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IMPACT OF THE FURRING ON FUEL CONSUMPTION OF STEAM-GENERATING INSTALLATIONS OF THE OIL GAS TECHNOLOGICAL TRANSPORT

The paper considers the problem of the impact of the furring on the heating elements of mobile steam generating installation (SGI), widely used in oil and gas industry for the dewaxing of wells, pipe-lines, oil and gas as well as other equipment by the saturated steam of high and low pressure, and for other domestic and industrial needs.

As steam-generating installations operate in field conditions at large distance from the main bases of their location (storage and registration), this leads to the forced consumption of physically and chemically untreated raw water. As a rule, this is subsurface natural water, water from rivers, lakes, pond, etc. Operation of steam-generating installations on the untreated water results in formation of the scale , which causes excess fuel consumption and failure of the steam generator boiler as a result of the coil burnout. However, even in the course of operation on the treated feed water the scale is formed on the walls of the coil, it decreases the operation efficiency and requires periodic descaling by means of acid treatment after 48 – 72 hours of operation.

Operators often create the conditions for the creation of the thick layers of the scale and excess fuel consumption for the obtaining of the needed amount of steam, as compared with the data, specified by the regulatory documents on the installations operation.

The paper contains the analysis of the impact of the scale layer thickness on thermal losses of the steam-generating installation boiler and the impact of the fur layer on the excess fuel consumption of the mobile steam-generating installation. Mathematical dependence of the excess fuel consumption on scale layer thickness is obtained. It was shown that the emergence of the scale causes not only economic but also ecological problems.

In order to eliminate the negative impact of the scale on steam-generating installation operation the construction of the cleaning element was suggested.

Application of the suggested device will enable to save up to 10.5 % of the fuel (approximately 121.5 kg/hr.). Taking into account the retail cost of the diesel fuel 27 UAH./l it is possible to achieve savings of 3280.5 UAH/ hour of the operation of one steam-generating installation.

Thus, problem, considered in the paper is rather important for the enterprises of oil and gas industry.

Key words: *mobile steam-generating installations, heat conductivity, fuel, heat transfer.*

Introduction

Mobile steam generating installations (MSGI), mounted on the automobiles, are used in oil and gas industry for the dewaxing of wells, pipe lines, oil gas equipment by the saturated steam of high and low pressure, as well as for other every day necessities and industrial needs.

Analysis of the operation conditions shows that their amount in the enterprises of oil and gas industry is not equally distributed (installations are not concentrated in one region or territory). Oil and gas administrations or other enterprises, dealing with the operation of the wells, storage or transportation of oil or gas have one or, in better case, two steam generating installations.

For such organizations it is not expedient to create special technological systems for treatment of the feed water. If the distance to the place of steam generating unit operation is not long, the feed water of boiling units, supplied for heating of the premises and other everyday necessities, is used. These feed waters, used for the supply of steam and hot water boilers are different by their physical and chemical properties.

Problem set up

Operation of steam operating installations in field conditions at long distance from the main bases of their location (storage and maintenance) leads to the forced consumption of the water that is not prepared physical and chemically, as a rule, it is underground water or water from rivers, lakes, ponds, etc. By physical and chemical properties these waters do not meet the requirements of the operation instructions [1 – 4], according the requirements the hardness must be less than 10 mg-eq/kg. According to different information sources [5 – 7] the hardness of the natural non-prepared water varies from 0.5 to 5.0 mg-eq/l, it is at least 50 times less than it is provided by the operation instructions for steam generating installation operation [1 – 4].

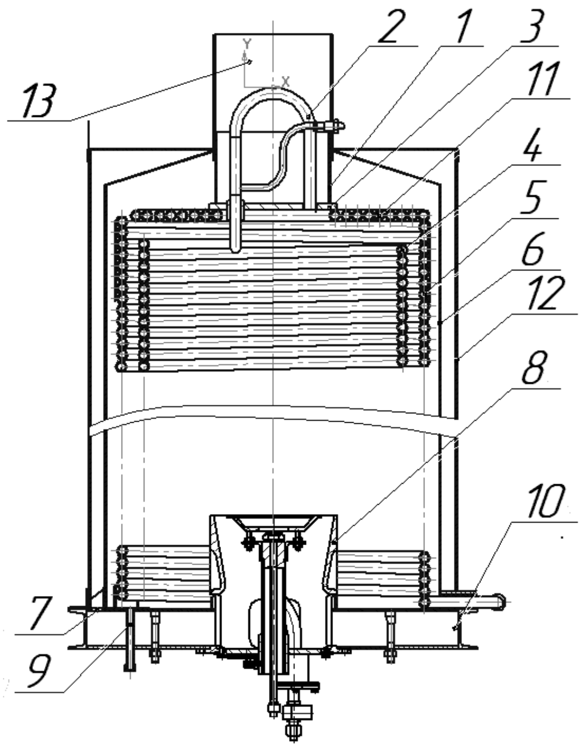
Functioning of steam generating installations on non-treated water leads to formation of the scale , which causes excess fuel consumption and failures of the boiler of steam generating unit due to coil burnout.

It is possible to solve the problem of avoiding (prevention) scale formation in the coils of steam generator, considering modern methods, aimed at the prevention of scale formation in boiler coil of the steam generator of the given type.

Analysis of the recent research and publications

Description and operation of the boiler.

Steam boilers of ППУА type are installed on mobile heat generating units. The arrangement of the steam boiler is shown in Fig. 1. [1 – 4]. The boiler is vertical, of cylinder form with twisted helical tubes, direct flow with bottom location of the burner.



1 – spark blowout; 2 – loop; 3 – cover; 4 – internal coil; 5 – external coil; 6 – internal housing; 7 – hole; 8 – burner; 9 – adapter; 10 – tray; 11 – helix; 12 – external housing; 13 – reject pipe

Fig. 1. Steam boiler

Heating surfaces are made in the form of two cylindrical coils: external 5 and internal 4.

External coil 5 in the upper part ends with flat helix coil 11. Ends of tubes of the external 5 and internal coil 4 are connected by a loop 2. The hole is closed by the cover 3, where cuts are provided in the places of loop pipes 2 passage. All the coils are made of boiler pipes 28x3.5 TS 14-3-460-75, pipes are made of steel 20. Space, formed by the cylindrical coils 4.5 and the wall of the internal housing of the boiler 6, is intended for the passage of flue gas.

Two cylindrical housings 6 and 12 of the boiler form circular chamber for the passage of air from the fan to the burner. For the passage of the air from the circular chamber into the tray 10 in its support there are holes 7.

Across the pipe the flue gases from the engine of the motor vehicle enter the lower chamber and provide the heating of the boiler and pump in winter period during the trip of the installation. Spark blow out of the mash type 1 is installed in the pipe of the boiler.

Adaptors 9 of the soot blower are brought outside of the boiler tray 10. In the bottom of the boiler there is a trap, where burner 8 is mounted. Flue gases from the boiler of steam generator pass across the outlet tube 13.

Sources of fur formation.

Scale and hard deposits are formed on the internal walls of the vessels of the steam evaporators and heat exchanging units, where evaporation or heating of the water takes place that contains various salts. The formed layer of substances may be called scale when its thickness achieves the size, that causes dangerous overheating of the metal walls or when the presence of these substances decreases economic efficiency of the unit operation. It should be noted that the layer of such substances, formed from the dissolved or weighted in the water compounds is called fur [8]. Fig. 2 shows the available scale in the pipes of the coil.

Fig. 2. Coil of steam generator with the layer of fur

Substances, arriving with the feed water to steam generators of various types, under certain conditions are able either to form the scale or deposit in the form of sediment (sludge) [9]. Scale is formed as a result of the interaction of water or agents present in it, with the surface of the boiler metal, that transfers heat and as a result of deposition of the substances, dissolved in the water during its boiling, heating and evaporation..

Scale , formed in steam generators according to the classification [9] by its composition may be divided into 5 groups:

- alkaline earth scale, consisting of the compounds of Ca and Mg. ;
- cupric scale, consisting mainly of the metal copper;
- iron scale, it is divided into silicate, ferrumsilicate, phosphatic and oxidic scales;
- aluminaferrumselicate and silicate SiO_2 overload;
- scale, consisting of highly soluble salts: $NaPO_4$, Na_2HPO_4.

By the predominant components deposits can be classified into silicon, sodium, magnesium, calcium, ferric, cupric, etc. [9].

Silicon deposits are available in the flowing part of the steam turbines; they consist of amorphous silica and crystalline SiO_2 (α – quarts) with the admixture of various sodium silicates.

Sodium deposits are often called saline deposits. They are in the pipes of the steam superheaters, on the blades of turbines, sometimes in straight-through boilers.

Calcium deposits are divided into carbonate, sulphate, silicate and phosphate, they are formed in raw water preheaters, in the pipes of steam turbines condensers, in cooling devices of the engines, etc. In these devices mainly CaCO3 scale with the admixture of magnesium subcarbonate, silicic, acid, ferric oxides and aluminium oxides, sometimes manganese carbonate and other compounds is formed.

Iron scale is divided into iron oxide, iron-silicate and ironphosphate. Ironoxide deposits are formed in steam boilers, supply pipes, condense return pipes, treated water pipe lines. Iron phosphate deposites are found in steam boilers.

Heat conduction of the scale is tens and often hundreds times less than heat conduction of steal, heat exchangers are made of. That is why, even the thinnest layer of the scale creates great thermal resistance, that leads to overheating of pipes and their ruptures [10].

Requirements to the feed water

Incorrectly treated water, used in the process of steam generating installations operation [4] stipulates the emergence of the scale layer with low heat conduction coefficient and, as a result, high thermal resistance of the pipes walls. This, in its turn, leads to the decrease of the efficiency factor of the boiler, excess fuel consumption for obtaining the necessary volume of steam, as compared with the normative data, specified in the operating and maintenance manuals. This is explained by the fact that in direct flow installations, namely, steam generators, as a result of evaporation the concentration of the salts, dissolved in the water, sharply increases [4].

Also, operation instruction [1 – 3] provides that the concentration of the washing solutions depends on the solubility scale sample or depending on the thickness of the deposition layer from 0.5 mm to 1 mm and from 1 mm to 1.5 mm the concentration of hydrochloric acid is 3.4 and 5 %, correspondingly. Concentration of the solution of more than 8 % is not recommended.

In the process of steam generation with the dryness value of 0.7 the concentration of the salts, dissolved in the residual water increases 3.5 times. By the degree of steam dryness 0.8 the concentration of the dissolved salts in the residual water increases 5 times and by the degree of the generated steam dryness 0.9 it increases 10 times. If the content of the salts in the water exceeds the boundary of their solubility and salts solubility at high pressures decreases greatly, then the scale will deposit rapidly at the internal heating surfaces of the steam installation [4]. Making use of the already known recommendations [5] if the thickness of the layer is 5 mm, the excess consumption of fuel is 30 %, and if the thickness is 10 mm – it increases 2 times. The scale formed leads to the excess of fuel consumption, burnout and rupture of steam generator boiler coil.

In [4] the acid treatment of steam generator coil is recommended in 48 – 72 hours of the operation. In this case rather large time interval of 24 hours is recommended, it is 50 % of the total operation time of the installation before the recommended cleaning. Operators, making use of such large interval of 48 – 72 hours of operation, prior to decision regarding the necessity of clearing the coil, often work at maximum time limit and create the conditions for the excess fuel consumption for generating the necessary volume of steam as compared with normative data of operation manuals.

Aim and tasks of the paper

The aim of the paper is the analysis of modern measures, aimed at prevention and elimination of the scale from the coil of the steam generator as well as the impact of the scale layer thickness on the excess fuel consumption in the process of steam generation.

Calculation of the impact of the wall scale thickness on the excess fuel consumption of the mobile steam generating installation

As it is known, the scale layer has very low thermal conductivity 1.163 – 3.79 W/(m·K) [11], that leads to the decrease of the amount of heat, transferred from the gases to the water. In its turn, it will result in the increase of the excess fuel consumption at the same capacity.

We will perform the calculation of the change of fuel consumption depending on the deposit thickness.

To simplify the calculation we will assume the cylindrical tube of the steam generator boiler coil as a flat wall.

We assume the following output data:

– temperature of the gases in the middle of the boiler 1000 – 1300° C [12], we assume to be 1120°C;
– temperature of the gases at the output of the boiler 160 – 180° C [12], we assume to be 180°C;
– temperature of water at the input in the boiler – 70° C;
– heat transfer coefficient from the gases to the wall α_1 = 65 W/m^2·K [2];
– heat transfer coefficient from the wall to the water α_2 = 3500 W/m^2·K [12];
– thermal conductivity of the steal wall of the coil λ_1= 46.5 W/m·K [2];
– thermal conductivity of the scale layer λ_2 = 1.163 – 3.79 W/(m·K) [11], we assume to be λ_2 = 1.2 W/m·K;
– lower heat value of diesel fuel Q_L = 42700 kJ/kg;

efficiency factor of the steam boiler $-\eta'_{SB} = 80\%$.

Parameters of heat boiler coil [3]:

– external diameter of the pipe – 0.028 m;
– wall thickness $-\ \delta_c$ = 0.0035 m;
– average diameter of the external coil – 0.652 m;
– average diameter of the internal coil – 0.568 m;
– number of turns – 49.

Heat transfer coefficient for the flat wall without the scale:

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_c}{\lambda_c} + \frac{1}{\alpha_2}} = \frac{1}{\frac{1}{65} + \frac{0,004}{46,5} + \frac{1}{3500}} = 63.46\ W/(m^2 \cdot K). \quad (1)$$

Heat transfer coefficient for the flat wall with the scale of 2 mm:

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_c}{\lambda_c} + \frac{\delta_н}{\lambda_н} + \frac{1}{\alpha_2}} = \frac{1}{\frac{1}{65} + \frac{0.004}{46.5} + \frac{0.002}{1.2} + \frac{1}{3500}} = 57.39\ W/(m^2 \cdot K). \quad (2)$$

Area of the convective heat exchange, m^2:

$$H = \pi dL. \quad (3)$$

where d – is the external diameter of the coil tube, m; L – is the length of the coil tube, m.

$$L = 0.568 \cdot 3.14 \cdot 49 + 0.652 \cdot 3.14 \cdot 49 = 187.7\ \ m.$$

Thus:

$$H = 3.14 \cdot 0.028 \cdot 187.7 = 16.5\ m^2.$$

Average temperature head:

$$\Delta t = \frac{\Delta t_g - \Delta t_s}{2.31 lg \frac{\Delta t_g}{\Delta t_s}}, \quad (4)$$

where Δt_g – is the difference of ambient temperatures at that end of the heating surface, where it is the greatest, ° C; Δt_s – is the difference of ambient temperatures at that end of the heating surface, where it is the smallest, ° C;

$$\Delta t_g = 1120 - 310 = 810^0 C,$$

$$\Delta t_s = 180 - 70 = 110^0 C.$$

Then:

$$\Delta t = \frac{810 - 110}{2{,}31 \lg \frac{810}{110}} = 351^0 C.$$

The heat, transferred from the gases to the water, if there is no scale:

$$Q = Hk\Delta t = 16.5 \cdot 63.46 \cdot 351 = 367566.06 \ J/s. \quad (5)$$

The heat, transferred from the gases to the water if the scale layer is 2 mm:

$$Q = Hk\Delta t = 16.5 \cdot 57.39 \cdot 351 = 332405.1 \ J/s. \quad (6)$$

Heat losses:

$$\Delta Q = 367566.05 - 332405.1 = 35160.96 \ J/s. \quad (7)$$

Excess of fuel consumption:

$$\Delta B = \frac{\Delta Q}{Q_H \cdot \eta'_{SG}} = \frac{35160.96 \cdot 3600}{42700 \cdot 0.8 \cdot 1000} = 3.7 \ kg. \quad (8)$$

$$\frac{3.7}{110} \cdot 100 = 3.37 \ \%. \quad (9)$$

Calculation for the scale of 0…8 mm of thickness we will carry out by means of Excel program. Results of the calculation are presented in Table 1.

Table 1

Results of the calculation of scale layer thickness impact on fuel consumption

Scale thickness, mm	Heat transfer coefficient, $W/(m^2 \cdot K)$	Heat, transferred to the water, J/s	Heat losses, J/s	Excess fuel consumption, kg/hr	Fuel consumptio n, kg/hr	Excess fuel consumption , %
0.0	63.466	367566.065	0.000	0.000	110.000	0.0
0.2	62.802	363718.741	3847.324	0.405	110.405	0.4
0.4	62.152	359951.123	7614.942	0.803	110.803	0.7
0.6	61.514	356260.758	11305.307	1.191	111.191	1.1
0.8	60.890	352645.297	14920.768	1.572	111.572	1.4
1.0	60.278	349102.480	18463.585	1.946	111.946	1.8
1.2	59.679	345630.140	21935.925	2.312	112.312	2.1
1.4	59.091	342226.195	25339.870	2.670	112.670	2.4
1.6	58.515	338888.643	28677.422	3.022	113.022	2.7
1.8	57.950	335615.562	31950.503	3.367	113.367	3.1
2.0	57.395	332405.101	35160.964	3.705	113.705	3.4
2.2	56.852	329255.479	38310.586	4.037	114.037	3.7
2.4	56.318	326164.984	41401.081	4.363	114.363	4.0
2.6	55.794	323131.966	44434.099	4.683	114.683	4.3
2.8	55.280	320154.837	47411.228	4.996	114.996	4.5
3.0	54.775	317232.066	50333.999	5.305	115.305	4.8

Termination of the table

3.2	54.280	314362.177	53203.888	5.607	115.607	5.1
3.4	53.793	311543.749	56022.316	5.904	115.904	5.4
3.6	53.315	308775.409	58790.656	6.196	116.196	5.6
3.8	52.846	306055.834	61510.231	6.482	116.482	5.9
4.0	52.384	303383.746	64182.319	6.764	116.764	6.1
4.2	51.931	300757.913	66808.152	7.041	117.041	6.4
4.4	51.485	298177.145	69388.920	7.313	117.313	6.6
4.6	51.047	295640.290	71925.775	7.580	117.580	6.9
4.8	50.617	293146.237	74419.828	7.843	117.843	7.1
5.0	50.193	290693.912	76872.153	8.101	118.101	7.4
5.2	49.777	288282.277	79283.788	8.355	118.355	7.6
5.4	49.367	285910.328	81655.737	8.605	118.605	7.8
5.6	48.964	283577.092	83988.973	8.851	118.851	8.0
5.8	48.568	281281.629	86284.436	9.093	119.093	8.3
6.0	48.178	279023.030	88543.035	9.331	119.331	8.5
6.2	47.794	276800.414	90765.651	9.565	119.565	8.7
6.4	47.417	274612.927	92953.138	9.796	119.796	8.9
6.6	47.045	272459.744	95106.321	10.023	120.023	9.1
6.8	46.679	270340.063	97226.002	10.246	120.246	9.3
7.0	46.318	268253.109	99312.956	10.466	120.466	9.5
7.2	45.964	266198.130	101367.935	10.683	120.683	9.7
7.4	45.614	264174.396	103391.669	10.896	120.896	9.9
7.6	45.270	262181.200	105384.865	11.106	121.106	10.1
7.8	44.931	260217.857	107348.208	11.313	121.313	10.3
8.0	44.597	258283.699	109282.366	11.517	121.517	10.5

According to the results of the calculation, the conclusion can be made, concerning the considerable impact of the scale on fuel consumption, even if its thickness is small, this leads to considerable excess of fuel consumption especially at large enterprises, where a great number of steam installations operate.

Thus, the conclusion can be drawn that the usage of water, hardness of which is less than 10 μg-eg/kg, and timely washing of the boiler will increase the time of installation operation and decrease the operation expenses.

Measures, aimed at prevention of the scale on the internal surface of thermal generator coil

Analysis of the operation conditions of mobile steam generating installations shows that their number at the enterprises of oil and gas industry is dispersed on the territory (they are not concentrated in one region or territory). Gas and oil administrations or other enterprises have one, at their best, several steam generating installations. It is not expedient for such enterprises to organize special technological systems for treatment of the feed water as they often use the feed water of the boiling units, used for heating of the buildings and other everyday needs. In this case the difference of physical-chemical properties of the feed water for steam and hot-water boiler is not taken into account.

However, even if the installation operates on the treated feed water, the scale is formed on the walls of the coil, the scale decreases the efficiency of operation and requires the periodic elimination by means of acid treatment after 48 – 72 hours of operation [4]. That is, the difference between boundary minimum and maximum of the time of the unit operation to recommended washing is 24 hours, it is 50 % of the time to boundary minimum.

The operators, making use of such great variation (48 – 72 hours) of the unit operation prior the decision-making regarding the necessity of cleaning the coil often work at maximal time limit and create the conditions for formation of the thick layers of scale and considerable excess fuel consumption for obtaining the necessary amount of steam, as compared with normative data of the operation manuals of steam generating installations.

Economically efficient method of scale deposit prevention is water softening by means of magnetic treatment [6]. The technology of such treatment consists in passing the water (at least 6 times) through the magnetic field in the direction, perpendicular to the action of the force lines of the magnetic field. As a result of such treatment, the salts, available in the water, do not form the scale but precipitate in the form of easily washed sludge. For the magnetic treatment devices with permanent and electric magnets, built in water-supply grid, are used.

In spite of the advantages of the magnetic treatment of water for the prevention of scale formation on the internal walls of the coils, this method did not find wide application. There is no scientific substantiation of the magnetic field impact on the properties of water [13] hence, the industrial application of the magnetic treatment of water for steam generation in thermal generators of the given type did not bring the desired results in spite of the fact that the cost of chemical treatment of water is far more expensive than the magnetic treatment.

The most actual by functional designation is a device for prevention scale deposit on the walls of the boiling tubes of the steam boilers [14], which consists of the cleaning element, located in the coil (boiling tube), the cleaning element itself consists of the twisted, corrugated tin plates, inserted in the internal part of the coil (boiling tubes). As a result of the introduction of such element, the scale will deposit on the surface of the inserted corrugated tube, which is removed if polluted and is replaced by another one. However the complexity of manufacturing and operation of such construction as well as the decrease of heat conduction of the artificially formed double-layer wall of the coil complicated its application in heat power engineering.

The problem of scale deposit is solved by means of usage of the special device (Fig. 3).

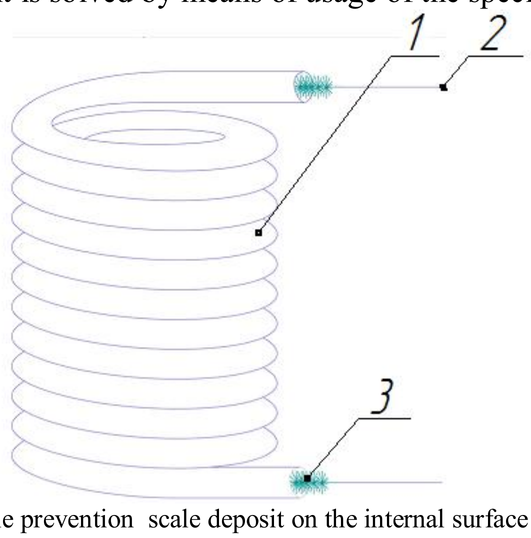


Fig. 3. Device for the prevention scale deposit on the internal surface of thermal generator coil

The device consists of the tube 1 of the thermal generator coil, inserted in the tube 1 on the full length of the cleaning element, which contains flexible cable 2, wires 3, located and fixed in cable, manufactured from the softer material than the tube of the coil. In this case cable 2 and wires 3 form flexible cable-ware-brush.

Cleaning element, manufactured in the form of the flexible cable 2, equipped with wires, manufactured from the material softer than the material of the coil, and the length of the wires and their fastening on the cable provides the location of the cleaning element in the coil with tension.

Realization of the cleaning element in the form of the cable, equipped with the wires, makes it similar to the wire-brush, which will move in the process of steam production and its wires will contact with the internal surface of the coil and prevent the deposit of the scale on the walls of the coil.

Manufacturing of the wired element from softer material will not wear the internal surface of the coil tube in the process of the interaction.

Introduction of the flexible cable in the construction of the cleaning element on the full length of the coil in the process of steam generation will prevent the scale formation on the total length of the coil.

In the process of steam generation in the coil of thermal generator, cable 2 is put in motion (the drive is not shown in Fig. 3) and contacts with the internal surface of the tube of the coil 1 by means of wires 3, built in it. As the wires 3 are mounted on the cable 2 in such a way, that they are located in tube 1 with the tension, then in the process of their contact with the internal surface of the tube 1 in case of possible scale deposit it will be eliminated from the surface and washed by steam-water mixture, available in the coil. During steam release, the created scale in the form of sludge will be eliminated from the tube 1 of the coil along with the steam.

The given device for the prevention of the scale deposit on the internal surface of thermal generators coils will enable to decrease the cost of the generated steam at the expense of fuel economy. Economic effect will grow with the increase of the output of steam generating installation itself.

Conclusions

On the base of the calculations, carried out, the conclusion is drawn and the regularities of the impact of the scale layer on the excess consumption of fuel by steam generating installations are obtained. The device, intended for minimization of the scale impact on the efficiency of the boiler and the cost of steam generation is proposed. The application of the given device will enable to save up to 10.5 % of fuel (approximately 121.5 kg/hrs). Taking into account the retail cost of the diesel fuel as 27 Uah/l it is possible to save 3280.5 Uah for an hour of the operation of one steam generating installation.

The important is the fact that economic fuel consumption will decrease ecological load.

Thus, the problem, considered in the paper is rather important for the enterprises of oil and gas industry.

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