COB-2019-2133
THERMAL EFFICIENCY OF ASPHALT HEATING SYSTEM TO INCREASE PUMPING PERFORMANCE

Paulo Roberto Wander
Douglas Luz
Unisinos Ave, 950, ZIP code 93022-750, São Leopoldo, RS, Brasil. University of Vale do Rio dos Sinos
prwander@unisinos.br
douglasluz@hotmail.com

Abstract. This paper presents a study on the heating system of asphalt storage tanks at an oil refinery. The study evaluates the efficiency in three thermally insulated tanks and with a steam coil heating system that are running poorly. Heat transfer studies to determine the thermal load as a function of external and storage temperatures were correlated with the energy supplied by the steam heating system. The results show that the current system cannot maintain the temperature in the initially designed conditions and an energy cost analysis shows that the asphalt must be stored at the highest possible temperature and use an auxiliary heat exchanger to reach the ideal pumping temperature. The design of the auxiliary heating system determined a thermal capacity of 631 kW with a thermal exchange area of 83 m².

Keywords: Asphalt, heating system, pumping performance

1. INTRODUCTION

Asphalt is a byproduct of the petroleum refining process and has its main use in the paving of highways. To obtain this product, petroleum is refined in distillation towers that are divided into intervals by temperature range to obtain different products like naphtha, kerosene and gas oils. The heavier fraction of the distillation tower is subjected to a second stage of vacuum distillation, where the light fractions are extracted, leaving a heavier product called the vacuum residue, commercially known as asphalt.

Rheological properties of asphalt are very important and several studies deal with this properties for different asphalt classes and mixtures. Viscosity is the most studied property and it's possible to find in literature curves showing kinematic viscosity as a function of temperature for asphalt binders with or without additives. The possibility of using lower temperatures is important for productivity and less environmental impact (BRAZIUNAS *et al*, 2013; COSTA *et al*, 2013).

In Brazil, this product is produced in refineries and is regulated by the National Petroleum Agency (ANP), which determines its quality specifications, regulates and supervises the distribution and market price by geographic region. According to ANP regulations, the minimum temperature for distribution of the asphalt is 140 °C to guarantee its good fluidity in the process of truck loading. In order to guarantee this temperature the company has storage tanks with vapor heating internally and thermal insulation for temperature conservation. During the pumping up to the filling terminals, thermostatically insulated and steam traced heating pipes are used.

According to Liu et al (2017), tubular heating in tanks are common in the oil industry and the plume formed by natural convection inside the tank is the most important factor affecting heat transfer, followed by the boundary condition of the tank. Costa et al (2013) studied two different heating configuration systems for asphalt in a tank: a large area serpentine and concentrated heating cartridges. Although there was a meaningful difference in the temperature distribution inside the tank for each heating method, both were able to heat the asphalt and prevent solidification.

The minimum storage temperature of the asphalt in the tank must guarantee its pumping by pipes and is given as a function of the viscosity of the product. According to Garcia (1992), the storage temperature should guarantee a maximum viscosity of 1100 cSt. From this value, the pumping is still possible up to 2150 cSt, however, with low efficiency and possible deterioration of the pumps. The maximum viscosity limit should be near the suction line of the pump, so the storage temperature in the tank should be kept slightly higher to ensure that any losses from the piping do not affect the correct operation of the system.

2. METHODOLOGY

The tank heat loss was determined considering five different areas for the heat transfer: the roof area, the bottom area, the dry sidewall area (above asphalt level), the wet sidewall area (below asphalt level) and the radiation. Empirical equations were obtained from Garcia (1992) and Hughes and Deumaga (1974), taking in account information specific for

this type of fluid and the insulating materials used. The heating system with a vapor tube inside the tank was modelled using a simple convection heat transfer equation and considering the heat transfer coefficient at the asphalt side, which is the controlling thermal resistance, as 40.5 W m^{-2} K^{-1}, obtained by Costa (2008) in a lab scale study of asphalt behavior in a storage tank. Fig. 1 shows the behavior of different asphalt classes with temperature and it is possible to see that high temperatures are needed to ensure pumping characteristics.
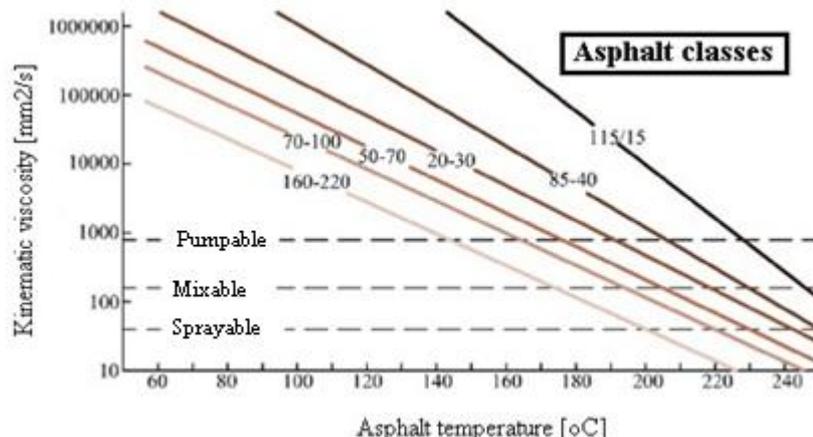

Figure 1 – Kinematic viscosity as a function of temperature for different asphalt classes (adapted from Braziunas *et al*, 2013)

An important consideration was regarding the climatic information of the city where the tank is located. According to the data from the National Metheorology Institute, collected between 1961 and 1990, the minimum average temperature is 10.3 ºC, in June, while the annual average temperature is 19.5 ºC. These values were used to determine the critical heating loss from the tank and the average power needed to keep the temperature throughout the year.

3. RESULTS

From the analysis of a sample of asphalt made in the laboratory, the kinematic viscosity is measured from ASTM D-4402 or NBR-14950 according to the Brazilian standard, at three different temperatures of the CAP 50-70 (Asphalt Oil Cement), classification of the current asphalt, (135, 150 and 177 ° C). These values are shown in table 1.

Table 1 – Kinematic Viscosity as a function of temperature

Temperature [°C]	Kinematic Viscosity [cSt]
135	322,7
150	163,0
177	68,61

With the values obtained it was possible to obtain a curve with R² of 0.9964, which suggests very good agreement to measured values and thus, obtain an equation to determine the viscosity at any temperature, which is presented in equation 1, where v is the kinematic viscosity and T is the temperature.

$$v = 4.10^{14}.T^{-5,672}$$

(1)

From Eq. 1 is possible to determine that the minimum temperature that ensures an appropriate viscosity (1100 cSt) is 109 ºC, and this temperature might be considered the minimum storage temperature.

The data to calculate the tank heat losses are presented in Table 2, according to the 5 areas mentioned before. The total loss for the lowest average external temperature of 10.3 ºC and storage temperature of 155 ºC is 162 kW.

Table 2 – Heat losses from the tank

Heat losses	U_{ext}[a] [W m^{-2} K^{-1}]	A_{ext} [m^2]	T_{asf} [ºC]	T_{ext} [ºC]	Q [W]
Wet side, Q_{cm}	1,0839	471,69	155	10,3	73983
Dry side, Q_{cs}	0,2168	24,40	155	10,3	765
Ceiling, Q_t	3,536	131,65	155	10,3	67360
Ground, Q_f	-	-	155	10,3	4495
Radiation, Q_l	0,2204	496,09	155	10,3	15828
Total, Q_{total} [W]					162431

[a] From Hughes and Deumaga (1974)

As can be seen at Table 2, the major losses are for the wet side and the ceiling (which is not insulated), which are the greater areas, since the radiation area is the sum of dry and wet areas. The difference from the original calculation of 133 kW can be considered acceptable, due to uncertainties common to this kind of calculation. Using the equations to compute different temperature conditions allowed to determine the results for different external and storage temperatures, showed in Fig. 2.
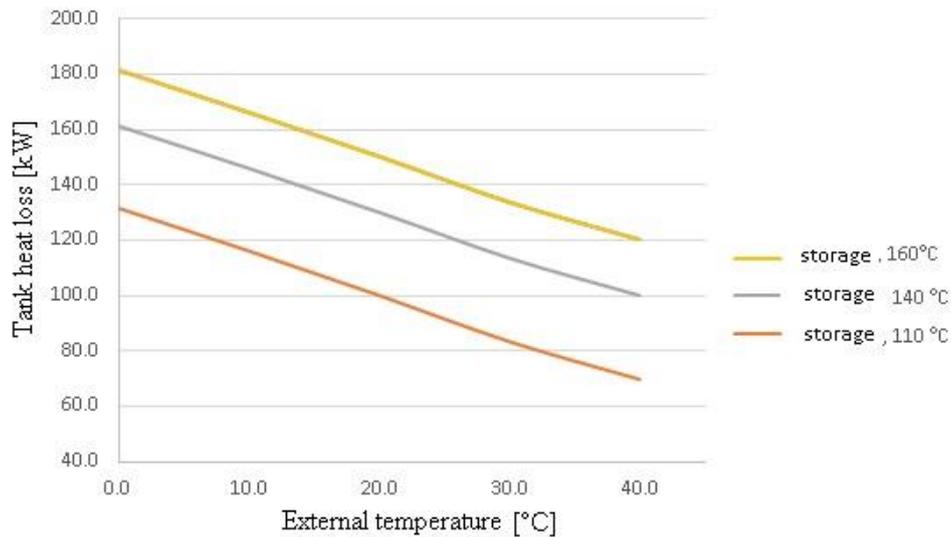

Figure 2 – Tank heat loss for different external and storage temperatures

To keep a constant temperature inside the storage tank, there is a heating system composed by a tube coil in which flows saturated water vapor. To calculate the heat transfer rate, convection inside the tube and the metallic resistances were not considered and the external convection coefficient of 40.5 W m^{-2} K^{-1} (COSTA, 2008) was used. Considering an available vapor temperature of 200 ºC and a heat transfer area of 52.27 m^2, it was possible to determine the heat transfer needed for different asphalt temperatures, as can be seen in Table 3.

Table 3 – Thermal power from vapor inside the tank

$T_{asf,}$ [ºC]	Q_{vap} [kW]
115	179,8
125	158,7
135	137,5
145	116,4
155	95,2

Combining the tank heat loss with the vapor heat transfer for different temperatures in Fig. 3, is possible to understand the equilibrium situation and the system possibilities. The horizontal dashed lines were obtained for the thermal power provided by the vapor heating system at the storage temperatures showed, while the inclined dashed lines for the same temperatures were obtained for the tank heat loss. The crossing point gives the external temperature where this equilibrium occur. When the external temperature is around 10.3 ºC, which is the lowest average temperature for the plant site, the asphalt temperature will stabilize at 133 ºC, while when the temperature is 19.5 ºC (annual average temperature), asphalt will be at 138 ºC. To keep asphalt temperature at 140 ºC, external temperature should be above 22.5 ºC during most part of the day.
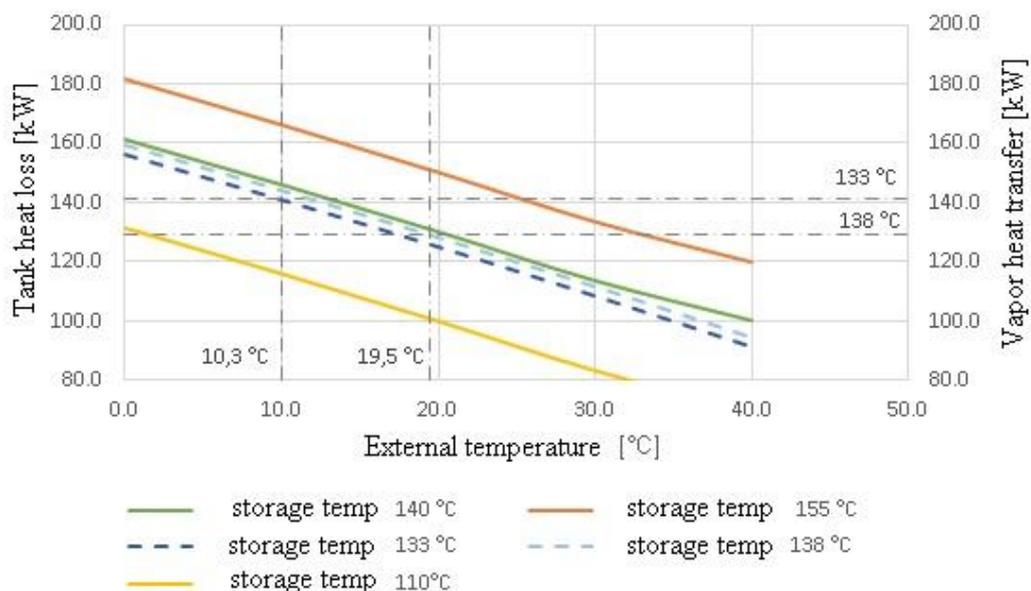
Figure 3 – Tank heat loss and vapor heat transfer for different temperatures

Since the pumping temperature to accomplish ANP regulations would be 140 ºC, the system is not able to keep the asphalt at the required temperature for most part of the time. A possible solution is to install an auxiliary heat exchanger close to the supply point. The vapor consumption needed for this heat exchanger has a cost, and the question is if there is a storage temperature, greater than the minimum of 110 ºC, but lower than 140 ºC, that would be more advantageous than keeping the asphalt closer to 140 ºC.

To obtain the mass flow rate of vapor and its cumulative amount for one week, a simple energy balance was performed considering the asphalt density and specific heat. For an average temperature of 135 ºC, the asphalt density was considered as 1006 kg/m^3 and the specific heat as 2152 J kg^{-1} K^{-1}. The maximum asphalt flow is 150 m^3/h, but the usual amount delivered in one day is 700 m^3 (705 ton). So, the heat exchanger dimensioning was done using the maximum flow and lower asphalt temperature, although the vapor consumption was obtained considering the daily asphalt mass and the annual average temperature. The energy balance for a 7 ºC heating and a volume flow of 150 m^3/h gave a thermal need of 631,2 kW, while the daily energy needed would be 10.620.120 kJ, which means a vapor consumption of approximately 27 tons for one week.

The vapor consumption was considered for both equipments (storage tank and auxiliary heat exchanger) with varying asphalt temperature. Keeping the external temperature fixed at 19.5 ºC (annual average), vapor consumption results can be found at Fig. 4, and it is clear that consumption decrease for higher storage temperature. Asphalt production delivers it at a temperature close to the desired temperature, so the vapor need in the storage tank is only to compensate for tank heat losses.

Considering the reality of the plant, the asphalt temperature is kept above 133 ºC for most part of the time, and the need is an increase of only 7 ºC of heating. With the temperatures considered and a "U" value of 120 W m^{-2} K^{-1} for heavy oil in the tubes and vapor condensing in the shell, according to Holman (1986), the area needed is 83 m^2, which can be obtained in a regular shell and tube heat exchanger.
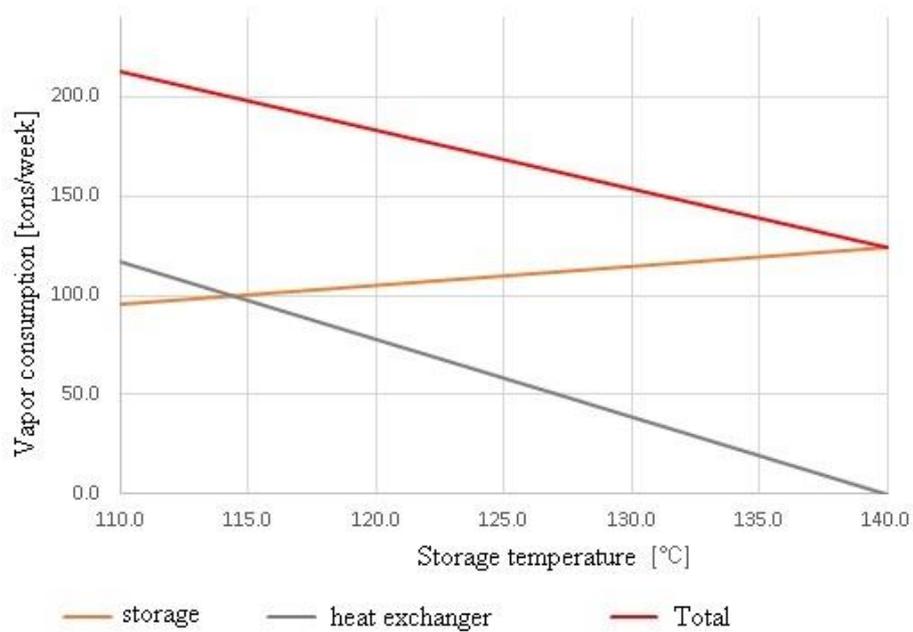
Figure 4 – Vapor consumption for both equipments

The overall system, with three tanks, tubing, pumping system, heat exchanger and buffer tank is depicted in Fig. 5. Looking at the whole system is possible to understand that the heat exchanger is the most viable option, since other options would represent a higher installation cost, like increasing the area of vapor tubing inside the tank or increasing insulation material over tank surface demand much more material and labor cost.
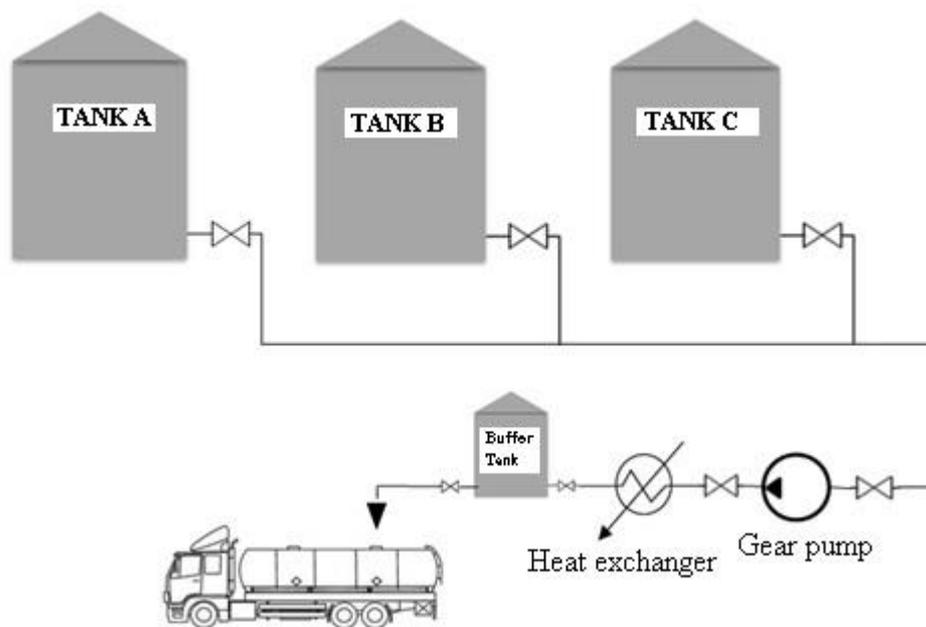

Figure 5 – Overall system

4. CONCLUSIONS

An analysis of heat losses for an asphalt storage tank was done and the temperature equilibrium for different external temperatures were obtained, revealing that the actual system is not able to keep the required temperature for most part of the year. An auxiliary heat exchanger to be used only for temperature adjustment was suggested and this solution was

considered the most cost effective for the whole system, since it is placed online and there is no need to stop the production and clean the storage tanks prior to its installation.

5. REFERENCES

Andrade, J., 1989. *Manual de Asfalto*. Rio de Janeiro: Instituto de Asfalto, v.1.

ANP, 2017. *Preço dos combustíveis.* http://www.anp.gov.br/wwwanp/petroleo-e-derivados2/asfalto> acesso em 16 de outubro de 2017.

Bernucci, L.B.; Motta, L.M.G.; Ceratti, J.A.P.; Soare, J.B., 2010. *Pavimentação asfáltica: formação básica para engenheiros*. Rio de janeiro: Petrobras.

Braziunas, J.; Sivilevicius, H.; Virbickas, R., 2013. "Dependences of SMA mixture and its bituminous binder properties on bitumen batching system, mixing time and temperature on asphalt mixing plant." *Journal of Civil Engineering and Management* 19(6):862-872.

Costa, C.A.S., 2008. *Estudo do comportamento térmico de tanques de armazenamento de asfalto*. UNIVERSIDADE FEDERAL DE SANTA CATARINA. Florianópolis.

Costa, C.A.S.; Mantelli, M.B.H.; Milanese, F.H.; da Silva, A.K.; Rucker, C.; Furlan, L.T., 2013. "Experimental and numerical study of an asphalt storage tank in a reduced scale." *Applied Thermal Engineering*, Vol 56, Issues 1–2, pages 101-109.

Domingos, M.D.I.; Pamplona T.F.; Faxina A.L.; Gigante A.C., 2012. "Viscosidade rotacional de ligantes asfálticos modificados de mesmo grau de desempenho". *TRANSPORTES*. ISSN: 2237-1346.

Garcia, R.; Bernardes, H.J.; 1992. *Manual de Utilização de Óleos Combustíveis Ultra viscosos*, 2ª edição, Belo horizonte.

Holman, J.P., 1996. *Heat Transfer*, 8th edition, McGraw-Hill, London, UK.

Hughes, R.; Deumaga, V., 1974. "Insulation Saves Energy", *Chemical Engineering*, May 27, pp. 95-100.

Liu, J.; Yan, K.; Liu, J., 2018. "Rheological properties of warm mix asphalt binders and warmmix asphalt binders containing polyphosphoric acid." *International Journal of Pavement Research and Technology*, Vol. 11, Issue 5, pages 481-487.

Zhao, J.; Dong, H.; Wang, X.; Fu, X., 2017. "Research on heat transfer characteristic of crude oil during the tubular heating process in the floating roof tank." *Case Studies in Thermal Engineering*, Vol. 10, pages 142-153.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.