US Energy Information Administration [4].**

The design of a refinery is a complex matter that is not addressed in this paper. Although, we can comment that as regulations have changed over the past years, refinaries have tended to become larger and more complex, with smaller refineries closing, which in turn has an effect on bitumen production and availability. One concern that has been raised in various press articles is what will be the effect on bitumen production.

## 2. Sulphur and bitumen

To discuss the effect on bitumen we have examined some of the published information that exists on the residual sulphur content in bitumen. The information dates back over a one-hundred-year period. In the publication "The Modern Asphalt Pavement" [1]sulphur is noted as a "chemical characteristic of interest." Richardson further notes that the greater part of the sulphur is present in the asphaltenes and that a range of 3.93 to 8.28 exists in "pure" bitumen. In the context of his work – the word pure reflects the subtraction of mineral matter from bitumens which are mined and can be considerable.

The bitumens which contained higher Sulphur levels were considered desirable and this resulted in Nicholson requiring a minimum of 3% sulphur in bitumen in specifications introduced in Chicago in 1915 [2], which limited the binders that could be supplied into the city.

The use of sulphur as a specification parameter was challenged by Lewis and Welborn in an extensive and detailed paper published in 1940 that showed that many binders without sulphur (or with lower levels) gave "satisfactory service behaviour" [3]. They selected asphalt that were representative of those in general use in the USA at that time and they reported levels of Sulphur ranging from 0.44 to 6.20%. The paper contained some discussion by Nicholson who noted that the "restrictive tests in our specifications" would continue until an accelerated service quality test has been fully developed and satisfactorily demonstrated and proven. At some stage after this publication, the sulphur requirement was discontinued but the exact timing is not known to the authors.Currently, the authors are not aware of any specifications that require or limit the amount of sulphur in bitumen.

During the Strategic Highway Research Program (SHRP) some effort was spent on characterizing the amount of sulphur in bitumens. Values of sulphur reported are given in Table 1[5,6] along with traditionaltestparameterspenetration and softening point. We have also shown the asphaltene content since this was mentioned in the earlier publication by Richardson [1]. The range of sulphur content in these bitumens is from 1.20 to 8.30%.

**Table 1: SHRP materials with reported sulphur content, %**

| Code | Source | PEN | SP, F | SP, C | A (in PI) | PI | Sulfur | Asphaltenes (n-Heptane) | Code | Source | PEN | SP, F | SP, C | A (in PI) | PI | Sulfur | Asphaltenes (n-Heptane) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AAA-1 | Llyodminster | 160 | 112 | 44.4 | 0.036 | 0.7 | 5.5 | 16.2 | AAQ | WY/CAN | 92 | 108 | 42.2 | 0.055 | -2.0 | 3.6 | 16.2 |
| AAA-2 | Llyodminster | 291 | 102 | 38.9 | 0.032 | 1.6 | 6 | 16.2 | AAR | Maya/WY | 76 | 120 | 48.9 | 0.043 | -0.5 | 4.6 | 18.4 |
| AAB-1 | WY Sour | 98 | 118 | 47.8 | 0.040 | 0.0 | 4.7 | 17.3 | AAS-1 | Arab Hvy | 64 | 121 | 49.4 | 0.045 | -0.8 | 5.4 | 18.4 |
| AAB-2 | WY Sour | 166 | 115 | 46.1 | 0.032 | 1.5 | 5.4 | 16.7 | AAS-2 | Arab Hvy | 96 | 112 | 44.4 | 0.047 | -1.1 | 6.76 | 17.1 |
| AAC-1 | Redwater | 133 | 109 | 42.8 | 0.044 | -0.6 | 1.9 | 10.1 | AAS-3 | Arab Hvy | 52 | 124 | 51.1 | 0.045 | -0.8 | 6.21 | 17.3 |
| AAC-2 | Redwater | 200 | 107 | 41.7 | 0.036 | 0.7 | 1.9 | 9.8 | AAT | Maya/Blenc | 63 | 120 | 48.9 | 0.046 | -0.9 | 5.1 | 17.3 |
| AAD-1 | CA Coastal | 135 | 118 | 47.8 | 0.034 | 1.1 | 6.9 | 20.5 | AAU | ANS/CA | 68 | 121 | 49.4 | 0.044 | -0.6 | 4 | 17.7 |
| AAD-2 | CA Coastal | 195 | 117 | 47.2 | 0.028 | 2.6 | 8.3 | 21.3 | AAV | ANS | 121 | 110 | 43.3 | 0.045 | -0.7 | 2.4 | 9.7 |
| AAE Blown | Llyodminster | 73 | 125 | 51.7 | 0.039 | 0.2 | 5.2 | 22.9 | AAW | WTx/Maya | 64 | 120 | 48.9 | 0.046 | -0.9 | 4.5 | 17.9 |
| AAF-1 | W.Tx Sour | 55 | 122 | 50.0 | 0.047 | -1.0 | 3.4 | 13.3 | AAX | Potaku/LA | 51 | 121 | 49.4 | 0.049 | -1.3 | 2.4 | 12 |
| AAF-2 | W.Tx Sour | 82 | 117 | 47.2 | 0.045 | -0.7 | 4.6 | 13 | AAY | Maya/Arab | 82 | 119 | 48.3 | 0.042 | -0.4 | 5.4 | 22.4 |
| AAG-1 | CA Valley | 53 | 120 | 48.9 | 0.049 | -1.4 | 1.3 | 5 | AA2 | Wtx/Cost | 58 | 117 | 47.2 | 0.051 | -1.6 | 4.4 | 9.2 |
| AAG-2 | CA Valley | 76 | 111 | 43.9 | 0.054 | -1.9 | 2.9 | 5 | ABA Blown | WTxl/S | 70 | 120 | 48.9 | 0.044 | -0.7 | 2.3 | 15.7 |
| AAH | Rangely | 95 | 114 | 45.6 | 0.045 | -0.8 | 2.8 | 15.9 | ABC | Ms Valley | 76 | 117 | 47.2 | 0.046 | -0.9 | 6.4 | 25.6 |
| AAJ | OK Mix | 67 | 118 | 47.8 | 0.047 | -1.1 | 1.9 | 10.6 | ABD | CA Valley | 47 | 120 | 48.9 | 0.052 | -1.6 | 1.6 | 7 |
| AAK-1 | Boscan | 70 | 121 | 49.4 | 0.043 | -0.5 | 6.4 | 20.1 | ABF | TiaJuana(H) | 66 | 119 | 48.3 | 0.046 | -1.0 | 3.5 | 15.4 |
| AAK-2 | Boscan | 154 | 108 | 42.2 | 0.042 | -0.3 | 6.9 | 19.2 | ABG | Laguna | 89 | 118 | 47.8 | 0.042 | -0.3 | 4.05 | 15.7 |
| AAL | Cold Lake | 156 | 107 | 41.7 | 0.043 | -0.4 | 5.5 | 18.9 | ABH | Russian | 98 | 114 | 45.6 | 0.044 | -0.7 | 2.69 | 19.5 |
| AAM-1 | W. Tex Inter | 64 | 125 | 51.7 | 0.041 | -0.2 | 1.2 | 4 | ABK | CA Wilm | 56 | 119 | 48.3 | 0.049 | -1.4 | 2.79 | 9.3 |
| AAM-2 | W. Tex Inter | 102 | 116 | 46.7 | 0.041 | -0.2 | 1.9 | 4.8 | ABL-1 | Boscan | 87 | 117 | 47.2 | 0.043 | -0.5 | 5.82 | 22.3 |
| AAN | Bow River | 90 | 110 | 43.3 | 0.052 | -1.6 | 4.3 | 15.7 | ABL-2 | Boscan | 169 | 106 | 41.1 | 0.042 | -0.3 | 6.28 | 17 |
| AAO | Arab Hvy | 106 | 115 | 46.1 | 0.042 | -0.3 | 5 | 16.4 | ABL-3 | Boscan | 137 | 111 | 43.9 | 0.041 | -0.1 | 5.86 | 20.8 |
| AAP | OK Mix | 71 | 120 | 48.9 | 0.044 | -0.6 | 1.7 | 12.6 | ABM-1 | CA Valley | 48 | 120 | 48.9 | 0.051 | -1.6 | 1.28 | 7.1 |

As can been seen from the data developed by the SHRP research the sulphur is significantly related to the asphaltene content of the bitumen consistent with the comments made by Richardson (see Figure 2). Bitumens with higher asphaltenes typically have more structure, but the correlation between a chemical parameter such as sulphur and a typical performance parameter such as penetration index is poor (see for example **Hata! Başvuru kaynağı bulunamadı.**) supportive of the work conducted by Lewis and Welborn (1940).

The rheology of the SHRP "core" binders have been more recently revaluatedin 2013 [7]. The "core" binderswere selected in the SHRP program as having sufficiently diverse performance histories, chemical and physical properties to warrant their being designated as the core or common asphalts in the asphalt program. We have evaluated the properties of these according to the PG range as specified by AASHTO M320, see Table 2. If we consider the performance of binders in terms of PG range versus Sulphur content, we can see that the binders with higher Sulphur are generally better performing, see Figure 4. We would suggest some caution with the interpretation of this data since this only represents the 8 core asphalts. However, we can comment that the use of binders with higher sulphur levels perform well according to the Superpave specifications.

The amount of data in the public domain on the amount of sulphur in asphalt binders/ bitumens is limited, but the general percentages reported over the past century are consistent with values from close to zero to just over 8%. It is interesting to note that Richardson and the SHRP researchers both noted an identical maximum value of 8.3% - even although the work conducted was over 80-years apart. This suggests that this aspect of bitumen selection and production has changed very little, a represents the fact that a residual product produced from a naturally occurring product has in fact remained remarkably consistent over the years.

While refiners are working to develop and optimize processes to make bitumen, it is unlikely that the general parameters for selection and refining will see significant changes in output from those previously reported in the literature. Lewis and Welborn's [2] work points to difficulties in the specification of a chemical parameter to exclude certain crude sources. While IMO 2020 will present interesting and challenging opportunities to the refinery industry, the bitumen quality assessment must rely upon proven methods such as those more recently developed by the SHRP research and/or older methods to classify products to ensure that performance is achieved in the field.

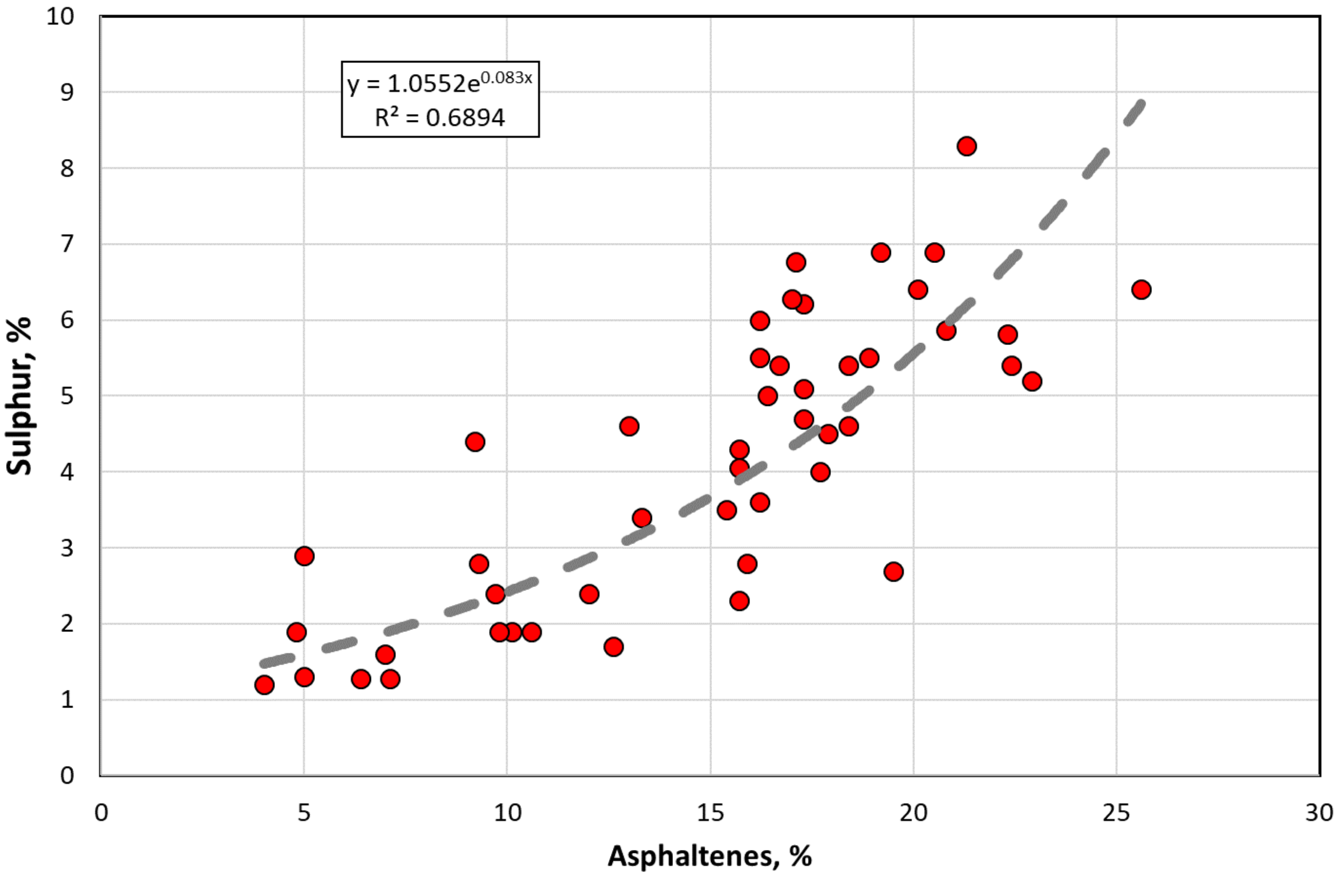



**Figure 2: Sulphur content versus asphaltenes %, taken from SHRP asphalts (bitumens)**

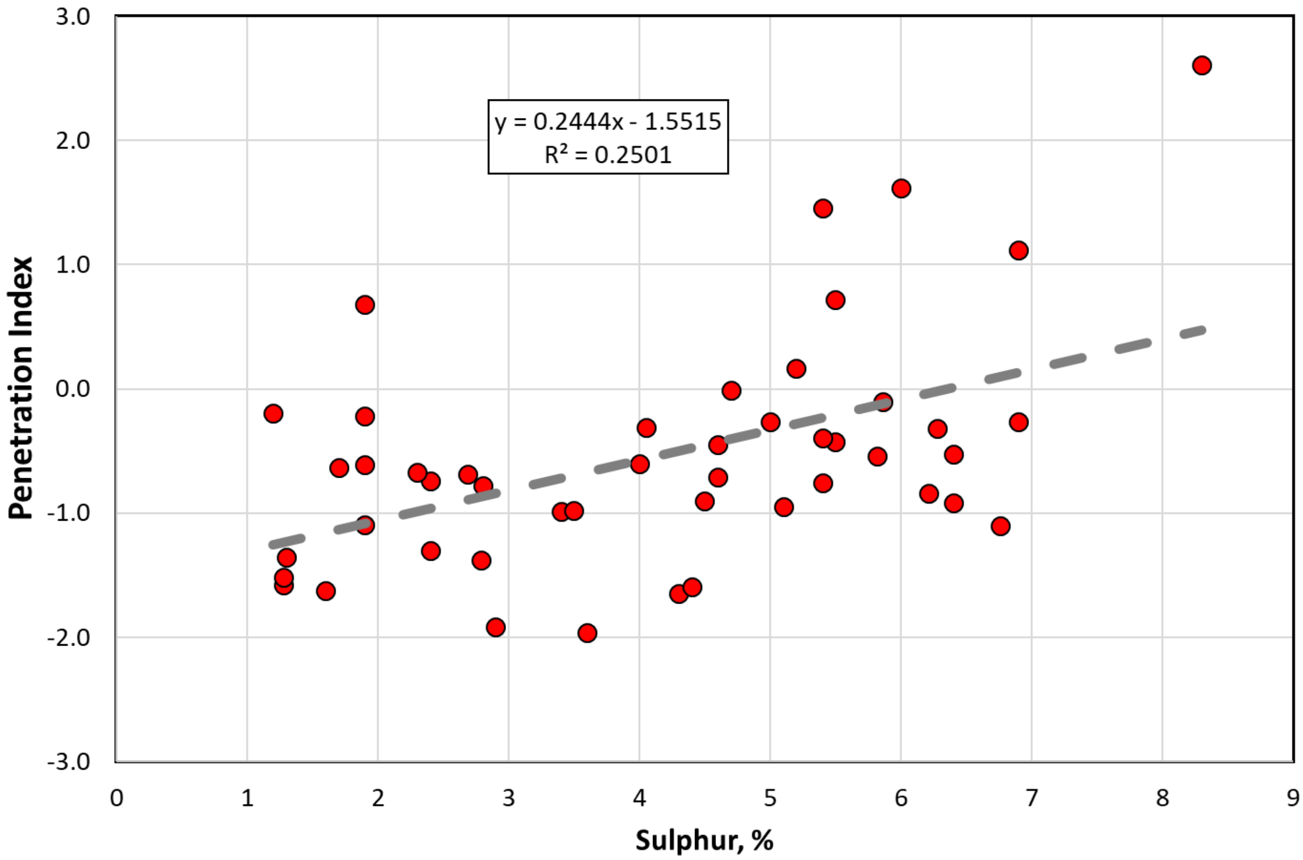
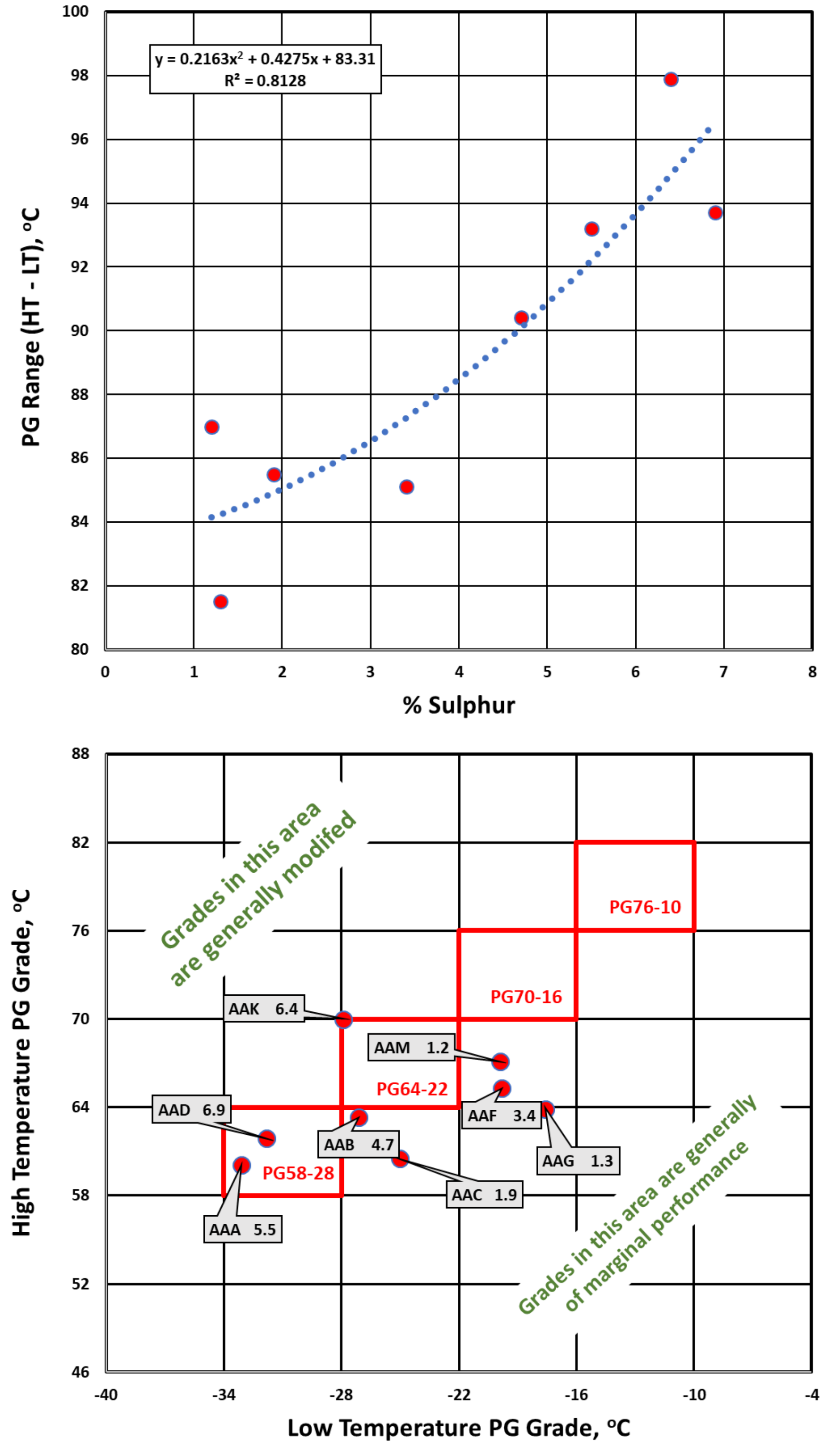



**Figure 3: Temperature susceptibility, as measured by penetration index, of bitumen (asphalt) with varying percentages of sulphur**

**Table 2:Data from evaluation of SHRP core asphalts**

| Binder | Grade Temperature | | | | | | |
|---|---|---|---|---|---|---|---|
| | G*/sinδ ≥1.0 kPa Orginal | G*/sinδ ≥2.2 kPa RTFOT | BBR (S) ≤300 MPa PAV S | BBR (m) ≥0.300 PAV | PG Low Temp Grade | PG High Temp Grade | ΔTc ($T_S - T_m$) PAV–20h |
| AAA-1 | 60.1 | 60.5 | -33.1 | -34.1 | -33.1 | 60.1 | 1.0 |
| AAB-1 | 63.3 | 63.6 | -29.5 | -27.1 | -27.1 | 63.3 | -2.4 |
| AAC-1 | 61.8 | 60.5 | -26.9 | -25 | -25 | 60.5 | -1.9 |
| AAD-1 | 61.9 | 65.1 | -31.8 | -32.7 | -31.8 | 61.9 | 0.9 |
| AAF-1 | 65.3 | 65.8 | -22.8 | -19.8 | -19.8 | 65.3 | -3.0 |
| AAG-1 | 65.3 | 63.9 | -17.6 | -20.2 | -17.6 | 63.9 | 2.6 |
| AAK-1 | 70 | 71.8 | -27.9 | -28.7 | -27.9 | 70 | 0.8 |
| AAM-1 | 67.1 | 67.5 | -27.1 | -19.9 | -19.9 | 67.1 | -7.2 |




*Note: Boxes in the figure show the SHRP core asphalt reference code and the Sulphur %*

**Figure 4: PG evaluation of SHRP Core asphalt binders versus the Sulphur content**

## 3. Concluding comments

The impact of IMO 2020 on the world bitumen (asphalt) market is difficult to predict due to the many complex market and business indications that exist. It is expected that some minor changes will occur to the sulphur levels in bitumen produced and that some crudes will be used for bitumen production that previously have not been used. Reviewing, historical data on bitumen production and the sulphur that is contained within those products we can make some key comments, as follows:

- Historical sulphur levels in bitumen have ranged with values from close to zero to just over 8%
- The greater part of the sulphur is associated with the heaviest fraction, the asphaltenes
- While performance has previously been asserted to be related to a minimum sulphur content this idea was abandoned in the 1940's since a more extensive evaluation failed to show linkage between the sulphur content and performance
- Generally, bitumens with higher sulphur levels have performed well

The bitumen industry will need to assess products to ensure this remains the case as more sour crudes are used in bitumen production. The testing needs to concentrate on those methods previously development to assess performance and those newer tests that are currently being developed.

## 4. References

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