ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Study of Temperature Fields in Bitumen Storages and Dehydration Reservoirs.

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ABSTRACT

The presented paper focuses on a search of ways to increase effectiveness of bitumen storages: pit-type storages and ground type storages. An assessment of temperature fields of bitumen in a period of storages' operation, as well as for dehydration reservoirs was conducted. It was established that in a case of heating bitumen in pit-type reservoirs, a significant portion of heat is spent inefficiently, because of use of a bottom intake from a main storage compartment to a pit and form a pit to reservoirs, used in a manufacturing process. Adopted layout of heating elements placement and design of ground reservoirs result in a gradual warming up of bitumen to a sufficiently high temperature in a whole volume of stored bitumen. Recommendations for an optimization of a process of bitumen's heating in storage reservoirs are presented. Temperature fields of bitumen in reservoirs for dehydration were studied. Main causes of high energy intensity and duration of the process are identified.
Keywords: bitumen, storage reservoir, heating, temperature, dehydration.

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INTRODUCTION

In contrast to a case of use of bitumen directly from delivering transport (i.e., without long-term storage) in asphalt-producing companies, in the Russian Federation many asphalt plants have their own storage facilities [3], [4]. Such an approach (an accumulation of bitumen in low season and a subsequent use in a period of active construction), which was formed in a conditions of plan-based economy of Soviet Union, is applicable in new economical conditions for two reasons: firstly, purchasing bitumen in winter due to a decrease of its price in that period of the year [1], [2], allows companies to be more flexible in a case of in making bids during contracts' tendering and specifying a final cost of road concrete mixes; secondly, the lack of logistics infrastructure for bitumen creates a possibility of plants shutdown, in a case of an improper execution of contracts by suppliers, that problem is virtually eliminated in a case of a company having its own stock of bitumen. Typically, such stocks may be 60-80, and sometimes 100% of a company's annual required volume of bitumen.

Despite an active implementation of a ground bitumen storage technology in metal reservoirs, there is still a large number of companies using pit-type storages [8]. Such storages are manufactured from concrete, reinforced concrete or, rarely, from metal and are equipped with steam, oil or electric heating systems. In a main storage compartment a pre-heating of bitumen (up to a liquid conditions, which starts, approximately, at 50-60 °C) is carried out, heating to a pumping temperature (80-100 ºC) is carried out in a pit – the deepest part of a storage, which is located in end or central part of a main storage compartment. Bitumen intake from a main storage compartment to a pit is conducted by gravity flow (due to a slope of a bottom of a main storage compartment) through a chute, which is a hole of an unconditioned size (as a rule, it doesn't exceed 1 m^2) in a wall of a pit near a bottom of a main compartment. An intake of bitumen from a pit after heating up to a pumping temperature is carried out by means of a bitumen gear pump through an intake pipe, which is usually located a few centimeters above heating elements of a pit.

The primary disadvantage of a pit-type storage is a possibility of bitumen watering due to atmospheric precipitations (in a case of a poor hydraulic protection) or groundwaters (if they occur nearby), which in future can become a reason for an implementation of bitumen dehydration manufacturing procedure, which is degrading quality and increasing energy expenses [11]. The problem of moisture removal is topical for many post-soviet states: for example, in Belorussia, code TKP 094 describes in details requirements for equipment for a dehydration and heating regimes. Bitumen dehydration is carried out in a traditional way, via evaporation of moisture in special dehydration boilers or in horizontal reservoirs by means of heating up bitumen by flame tubes, oil and steam heating elements or thermoelectric heating elements. A duration of bitumen dehydration is quite large and is dependent on amount of bitumen and percentage of moisture. As bitumen has high viscosity even with temperature of 100 ºC , and moisture is located mainly in a bottom of bitumen column, dehydration process begins when temperature is significantly higher then boiling point temperature of water [11].

A process of bitumen storage in pit-type facilities has low production standards (there is a risk of a contamination stored bitumen), a large surface "bitumen mirror" and free access of air to a storage is causing its oxidation, although a degree of degradation is comparable with the one of for bitumen in ground storages [12], [15] and for bitumen in intermediate reservoirs for short-term storage in heated condition [14].

However, from a point of view of energy expenses for an entire process of bitumen preparation, with a condition of an exception of a moisture ingress in pit-type storages, such type of a storage has certain advantages, namely, to fill a main compartment it does not require a heating up to 100-120 °C as in a case of filling ground storage tanks. Discharge of bitumen from railway tanks is possible by means of gravity flow at temperature of approximately 50 °C, which allows to save approximately 90-126 MJ of heat for ton of bitumen only during a process of a storage filling.

The ground storage technology implies use of metal reservoirs (vertical and horizontal), which total volume can reach few thousand tons. This method of storage is well-known abroad. Requirements and basic characteristics are identical: reservoirs are equipped with thermal insulation in order to reduce heat loses, although, there is an opinion that this is not reasonable [6], [7]; for heating of bitumen oil or, more rarely, electrical heating systems are used [4], [5]. Heating elements are located at a bottom, oil system are, as a rule, contain wall-mounted heating elements, in order to prevent "folding" during pumping out of bitumen from a reservoir. Binder is heated up to temperature, which allows its pumping, after that is pumped by means of a bitumen pump in reservoirs, used in a manufacturing process, for further heating. As in a case of a pit type storage, intake pipes of a bitumen pump are located in a zone of heating elements.

For storages of pit type and ground type, there is so-called transition period – a period of time, which is required for a storage to reach a steady production of bitumen volume, which will be used during working shift; its duration can be up to a few weeks. During that time the major part of bitumen melts and heats up to temperature, which allows it to reach viscous condition (in a main compartment of a pit type storage) and up to a temperature, which makes it suitable for pumping (in a pit type storage and in a ground reservoir).

Any type of storage are one of the main sources of energy consumption of asphalt plants [19].

The focus of the presented study is a search for ways to improve energy efficiency of existing technology of bitumen preparation during storing at manufacturing plants, which is inspired by a main course of the Government of Russia [16]. In order to achieve set tasks, an evaluation of temperature fields of bitumen in typical ground and pit type storages was carried out.

METHODOLOGY

a. Objects of research

As objects of research we selected typical bitumen storages of a pit type and a ground type of equal volume and horizontal reservoirs for dehydration. Measurements were carried out in a high point of construction season, when storages were steadily producing required amount of bitumen in a working shift.

a1. Pit type storage

Pit type storage was a two-section covered reservoir made from reinforced concrete with a capacity of 1000 tons and an internal end side pit between main storage compartments. Heating method: in a main storage compartment – steam, via bottom mounted heating elements; in a pit – NSP-type electric heating elements. In the moment of conducting measurements, amount of bitumen in a compartment was approximately 450 tons (with total of 900 tons in a whole storage). A method of bitumen intake in a pit was through a chute, located in a bottom, from chute to reservoirs, used in a manufacturing process, bitumen was transported by menas of ground flixible hose.

a2. Ground type storage

Ground type storage is a metal reservoir [18] with a capacity of 1000 tons with thermal insulation from URSA GEO M-25 (0.10 m) glass wool mats. Heating method was oil heating, by means of wall-mounted and bottom-mounted heating elements. In the moment of conducting measurements, amount of bitumen in a compartment was approximately 600 tons.

a3. Dehydration reservoir

The metal horizontal reservoir [18] with a capacity of 25 m^3 with thermal insulation from URSA GEO M-25 (0.10 m) glass wool mats. Heating method was electrical heating, by means of six one-phase thermoelectric heaters, combined in two three-phase sections (3 pieces in each), which are mounted on stand in a central part of a reservoir. During carrying out of measurements an amount of bitumen didn't exceed 15 tons.

b. Measurement instrumentation

b1. Pit type storage

For measuring of temperature fields of bitumen in a pit type storage, as temperature sensors impedance transformers of DTS TSM-50M type with three wire connection scheme were used, signal registration was conducted by microprocessor based measurement and control tool TRM 2A-N.TS.R (basic reduced error limit in a case of coupling with TSM type sensor is ±0.25 %). Sensors were mounted on a meaasurement probe with 0.5 m spacing

b2. Ground type storage

For measuring of temperature fields of bitumen in a ground type storage, as temperature sensors impedance transformers of DTS TSM-50M type with three wire connection scheme were used, signal registration was conducted by microprocessor based measurement and control tool TRM 1A-N.TS.R (basic reduced error limit in a case of coupling with TSM type sensor is ±0.25 %).

c. Dehydration reservoir

In that case measuring equipment was the same as in a case of a pit type storage.

d. Measurement methodology

d1. Pit type storage

Six cross-sections for measurement were selected: three in a main compartment (at distances of 1.5, 3.5 and 5.0 m from a wall of a pit along an axis of a chute) and three cross-sections in a pit (one was in a center, two near the walls adjacent to main compartments). In order to have access into a main a compartment, holes with diameter, necessary for the probe introduction were drilled. The measuring probe was immersed into bitumen. Measurements were taken, when within 5 minutes changes of results didn't exceed ±0.5 ºC. Measurements were conducted before pumping out of bitumen from a pit and immediately after it.

d2. Ground type storage

Temperature sensor on safety rope was descended through a latch of RVS-1000 reservoir with stops in points, designated for measurements. The selected measurement step was 1 m. In order to compensate inertia of the sensor during measurements, results in each point were registered only when within 5 minutes changes of results didn't exceed ± 0.5 ºC.

d3. Dehydration reservoir

The measurement probe was descended via a latch (located near one of end walls of the reservoirs) and was placed vertically on the bottom of the reservoir at angles of 45º and 90º to vertical axis of the reservoir. Measurements were taken in four cross-sections: at distances of 0.1, 1.0, 2.0 and 3.0 m from end wall of the reservoir, which was on a side of the latch. Measurements were taken, when within 5 minutes changes of results didn't exceed ±0.5 ºC. Temperature fields measurements in dehydration reservoir were conducted after pumping in of bitumen, then every 5 hours and after the end of bitumen dehydration process.

In the same time with measurements of temperature fields, bitumen water content was registered. In order to do that, samples of bitumen were taken from the reservoir (from lower, middle and top layers of bitumen in the reservoir); samples were weighted before and after dehydration, carried out using electric heater.

RESULTS

a. Pit type storage

Figure 1 presents temperature fields of bitumen of pit type storage before and after pumping out of bitumen from a pit.

Results of temperature fields measurements showed, that the most heated bitumen is located in the top layer, both in the main compartment and the pit. At the same time, thickness of heated bitumen layer in the main compartment is bigger in the zone, located near a pit, which is, most probably, related with heat transfer from a wall of the pit and free ingress of bitumen, heated in the pit through unclosed chute.

A location of the most heated bitumen in the top layer of stored bitumen wasn't a surprise: it is known, that heated bitumen has lesser density and tends to go up, the surprising was a location of the chute, which was at the bottom of main compartment, i.e. in the place, where bitumen has the lowest temperature. The same is true for a pit: the point of bitumen intake is located in the zone of the least heated bitumen.

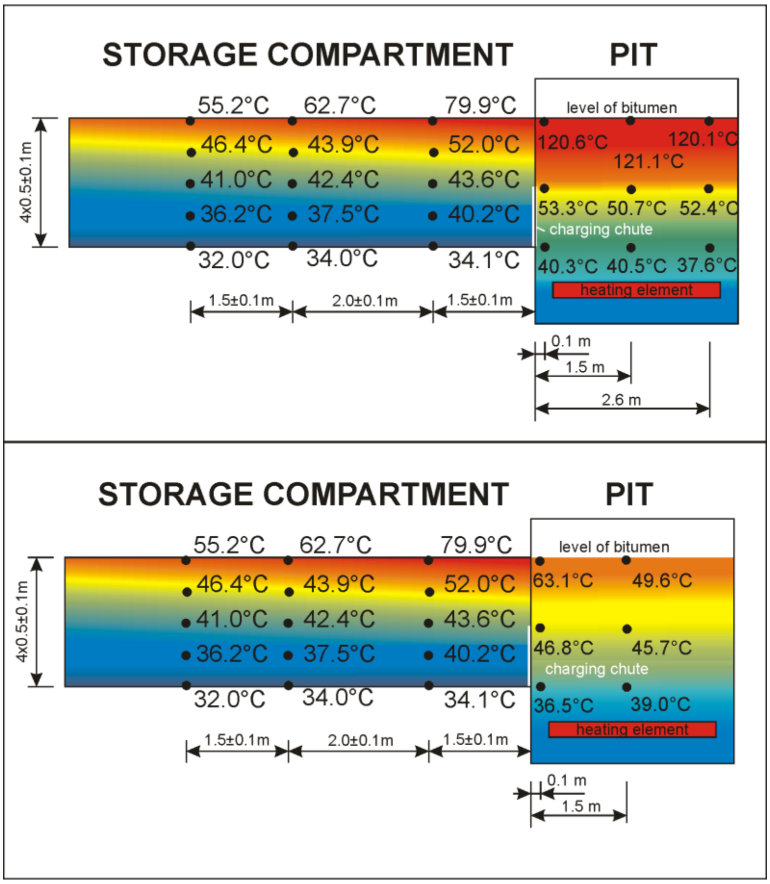

Figure 1. Temperature fields of bitumen in a pit type storage before pumping out of bitumen from the pit (top) and after pumping out (bottom)

Another interesting point is a distribution of temperature values of bitumen along height, both the main compartment and the pit. That values is 23-45 ºC in the main compartment and 80-83 ºC in the pit. However, it should be noted, that information, that bitumen located under heating elements can have temperature which is several tens of degrees lower, then in the main volume of heated bitumen (but, in a case of reservoirs, used in a manufacturing process), was presented in the earlier studies [13].

After pumping out of bitumen from the pit, filling of the pit is conducted mainly due to bitumen of lower layers, coming from the cute, which is the least heated one.

b. Ground type storage

The values of temperatures in the measurement points of the groun type reservoir RVS-1000 are presented in table 1.

Table 1. Results of meaurementes of temperature fields in RVS-1000 reservoir

Bitumen temperature, ºC, at distance from the bottom of the reservoir							Temperature, ºC	
1 m	2 m	3 m	4 m	5 m	6 m	7 m	Air	On a surface of thermal insulation
137.8	137.9	138.0	138.1	138.2	138.2	138.2	30	39

During measuring temperature field in a ground reservoir a large difference in bitumen temperature along a storage's height wasn't found, only slight, within limits of measurement tool error, decrease of bitumen temperature near heating elements (neat the bottom of the reservoir) as compared to temperature of bitumen in top layers was detected. Since the studied reservoir has thermal insulation and sufficiently powerful heating system, it is, generally, a large heated thermos. After starting of the heating system, during a certain period of time a gradual heating-up of bitumen volume takes place (most probably, temperature fields distribution in that period is similar to the one, that was obtained for pit type reservoirs), up to the moment, when temperature stabilizes. After that, heating system works only to compensate the heat losses to environment.

c. Dehydration reservoir

Figure 2 shows temperatures fields of dehydration reservoir in a case of bitumen moisture content of 3.1 %. Similar temperature fields have been obtained in studies of bitumen with moisture content of 3.7 and 4.6 %, dehydration time was 12 and 14 hours, respectively.

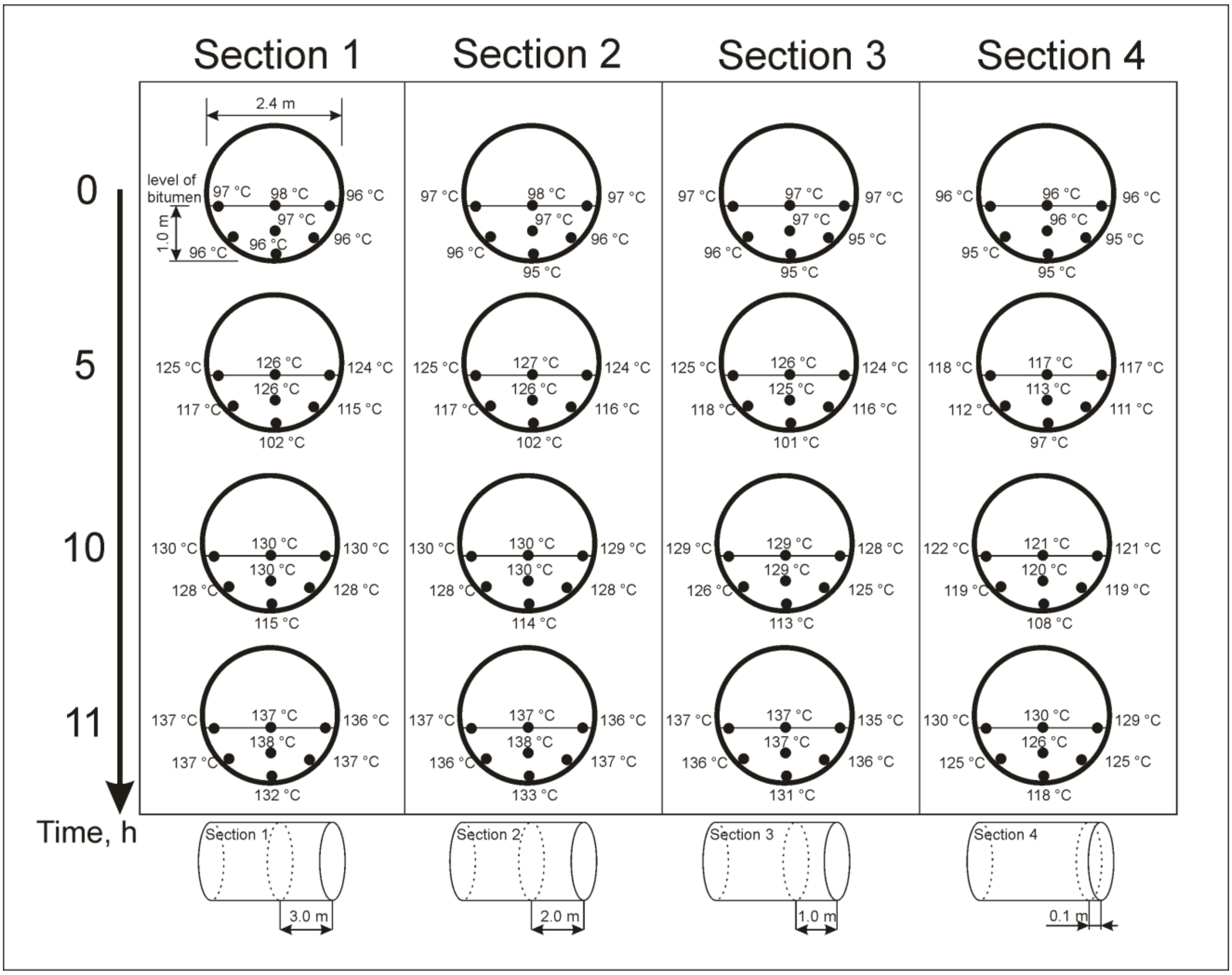

Fig. 2. Thermal fields of bitumen in the dehydration reservoir (in a case of bitumen moisture content of 3.1 %)

Discussion

A difference in temperature of bitumen along height of a layer in dehydration reservoir reaches 25-30 ºC and more. At the same time, temperature of upper layer, where bitumen is in film (foam) condition and is oxidized by oxygen of air, in average reaches 125 ºC, which should lead to a decrease of bitumen quality . Also, temperature is sufficiently high in the middle layer of bitumen, located over heated zone. Bitumen temperature in directions of side and end walls of th reservoir is decreasing, which is caused not only by heat losses from an outer surface of the reservoir, which dependent on quality of thermal insulation, air temperature, wind speed, but also by low heat transfer in a volume of bitumen related with poor free convection in the highly viscous bitumen.

At the same time, positioning of electrical heating elements in the middle part of volume of the dehydration reservoir leads to formation of zones of stagnant bitumen near side and end walls of the reservoir, as well as in the layer near the bottom, and, as a consequence, to an increase of length of the dehydration process.

a. Pit type storage

Analysis of the obtained data and the methods of bitumen intake (in the pit through the bottom chute, in reservoirs, used in the manufacturing process, through intake pipe located near heating elements) it can be concluded, that a large part of energy, spent on heating of bitumen, is spent in an unreasonable way. With such a distribution of temperature in pit type storages, the most reasonable way is to use a surface intake for bitumen both from the main compartment and the pit [23]. In order to implement that method, it is necessary to have several chutes located at various heights or one chute with height equal to entire height of bitumen volume in the main compartment. Filling of the pit should be carried out through a chute, located in the top, in beginning of construction season and, as bitumen is spent, chutes, which are the closest to a surface of bitumen in the main compartment, should be used.

Another necessary condition is a possibility to close a chute, because it was experimentally determined, that bitumen can freely enter the main compartment from the pit through an open chute.

A traditionally used bottom type intake of bitumen (in a case of positioning of an intake pipe of a bitumen pump in a zone of heating elements) in combinations with open access of bitumen through a chute, as it was observed in the studied case, leads to the situation, when after an insignificant period of time, due to ingress of cold bitumen from the main compartment in a zone of heating elements in the pit, further intake by a pump becomes impossible: part of bitumen (from upper layers), despite of being ready for a further treatment, remains in the pit.

A surface intake from the pit is a way to solve those problems, and it can be implemented by means of an installation of intake pipes of a bitumen pump on different levels or by means of using a flexible intake pipe (rubberized metal hose) in a surface layer (it can be controlled by an operator or by floats).

The most reasonable design for pit type bitumen storages, which allows to implement a surface intake of heated bitumen from the storage to the pit and to solve the problem of an ingress of heated bitumen from the pit to the storage, is to install inside the pit near the chute a metal screen in a shape of a half of side surface of truncated pyramid. An installation of a screen in the pit allows to continuously intake bitumen from the storage to the pit with the open chute. Slide shutters, installed in the side wall of the pit, in that case may be installed both from a side of the storage and from a side of the pit (on a condition of their hermiticity). A screen is mounted in the pit in a way, that allows to separate flow of bitumen, entering the pit from the upper and the most heated layer of the storage, and bitumen, which is heated in the pit.

That kind of a screen design and its positioning in the pit allows bitumen, entering the pit, to come directly in the local zone of the pit's heating elements, where it is heated up to a specified temperature with a certain agitation, which increase heat transfer coefficient. An installation of the described screen with controlled slided shutters, as well as necessary heat capacity of heating system in the pit allows to provide continuous flow of bitumen in the pit with a continuous pumping out of heated to a specified temperature bitumen from the pit. That regime allows to considerably increase productivity of a bitumen storage and save energy in the same time.

One of the alter

natives is using pit type storages, which are not equipped with a pit, in that case, in order to pump out bitumen from the storage compartments so-called mobile pit is used. That design isn't new, it was mentioned in studies, conducted in times of Soviet Union [24], however, contemporary works [21] confirm, that the approach is reasonable. In 2008, within a frame work of the Federal Road Agency funded research, a pilot sample of the mobile pit with electric heating system was manufactured. Its testing was carried out in asphalt plant FGU LEP-34 (Kamensk-Shakhtinskiy, Rostov oblast). An innovative solution in the case of that device was an implementation of vibrating sections of heating elements, which allowed to increase heat transfer coefficient from heater due to shift from free convection to forced convection. According to the results of the study, heat transfer increased in 1.5 times. The device is transported on polyspast inside the main compartment and is placed in a position, where it is necessary to intake bitumen. A localization of heated zone in a specified volume, which is the approach implemented in the mobile pit, allows to avoid problems of traditional pit-type storages.

b. Ground type storage

Gradual heating and stabilization of bitumen temperature in a whole stored volume on a quite big value (138 °C) is definitely have a negative impact on quality of bitumen, and it is a reason for an increase of temperature gradient between the reservoir surface and environment, and, as a consequence, a cause of increased heat losses. At the same time position of intake pipes near the bottom heaters increase time between a first start up of heating system and a first bitumen intake from a storage. The solution for that problem is a localization of bitumen in volume, which is specified for a production purposes [22]. At the same time, the main volume of stored bitumen must be kept in viscous condition (temperature doesn't exceed 50-60 °C).

One of engineering solutions may be use of the mobile pit described above. A unit, attached under a roof of a reservoir and having a capability to move along the height, has sections of heating elements (usually electric heaters) and metal housing. Vibrating heaters can be used for increased energy efficiency. Bitumen intake in that case is carried out using a flexible intake pipe.

A heated zone can be also localized in a lower part of a vertical reservoir, limiting a zone above traditionally used bottom heaters (other heating systems can be used in that case). A protective housing should be equipped with thermal insulation, in order to decrease heat losses in environment and to avoid heating of all stored bitumen; acceptable losses should have value, necessary to keep bitumen in a storage in viscous condition.

c. Dehydration reservoir

Heat transfer via free convection in bitumen dehydration reservoir is long and its efficiency is low. Exit of steam bubbles from bitumen is complicated by its high viscosity. That disadvantage is aggravated by a significant length of a distance of steam exit, which is determined by sized of a reservoir and volume of bitumen in it.

An improvement of that technology is related with using more effective ways of heat transfer, for example, a movement of a heating element's surface along heated media (including vibration of heaters), which facilitates transfer to force convection [11] and an improvement of steam exit.

Moreover, an increase of energy efficiency during dehydration is achievable by means of decreasing a distance of steam's exit through a decrease of thickness of a binder's layer (dehydration in a thin layer), including using that kind of energy sources as microwave sources (SHF-sources).

CONCLUSIONS

1. Pit type storage

Implemented heated systems, combined with methods of bitumen intake (both from the main compartment to the pit and from the pit to the reservoirs, used in the manufacturing process) leads to unreasonable use of heat, emitted by heaters: heat of the most heated bitumen of upper layers in the main storage compartment is used in a form of losses in environment. In the same time, the least heated bitumen of lower layers is used for filling the pit.

2. Ground type storage

The bottom heating and good thermal insulation facilitates gradual heating of all stored bitumen, which can lead to its degradation. At the same time, position of intake pipes near heaters doesn't allow, in a case of existing layout of storages, to carry out a first intake of bitumen in short term (in a beginning construction season).

3. Dehydration reservoir

Bitumen dehydration process, in a case of used technology, is long and have high energy-intensity, which is determined by percentage of moisture content in bitumen. In average, temperature in the reservoir doesn't exceed 130 ºC before final removal of moisture. At the same time, a quite low increase of temperature in time was observed, which is, presumably, related with heat losses with evaporated moisture and significant expenses for a transformation of water into steam.

ACKNOWLEDGMENTS

The presented study was carried out within framework of scientific and educational project of the Program of strategic development of federal state public educational institution of higher professional education "Rostov State University of Civil Engineering" for 2012-2016.

Authors would like to express their gratitude to chief engineer of "KDSM" ltd. A.I. Plotnikov and deputy director of "KDB" ltd. A.A. Chubachuk, who kindly allowed to use technological facilities of the named companies as research sites.

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