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Effectiveness analysis of external heating system of gauge tank of pumping unit using exhaust piping of the IC engine [*]

S. O. Kireev[1], V. N. Stepanov[2], M. V Korchagina[3], A. V. Yefimov[4]**
[1, 2, 3, 4] Don State Technical University, Rostov-on-Don, Russian Federation

Анализ эффективности системы внешнего обогрева мерной емкости насосной установки от выхлопной системы двигателя внутреннего сгорания[***]

С. О. Киреев[1], В. Н. Степанов[2], М. В. Корчагина[3], А. В. Ефимов[4]**
[1, 2, 3, 4] Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация

Introduction. The heating efficiency or regulation of the operating temperature of the fluid located in the gauge tank of a mobile pumping unit (PU) using the exhaust system of the internal combustion engine (ICE) is studied. The paper objective is to improve the design process and to reduce costs of field experiments.

Materials and Methods. To solve this problem, numerical analysis methods were used when calculating the heating systems of the gauge tank with the external location of the pipeline from the ICE exhaust system by the example of the widely used installations (TsA-320, UNB, AChF, etc.). Siemens STAR-CCM+, a non-stationary non-linear solver of gas-dynamic processes, was used, which evaluates the correctness of the problem statement and reduces significantly the costs of full-scale field tests.

Research Results. The study was conducted for the operating conditions of the cementing unit on the Kamaz-43118 chassis with the SIN-32 pump and a drive from the power take-off attachment on the gearbox of the chassis engine. In the calculation model, a convection-type heat transfer was applied between the body of the gauge tank and the surrounding air; between the body of the gauge tank and the liquid; between the chassis exhaust system duct and ambient air; between the exhaust system duct and exhaust gases. The following study results were obtained: characteristic curves of the temperature variation of the gauge tank liquid at the watch points; the distribution of the temperature field of the liquid in the gauge tank; the distribution of the ambient air temperature field; lines of flows and ambient air speed field and of the ICE exhaust gases.

Введение. Статья посвящена исследованию эффективности обогрева или поддержания рабочей температуры жидкости, находящейся в мерной емкости передвижной насосной установки, от выхлопной системы двигателя внутреннего сгорания. Цель работы — совершенствование процесса проектирования и снижение затрат на натурные эксперименты.

Материалы и методы. Для решения поставленной задачи были использованы методы численного анализа при расчете систем обогрева мерной емкости с внешним расположением трубопровода от выхлопной системы двигателя внутреннего сгорания (ДВС) на примере широко распространенных установок ЦА-320, УНБ, АЧФ и др. Применен нестационарный нелинейный решатель газодинамических процессов (Siemens STAR-CCM+), позволяющий оценить правильность постановки задачи и значительно сокращающий затраты на полномасштабные натурные испытания.

Результаты исследования. Исследование проводилось для условий работы цементировочного агрегата на шасси «Камаз-43118» с насосом «СИН-32» и приводом от коробки отбора мощности на коробке переключения передач двигателя шасси.

В расчетной модели применен конвекционный тип теплопередачи между корпусом мерной емкости и окружающим воздухом; между корпусом мерной емкости и жидкостью; между трубопроводом выхлопной системы шасси и воздухом окружающей среды; между трубопроводом выхлопной системы и выхлопными газами.

В результате исследования получены графические зависимости изменения температуры жидкости мерной емкости в контрольных точках; распределение поля температур жидкости в мерном баке; распределение поля температур окружающего воздуха; линии потоков и поля скоростей окружающего воздуха и выхлопных газов ДВС.

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[**] E-mail: kireevso@yandex.ru, st_fem@bk.ru , ms.korchaginamv@mail.ru, spu-45.2@donstu.ru

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Discussion and Conclusions. The study has revealed poor effectiveness of the considered structure. The data analysis allows us to offer an improved design of the gauge tank heating. The results obtained in the work can be used in the calculations of such devices used in the hydraulic fracturing units and grout machines.

Обсуждение и заключения. В ходе исследования выяснилась недостаточная эффективность рассматриваемой конструкции. Анализ данных позволяет предложить усовершенствованную конструкцию обогрева мерной емкости. Результаты, полученные в работе, могут быть использованы при расчетах подобных устройств, применяемых в установках гидроразрыва пласта и цементирования скважин.

Keywords: mobile pump unit, gauge tank, water feeding pump, high pressure pump, internal combustion engine (ICE).

Ключевые слова: передвижная насосная установка, мерная емкость, водоподающий насос, насос высокого давления, двигатель внутреннего сгорания (ДВС).

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Образец для цитирования: Анализ эффективности системы внешнего обогрева мерной емкости насосной установки от выхлопной системы двигателя внутреннего сгорания / С. О. Киреев [и др.] // Вестник Дон. гос. техн. ун-та. — 2019. — Т. 19, № 2. — С. 164−169. https://doi.org/10.23947/1992-5980-2019-19-2-164-169

Introduction. The deposits of hard-to-recover hydrocarbons in the northern latitudes of Russia are confined to low-permeable, low-drained, heterogeneous and segregated reservoirs. Whereas it is necessary to develop such oil and gas areas, need arises for a guaranteed the above-zero temperature of the liquid that is in the gauge tank of the installation. This problem remains relevant in the construction and workover of wells.

The quality of hydraulic fracturing (HF) fluid, drilling fluid and cement slurry is affected by the following factors:

- types of rocks that interact with these systems;
- well depth (pressure);
- bottomhole temperature.

We will accept two statements of the TNK-BP standard “Quality and Compliance under HF”:

1) liquid chemicals specific for mixing at the well pad should be stored or transported above 15ºC;

2) storage, transportation, testing and injection of all liquid reagents should be carried out above 15ºC, regardless of weather conditions [1].

The temperature of the system should not be lower than 8–10° C for all types of work on the preparation of the tempering fluid, pressurizing systems and systems of drilling and flushing solutions [2].

The 1979 oil and gas equipment literature mentions the use of a chassis or deck engine (TsA-320A cementing unit) for heating the exhaust gas system of the engine [3]. There are references to the vent dehumidifying system of the booster pulser hydraulic unit in two operating manuals: “Pumping units UNB-1000, UNB-800, UNB-630” and “Cementing hydraulic fracturing unit ACF-1050. UPETROM”. In the operating manuals of “Two-pump mobile unit UNP-320 × 40” and “Pumping unit UNB-125-50 SO”, the items on operating the drying and heating systems are highlighted.

In the present paper, the effectiveness of external heating system of gauge tank of pumping unit using exhaust piping of the IC engine is analyzed.

Materials and Methods. Methods of numerical simulation were used. As examples, the widespread installations of the TsA-320, UNB, AChF, and others were considered.

The application of numerical methods permits to assess the correctness of the problem statement (with an error of an idealized model selection), reduces significantly the cost of full-scale field tests or fully proves the design-engineering inefficiency of the problem. In the absence of statistical data on the problem under study, the results of numerical methods narrow the spectrum of the field problems to be solved. The non-stationary nonlinear solver of gas-dynamic processes (Siemens STAR-CCM +) [4] was applied as a numerical method tool.

For the numerical study, the problem of heating a two- compartment gauge tank was selected. For this purpose, the cementing unit on the Kamaz-43118 chassis with the SIN-32 pump and a drive from the power take-off attachment on the gearbox of the chassis engine were used. In the rear zone of the chassis truck, capacity of 2 × 2 m^3 was installed. It is an all-welded sheet-metal construction which has two compartments with a sloping bottom and bottom valves. In the scheme proposed for calculation and analysis, the exhaust pipe (heating pipe) passes under the bottom of the gauge tank and rises upwards along the wall of the left tank (Fig. 1).

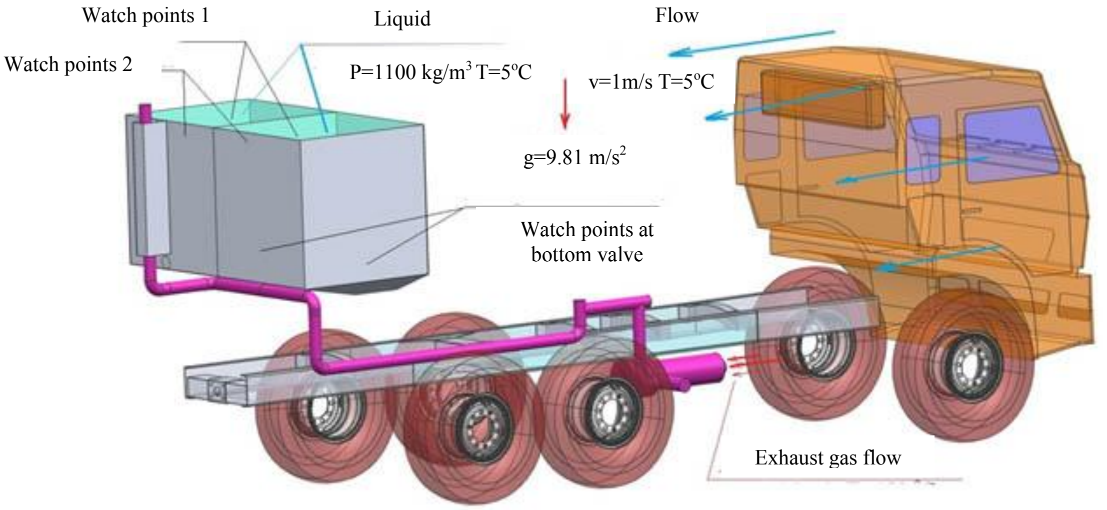

Fig. 1. Idealized design model of cementing unit on “Kamaz-43118” chassis with “SIN-32” pump

Research Results. The study was conducted for the following operating conditions of the unit at the field:

- pump unit is fixed;
- ambient temperature (air) is 5°C above zero;
- wind speed is 1.0 m/s;
- liquid density in both sections of the gauge tank is 1100 kg / m3;
- liquid temperature in gauge tank is 5°C above zero.

In the calculation model, a convection-type heat transfer was applied between the following media was used:

- body of the gauge tank and the surrounding air;
- body of the gauge tank and liquid;
- chassis exhaust system duct and ambient air;
- exhaust system duct and exhaust gases.

To simplify the task, air was used as exhaust gases to eliminate the application of a multiphase solver.

Air parameters were as follows: density was 1.184 kg m^3; thermal conductivity was 0.026 W/m·K; specific heat capacity was 1003.6 J/kg·K.

The parameters of the liquid in the gauge tank were as follows: density was 1100 kg/m^3; thermal conductivity was 0.569 W/ m·K; specific heat capacity was 4217 J / kg·K.

The material parameters of the steel body of the gauge tank and the exhaust system duct were as follows: density was 7832 kg/m^3; thermal conductivity was 63.9 W/m·K; specific heat capacity was 434.0 J/kg·K; thickness of the body sheet of the gauge tank was 4 mm; exhaust pipe thickness was 3 mm [5].

The exhaust gas outlet temperature of the ICE manifold was 450° C [5, 6]; the exhaust outlet flow of the engine manifold was 35 m/s [5].

The calculation (see Fig. 1) was made from the ICE working condition for 1800 seconds (30 minutes). The test points of the liquid temperature were obtained for the left and right compartments of the gauge tank at the bottom valves at a distance of 200 mm from the bottom, at a distance of 1000 mm from the bottom (T1), and at a distance of 1000 mm from the bottom and 200 mm from the back wall (T2). The liquid temperature lines during the ICE operation for 30 minutes are shown in Fig. 2. The temperature fields and current lines are shown in Fig. 3–6.

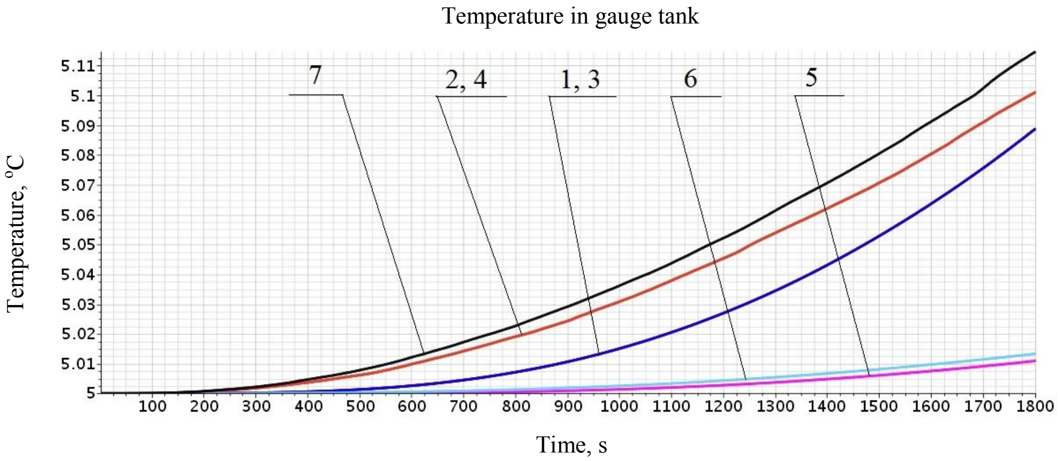

Fig. 2. Liquid temperature lines of gauge tank at watch points: 1 is temperature at top point of left gauge-tank compartment; 2 is temperature in left compartment (point 1); 3 is temperature in left compartment (point 2); 4 is temperature in left gauge-tank compartment at bottom valve; 5 is temperature in right compartment (point 1); 6 is temperature in right compartment (point 2); 7 is temperature in right gauge-tank compartment at bottom valve.

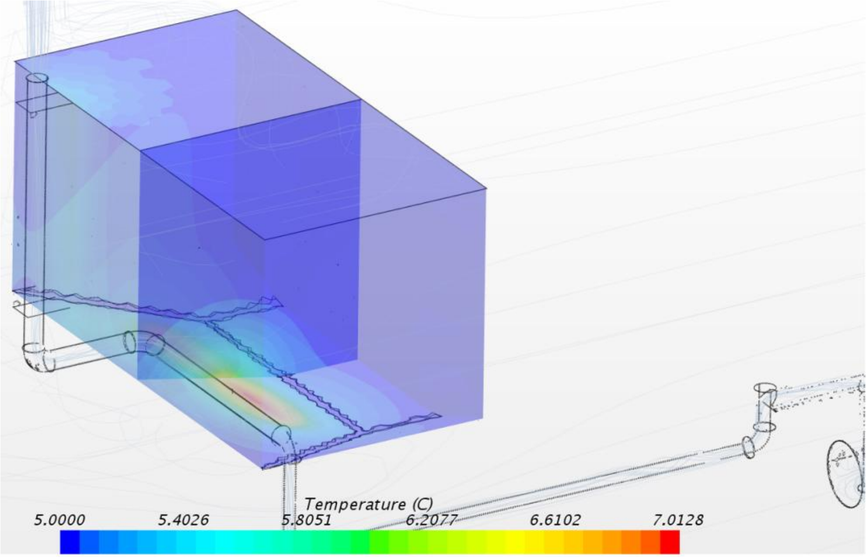

Fig. 3. Distribution of liquid temperature field in gauge tank (left view)

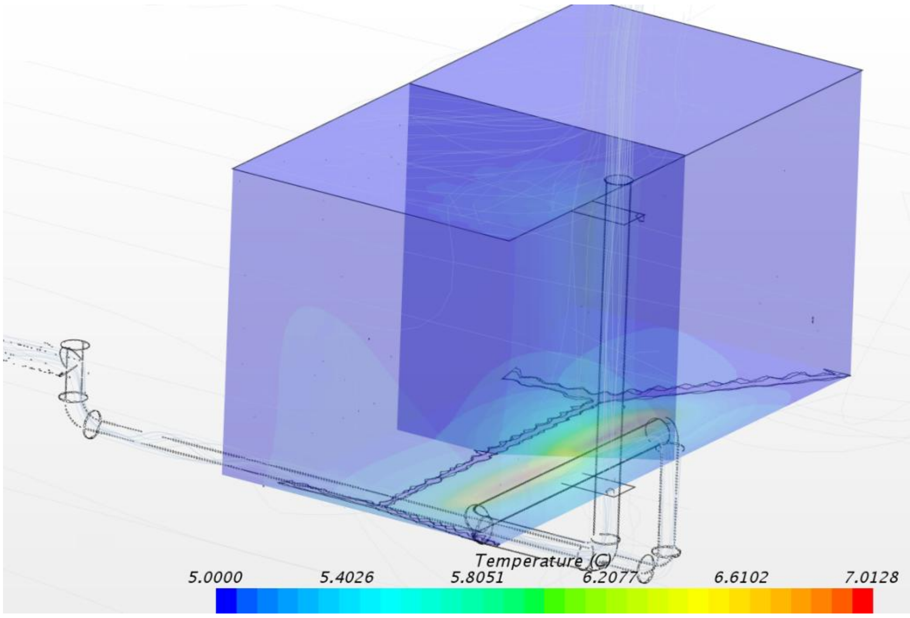

Fig. 4. Distribution of liquid temperature field in gauge tank (right view)

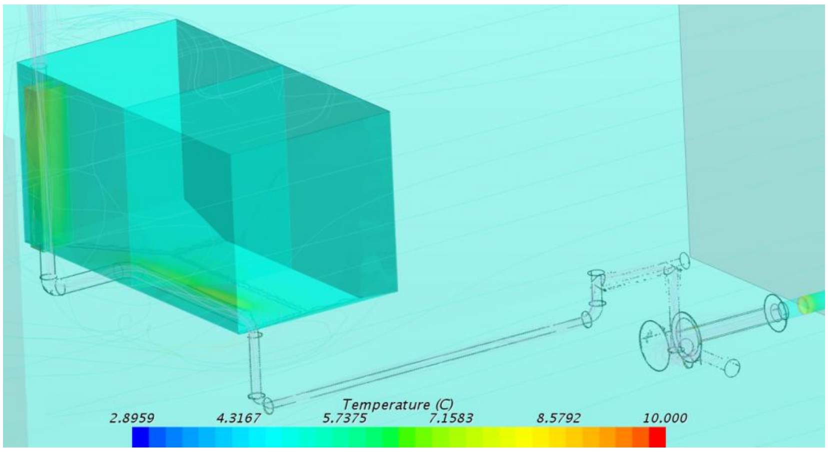

Fig. 5. Distribution of ambient air and gauge-tank body temperature field

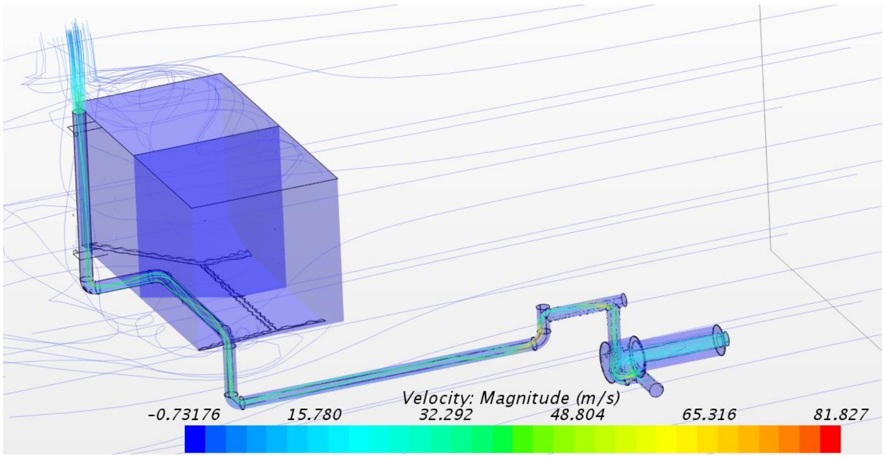

Fig. 6. Flow line and speed field of ambient air and ICE exhaust gases

Discussion and Conclusions. The calculation results obviously demonstrate that for 30 minutes of the ICE operation and convection heat exchange between the hot exhaust pipe, air and liquid in the gauge tank at the test points at the bottom valves, the liquid is heated up to 0.1° C in the left compartment and to 0.1 ° C in right compartment.

This brings us to the following conclusion: at the considered variant of the constructive solution, most of the thermal energy is directed to the operator’s cabin heating. This is a positive factor, but not a solution to the problem. The studies and graphical dependences show that it is required to place the exhaust tube directly in the gauge tank for a more efficient distribution of heat flows inside the gauge tank and in the environment. Given the design features, it is advisable to place the pipe inlet at the bottom of the right side of the tank and, passing through the left side, direct it along the tank up to the relief passage.

In order to determine the possibility of heating the gauge tank, it is necessary to carry out calculations for a new schematic construction.

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Authors:

Kireev, Sergey O.,
Head of the Oil and Gas Complex Machinery and Equipment Department, Don State Technical University
(1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr.Sci. (Eng.), professor,
ORCID: http://orcid.org/0000-0001-9352-3852
kireevso@yandex.ru

Stepanov, Valentin N.,
senior lecturer of the Oil and Gas Complex Machinery and Equipment Department, Don State technical
University (1, Gagarin sq., Rostov-on-Don, 344000, RF),
ORCID: https://orcid.org/0000-0002-1425-9174
st_fem@bk.ru

Korchagina, Marina V.,
associate professor of the Oil and Gas Complex Machinery and Equipment Department, Don State Technical
University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand.Sci. (Eng.),
ORCID:http://orcid.org/0000-0001-7092-7176
ms.korchaginamv@mail.ru

Yefimov, Andrey V.,
associate professor of the Oil and Gas Complex Machinery and Equipment Department, Don State technical
University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand.Sci. (Eng.), associate professor,
ORCID: https://orcid.org/0000-0001-9940-9030
spu-45.2@donstu.ru