newfoundland labrador
hydro
a nalcor energy company

Hydro Place. 500 Columbus Drive.
P.O. Box 12400. St. John's. NL
Canada A1B 4K7
t. 709.737.1400 f. 709.737.1800
www.nlh.nl.ca

December 23, 2014

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, Newfoundland & Labrador
A1A 5B2

Attention: **Ms. Cheryl Blundon**
_____**Director Corporate Services & Board Secretary**

Dear Ms. Blundon:

Re: **Newfoundland and Labrador Hydro - the Board's Investigation and Hearing into**
Supply Issues and Power Outages on the Island Interconnected System: Supplementary
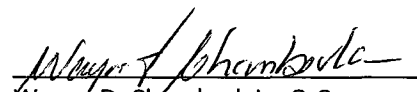**Response in Relation to DD-NLH-118**

In its response to the Board's Request for Information DD-NLH-118, Hydro indicated that additional
documentation would be supplied to the Board when the related work was completed. In this regard,
please find enclosed the original and 12 copies of the following:

Stantec Final Report – Holyrood TGS Fuel Oil Specification Review (re: DD-NLH-118).

We trust the foregoing is satisfactory. If you have any questions or comments, please contact the
undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Wayne D. Chamberlain, Q.C.
General Counsel & Corporate Secretary

WDC/jc

cc: Gerard Hayes – Newfoundland Power   Thomas Johnson – Consumer Advocate
        Paul Coxworthy – Stewart McKelvey Stirling Scales   Danny Dumaresque
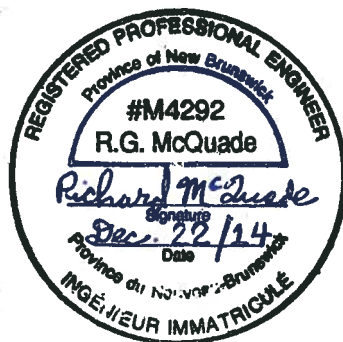ecc: Roberta Frampton Benefiel – Grand Riverkeeper Labrador

Holyrood TGS Fuel Oil
Specification Review – Final

Stantec

Prepared for:
Newfoundland and Labrador
Hydro

Prepared by:
Stantec Consulting Ltd.
845 Prospect Street
Fredericton, NB E3B 2T7

133546369_8_8

December 22, 2014

Table of Contents

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

i

LIST OF APPENDICES

APPENDIX A   TEMPERATURE VS VISCOSITY CURVES

Stantec

Executive Summary

In January and February, 2013, Newfoundland and Labrador Hydro (NLH) received four fuel oil shipments at the Holyrood Thermal Generating Station (HTGS) from its new supplier, Trafigura AG. Following these deliveries, Holyrood faced a number of operational and maintenance problems with the fuel oil system equipment on site. HTGS also experienced two fuel oil spills as a result of problems with the fuel oil system. As a result of the clean-ups, repairs, and replacements following these oil deliveries, NLH experienced significant unforeseen expenses. Subsequent to the above events, NLH engaged Stantec Consulting Ltd. (Stantec) to perform a review of its fuel oil specification.

The current market for residual or heavy fuel oil is and has been heavily impacted by the ever increasing demand that lighter hydrocarbons in the form of lighter petroleum products such as jet fuel, gasoline and diesel oil be obtained from the crude oil that is sent to oil refineries. This has led to additional refining processes being installed in refineries to accomplish the objective of extracting more of the lighter petroleum products from the crude oil processed. As a result of this additional oil processing driven by market demand, the residual oil that is available for sale today is a blended product rather than a straight run residual as it would have been in the 1950s, 1960s, and 1970s. This blended residual oil product is based upon a cracked residual, which is much heavier than earlier straight run residual oils, being blended with a lighter product (cutter stock or cutter oil) to achieve the desired parameters contained in the refiner's or buyer's specifications.

The quality of a residual oil being sold today is also impacted by a depletion of oil reserves which has led to decline in the quality of the crude oil that is available for refining into petroleum products. As well, currently in the US, residual oil represents less than 3% of a refinery's yield while in Canada it represents 5%. A product that represents such a small portion of a refiner's production and revenue stream will receive less attention to product quality than the larger quantity and more profitable products.

As discussed further in this report, the characteristics of the cracked, blended residual fuel oil product sold today can vary from shipment to shipment. Many of the characteristics of the cracked, blended products also present additional problems in handling and combusting in a thermal generating station than straight run residual oils. Unfortunately, even if a purchaser requires a supplier to meet all of the various standards and specifications that are currently in existence, this is not a guarantee against encountering problems in the handling or burning of the cracked, blended residual fuel oils.

The current NLH fuel oil specification was reviewed to determine if it could be improved. The following changes to the NLH specification are recommended: increasing API gravity from 5 to 10, a slight increase in the minimum heating value from 6,300,000 Btu per barrel to 6,400,000 Btu

per barrel, adding a minimum value of 100 cSt for kinematic viscosity, and adding limits for maximum aluminum content of 50 mg/kg and maximum silicon content of 75 mg/kg. These latter two constituents have become a concern because of possible carryover of catalyst fines from the refinery process known as catalytic cracking. These catalyst fines can be very abrasive in nature and can cause significant erosion damage to power plant equipment such as pumps, control valves and oil burner atomizer tips.

Stantec

1.0   INTRODUCTION

Newfoundland and Labrador Hydro (NLH) owns and operates the Holyrood Thermal Generating Station (HTGS), which has a generating capacity of 490 MW. The station is an essential part of the Island Interconnected System and produces up to 40 percent of the Island's annual energy requirements.

HTGS is composed of three thermal generating units along with sub-systems that are vital to its daily operation. The generating station consists of a central plant containing all thermal generating equipment used for the production of electricity, and several support buildings in an area stretching over one square kilometer. The generating station was constructed in two stages. The first stage, commissioned in 1969, consists of two Combustion Engineering oil fired boilers and two Canadian General Electric turbine generator sets. The second stage was commissioned in 1979 and consists of a Babcock and Wilcox boiler and a Hitachi turbine generator set. All three generating units were originally rated at 150 MW, but in 1988 the two Combustion Engineering/Canadian General Electric units were upgraded to a capacity of 170 MW each.

In January and February, 2013, NLH received fuel oil shipments at HTGS from its new supplier, Trafigura AG which met NLH's current fuel oil specification. Following receipt of the fuel shipments, HTGS faced a number of operational and maintenance problems with the fuel oil system equipment on site. The affected equipment included: the main fuel oil tank suction heaters, the fuel oil day tank, the fuel oil suction strainers, the fuel oil pumps, the fuel oil heat exchangers, the fuel oil recirculation and control valves and the boiler burner nozzles. HTGS also experienced two fuel oil spills in 2013, substantially contained in the tank farm, due to premature wear on the tubes on the suction heater of fuel oil tanks 1 and 2. Poor fuel quality which could not be identified by use of the current specification was determined as a contributor to premature failures on the aforementioned operating equipment.

NLH decided that as part of its action plan to prevent future oil system problems it would issue a request for proposals to engage an external consultant to review the HTGS fuel system and equipment design and to evaluate the current fuel specification to determine what changes, if any, are to be considered or evaluated. Stantec Consulting Ltd. (Stantec) was contracted by NLH to perform this review and submit a report containing the findings resulting from its work. The findings and recommendations resulting from the review and analysis conducted by Stantec are detailed in the subsequent sections of this report.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

1.1

2.0   HEAVY FUEL OIL EVOLUTION

2.1   INTRODUCTION

Much of the product being sold today as heavy (also known as residual) fuel oil is not the same product that was sold 30 years or more ago as heavy fuel oil. In attempting to understand the characteristics of the current heavy fuel oil product and its impact on the operation of a thermal generating station, it is important to be aware of this fact. There are differences in composition and therefore chemical and physical properties of the current heavy fuel oil product compared to the product available in earlier times that for the most part have negatively impacted its use as a fuel for the generation of electricity. These changes have been brought about by a variety of economic, technical and depletion of reserve (crude supply) reasons.

2.2   HYDROCARBONS

Crude oil as extracted from the earth consists of hundreds of different hydrocarbon compounds. These hydrocarbons are chemical compounds that consist exclusively of the elements of hydrogen and carbon. However, the number of hydrogen and carbon atoms contained in a hydrocarbon compound and the manner in which they are joined or bonded together can vary widely, hence the number of hydrocarbon compounds found in crude oil. In addition to hydrocarbons, crude oil will typically also contain other components such as sulfur bearing compounds, water, sediment and other minerals. These other components are considered contaminants as they adversely impact most uses for the products that are obtained from crude oil, including combustion of fuel oils, and with the exception of sulfur, are not combustible.

The characteristics of all matter, including hydrocarbons, depend on the atoms of the various elements they are composed of and how these atoms are attached to each other in groups called molecules. As noted above, in the case of hydrocarbons, the elements and atoms of concern are carbon and hydrogen. Even though all hydrocarbons are primarily composed of hydrogen and carbon, the manner in which they are connected and arranged into the molecules forming the hydrocarbon will determine the properties and characteristics that a particular hydrocarbon displays. The many hydrocarbons found in oils can be subdivided into four major groups known as Paraffins, Aromatics, Naphthenes, and Olefins. Each of these groups has different characteristics.

Paraffins or paraffinic hydrocarbons have single chemical bonds between the carbon and hydrogen atoms that compose them. The atoms may be arranged in either a straight chain fashion or a branched chain fashion. Methane and propane are examples of paraffins. This group of hydrocarbons is the lightest of the four major groups, i.e., lowest molecular weight, specific gravity and highest API gravity. They burn cleanly, which is beneficial for use as a fuel.

Aromatics are the heaviest of the four major classes of hydrocarbons. They contain a higher proportion of carbon than the other three classes arranged in one or more six-membered

![Stantec logo]

carbon rings. Benzene and styrene are examples of aromatics. Aromatics are very stable under heat and are moderately chemically active. They have a tendency to smoke when burned due to their high carbon content. Aromatic hydrocarbons are present in cracked oils in greater percentages than in straight run oils, which is why cracked oils are the heavier of the two. (Note: straight run oil and cracked oil are defined and discussed further below.)

Naphthenes or naphthenic hydrocarbons generally have more than four carbon atoms in them. They are stable compounds chemically but do burn well. They are usually found in the heavy portions of fuel oils. Cyclopentane and cyclohexane are members of the Naphthenes group.

Olefins, the fourth major class of hydrocarbons, do not naturally occur in crude oil but are man-made in the cracking processes discussed below. Thus, they are not found in straight run oils but are found in large quantities in cracked oils. They are more chemically active than the other three classes of hydrocarbons and are subject to oxidation and polymerization forming gums, which can cause problems with both the handling and combustion of fuel oils. The key characteristic of olefins is the absence of two hydrogen atoms from what would otherwise be a paraffin structure with a full complement of hydrogen atoms. Olefins that are of primary interest in oil refining are propylene (C_3H_6) and butylene (C_4H_8).

2.3   OIL REFINERY PROCESS EVOLUTION

Raw or unrefined crude oil is not generally useful in industrial applications and certainly is not useful in commercial and residential applications. However, if the crude oil is processed or refined in the processing plants known as oil refineries, wherein the various components or fractions contained in the crude oil can be separated and upgraded then a significant number of useful and desired products can be obtained. These products include jet fuel, kerosene, gasoline, lubricants, solvents and both distillate and heavy fuel oils.

Gasoline, which is used in precision built internal combustion engines, and lubricants, which are often utilized where close tolerances are required as well as great stability under extreme pressure and high temperatures demand the highest product quality and therefore the most comprehensive amount of refining. In the case of fuel oils, however, particularly heavy or residual fuel oils that are utilized in the large furnaces of electric utility sized boilers, there is less concern given to the chemical and physical characteristics of the product and therefore less refining performed upon these products. Indeed, up until the last several decades residual fuel oil only underwent physical separation from the crude oil through the process known as distillation. No further processing was performed upon it.

In the very early days of oil refining, i.e., the second half of the nineteenth century, crude oil was processed primarily to extract the kerosene content (**Ref. 1**) as at that time there was no market for the heavier or the more volatile fractions of the crude oil. Indeed, gasoline, a lighter fraction than kerosene, was considered a waste and was commonly dumped into the nearest river. The invention of the automobile with its internal combustion engine shifted the demand for

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.2

petroleum derived products to gasoline and diesel oil, which even today remain among the primary products produced from crude oil in a refinery.

Reference 2 indicates that the equipment utilized in these early days of refining was primitive and simple, consisting of an externally heated drum containing crude oil with a tube extended from it to deliver evaporated vapors to an area of lower surrounding temperature where the vapors would be condensed into a liquid phase. The refining processes evolved and increased in type, number and complexity, driven by a number of factors including advancements in technology, changes in demand for different and more product types, such as gasoline and jet fuel, and to react to changes in crude oil supply which have different chemical and physical characteristics. Modern oil refineries contain numerous processing units but as will be discussed in more detail below, the majority of these units are directed at producing the largest amount of lighter weight fractions from the crude oil to the detriment of heavy or residual fuel oil.

In modern refineries the first step in separating the various fractions that comprise crude oil takes place in the crude distillation unit. In this process unit the crude oil is heated prior to entering an atmospheric distillation column. The distillation column utilizes the physical property of boiling point (BP) to accomplish the separation of the various fractions from the incoming crude. The fractions at the top of the distillation column, which are the lighter fractions, have lower boiling points than the heavier fractions at the bottom of the column. The heaviest fraction that leaves at the bottom of the distillation column is known as the "straight run" or "long" residue.

This first process step in the refining of crude oil provides the basis for the two major classifications of fuel oils, namely, "distillate" and "residual". Those fractions of the crude oil that are distilled, i.e., vaporized (and subsequently condensed) are classified as distillates. Those fractions of the crude that are not distilled, i.e., did not vaporize and leave the bottom of the distillation column as a residue are classified as residuals.

In earlier times (1950s, 1960s, and at least early 1970s), this straight run residue was sold as heavy (residual) fuel oil without further processing. Compared to the heavily cracked, blended mixtures that are sold today as heavy fuel oil, the straight run residual oils burned cleaner and offered less problems in storage, handling and combustion. It is to be noted that separation by distillation is a physical process so that no chemical transformations have occurred in the components and molecules that comprise the straight run residual product.

Following the atmospheric distillation process further refining of the straight run residual normally takes place in one of four additional processes, namely, "Vacuum Distillation", "Visbreaking", Thermal Cracking" and "Catalytic Cracking" (**Ref. 2 & 3**). Which of these processes is utilized depends on a multitude of factors including, source of crude oil, refining techniques available at the refinery processing the oil, market demand for the various products and current pricing for fuel oils and the other petroleum derived products.

The vacuum distillation process is similar to atmospheric distillation except that the process takes place under vacuum. Normally the feedstock to this process is the straight run residual from the

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.3

atmospheric distillation unit. The vacuum unit makes use of the natural relationship that as pressure decreases, such as under vacuum conditions, the boiling point of liquids decrease. Thus the vacuum distillation unit allows more of the heavy end of the distillate components in the straight run residual to be separated without fear of cracking the residual, which would occur at higher temperatures needed at atmospheric or higher pressure conditions.

The separated distillate products are drawn off from the top of the vacuum unit. The heavy material removed from the bottom of the vacuum unit and appropriately called "vacuum bottoms" can be used as feedstock to an asphalt plant, feedstock to a thermal cracker or as blending component for residual fuel oil product. These vacuum bottoms will be much higher in viscosity and of a lower API gravity than the straight run residual from which they were derived.

As an alternative to vacuum distillation, the straight run residual produced in the atmospheric distillation unit can be fed to a thermal cracking unit or "Thermal Cracker". In addition to straight run residual, the vacuum bottoms discussed above, cat cracked heavy gas oil or cycle oil may also be fed to the thermal cracker. The method used in the thermal cracker is almost the same as that used in the initial atmospheric distillation stage, but higher temperatures and pressures are used. However, unlike the atmospheric distillation process where only physical separation occurs, in the thermal cracking unit chemical reactions take place. These chemical reactions, known as "cracking", involve the breaking up of hydrocarbon molecules contained in the feed stock to the unit.

The cracking of the hydrocarbon molecules involves splitting or breaking of some of the chemical bonds holding the hydrogen and carbon elements together, creating both smaller or lighter molecules and larger or heavier molecules. The lighter molecules are formed because a small piece of a larger molecule has been broken off. The heavier or larger molecules are formed when the remaining portion from one molecule unites with another molecule of larger size to form a molecule that is heavier or larger than either of the two uniting molecule portions.

Typical products obtained from the thermal cracking process are gasoline, No. 2 (distillate) oil and No. 5 or No. 6 residual oil (**Ref. 2**). The resulting oils are called "cracked oils". The cracked residual oil tends to have high olefin, naphthene and aromatic contents (**Ref. 5**).

In the catalytic (cat) cracking process, the same basic chemical reactions take place as in the thermal cracker but the reactions and the resulting products are obtained not by high temperature but through the use of a catalyst. A catalyst is a substance that can increase the rate of a chemical reaction without entering into the reaction or being chemically altered itself. The catalyst aids in accomplishing the desired cracking of the feed to the unit at lower temperatures and pressures than are required in a thermal cracker. The primary goal of the cat cracker is to convert as much of the heavy feed material as possible into gasoline.

The feed material to the cat cracker is often straight run residual but can also include thermally cracked products such as the No. 2 distillate oil. As in most other refinery units, the feed to the cat cracker is first heated during which it may be either vaporized or remain in the liquid state.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.4

The heated charge is then introduced into a reactor. The reactor contains the catalyst that promotes the required cracking. The catalyst may be in a number of different physical forms and shapes. After the reactor the products are then directed into the fractionator as with other processes and the separated products are then sent to their respective storage tanks.

The resulting products from the cat cracking process include gasoline, No. 2 distillate and slurry oil. The slurry oil is a high pour point (24 – 38°C (75 – 100°F)), low viscosity product that is generally blended with other refinery products to produce a No. 6 residual fuel oil. As with thermal cracking process, the oils resulting from the catalytic cracking process are also known as cracked oils.

The last of the four major refinery processes that can follow the primary process of atmospheric distillation is called "Visbreaking". The process name derives from a result of the process, i.e., reduction or breaking of the viscosity of the residual oil (**Ref. 4**). The process is non-catalytic and is essentially the same as the thermal cracking process but employs lower temperature than a thermal cracker. As with the cracking processes discussed above, the main objective for the Visbreaker process unit is to reduce the quantity of residual oil that will be produced from the crude oil processed in favour of lighter, more valuable products. In the case of Visbreaking this includes gasoline and middle distillates.

The common feedstock to the Visbreaker is the residual or bottoms from the vacuum distillation process (vacuum bottoms). The residual produced from the Visbreaker unit is higher in API gravity and lower in viscosity than the original vacuum bottoms feedstock (**Ref. 2**). This residual is mixed with a diluent (a lighter refinery product) known as "cutter stock" and then marketed as residual fuel oil. The benefit of the Visbreaker unit is that the amount of lighter cutter stock that has to be blended with the Visbreaker residue to make a marketable residual fuel oil is less than the cracked products, e.g., gasoline and middle distillates are freed up by the Visbreaker so that there is less residual oil produced from the crude oil entering the refinery (**Ref. 5**).

2.4 CONTAMINANT CONCENTRATION

Another degradation in the quality of residual fuels that is present today compared to the straight run residuals oils that were available through the 1970s, is the contaminant concentration (particularly ash, metals, and sediment) which has increased since that time. This has resulted from three major factors. The first is the depletion of oil reserves whereby the higher quality reserves originally available have been replaced by lower quality reserves that are higher in contaminants as the source of the crude oil entering refineries.

The second factor is the concentration of contaminants in the cracked oils currently used to produce much of the residuals oils available for sale. As a result of the operation of the various refinery process units discussed above, the contaminants in the feedstock to these process units do not leave with the lighter product cuts that are distilled or flashed off but rather are retained in the residual product leaving the process unit. The more processing stages that a given residual

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.5

has undergone, the greater the concentration of contaminants in the residual compared to the concentration in the crude oil that entered the refinery.

The third factor is the carryover of catalyst from the modern refining process of catalytic cracking discussed previously. Aluminum and silicon are the basis for most of the catalysts that are utilized. Depending on the form of the catalyst that is carried over into the oil, significant damage can be done to power plant equipment including pumps, valves, heaters and most importantly from a combustion standpoint, the atomizer assemblies of the oil burners.

2.5   MARKET TREND IMPACT

The unceasing and ever increasing demand for lighter products such as jet fuel, gasoline and diesel oil has negatively impacted the quality as well as quantity of residual oil available in the marketplace today. Schmidt (**Ref. 2**) indicates that at the time of his publication (1985) the volume of the various products had changed considerably from previous times such that the average distillate yield, namely gasoline, kerosene, fuel oil distillate and jet fuel had increased to 79% while the residual oil yield had fallen to 9%. The yield of a product is the percentage that the quantity of the product produced represents of the total crude oil quantity that entered the refinery.

The US Energy Information Administration (EIA) data shows that between January 1993 and July 2014, US refinery yield of residual fuel oil decreased from 6.1% to 2.4% (**Ref. 6**). The Canadian Fuels Association (**Ref. 7**) indicates that currently approximately 5% of each barrel of crude entering a Canadian refinery ends up as residual fuel oil. Refiners will pay more attention to the quality of the lighter products that represent a larger product percentage and, therefore, larger revenue flow to their operation than they will to the quality of residual oil. Further, since residual oil represents a much smaller percentage of production and profit to refiners, customers for this product are in the position of "quality takers" rather than "quality dictators".

2.6   SUMMARY

In summary, prior to the 1970s, most residual oils would have been straight run oils. However, today most residual fuel oils are produced from cracked oils that are then blended with lighter refinery cuts to produce an oil that meets a refiner's or customer's specifications. These cracked oils are produced from process unit residuals that are heavier, more viscous and contain higher contaminant levels than the straight run residual oils of past years. This negatively impacts the use of residual oil as a fuel in a thermal power station. Additionally, the significant drop in the use of residual fuel oil means that the remaining customers for this product have less ability to influence product quality.

The end result of this evolution of the residual fuel oil currently available in the marketplace is that the residual fuel oil product available today is more troublesome, if not inferior, for use as a fuel in a thermal generating station. Even if a user attempts to obtain a product that conforms to

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.6

all the standards and test procedures that exist, this will still not guarantee that problems will not be experienced in the handling or combustion of the fuel oil.

As will be discussed in the following section of this report, given the large number of potential hydrocarbon compounds that may be present in residual oil, which is affected by both the source of the crude oil and the number and type of processing operations that have been performed to obtain the residual oil, it is not possible to completely define or characterize an oil. Therefore, it is not possible to completely define all the potential behavioral aspects of a given oil. Further, as crude oil sources and market demands change, refinery operating practices will also change. The end result may be changes in oil parameters that have negative impacts on the intended use for a given type of oil. A well-constructed fuel oil specification will minimize the risk to operational reliability and availability by placing proper limits on the oil parameters known and/or proven to have negative impacts on the intended use for the oil.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

2.7

3.0   HEAVY FUEL OIL PARAMETERS

This section of the report will discuss each of the various parameters associated with specification of a residual fuel oil. This discussion will include requirements of ASTM and Canadian standards, the parameter limits of other utilities where they are known, and the current NLH limits for each parameter. Section 4 will detail the Stantec recommendations for a revised fuel oil specification.

Martin et al (**Ref. 10**) indicates that since fuel oils are complex compounds of hydrogen and carbon they cannot be classified rigidly by chemical formula or definite physical properties. Additionally, the arbitrary divisions or classifications of the many varieties of petroleum derived fuel oils are based more on their application than on chemical or physical properties. Large variations in properties among oils sold on the market for the same purpose can therefore exist. It should be noted, therefore, that meeting specified values for these parameters is not a guarantee that problems will not be encountered.

3.1   STANDARD SPECIFICATIONS

There are two primary standard specifications for fuel oils available to the consumer of oil in Canada. These are ASTM D396 entitled "Standard Specification for Fuel Oils" and CAN/CGSB 3.2 entitled "Heating Fuel Oil". In international markets, where the majority of fuel oil produced in the world is sold, ASTM D396 is more widely known and applied. Within Canada, refiners normally follow CAN/CGSB 3.2. An oil meeting requirements of one of these standard specification would likely meet at least some of the requirements of the other.

ASTM D396 does not have extensive requirements for residual oil. In Clause 4.2 of Section 4, General Requirements, there is a requirement that "All grades containing residual components shall remain uniform in normal storage and not separate by gravity into light and heavy oil components outside the viscosity limits for the grade".

In Section 5, Detailed Requirements, there are only three parameters for which there are specified values that No. 6 (residual) oil is required to meet. These are; flash point, water and sediment, and kinematic viscosity. With respect to water and sediment, it is further detailed that the amount of water by distillation by test method D95 plus the sediment by extraction by test method D473 shall not exceed the total given in the table. Additionally, for No. 6 oil, the amount of sediment by extraction shall not exceed 0.50% by mass and a deduction shall be made for all water and sediment in excess of 1.0% by mass.

In the case of Kinematic viscosity, it is further detailed that for No. 6 oil, where low sulfur fuel oil is required (as it currently is at HTGS) fuel oil falling in a lower grade down to and including Grade No. 4 can be supplied by agreement between the purchaser and supplier. It is also stated that where low sulfur No. 6 oil is required, that it shall be classified either as low pour (+15°C/59°F maximum) or high pour point for which there is no maximum value given.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.1

In addition to the parameters specified by ASTM D396, CAN/CGSB-3.2 adds total sediment and ash content on a mass basis. With respect to kinematic viscosity, CAN/CGSB-3.2 specifies the viscosity limits at 50°C (122°F), whereas D396 specifies viscosity at 100°C (212°F). The parameters and their values specified by the two standards are tabulated below.

Parameter	ASTM Test Method	ASTM D396 Value	CGSB-3.2 Value
Ash, %mass, max.	D482	Not Specified	0.20
Flash Point, °C, min.	D93 (Proc. B)	60	60
Water and Sediment, %vol. max.	D95 and D473	2.00	1.00
Sediment, %mass, max.	D473	0.50	Not Specified
Total Sediment, %mass, max.	D4870	Not Specified	0.20
Kinematic Viscosity at 100°C, mm^{2}s (Cst) Max/min	D445	15.0/50.0	Not Specified
Kinematic Viscosity at 50°C, mm^{2}s (Cst) Max/min	D445	Not Specified	650/100

In Europe, a commonly utilized fuel oil specification is the British Standard, BS 2869 entitled: "Fuel Oils for Agricultural, Domestic, and Industrial Engines and Boilers – Specifications". It is quite similar to ASTM D396 and CAN/CGSB-3.2 in terms of fuel oil parameter requirements. BS 2869 does not place any limits on the metal contaminants vanadium, sodium, aluminum and silicon.

3.2   API GRAVITY AND DENSITY

API gravity, which was developed by the American Petroleum Institute and the US National Bureau of Standards works inversely to density, i.e., the lower the API gravity the higher the density and the heavier the oil. Schmidt (**Ref. 2**) indicates that while many users have previously placed all their faith in the specification of API gravity alone, this is not advisable in current times. Unlike in previous periods where most residual oils were straight run products, due to the refining

 Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.2

processes currently utilized by refiners that are designed to remove the maximum amount of lighter hydrocarbons form the crude, the blending of products to obtain a specific customer specified value, and the many different crude types being processed, an API gravity specification does not indicate anything definite or specific. Two oil products with the same API gravity can exhibit many different characteristics, particularly if one oil is unblended while the other oil is a blend of residual and distillate components.

Although the API gravity is not a guarantee of a specific characteristic, it can provide general indications. Typically, for unblended oils, the lower the API gravity of an oil, the greater its viscosity, the higher its carbon content, the lower its hydrogen content, the lower its heating value per pound of oil, and the slower the rate of combustion, which means a longer flame length.

NLH currently allows an API gravity of 5 in its fuel specification. This is below (approximately half) of the minimum API gravity that the other Canadian utilities who burn residual fuel oil allow in their specifications. In the days of straight run residual oils, API gravity was typically between 10 and 15. Allowing an API gravity of 5 almost certainly rules out the possibility of being supplied a straight run residual and likely means that a fuel supplier will use the very heaviest of its residues as the basis for the residual oil product that is supplied. As has been discussed in Section 2, the heavier the residue the higher the concentration of the impurities that were originally contained in the crude oil from which it originates. Additionally, aromatic hydrocarbons including asphaltenes will be concentrated in heavy, cracked residues.

Although not a consideration for combustion, it is noted that 5 degree API gravity oil has a specific gravity greater than one and so is heavier than water. Therefore, in a marine environment spill, a 5 API gravity oil may not float. All existing oil spill technology is based on recovery of floating oil slicks. A 10 degree API oil has a specific gravity of one and, therefore, should float if spilled from a ship.

3.3   HEATING VALUE

Heating value is a measure of the energy that can be derived from the combustion of fuel oil. The primary value of a fuel is the amount of energy that it can supply. In the boilers at the HTGS, the chemical energy initially contained in the fuel oil is converted to thermal energy in the form of superheated steam that is supplied to the turbines which drive the electrical generators. Heating value is normally determined in the laboratory through the use of a "bomb calorimeter".

Heating value can be determined on a gross or total basis denoted as the Higher Heating Value (HHV) or on a net basis commonly known as the Lower Heating Value (LHV). The difference between the two is that the HHV includes the latent heat of evaporation of the water vapor formed during combustion whereas the LHV does not. In North America, HHV is used to calculate boiler efficiency. Gas turbine efficiency, however, is calculated on a LHV basis.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.3

When the API gravity of oil changes, the heating value will also change, however, the change will be in the opposite direction depending on whether the heating value is expressed on a volumetric (gallon) or weight (pound) basis. Thus, when the API gravity of a fuel oil increases, the heat value per gallon decreases but the heat value per pound increases. The explanation for the difference in change between a volumetric based heating value and a weight based heating value is as follows.

An increase in the API gravity of an oil occurs because the hydrogen content of the oil increases while the carbon content decreases. Since hydrogen has a HHV of 62,000 Btu/lb while carbon has a HHV of 14,600 Btu/lb, as the hydrogen content increases, the heating value per pound also increases. At the same time, the density, i.e., weight per unit volume of the oil will decrease because hydrogen is fourteen times lighter than carbon. However, since the weight per gallon decreases at a faster rate than heat value per pound increases with API gravity, the heating value for the higher API oil on a gallon (volumetric) basis is less. Since oil is sold on a volumetric basis, i.e., US barrel (1 barrel = 42 gallons), a lower API gravity means a larger energy content for each gallon. Thus, many buyers want to purchase as low an API gravity oil as possible to maximize the total energy content in the oil volume they purchase. However, buying the lowest API gravity oil available poses a number of operational risks due to the other characteristics of low API gravity oil, including concentration of contaminants, higher olefin and asphaltene content and higher viscosity.

The current NLH fuel oil specification states a minimum heating value of 6,300,000 Btu per barrel and a minimum 5 API gravity. Schmidt (**Ref. 2**) indicates that unblended, 10 API gravity oil has typical heating values of 152,280 Btu/ gallon and 18,260 Btu/lb. A heating value of 152,280 Btu/gallon equals 6,395,760 Btu per barrel. Since the heat value per gallon increases as the API gravity decreases, it follows that a 5 API gravity oil should have a heating value greater than 6,395,760 Btu per gallon. Therefore, it appears the heating value per barrel contained in the current NLH fuel oil specification is low for a 5 API gravity oil.

Another Canadian utility specifies a minimum heating value of 6, 325,000 Btu per barrel with a 10 API gravity. A second other Canadian utility specifies heating value on a weight basis with a normal value of 18,100 Btu/lb and an allowable range of 17,850 to 18,330 Btu/lb. The Platts assessments indicate a minimum heating value of 6,363,000 Btu per gallon.

In North America, boiler efficiency is calculated by the heat loss method given in American Society of Mechanical Engineers (ASME), Power Test Code 4 (PTC 4), Fired Steam Generators. (At the time the HTGS boilers were supplied this was PTC 4.1). Heat losses are calculated as a percentage of the fuel heating value expressed on a weight (Btu/lb) basis. The summary performance sheets for Boilers No. 1 and No. 2 provided by NLH indicate that the boiler efficiency is based on an oil heating value of 18,450 Btu/lb. If the heating value on a weight basis increases, the boiler efficiency increases, which in turn helps plant efficiency.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.4

Note that combustion is a weight based reaction and not a volumetric based reaction. However, since oil is purchased on a volumetric basis, it makes more sense to specify the minimum required heating value on a volumetric basis, in this case US barrels.

3.4   FLASH POINT

This parameter is chiefly concerned with safety in handling and storing the fuel oil, i.e., fire risk rather than performance as a fuel in a boiler or other combustion device. The flash point is the temperature at which oil being heated will produce vapors that flash when ignited by an external flame. Both ASTM D396 and CAN/CGSB-3.2 specify a minimum flash point of 60°C for No. 6 oil. The required ASTM test method is D93. The current NLH specification requires a minimum flash point of 66°C as determined by D93 and therefore is in compliance with both ASTM D396 and CAN/CGSB-3.2.

3.5   POUR POINT

As the temperature of an oil is reduced, it will congeal into a semi-fluid or a solid immovable mass depending on whether it is a distillate or residual oil, respectively. This is primarily due to the separation of wax from the oil. The temperature at which a specific oil will just flow under standardized conditions is defined as the pour point. The pour point of a residual will be higher than for distillate oil. Schmidt (**Ref. 2**) indicates that typical pour points for straight run Grade No. 6 oil range between 10°C (50°F) and 24°C (75°F) while those for cracked No. 6 oil range between -1°C (30°F) and 4.4°C (40°F).

Currently, the NLH fuel oil specification requires a maximum pour point temperature of 15°C (59°F), which according to ASTM D396 would classify it as a low pour point oil. This would seem reasonable given the location of the HTGS and the climatic conditions experienced. CAN/CGSB-3.2 has no specified limiting value for pour point of a No. 6 oil. Another Canadian utility specifies a pour point of 21°C (70°F) maximum. A second Canadian utility specifies a normal value of 16°C (65°F) but allows a range of 5°C to 70°C. The 15°C value currently specified by NLH is deemed the best from an oil handling perspective given the location of the station and the regional climatic conditions.

3.6   VISCOSITY

Similar to API gravity, viscosity has been treated by many purchasers in the past as a key indicator of the quality of a fuel oil. This is not the case, particularly in the modern marketplace where most residuals are cracked and blended products. While not an indicator of quality viscosity is a measurement of a fluid's resistance to flow. It is an important consideration in terms of pumping and conveying the fuel oil between the various pieces of the power plant's equipment from the storage tanks through to the burners. Proper viscosity is also an important consideration for atomization and combustion.

![Stantec]

As the grade number of an oil increases, its viscosity increases since the higher grade number oils contain the majority of the heavy weight hydrocarbons that were found in the crude oil from which they were produced. Any oil's viscosity can be lowered by increasing its temperature, and for thermal stations like HTGS, this characteristic is employed in the design and operation of the fuel handling system. As is typical for many oil fired power plants, the heating for viscosity reduction at HTGS takes place in two stages. The first stage occurs at the suction located inside the main storage tanks. These heaters are utilized to heat the oil sufficiently to permit it to flow out of the tank and through piping to the station's fuel oil day tank. The second stage heating occurs in the pumping and heating sets that form part of the fuel handling system for each unit. The heat exchangers contained in these sets are designed to heat the oil to a temperature sufficient to achieve the viscosity required by the oil burners.

ASTM D396 specifies a viscosity requirement at 100°C (212°F). CGSB-3.2 and most users in Canada specify viscosity at 50°C (122°F). As shown above CAN/CGSB-3.2 specifies a maximum viscosity of 650 cSt and a minimum viscosity of 100 cSt at 50°C (122°F). NLH currently specifies a maximum viscosity of 700 cSt at 50°C (122°F) while the two other Canadian utilities specify 350 SSF (equivalent to 745 cSt) and 300 SSF (equivalent to 640cSt) maximum, respectively, also at 50°C (122°F). The viscosity specified by NLH therefore lies between that specified by the other two Canadian utilities.

3.7   SULFUR CONTENT

The sulfur content in residual oil is a function of the chemically bound sulfur in the crude oil from which it is produced. It is mostly contained in organic compounds in the crude oil. Some 70 to 80% of the sulfur that was in the crude ends up in the distillate and residual fractions (**Ref. 2**). Typically, as the grade number of the oil increase, so does its sulfur content as sulfur like other contaminants in the crude oil is concentrated in the residuals by a result of the refining processes.

The most widely known objection to sulfur is that of an air pollutant, which is a significant contributor to acid rain. Sulfur is known as a "pass through" pollutant because almost all the sulfur that is contained in the fuel is oxidized to sulfur dioxide (SO_2) and is emitted to the atmosphere from the boiler stack. This occurs regardless of the boiler type or burners used to burn the oil. Most jurisdictions have passed regulations to either limit sulfur content in the fuel or SO_2 emissions to the air because of the air pollution concern. In the presence of excess air that is found in almost all boiler furnaces, a small percentage of the SO_2 will be further oxidized to SO_3.

Unfortunately, SO_3 is more problematic than SO_2 from both air pollution and plant corrosion perspectives. Unlike SO_2, which can be removed from boiler flue gases by a wet flue gas desulfurization (WFGD) system, SO_3 cannot be removed because it is not soluble in the scrubbing liquor utilized in a WFGD system. SO_3 requires another air pollution control device downstream of the WFGD system, typically in the form of a wet electrostatic precipitator (WESP). In the case of cold end boiler corrosion, SO_3 combines with moisture in the flue gas to form sulfuric acid (H_2SO_4), which aggressively attacks carbon steel.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.6

In addition to air pollution, sulfur poses a number of additional concerns to the operation and maintenance of boilers and therefore thermal generating stations. Specifically, the sulfur oxides produced by combustion of the sulfur in the oil produce both high temperature and low temperature corrosion in boiler components and ductwork. The explanation of how sulfur combines with vanadium to produce high temperature corrosion in the superheater and reheater sections of utility boilers is given below in the discussion on vanadium. In the back end or low temperature section of the boiler if flue gas temperatures drop to the acid dewpoint level, the SO_3, combines with moisture condensed from the flue gas to form sulfuric acid, H_2SO_4, which will aggressively corrode carbon steel surfaces. Components of concern include the airheater(s) and ductwork and equipment downstream of the airheater.

The current NLH fuel oil specification requires a maximum sulfur content of 0.7% by weight as dictated by regulations. This places the residual oil purchased by NLH in the category of a low sulfur residual oil. Neither ASTM D396 nor CAN/CGSB-3.2 limit sulfur content of No. 6 oil. One of the other Canadian utilities whose oil fired thermal station is equipped with a WFGD system specifies a normal sulfur content of 2.5% but permits a range from 1.5% to 3.0% by weight. A second other Canadian utility whose oil fired station is not equipped with a WFGD system, specifies a maximum sulfur content of 2.2% by weight.

3.8   VANADIUM CONTENT

For utility boilers firing residual fuel oil such as those at the HTGS, vanadium is one of the most troublesome metallic components that can be contained in the oil fired in the boiler. This is due to the severe corrosion it can cause and its role as a catalyst in converting sulfur dioxide (SO_2) to sulfur trioxide (SO_3).

When vanadium is oxidized in the burner flame it forms vanadium pentoxide, V_2O_5. If sodium is also in the oil it will form Na_2O. These two compounds combine to form a range of compounds that have melting points as low as 540^oC (1000^oF). Although this temperature is above the tube metal temperatures for the tubes forming the furnace waterwalls, it is in the tube metal temperature range for tubes in the finishing sections of the superheater and reheater bundles. Sulfur, which is also contained in residual fuel oils, will produce SO_3, which can combine with Na_2O to form Na_2SO_4 in the ash deposit. Na_2SO_4 and V_2O_5 also form low melting point mixtures. When these low melting point mixtures form liquid deposits on the superheater and reheater tubes they act like a flux to dissolve the iron-oxide protective film on the outside of the tube and facilitate the transfer of oxygen from the flue gas to the metal surface (**Ref. 8**). This corrosion mechanism is known as high temperature corrosion and can produce more rapid and severe corrosion than that produced by other contaminants which remain in a solid state.

Neither ASTM D396 nor CAN/CGSB-3.2 places any limit on vanadium content in residual oil. The current NLH fuel oil specification limits vanadium content to 200 mg/kg, equivalent to 200 parts per million by weight (ppmw). Two other Canadian utilities have a limit of 300 ppmw and a normal value of 300 ppmw but an allowable range of 50 to 450 ppmw, respectively. The NLH specification is therefore more stringent that the other two Canadian utilities.

Stantec

3.9   SODIUM CONTENT

Sodium is a contaminant that can be present in crude oil as one of the complex metallic compounds contained in the oil. Sodium may also stem from salt (sodium chloride) contained in moisture that either originates with the crude oil or is unintentionally added to the oil in sea transport. Sodium plays an important part in the high temperature corrosion mechanism previously discussed in the vanadium parameter section above. It can also react with refractories causing damage to them.

Neither ASTM D396 nor CAN/CGSB-3.2 places any limits on sodium content in residual oil. The current NLH fuel oil specification limits sodium content to 50 mg/kg. This is comparable to other Canadian utilities, one of who has the same limit and another who states a normal value of 30 mg/kg but allows a range of 15 to 75.

3.10   ASH CONTENT

Ash content is the non-combustible residue resulting from the oxidation of organometallic compounds contained in the crude oil. As has been discussed in Section 2, these compounds are concentrated during the refining process and cannot be easily removed by physical methods such as centrifuging or filtering. There can be up to 25 different metals in crude oils. Amongst the most prevalent are iron, nickel, calcium, aluminum and sodium (**Ref. 9**). In the case of residual produced by the catalytic cracking process, another source for metal contained in the oil is carryover of the metal based catalyst used in the reactor vessel of this process.

Ash presents two major types of problems for the high temperature, high pressure, steam boilers used in the generation of electricity, namely fouling (and in some cases slagging)and high temperature corrosion. Fouling and slagging impair heat transfer to boiler surfaces and lowers boiler efficiency. High temperature corrosion can cause significant damage to the superheater and reheater sections of utility boilers. The main culprits in this corrosion are vanadium and sodium. The high temperature corrosion mechanism was previously discussed in the vanadium parameter section above.

CAN/CGSB-3.2 specifies a maximum ash content of 0.20% by mass for No. 6 oil. ASTM D396 does not specify a limit for this parameter. The current NLH fuel oil specification limits ash to 0.1% by mass. One of the other Canadian utilities has the same limit for ash while another Canadian utility does not specify a limit for this parameter. The existing NLH limit for ash is better than required by CAN/CGSB and a more stringent level would likely be difficult to obtain. The low limit on ash means that the metals content of the oil supplied must also be low.

3.11   WATER AND SEDIMENT CONTENT

Although water and sediment can remain in residual oil after it has been refined, these can also be added subsequently by the handling and transportation of the oil. This is especially true for marine transport, which is used to deliver fuel oil to the HTGS. These are generally not a concern

in lighter oils as they are only present in very small amounts, if at all. As with the other non-hydrocarbon components of oil, water and sediment are concentrated in the residual oil as a result of the refining processes the oil is subjected to. Sediment can cause problems with the plugging of strainers and filters, and possibly erosion of atomizer tips and valve internals. Water subtracts from the heat available to make steam since it requires heat to be vaporized and leave as one of the gases making up the flue gases discharged from the boiler. As in the case of the current NLH fuel oil contract, most contracts will include a provision for a reduction in price if water content is found to exceed the specified maximum.

The current NLH specification limits water by distillation (ASTM D95) to 0.5% by volume maximum and sediment by extraction (ASTM D473) to 0.2% by weight maximum. This is significantly less than what is allowed in ASTM D396 and in CGSB-3.2 , which is for the combination of water and sediment not to exceed 1% by volume. Both of the other two Canadian Utilities who burn residual oil specify water by distillation to be 1% by volume maximum and sediment by extraction to 0.25% by weight maximum.

3.12   ASPHALTENE CONTENT

Asphaltenes are the long chain, heavier weight hydrocarbons with molecular weights in the 1,000 to 20,000 range that belong to the aromatic class of hydrocarbons (**Ref. 11**). They are the last of the hydrocarbon molecules in residual oil to combust and produce longer flame length. As noted in Section 2, aromatics are less stable than paraffinic or naphthenic hydrocarbons.

Asphaltenes are chiefly found in the residues of the vacuum distillation, cracking and Visbreaking refinery process units. Metals and other contaminants that were present in the crude oil will be concentrated in the asphaltenes. They are typically suspended in colloidal form in the oil, i.e., they are solid particles suspended in the liquid oil phase so that the oil is not a true total liquid, and can drop out of suspension forming sludge layers in storage tanks and deposits in filters and heat exchangers causing blockage and loss of performance. Unlike wax that may precipitate out of solution with a drop in oil temperature, and can be re-dissolved upon heating of the oil, asphaltenes cannot be removed in this manner or by any other practical means available in a power plant.

Neither ASTM D396 nor CAN/CGSB-3.2 places any limits on asphaltene content in residual oil. The current NLH fuel oil specification limits asphaltene content to 8% by weight. Comparing this value to the other two Canadian utilities burning residual oil reveals that one has a limit of 9% by weight while the other states a normal value of 9% by weight but allows a range of 4 to 15%. Typically, asphaltene content above 10% is considered to significantly increase the probability of problems.

3.13   STABILITY AND COMPATIBILITY

Stability is the ability of a single residual fuel oil to resist forming deposits caused by segregation or separation of a component from the rest of the oil. Instability refers to the tendency of an oil

Stantec

to produce a deposit by itself (**Ref. 11**). Straight run residuals are inherently more stable that cracked residual oils. Compatibility is the ability of a residual oil to resist deposition when blended with another oil, either residual or lighter. Two oils even though they may be stable themselves may prove incompatible when blended.

Asphaltenes are of primary concern in both instability and incompatibility of fuel oils. The asphaltene colloid can be made unstable by external stresses or blending one oil with another with which it is incompatible, leading to precipitation and formation of a sludge or tar like deposit. Blending paraffinic oil with an aromatic cracked oil has been found to be more likely to produce asphaltene precipitation than blending two aromatic oils (**Ref. 4**). Additionally, thermally cracked distillate oils are better to use as blending oils than catalytically cracked or straight run distillate oils. This is because the thermally cracked distillate oils have a greater percentage of aromatic hydrocarbons, which maintains the proper equilibrium in the residual oil product after blending (**Ref. 2**).

Segregation and settlement of sediment or asphaltene from an unblended residual oil is a process that typically takes months to occur. However, blending of incompatible oils can produce very rapid sludge buildup.

As noted above in Section 3.1, ASTM D396 does have a generally stated requirement that all grades containing residual components shall remain uniform in normal storage and not separate. CAN/CGSB-3.2 has a general requirement that heating fuel oils shall be stable, homogenous mixtures. The most generally accepted method currently used for testing stability of residual oils is ASTM D 4740; Standard Test method for Cleanliness and Compatibility of Residual Fuel by spot test.

The same test method is used for both cleanliness and compatibility. A drop from a prepared sample is allowed to fall on a sample paper that is maintained at 100°C in an oven for one hour and then the spot is compared to a reference spots numbered from 1 to 5 and the spot on the paper is assigned the number of the reference spot closest to it in appearance. In the case of cleanliness, the sample is prepared from a single, unblended residual oil. In the case of compatibility, the sample is prepared from a blend of residuals blended in the same ratio they are meant to be utilized at. A reference spot number of 1 is considered to indicate a stable oil in the case of a single unblended oil and a compatible blend in the case of a blended residual product. A reference spot number 5 is the least desirable result and likely portends stability and compatibility problems.

The current NLH fuel oil specification stipulates that cleanliness shall be a Spot 1 maximum. As noted above, this is the best result that can be obtained from the specified test method and so should mean that only stable oil is supplied to HTGS. One of the other Canadian utilities burning residual oil also stipulates that cleanliness shall be a maximum of reference Spot 1. The other Canadian utility does not include either cleanliness or compatibility in its fuel oil specification.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.10

3.14   ALUMINUM CONTENT

Aluminum can be present in the crude oil as extracted from the ground and then be concentrated in subsequent refining of the residual oil, particularly cracked residuals as has previously been described. With the introduction of catalytic cracking another method of adding to the normally occurring amount of aluminum content has been introduced, which can occur by carryover of catalyst from a catalytic cracker. Aluminum based catalysts are commonly utilized in this piece of oil refining equipment. If carried over the catalyst fines can be very abrasive to internal surfaces particularly where there are close tolerance and/or small openings such as in control valve internals and oil burner atomizer tips.

Neither ASTM D396 nor CAN/CGSB-3.2 places any limits on aluminum content in residual oil. One of the other Canada utilities gives a normal value of 13 ppm by weight (equivalent to mg/kg), but allows a range of 5 to 65 as determined by ASTM D5184. A Florida utility limits both aluminum and silicon content to 120 ppm. The Platts assessment limits both aluminum and silicon content to 200 ppm. The American Bureau of Shipping (**Ref. 3**) indicates that a number of major diesel engine builders have concluded that 30 ppm of alumina in the marine residual oil supplied to the engines is the upper limit for successful engine operation.

Since a diesel engine contains a number of components that need to maintain close tolerances between moving parts, it would be more sensitive to aluminum contamination in the fuel oil than the boilers at HTGS. However, there are a number of components in the HTGS fuel oil system such as the oil flow control valve and the oil burner atomizers that include close tolerances and/or small flow passages, which would be affected in a similar manner to diesel engine components, i.e., they would experience increased wear and abrasion with increasing aluminum and silicon levels. This is particularly so where the increased aluminum content is the result of catalyst fines (which are very hard, abrasive particles) carryover rather than an increase in the aluminum content of the crude oil from which a residual oil was produced.

3.15   SILICON CONTENT

Other than the limit on aluminum content specified by one of the other Canadian utilities, all of the above discussion on aluminum also applies to silicon. The same Canadian utility that imposes the limit on aluminum content stated in the section above also specifies a limit for silicon. In this case a normal value of 50 parts per million by weight (ppmw) and a range of 10 to 250 ppmw is stated.

3.16   HYDROGEN SULFIDE CONTENT

This parameter is a more recent inclusion to a fuel oil specification than most of the other parameters since it is included not because of a performance or energy content concern but because of a human health and safety concern. There appears to be a number of different methods utilized to measure hydrogen sulfide (H_2S)and these methods measure hydrogen sulfide in different phases (physical states) and in different locations. ASTM D 5705 test method

 Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.11

determines hydrogen sulfide in the vapor phase above the liquid surface of a residual oil sample. The results are determined in parts per million by volume (ppmv) and the applicable range is 5 to 4000 ppmv. The test method indicates that it does not necessarily simulate the vapor phase concentration of hydrogen sulfide in a residual oil storage tank.

The current NLH fuel oil specification stipulates that hydrogen sulfide concentration should not exceed 2 mg/kg in accordance with test method IP-570. This is a mass concentration of hydrogen sulfide in the liquid phase. Neither ASTM D396 nor CAN/CGSB-3.2 places any limits on this parameter. One of the other Canada utilities specifies a hydrogen sulfide concentration of 200 ppmv as determined by a test method named "Exxon AM-S90-003". It appears this is a proprietary test method and no details could be obtained.

It should be noted that H_2S content, as determined by the above testing method, does not correspond to oil sulfur content. Thus, a low sulfur content oil such as that currently being purchased by NLH may produce a higher H_2S concentration in the vapor space of a tank than an oil with a higher sulfur content. The higher H_2S content would likely result from an upset in the refining process used to produce the low sulfur oil.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

3.12

4.0 RECOMMENDED CHANGES AND FUEL OIL SPECIFICATION

4.1 CURRENT NLH OIL SPECIFICATION

The current fuel oil specification utilized by NLH is provided below. This specification incorporates a number of revisions that have been made over the years. The biggest change was the dropping in sulfur content to its present low limit of 0.7%. Additionally, API gravity was dropped to a minimum of 5 degrees, and vanadium and hydrogen sulfide content limits were added.

Parameter	Test Method	Minimum	Maximum
Gravity API at 60 F (Min)	D 4052	5	-
Flash Point, Degrees °C (Min)	D 93	66	-
Pour Point, Degrees °C (Max)	D 97	-	15
Kinematic Viscosity @ 50°c, mm²/s, (cSt) (Max)	D 445	-	700
Sulfur % by Weight (Max)	D 4294	-	0.70
B.T.U.'s Per barrel (Min)	D 240	6,300,000	-
Ash by Weight, % (Max)	D 482	-	0.1
Sediment by Weight, % (Max)	D 473	-	0.2
Water by Volume, % (Max)	D 95	-	0.5
Cleanliness	D 4740	-	1
Asphaltenes by Weight, % (Max)	D 6560 / IP-143	-	8
Sodium, mg/kg	D 5863	-	50
Vanadium, mg/kg	D 5863	-	200
H2S (mg/kg)	IP-570		2

4.2 PARAMETERS TO BE RETAINED

It is recommended that the following parameters from the current NLH fuel oil specification, tabulated below, be retained. These parameters are considered to still represent acceptable requirements for residual fuel oil that will be utilized for the production of electricity in a thermal generating station.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

4.1

Parameter	Test Method	Minimum	Maximum
Flash Point, Degrees °C (Min)	D 93	66	-
Pour Point, Degrees °C (Max)	D 97	-	15
Kinematic Viscosity @ 50°c, mm²/s, (cSt) (Max)	D 445	-	700
Sulfur % by Weight (Max)	D 4294	-	0.70
Ash by Weight, % (Max)	D 482	-	0.1
Sediment by Weight, % (Max)	D 473	-	0.2
Water by Volume, % (Max)	D 95	-	0.5
Cleanliness	D 4740	-	1
Asphaltenes by Weight, % (Max)	D 6560 / IP-143	-	8
Sodium, mg/kg	D 5863	-	50
Vanadium, mg/kg	D 5863	-	200
H2S (mg/kg)	IP-570		2

4.3   RECOMMENDED CHANGES

There are a few changes that are recommended to the existing NLH fuel oil specification, which are discussed below. These changes are based solely on technical considerations and do not consider any economic impact.

4.3.1   API Gravity

It is recommended that the minimum API gravity of 5 specified by NLH be increased to 10. With the current minimum, it is probable that the residual oil product that is supplied will be a blend that has as its basis a very heavily cracked residue. As has been discussed in earlier sections of this report, contaminants including metals and sediment are concentrated in residuals. The more refining the residual is subjected to, the higher this concentration will be. Additionally, heavily cracked residuals will contain higher percentages of olefins and aromatic hydrocarbons including asphaltenes. Raising the minimum API gravity should reduce the concentrations of these undesirable components.

4.3.2   Heating Value

While not unreasonable, the heating value currently specified by NLH is near the bottom of the typical range for residual oil, although variations from the specified level can result in supplier costs or benefits. This is financially detrimental to NLH due to the conversion factor that is used in rate setting for its industrial and utility customers. It is still considered advisable to revise the heating value from the current value of 6,300,000 Btu per barrel to 6,400,000. This is not a significant increase but will mean a greater energy content in the fuel oil volume purchased.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

4.2

4.3.3 Blended Product

As has been previously discussed, mostly all of the residual oil sold today is a blended product. Although a specific value cannot be stipulated, it is recommended that NLH seek to modify its existing fuel supply contract to require that the residual fuel oil product they are to be supplied with be blended before being off loaded at the HTGS marine terminal. This should eliminate receiving separate products or cuts at the HTGS terminal and expecting that they will mix in the transfer piping and storage tanks at the station, which would present a high risk for precipitation and/or sludge accumulation. Additionally, where a blended product is being supplied, the ASTM D4740 test method for cleanliness must be performed on a sample blended in the exact proportions as the residual product to be off loaded at the HTGS marine terminal if it is to provide any useful or accurate information about the oil supplied. This test result must be received before offloading begins so that NLH can exercise their right to refuse shipment if the results are not acceptable.

4.3.4 Aluminum Content

This parameter is not currently included in the NLH fuel oil specification. Damage to fuel system equipment is particularly likely if the aluminum is in the form of catalyst fines rather than a metallic compound that was contained in the crude oil and concentrated in the residual oil. The catalyst fines are very hard, abrasive particles.

There is no proven or industry established concentration level, which will ensure that if the aluminum content is maintained below this level no damage will occur to the components of a fuel oil system in a thermal generating station. As noted in Section 3.3 one of the other Canadian utilities that burns residual oil has established a nominal value of 13 ppm and a range of 5 to 65 ppm for aluminum content. It is therefore suggested that a limit of 50 mg/kg (ppmw) be added to the existing NLH fuel oil specification. This is seen as a reasonable level, in line with the other Canadian utility practice that will potentially afford some degree of protection against the kind of rapid, extensive damage experienced at HTGS in 2013.

4.3.5 Silicon Content

This parameter is also currently not included in the NLH fuel oil specification. The reason for adding a limit for silicon content to the existing NLH fuel oil specification is the same as that stated above for aluminum content. As in the case of aluminum, there is no accepted industry standard for an allowable level of silicon content in residual oil. As noted in Section 3.16, the same Canadian utility that has established a range for aluminum content has established a nominal value of 50 ppm (mg/kg) and a range of 10 to 250 ppm (mg/kg) for silicon. It is suggested that a silicon limit of 75 mg/kg (ppmw) maximum, be added to the existing NLH fuel oil specification.

![Stantec logo]

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

4.3

4.3.6   Discharge Port Sampling and Analysis

NLH's current fuel contract for HTGS requires the fuel supplier to have sampling and analysis of the fuel loaded at the dispatch port performed. Further, if the results of the analyses indicate that any of the parameters of the NLH oil specification are not being met, NLH has the right to refuse the shipment. As was discussed in Section 4.3.3 above, it is important that this sampling and analysis be carried out on the blended product that is to be supplied using existing NLH testing methods.

Currently aluminum and silicon are not included In the NLH oil specification, but if they are added as recommended above, then analysis of discharge port samples would need to include these parameters. The test method for determination of aluminum and silicon in the oil, namely ASTM D5184, requires the production of ash from an oil sample and therefore takes some time to complete. Beyond the sample preparation and analysis times, the sample must spend 10 hours in a furnace. Thus, two days is probably the shortest time in which results can be obtained for the determination of aluminum and silicon content. This means that the ship may have sailed from the dispatch port at which the samples were taken before the results can be obtained.

In order to prevent the kind of equipment damage experienced in 2013, it is important to prevent a situation where an oil shipment having a higher than specified silicon or aluminum content is off loaded into the HTGS tank farm. To accomplish this, it is necessary that discharge port sample analysis results be obtained before offloading from the delivery vessel begins at the HTGS marine terminal. Then, if results showed that aluminum or silicon content was above the specified maximum value, the shipment could be rejected.

4.3.7   Oxidation Stability

As noted in Section 2.2, residual oils available today are mainly cracked rather than straight run residuals. These cracked residuals may contain significant quantities of olefins which are potentially subject to oxidation and polymerization. Investigation has determined that while there are test methods (ASTM D2274 and D4625) to determine the oxidation stability of distillate oils, there are no such published methods for residual oils. Thus, while a potential problem may exist due to gum formation resulting from oxidation and polymerization, there is currently no addition to the NLH specification that can be recommended to help alert HTGS staff to this potential problem.

There are two appendices attached to test method ASTM D4870, namely, thermal aging and chemical aging procedures. Test method D4870 is used for determination of total sediment in residual fuels and is primarily utilized in the marine residual sector of the oil market. There is a possibility that one of the aging procedures could be utilized to condition an oil sample as a means to test for stability. However, this would require research, to determine acceptable test method limits.

Stantec

4.3.8   Minimum Viscosity Limit

Although a limit on the maximum viscosity that a residual oil can exhibit is normally the main concern for users of residual oil, some users will also limit the lowest viscosity that residual oil supplied to them can exhibit. Typically oil refiners will want to supply residual oil with as high a viscosity as possible since lowering the viscosity will require using additional, more valuable lighter products to obtain a lower viscosity. If the viscosity of a residual oil falls too low then obtaining design delivery from fuel oil pumps that were designed for pumping higher viscosity oil can be jeopardized.

The two other Canadian utilities burning residual oil indicate lower limits of 95 SSF (200 Cst) and 150 SSF (320 Cst) at 50°C (122°F). The Canadian standard specification CAN/CGSB-3.2 states a lower limit of 100 Cst at 50°C (122°F) for residual oil. It is suggested that the CAN/CGSB-3.2 lower limit for kinematic viscosity be added to the current NLH fuel oil specification.

4.4   RECOMMENDED FUEL OIL SPECIFICATION

The recommended fuel oil specification is provided below. The changes from the current NLH specification are illustrated in red.

Parameters	Test Method	Minimum	Maximum
Gravity API at 60 F (Min)	D 4052	10	-
Flash Point, Degrees °C (Min)	D 93	66	-
Pour Point, Degrees °C (Max)	D 97	-	15
Kinematic Viscosity @ 50°c, mm^2/s, (cSt) (Min/Max)	D 445	100	700
Sulfur % by Weight (Min/Max)	D 4294	-	0.70
B.T.U.'s Per barrel (Min)	D 240	6,400,000	-
Ash by Weight, % (Max)	D 482	-	0.1
Sediment by Weight, % (Max)	D 473	-	0.2
Water by Volume, % (Max)	D 95	-	0.5
Cleanliness (Note 1)	D 4740	-	1
Asphaltenes by Weight, % (Max)	D 6560 / IP-143	-	8
Sodium, mg/kg	D 5863	-	50
Vanadium, mg/kg	D 5863	-	200
H2S (mg/kg)	IP-570		2
Aluminum (mg/kg)	D 5184	-	50
Silicon (mg/kg)	D 5184	-	75

 Stantec

RECOMMENDED CHANGES AND FUEL OIL SPECIFICATION
December 22, 2014

Note 1. Where a blended residual oil product is supplied it shall be blended prior to being off loaded at the HTGS marine terminal. Test method D4740 shall be conducted on samples blended in the exact proportions to the residual oil product to be off loaded at the HTGS marine terminal.

Stantec

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

4.6

5.0   FUEL SYSTEM OVERVIEW

As part of the fuel oil specification review a high level overview of the existing fuel oil system at HTGS was performed. A discussion of this overview follows.

5.1   SYSTEM CONFIGURATION

The HTGS fuel system originates at the marine terminal located approximately one kilometer from the station. Fuel oil is unloaded from a ship docked at the terminal and transported to one of four storage tanks via a sixteen inch pipeline. The pipeline is electrically heat traced and insulated. It is also equipped with instrumentation to allow remote monitoring (in the HTGS control room) of pipeline parameters such as temperature and pressure.

Each of the four storage tanks has a total capacity of 217,000 barrels and a usable capacity of approximately 203,000 barrels. The bottom meter of the tanks is unusable storage volume. Each tank is equipped with two suction heaters one located at each oil outlet from the tank. From the tank farm the oil flows to a station day tank located behind the main boiler building. The purpose of the suction heaters is to raise the temperature of the oil and thereby decrease its viscosity to assist the flow of oil in the pipeline that connects the tank farm to the station day tank and allow the unit supply pumps located in the unit pumping and heating sets to operate properly.

Oil is withdrawn from the day tank separately by each of the three unit pumping and heating sets. Each generating unit has a pumping and heating set that consists of a dual basket type inlet filter, dual fuel oil transfer pumps, dual fuel oil heaters (shell and tube heat exchangers) and a dual basket type outlet filter. From the outlet of the unit pumping and heating sets the oil is directed through a piping system that connects to each of the burners installed in the boilers.

Located in the piping system containing the oil pumping and heating systems are fuel oil flow control valves that modulate to control the oil flow to the burners based on boiler demand. The fuel oil piping systems also include short and long recirculation lines and control valves. The short recirculation lines allow oil to be recirculated from the outlet of the pumping sets back to the day tank while the long recirculation lines allow the oil to be recirculated from the burner fronts back to the day tank. The long recirculation system plays a critical role is ensuring that fuel oil of the proper temperature and viscosity enters the burner as quickly as possible after the burner oil block valves are opened during the burner light off process. Discussions with plant operating personnel confirmed that the control system includes permissives that require set temperatures in the long recirculation piping to be obtained before burner oil block valves can be opened.

The controls for the oil system are contained in the distributed control system (DCS) that oversees the entire station operation. With the proper screen selection, operators are able to monitor the status of the fuel oil handling systems and control their operation from the operators stations located in the station control room. An important parameter for operations staff to adjust and

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

5.1

monitor is the setpoint for the oil temperature leaving the unit oil heaters. This is discussed further under Oil Burners.

The configuration of the fuel oil system including level of redundancy for equipment is typical of modern oil fired generating stations.

5.2   STORAGE TANK SUCTION HEATERS

The storage tank suction heaters are of the typical configuration for this purpose, namely a tube bundle which projects into the tank and in which steam is circulated through the tubes and oil flows over the outside of the tubes. The heater bundle is bolted to and support from a tank nozzle. As the oil flows over the tubes it picks up heat from the steam increasing in temperature and lowering its viscosity. The data sheet for the tank suction heaters indicate that each heater is designed for heating 73,386 kg/h (162,000 lb/h) of oil from 27°C (80°F) to 60°C (140°F). Thus the two heaters can heat a total oil flow of 146,772 kg/h (324,000 lb/h). The data given on the boiler summary performance sheets yield a total oil flow of approximately 111,805 kg/h (246,530 lb/h) with all three boilers operating at maximum continuous rating (MCR). The suction heater capacity installed is, therefore, more than adequate.

It is unavoidable that some coking of oil will occur on the outside of the tubes making up the suction heaters. At a minimum, an annual assessment of the heater performance should be conducted to estimate the amount of deposition/coking that has occurred and to determine if further action is required to remediate heater condition. Problems can be expected if separation of oil components occurs in the tanks and heavy asphaltenes settle onto tube exterior surfaces. The most practical course of action to prevent oil separation in the tanks is to require that all oil shipments be blended prior to being off loaded at the HTGS marine terminal and ensuring that cleanliness testing (ASTM D4740) is performed on the ship's composite.

5.3   PUMPING AND HEATING SETS

Each of the units has a pumping and heating set that filters the oil, increases oil pressure to that required for the burners and increases the oil temperature to that required to achieve the proper viscosity at the burners. The strainers, pumps and heat exchangers contained in the sets are provided with redundancy, i.e., one of each component is in operation while its duplicate is in a standby mode.

There are two sets of dual basket strainers, one set before the pumps and one set after the pumps, contained in each pumping and heating set. The dual basket design allows for one basket strainer to be removed and cleaned while the other stays in service. The strainers have an opening size of 1/8 inch, which is too large to collect catalytic cracker fines. Putting a filter ahead of the oil pumps that would be capable of collecting catalytic fines is likely not practical as it would probably severely restrict oil flow to the pumps and possibly lead to pump cavitation. The most practical approach is to ensure that testing for aluminum and silicon contents is carried out and the results obtained before the oil shipment is off loaded at the HTGS terminal so that

Stantec

the shipment can be rejected if aluminum and silicon content do not meet the specified maximum contents.

There are two 100% duty oil pumps located in each unit pumping and heating set. The oil pumps are of positive displacement design, which is the common and recommended type for viscous fluids such as residual fuel oil. The delivery volume from a positive displacement pump is actually more constant than from a centrifugal type pump, which aids stability of burner operation and the combustion process. The pump capacities were compared to the oil flow required for boiler MCR conditions as stated on the boiler performance sheets and are found to have adequate capacity.

As is accepted practice for heavy fuel oil heaters, the heaters installed in the pumping and heating sets at HTGS are of the shell and tube design and of carbon steel construction. The shell and tube design is very robust, which is desired to prevent leaks of oil into the steam and condensate. Documentation reviewed for the heater exchangers provided as part of Unit 3 pumping and heating set indicated that the heat exchangers were designed to heat 175 USGPM of oil from 110°F (43°C) to 260°F (127°C). The summary performance sheet for Boiler 3 indicates that at MCR condition the boiler consumes 72,050 lb/h (32,675 kg/h). At an oil temperature of 110°C (43°C) this represents approximately 150 USGPM assuming a 10°API gravity oil. The design outlet temperature of 260°F (127°C) is significantly higher than needed to obtain the required burner viscosity of 140 SSU. As the required oil outlet temperature drops, the more oil that can be heated. The heat exchangers are therefore more than adequate for the duty intended. Complete design information was not available for units 1 and 2.

5.4   OIL BURNERS

The burners on Boilers 1 and 2 are arranged in a tangential firing pattern wherein the burners are located in the four corners of the furnace and are aimed so that their flames tangentially intersect an imaginary circle in the center of the furnace. At loads from approximately 25% of boiler MCR and above the flames merge and a single large fireball is created in the furnace. The burners in Boiler 3 are arranged in a wall firing pattern where the burners are installed across the front wall of the boiler on three levels.

All burners utilize atomizer assemblies that are known as "dual fluid atomizers" in which two fluids, the oil to be atomized, and a fluid used to assist with atomizing the oil into fine droplets, are injected and mixed. The dual fluid atomizer is an improvement over an earlier method known as mechanical atomization that relied solely on pressure to atomize the oil to be burnt. Compared to mechanical atomizers, dual fluid atomizers require lower oil pressure, produce a finer, more uniformly distributed oil droplet spray pattern, offer a larger turndown range, and more importantly, provide more stable combustion with heavy aromatic hydrocarbons that are a feature of cracked residuals. The disadvantage of dual fluid atomizers is the steam consumed in the atomizer, which represents a loss of treated water from the power production cycle.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

5.3

HOLYROOD TGS FUEL OIL SPECIFICATION REVIEW – FINAL

A critical parameter for all atomizers is the viscosity of the oil entering the atomizer since the atomizer is designed on the basis of a specific fluid viscosity and if the proper fluid viscosity is not supplied to the atomizer, its performance will not be as predicted by its design. In the situation where the oil arrives at the burner at higher than design viscosity, the oil droplets existing the atomizer tips will be larger than the droplet size designed for. These larger droplets will likely not combust completely. This will produce large porous cenospheres of unburned carbon and ash that will leave the furnace suspended in the flue gas. This represents a loss of energy and also negatively impacts air pollution.

The boiler manufacturer for Boilers 1 and 2, has supplied burners that require an oil viscosity of 100 Saybolt Second Universal (SSU) entering the burner while the burners in Boiler 3 require an oil viscosity of 140 SSU. The thermal performance specialist at the HTGS utilizes an excel program that was provided by the supplier for Boilers 1 and 2 to determine what oil preheat temperature is required for each shipment of oil based on the viscosity test results for the oil. The thermal performance specialist provides the recommended oil preheat temperatures to the operations department.

Laboratory viscosity testing of oil is normally performed at only one temperature. Stantec requested NLH to perform testing of an oil sample at two different temperatures to allow a temperature versus viscosity chart to be plotted. This was conducted on the shipment received in September 2014 at two different temperatures. The results obtained were 100.2 Cst at 50°C (122°F) and 12.33 Cst at 100°C (212°F). Stantec used these results to plot a curve of temperature versus viscosity and compare the required oil preheat temperatures obtained from that curve to those obtained from the curves utilized by the thermal specialist at HTGs.

The curve plotted by Stantec utilizes viscosity in SSU. The laboratory test results converted to this basis are 465 SSU at 50°C (122°F) and 67.6 SSU at 100°C (212°F). The curves produced by the excel program in use at HTGS plot viscosity in units of Saybolt Seconds Furol (SSF). The laboratory test result of 100.2 Cst at 50°C (122°F) is equivalent to 48.6 SSF at this temperature. Using the HTGS excel generated curves, it was determined that required oil preheat temperature for Boiler 1 and 2 is 85°C (185°F) for the latest oil shipment. Boiler 3 requires an oil preheat temperature of 76°C (169°F). The curve plotted by Stantec gives 84°C (183°F) as the oil preheat temperature required by Boilers 1 and 2 and 75°C (167°F) required by Boiler 3. Given the accuracy limits of the Stantec curve, the results from both sets of curve can essentially be considered identical. The Stantec curve therefore confirms the program currently utilized at HTGS for determination of oil preheat temperatures.

As discussed above, oil preheat temperatures are important operating parameters. As currently occurs, it is important to ensure that operations are using the oil preheat temperatures provided by the station thermal specialist. Copies of the curves used to determine the oil preheat temperatures detailed above are contained in Appendix A.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

5.4

6.0 REFERENCES

1. http://en.wikipedia.org/wiki/Oil_refinery; accessed on September 9, 2014.

2. Schmidt, Paul F, "Fuel Oil Manual", Fourth Edition, Industrial Press Inc., New York, 1985.

3. Notes on Heavy Fuel Oil, American Bureau of Shipping, 1984, Copyright 2001.

4. http://en.wikipedia.org/wiki/Oil_Visbreaker, accessed on September 24, 2014.

5. Leffler, William, L., "Petroleum Refining for the Non-Technical Person", Second Edition, PennWell Publishing Company, Tulsa, 1985.

6. http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MRERYUS3&f=M; accessed on September 30, 2014.

7. Canadian Fuels Association, "The Economics of Petroleum Refining, Understanding the business of processing crude oil into fuels and other value added products", December 2013.

8. French, David N., "Metallurgical Failures in Fossil Fired Boilers", Second Edition, John Wiley & Sons, Inc., 1993.

9. Bechtel Corporation, "Gas Side Corrosion in Oil Fired Boilers", prepared for US Agency for International Development, Contract No. EUR-0030-C-00-2055-00, November 1994.

10. Martin, C. J. and Lindsey Hicks, "Burner, Heating, and Lighting Fuels", ASTM paper MNL1-EB/May 2010.

11. Holmes, J.W. and J. A. Bullin, "fuel Oil Compatibility Probed", Hydrocarbon Processing September 1983, copyright 2006, Bryan Research & Engineering Inc.

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

6.1

APPENDIX A

Temperature vs Viscosity Curves

Stantec

Appendix A   - TEMPERATURE VS VISCOSITY CURVES

clm v:\1335\active\133546369\8_mechanical\8_report\rpt_rgm_20141222_holyrood tgs _fuel_oil_specification_review only .docx

A.1

Atomization Temperature vs Fuel Oil Viscosity Units 1 & 2

Chart: Atomization Temperature (C) vs Fuel Oil Viscosity SSF @ 122 F (50C)

Data points: 77, 85, 91, 96, 100, 104, 107, 110, 113, 116, 119, 121, 124
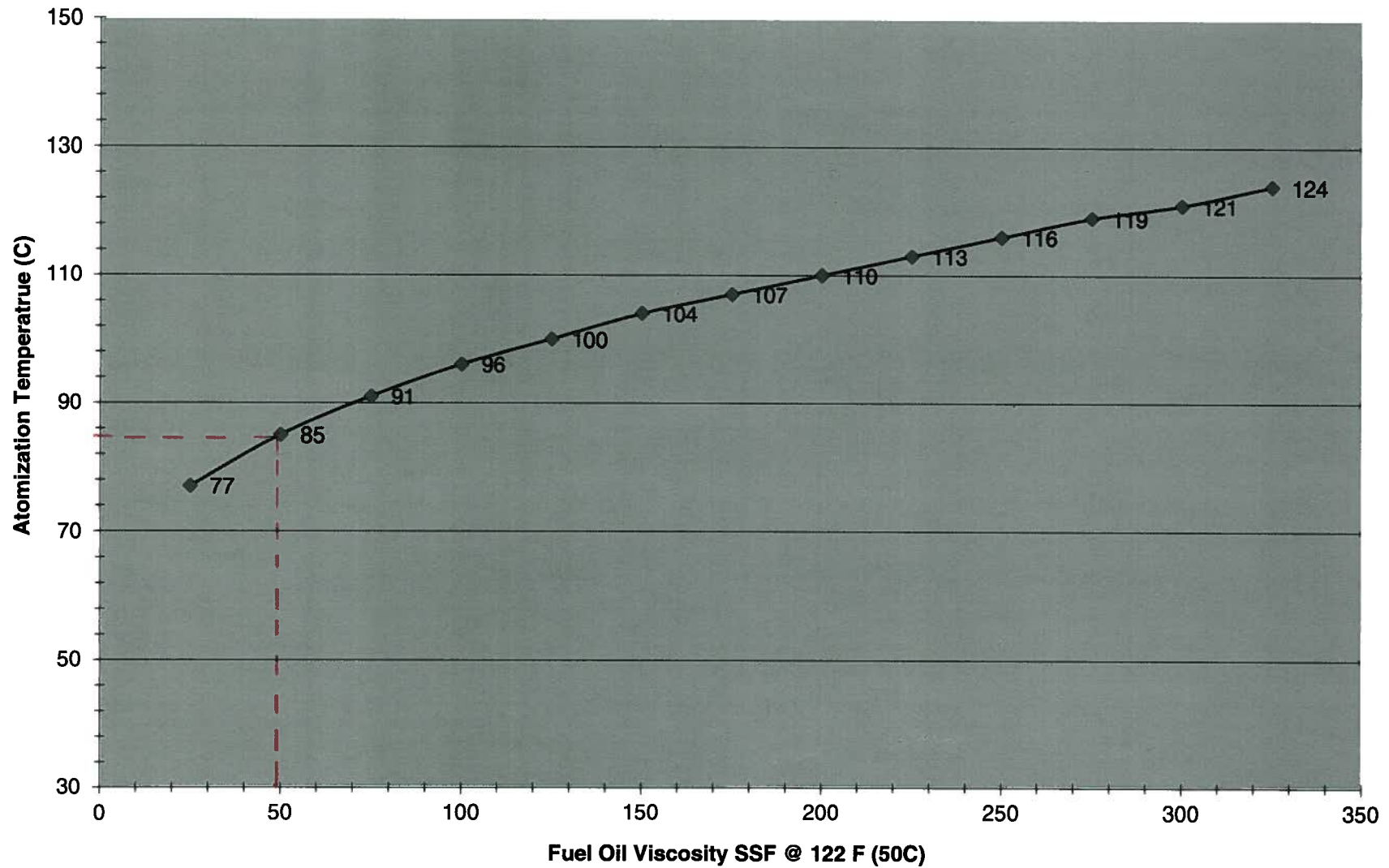
100 Cst @ 50°C = 48.6 SSF

∴ REQUIRED ATOMIZATION TEMP = 85°C = 185.9F

Unit 3 (140 SSU)
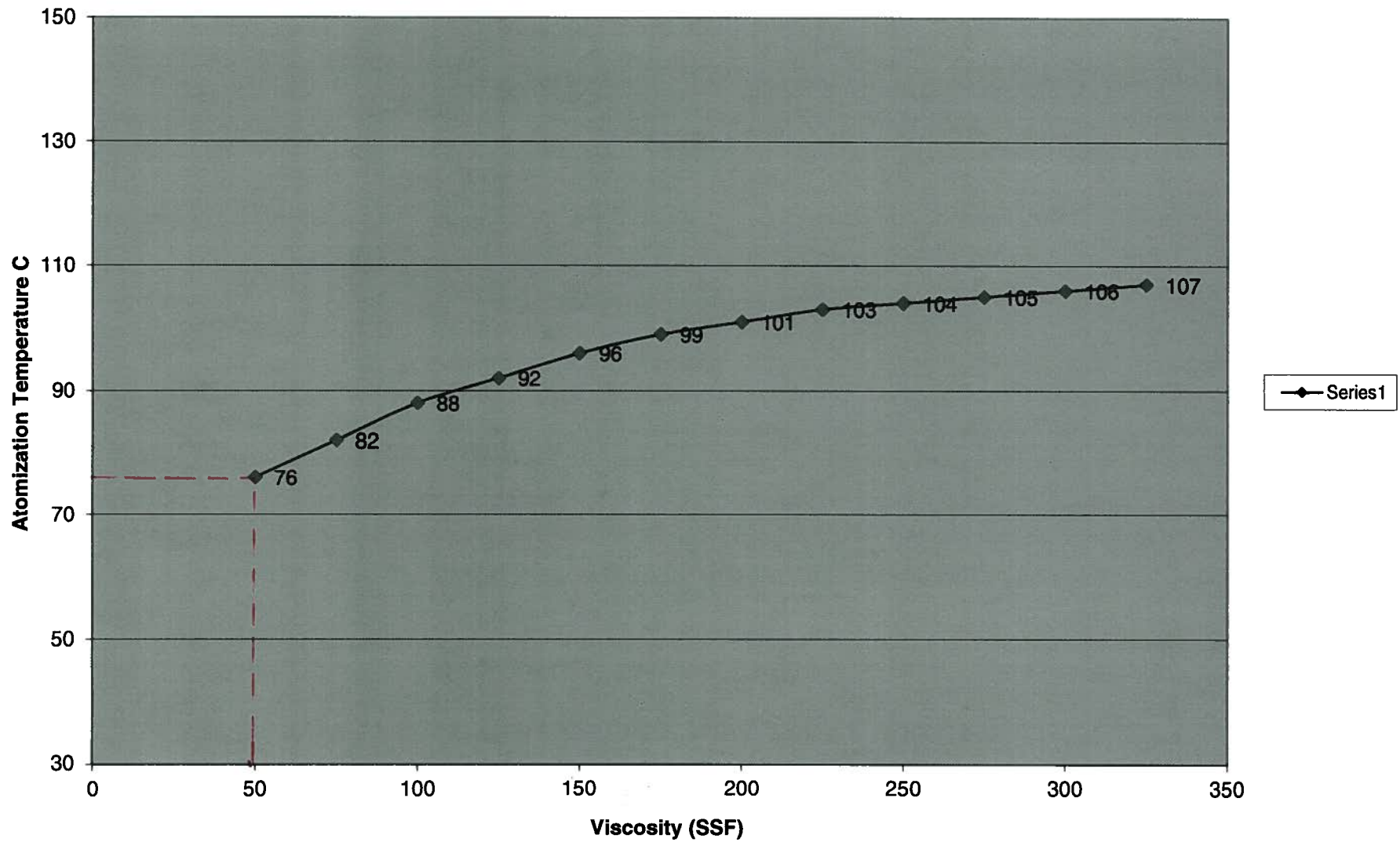
100 Cst @ 50°C = 486 SSF

∴ REQUIRED ATOMIZING TEMPERATURE = 76°C = 169°F.

RESULT FOR BOILERS #1 & 2 (100 SSU) REQUIRED OIL TEMPERATURE = 183°F / 84°C

RESULT FOR BOILER #3 (140 SSU) REQUIRED OIL TEMPERATURE = 167°F / 75°C

STANTEC CURVE

APPENDIX B — ENGINEERING DATA

Saybolt Universal Viscosity Chart

CRANE

TEMPERATURE, DEGREES FAHRENHEIT

AMERICAN STANDARD
ASA No. Z11.39-1939

A.S.T.M. STANDARD VISCOSITY-TEMPERATURE CHARTS
FOR LIQUID PETROLEUM PRODUCTS (D 341)
CHART B: SAYBOLT UNIVERSAL VISCOSITY, ABRIDGED

(This A.S.T.M. chart is used to determine the viscosity of a petroleum product at any temperature if its viscosity at two different temperatures is known. When the 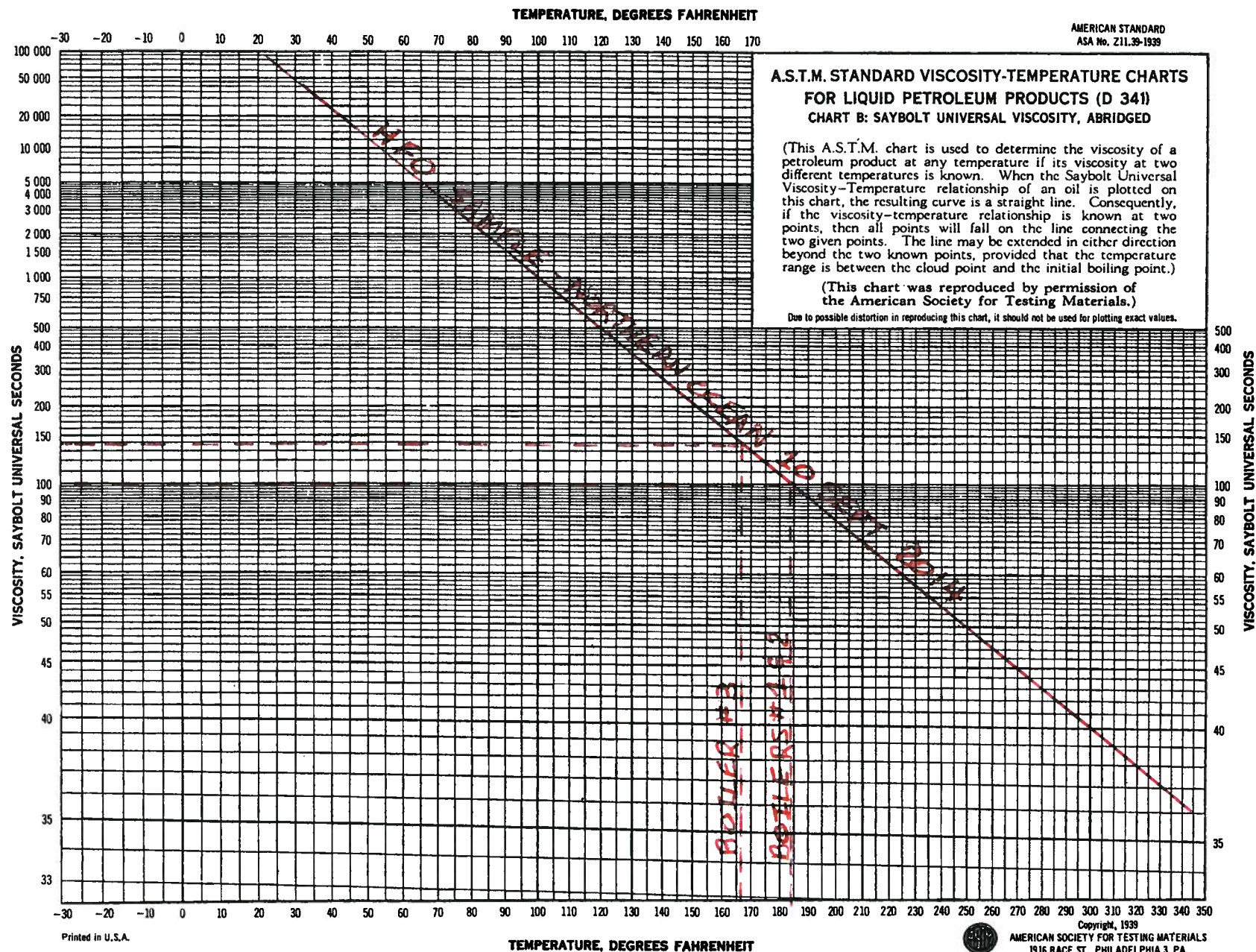Saybolt Universal Viscosity–Temperature relationship of an oil is plotted on this chart, the resulting curve is a straight line. Consequently, if the viscosity–temperature relationship is known at two points, then all points will fall on the line connecting the two given points. The line may be extended in either direction beyond the two known points, provided that the temperature range is between the cloud point and the initial boiling point.)

(This chart was reproduced by permission of the American Society for Testing Materials.)

Due to possible distortion in reproducing this chart, it should not be used for plotting exact values.

VISCOSITY, SAYBOLT UNIVERSAL SECONDS

Printed in U.S.A.

Copyright, 1939
AMERICAN SOCIETY FOR TESTING MATERIALS
1916 RACE ST., PHILADELPHIA 3, PA.

TEMPERATURE, DEGREES FAHRENHEIT