CHEMICAL ENGINEERING TRANSACTIONS
VOL. 76, 2019
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Petar S. Varbanov, Timothy G. Walmsley, Jiří J. Klemeš, Panos Seferlis

ISBN 978-88-95608-73-0; **ISSN** 2283-9216
DOI: 10.3303/CET1976077

Development of Industrial Production of Impregnating Compositions for Road Coatings Based on the Concept of CALS

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One of the most effective and cost-efficient ways to protect the road surface is the impregnation of the upper layer with a special chemical composition. For the selection of materials with the necessary set of properties, the corresponding municipal computer systems are created, carrying out system analysis and selection of optimal compositions of road chemistry products. One of such systems is developed under the leadership of Dr A. Glushko – a computer quality management system for impregnating compositions for road surfaces.
The protective impregnating composition obtained by us serves to protect the surface of asphalt concrete roads from negative impacts. The composition maintains low water saturation of the surface layer of the asphalt concrete pavement, as well as restores the surface layer of the binder component.
The pilot plant created by us is designed to obtain protective formulations of a given composition in quantities sufficient to conduct extended tests on selected pavement areas. The plant consists of four main hardware components: a bitumen loading unit; unit of heating of bitumen and petroleum resin (PS); the binder component preparation unit; impregnating composition preparation unit. The binder component preparation unit and impregnating composition preparation unit are interdependent, have common hardware and are equipped with an operating system that controls the on/off switching of the impregnating composition preparation unit depending on the state of the technological process in the binder component preparation unit.
The development of pilot production of protective impregnating compositions was carried out using the most modern and promising computer support system - CALS-technology (Continuous Acquisition and Lifecycle Support). The informational CALS-project contains general drawings of the entire pilot industrial production, drawings of individual units, as well as the most important elements of the units (passive mixer, active mixer, etc.).
The use of CALS technologies for analytical monitoring and the development of modern industrial production has undeniable advantages. The introduction of informational CALS technologies in the development of a computer quality management system and modular production of road impregnation compositions allows not only to improve the quality of analytical, research and design work, but also to provide complete computer support, including all necessary documentation in electronic form.

1. Introduction

The continuous growth of the motor vehicle fleet, the increase in the volume of cargo turnover and passenger traffic impose ever more stringent requirements on the maintenance of roads and streets, as well as on ensuring traffic safety along them. One of the key tasks of the road maintenance technology is the preservation of the quality of asphalt concrete pavement, which shows its integrity and ensures the adhesion of the wheel to the roadway. Road chemical services created artificial chemical compositions - impregnating asphalt concrete pavement as an effective solution to these problems.
In nowadays, it is a few works in the scientific literature, which are devoted to road impregnations. They consider the content of some compositions (Ubaskina et al., 2016) or separate stages of the production of road

Paper Received: 16/03/2019; Revised: 05/04/2019; Accepted: 23/04/2019
Please cite this article as: Priorov G., Bessarabov A., Glushko A., 2019, Development of Industrial Production of Impregnating Compositions for Road Coatings Based on the Concept of CALS, Chemical Engineering Transactions, 76, 457-462 DOI:10.3303/CET1976077

impregnations (Chigorina et al., 2016). In this paper, for the first time, the issues of computer analytical monitoring and automated development of industrial production of impregnating compositions are considered.
The protective impregnating composition developed by us serves to protect the surface of asphalt concrete roads from negative impacts. The composition maintains low water saturation of the surface layer of the asphalt concrete pavement and also restores the surface layer of the binder component used in road construction. Impregnation in one of the options can be applied immediately after laying the pavement to provide hydroprotection of the plots (Ryabenko et al., 2016).
For the selection of materials with necessary properties, the corresponding municipal computer systems are created, carrying out both system analysis and selection of the optimal compositions of road chemistry products. One of these systems is a computer quality management system for impregnating compositions for road surfaces. The software of the system is based on the informational CALS-standard ISO-10303 STEP (Continuous Acquisition and Lifecycle Support - continuous information support of the product or product life cycle) (Bessarabov et al., 2010).

2. Computer quality management system for the analysis of road impregnations

At the upper level of the developed CQM-system (Figure 1), the impregnating compositions are classified by their purposes. Two main categories are highlighted: restoring (rejuvenating) compounds (category 1) and compositions for protecting asphalt concrete pavements (category 2). In both considered groups, the impregnating compositions are combined by type of their base: there are distinguishing reducing compositions based on petroleum bitumen (subcategory No. 1.1), clays (subcategory No. 1.2) and industrial petroleum oils (subcategory No. 1.3). Materials from the second group of impregnations (category No. 2), as a rule, do not affect the asphalt structure, only creating a protective layer over it, including for decorative purposes.
After analyzing the compositions of protective impregnations, we found that the majority of such compositions are based on polymeric materials. There are also alkaline-based protective compounds (StreetBond150), refined resins (Star Aviator), and coal-based (Star Micropave Supreme) containing bitumen (Star Micropave Aviator, Star Micropave ProBlend).
Technologically, the production of restorative bitumen-based impregnations can be organized in three different ways: heating the bitumen to the required (process) temperatures, diluting the bitumen with light (usually organic) solvents, or emulsifying bitumen. These methods are reflected in the second level subcategories of subcategory No. 1.1 “Impregnating compositions based on bitumen”.

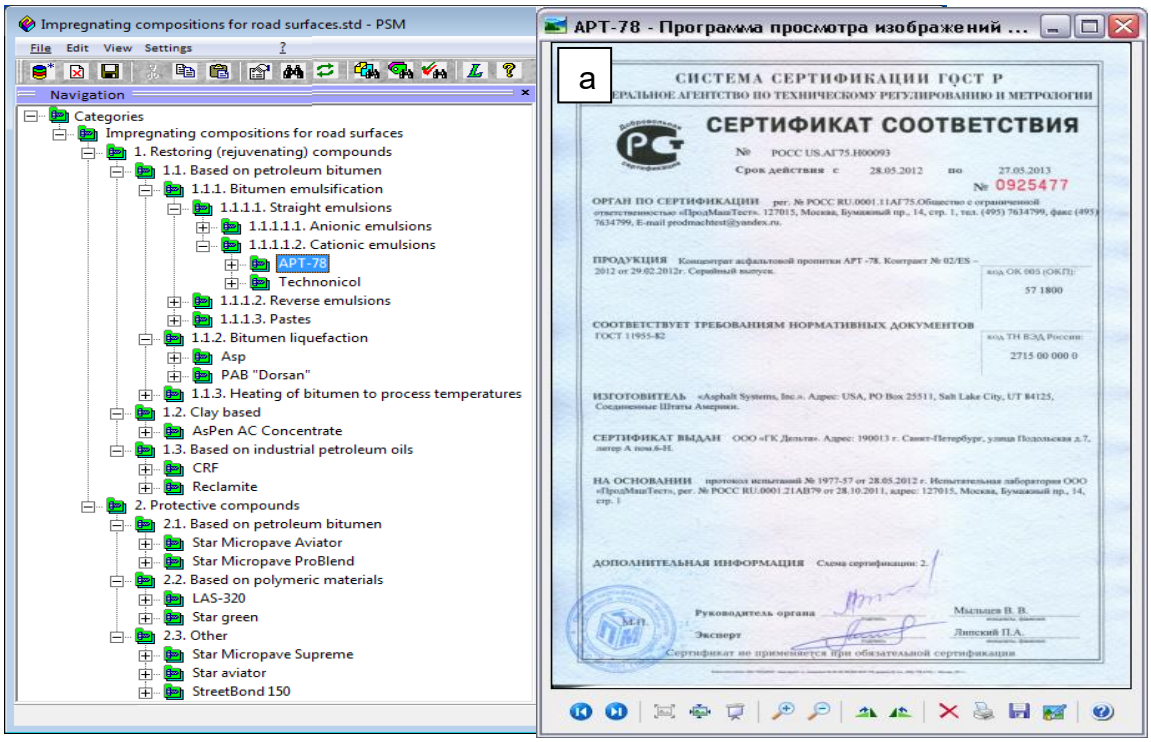

Figure 1. Element of CALS-project "Impregnating compositions." Reducing agents - Oil bitumen - Emulsification of bitumen - Direct emulsions - Cationic emulsions – «APT-78» (a - certificate of conformity "APT-78").

Of greatest interest are road impregnations obtained by emulsifying bitumen: direct and inverse emulsions (sub-categories No. 1.1.1.1 and 1.1.1.2). By the type of emulsifier used, bitumen emulsions are subdivided into anionic and cationic. Highlighted at Figure 1 impregnating compound APT-78 is designed to preserve, restore and modify the vital properties of asphalt. APT-78 re-binds and stabilizes the coating, compacting and restoring the binder components of the asphalt concrete, while improving the appearance of the asphalt.

Based on the analysis carried out for each impregnation, we developed several groups of quality indicators (Figure 2): organoleptic (subcategory No. 1), physical and chemical (subcategory No. 2), physicomechanical (subcategory No. 3), technological (subcategory No. 4), environmental (sub-category number 5) and operational (sub-category number 6).

Several key quality indicators are identified for each group and are determined in accordance with GOST or other regulatory documents for each impregnation. For example, in subcategory No. 1 “Organoleptic indicators”, such quality indicators as appearance, colour, and smell are combined (sub-categories No. 1.1, 1.2, and 1.3). After analyzing the collected documentation for various impregnations, as well as GOST 18659-81 and GOST R 52128-2003 ("Emulsions bitumen road. Technical conditions"), in the subcategory No. 2 "Physical and chemical indicators" 5 positions were allocated: conditional viscosity, content binder with emulsifier, mass fraction of nonvolatile substances, brittleness temperature and flash point. The system contains data on the method of determination and the according to instruments, which are used for each indicator.

In subcategory No. 3 “Physicomechanical indicators” the most important controlled indicators of the quality of road impregnations are presented: the softening temperature around the ring and the ball, elongation, uniformity, brittleness temperature and flash point. In subcategory No. 4 “Technological parameters” the main quality indicators, characterizing the interaction of impregnation with the road surface, are presented: drying time of the film on the surface, volatility, efficiency coefficient, adhesion with mineral materials and needle penetration depth.

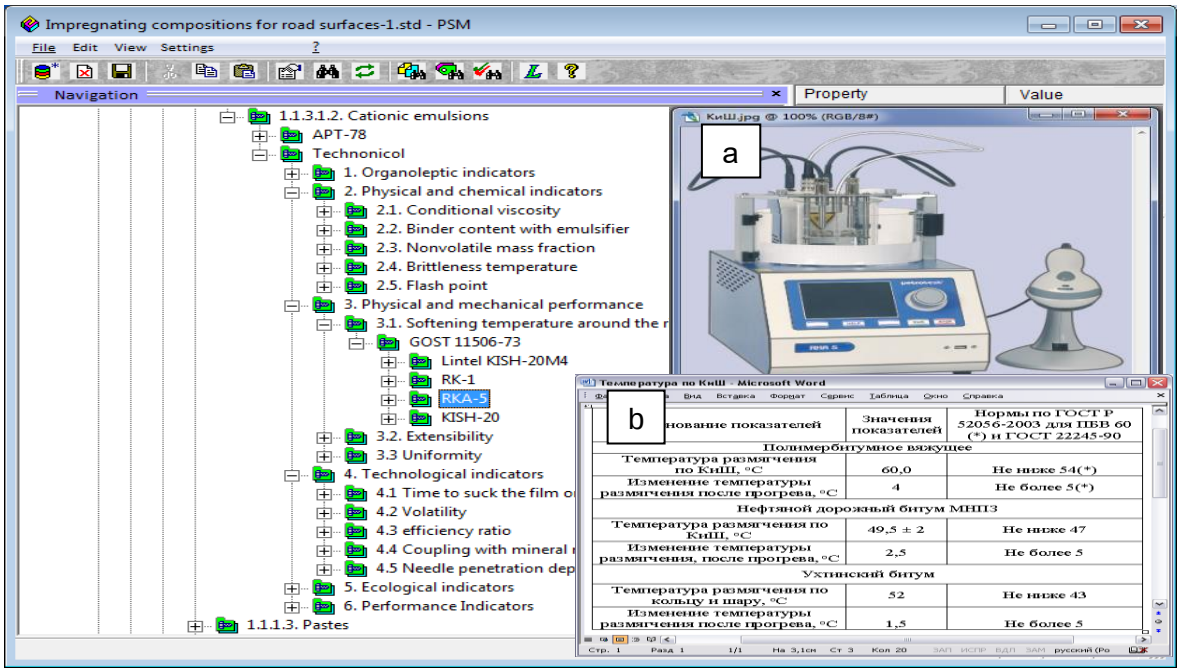

Figure 2: The element of CALS-project "Impregnating compositions." Cationic emulsions - Technonicol - Physical and chemical indicators - Softening temperature around the ring and ball (a - RKA-5 apparatus; b - the softening temperature of bitumens).

One of the most important physical-mechanical parameters is the softening temperature around the ring and the ball (sub-category No. 3.1). The method of determination is described in GOST 11506-73 and ODM 218.7.004-2008. The apparatus used for testing consists of a glass (bath) of heat-resistant glass; brass stepped rings; metal plates (the upper plate has three holes: two for placing the rings and a third for the thermometer); tripod supporting plates; metal lining guide for concentric placement of balls (it is allowed to carry out determination without guide lining); steel balls according to GOST 3722-81 each and thermometers of mercury type TN-3 and TN-7 according to GOST 400-80. Requirements for the instruments used are listed in the appropriate subcategories of the CQM-system. The developed CQM-system allowed a multi-criteria analysis of

modern road impregnation compositions for use on the asphalt concrete pavement of the roads of the Russian Federation, as for several reasons the asphalt concrete pavement is ageing much earlier than the turnaround time. The disadvantages of the following traditional solutions are the imbalance of the following properties: lack of elasticity and low strength properties; insufficient penetration rate in asphalt concrete pavement; unacceptably long curing time.

The analysis of climatic conditions and road conditions showed that none of the available brands of impregnations does not fully meet the requirements for the quality of maintenance of road facilities. It has been shown that on the roadways of the Russian Federation, restorative impregnation with sealing, water repellent and other properties, not containing water, having no friction particles as impurities, high speed of drying on the road surface, adequate road conditions and application technology is promising for use. As a result, we invented an innovative composition of the road impregnating composition, including petroleum bitumen, petroleum resin and an organic solvent (mineral oil and surfactants can be used in solution with it), and the technology of its use by the existing fleet of road machinery. A patent has been obtained for this invention: “A method for treating road asphalt concrete pavements” (No. 2012153391 of December 11, 2012).

The protective impregnating composition developed by us provides protection of the surface against asphalt concrete damages from negative impacts. The composition maintains a low water-saturated surface coating and asphalt concrete pavement. The composition can be used immediately after installation. A pilot plant was created, specially designed for the preparation of protective compositions.

3. Development of a CALS project for the production schedule of a pilot plant

The pilot plant consists of four main hardware modules (nodes): bitumen loading unit; site heating bitumen and petroleum resin (PS); a knot of preparation of the knitting component; site preparation of the impregnating composition. Two installation units (bitumen loading, bitumen heating and PS) are independent. The binder component preparation unit and the impregnating composition preparation unit are dependent on each other, have common equipment and are equipped with a control system that controls on/off of the impregnating composition preparation unit depending on the state of the process in the binder component preparation unit.

The development of modular production of impregnating compositions was also carried out in the framework of CALS technology. We have reviewed in detail the main stages of the computer description of the life cycle (LC) of a product in the CALS concept (Vinodh 2011). The greatest attention in this work is paid to the development of technological regulations, the basis of the information structure of which is the “Provision on the technological regulations of production at the enterprises of the chemical complex”. In the developed standard structure of the technological regulations for the production of road impregnations, 14 subcategories are highlighted (Figure 3), of which we will elaborate more on subcategory No. 13 “Drawings of the technological production scheme”.

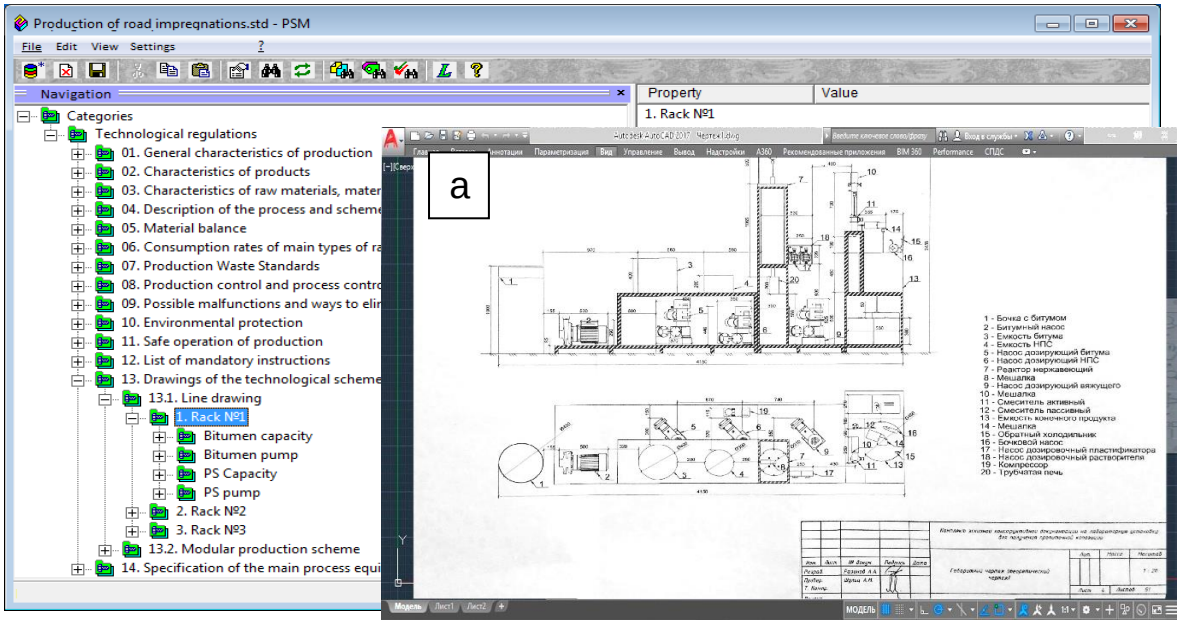

Figure 3: CALS-project of process regulations pilot plant (a - layout drawing of the technological scheme).

In this subcategory, 2 information clusters are considered: the layout drawing (Figure 3-a) and the modular production scheme. A subcategory of the CALS project "13.2. The modular scheme of production" is divided into four blocks (Figure 3). The preparation of initial components is carried out in two nodes (blocks): bitumen loading unit; site heating bitumen and PS. The main process - modification of bitumen is carried out in the site of preparation of the binder component (Figure 4). The bitumen and the pump station come through heated pipelines (Figure 4-a, pos. TB-13 and TB-18) to the dosing pumps (pos. ND-19 and ND-20).

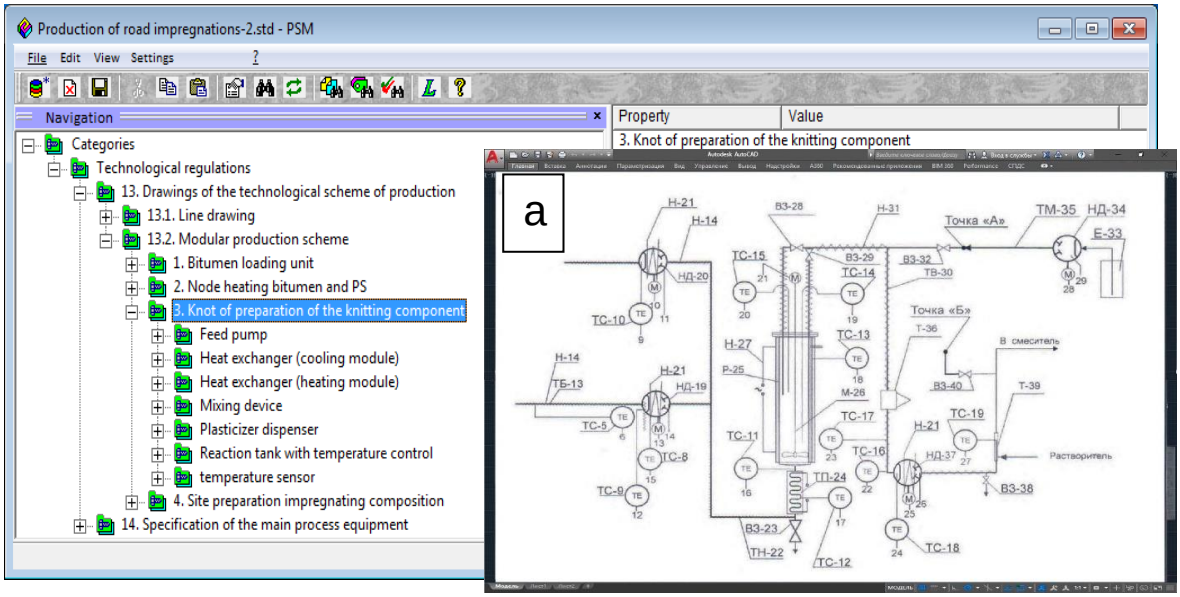

Figure 4: The element of the CALS-project of the technological regulation (a – the node for the preparation of the binder component).

When the bitumen and the pumping station reaches the set temperature, the pumps ND-19 and ND-20 are turned on manually and the supply of bitumen and pump to the reaction tank P-25. The feed lines of bitumen and PS are connected and enter the reaction tank R-25 through the TN-22 pipeline and through a tube furnace. The tube furnace (Figure 4-a, pos. TP-24) serves to quickly heat the mixture of bitumen and PS to a modification temperature that usually lies in the range of 175 - 180 °C (Chigorina et al., 2016).

The reaction tank is a vertical flow reactor operating in perfect mixing mode. The reactor is equipped with a mixing device - a propeller stirrer. The set temperature is maintained automatically with the help of a heating jacket and a TC-14 resistance thermometer. Unloading of the modified bitumen is forced by the dosing pump through a pipeline immersed in the reaction vessel through the lid of the reaction vessel. By changing the length of the submerged part of the pipeline, we can change the working volume of the reactor. The residual amount of modified bitumen, at the end of the process, is pumped by switching the valves to the “closed” or “open” position. In this case, the selection of modified bitumen starts from the bottom of the reaction vessel. At the outlet of the reaction vessel, there is an input to the pipeline of the binder component with a shut-off valve for feeding the plasticiser with the help of a metering pump of the binding component from the plasticiser container. The inclusion of the plasticising metering pump occurs automatically when the binder component enters the pump. From the metering pump, the binder component enters the heat exchanger. The metering pump and heat exchanger are common to the two nodes. For the knot of the binder component, the pump performs the function of selecting the binder component, and for the knot of obtaining the impregnating composition, the metering component into the mixer. For the knot of the knitting component, the heat exchanger performs the function of cooling the knitting component to 130 °C, and for the knot of receiving the impregnating composition - the pre-mixer. This scheme is applied to the trouble-free operation of the preparation unit for the impregnating composition (Figure 5) since without intensive mixing of the cold oil solvent with the hot binder component, resinous products precipitate. Then the binder component is dosed from the reaction tank by the pump into the heat exchanger. Cooling of the binder component occurs due to the supply of an oil solvent by a dosing pump from the oil solvent container to the external tube of the heat exchanger. At the outlet, the cooled binder component and the heated oil solvent are mixed and fed into the input element of the cooling unit - a passive mixer (Figure 5-a), which is based on dividing/connecting the streams for pre-homogenization.

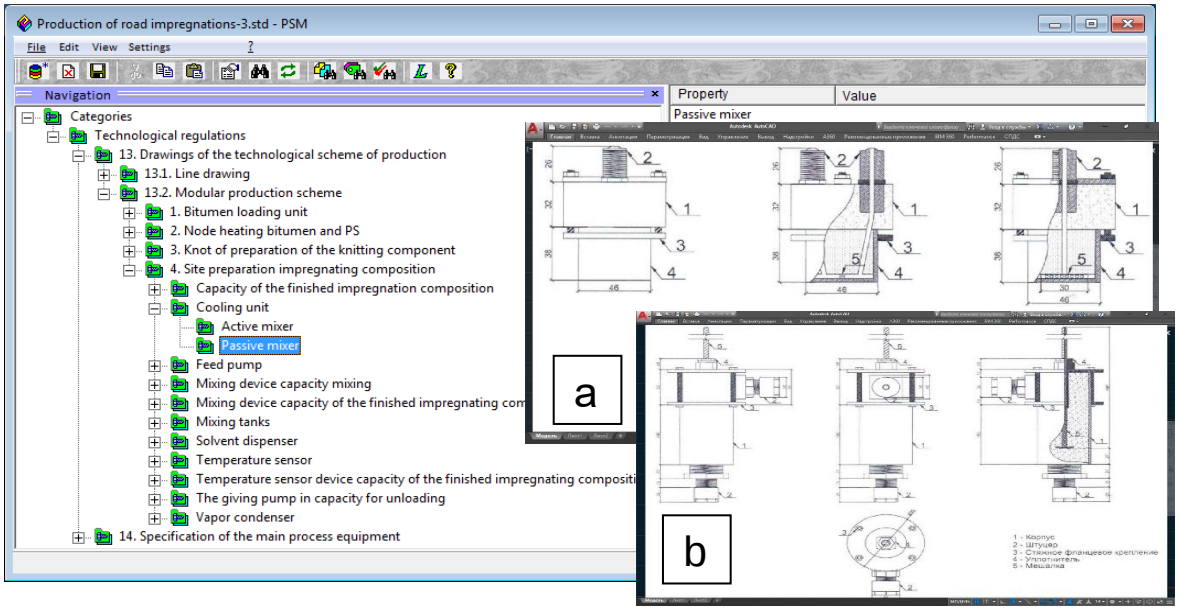

Figure 5. CALS-project for the production of road impregnation. Site preparation is impregnating composition (a - active mixer; b - passive mixer).

From the mixer, the impregnating composition enters the active mixer (Figure 5-b), equipped with a mechanical stirrer. The homogenised impregnating composition from the mixer enters the container of the finished impregnating composition, equipped with a mechanical stirrer and a coil heat exchanger - cooler of the finished composition. To prevent the release of oil solvent vapours to the atmosphere, a reflux condenser is installed on the lid of the tank. The informational CALS-project of the process schedule contains general drawings of the whole pilot production, drawings of individual modules (nodes), as well as the most important elements of the modules (passive mixer, active mixer, etc.).

4. Conclusions

For the first time, on the basis of the CALS concept, modular production and a computer quality management system for impregnating compositions for road asphalt concrete pavements have been developed. The systematization of quality indicators for the proposed information clusters has been carried out. The structure of the CALS-based computer-aided design system includes all stages of the development of technical documentation for the modular production of road impregnations. The introduction of informational CALS technologies allows not only to improve the quality of analytical, research and design work, but also to provide complete computer support, including all necessary documentation in electronic form.

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