AD 682590

TRANSLATION NO. 2386

DATE: 2 Feb 1969

DDC [redacted]

[redacted]

DDC

FEB 27 1969

E

DEPARTMENT OF THE ARMY
Fort Detrick
Frederick, Maryland

This document has been approved for public release and sale; its distribution is unlimited

10

[redacted]

2386

INVESTIGATION OF HEAT TRANSFER AND AERODYNAMIC RESISTANCE OF PIPE CLUSTERS WITH A DUST-LADEN FLOW OF GAS

/Following is the translation of an article by F. P. Kazakevich and A. M. Krapivin, Candidates of Engineering Sciences, Dnepropetrovsk Institute of Railroad Transportation Engineers, published in the Russian-language periodical Izvestiya Vysshikh Uchebnykh Zavedeniy, Energetika (Herald of the Higher Educational Institutes, Power Engineering), No 1, 1958, pages 101—107./

In a whole number of cases heat exchange devices work under conditions of a dust-laden flow of gas. The contamination of heating surfaces which takes place here leads to a worsening of the operational indices of functioning of the unit.

The absence of reliable data on the basic regularities of the process of contamination, and also on the influence of various factors on heat transmission and aerodynamic resistance in a dust-laden flow of gas does not make it possible, with the necessary accuracy, to make calculations of industrial heat exchangers and to select the most optimum installation for their heating surfaces.

Deposits on the outer heating surfaces of heat exchangers may be loose and friable or solid, and sometimes even cemented.

The first and still the only work on the study of the process of formation of friable ashy deposits on pipe clusters under laboratory conditions was the work of the VTI /1/.

In the experiments at the VTI (All-Union Institute of Heat Engineering imeni F. E. Dzerzhinskiy) conditions of work were reproduced which were close to those which take place in boilers.

In the present work the study of heat transfer and aerodynamic resistance of pipe clusters was conducted on an experimental gas conduit which was connected to a KU-50 waste-heat boiler of an open-hearth furnace.

The KU-50 waste-heat boiler belongs to coil boilers with multiple forced circulation.

As can be seen from Figure 1, it consists of a drum-separator, evaporation section, water economizer, and steam superheater. The heating surface consists of vertical coils which are curved from pipes with Ø 32 x 3 mm and situated in one horizontal gas conduit.

Flue gases, passing through the waste-heat boiler, are drawn off by an exhaust fan and directed into a stack. In leaving the open-hearth furnace the flue gases carry with them a considerable amount of charge dust, which falls out along the path of movement of the gases, thus obstructing the slag grates of the regenerator, the horizontal flue, and the heating surface of the waste-heat boiler.

The average concentration of charge dust in flue gases before the waste-heat boiler comprises no less than 5—6 g/m^3 (NTP).

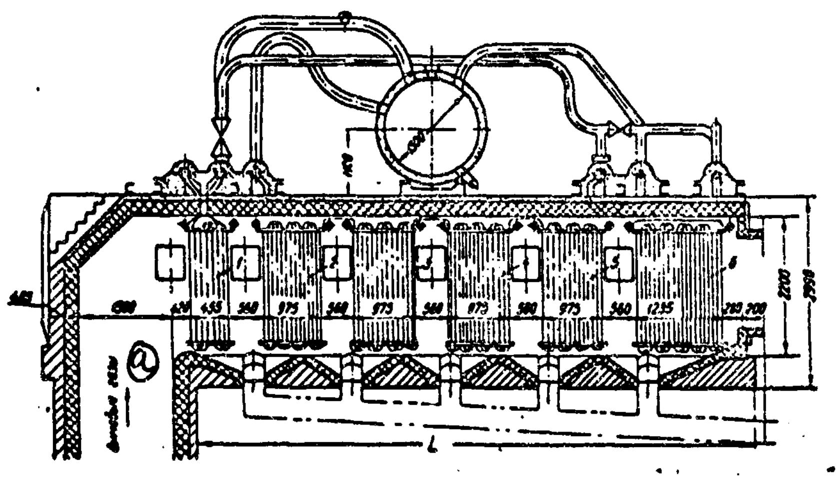

Figure 1. Diagram of the KU-50 waste-heat boiler.
1 - steam superheater; 2, 3, 4, 5 - evaporating coils; 6 - economizer.
Key: (a) - flue gases.

The fractional composition of dust is characterized by a predominance of particles of small dimension (10—15 microns). The deposits on the coils of the waste-heat boiler represent a finely-divided mass made up mainly of Fe_2O_3 (around 60%), $Si\ O_2$ (2—4%), $Ca\ O$ (2—5%), and S (3—8%).

Discription of the Experimental Unit and Methods of Investigation *

* Participating in the experiments was I. G. Veselyy, laboratory worker in the department of heat engineering of the DIIT.

The experimental unit (Figure 2) was a tube, made out of sheet steel, with a height of 415 mm and width of 750 mm. In the center section of the tube was the test pipe cluster, composed of pipes with an external diameter of 32 mm.

For visual observation the side walls of the aerodynamic tube in the area of the cluster were made removable.

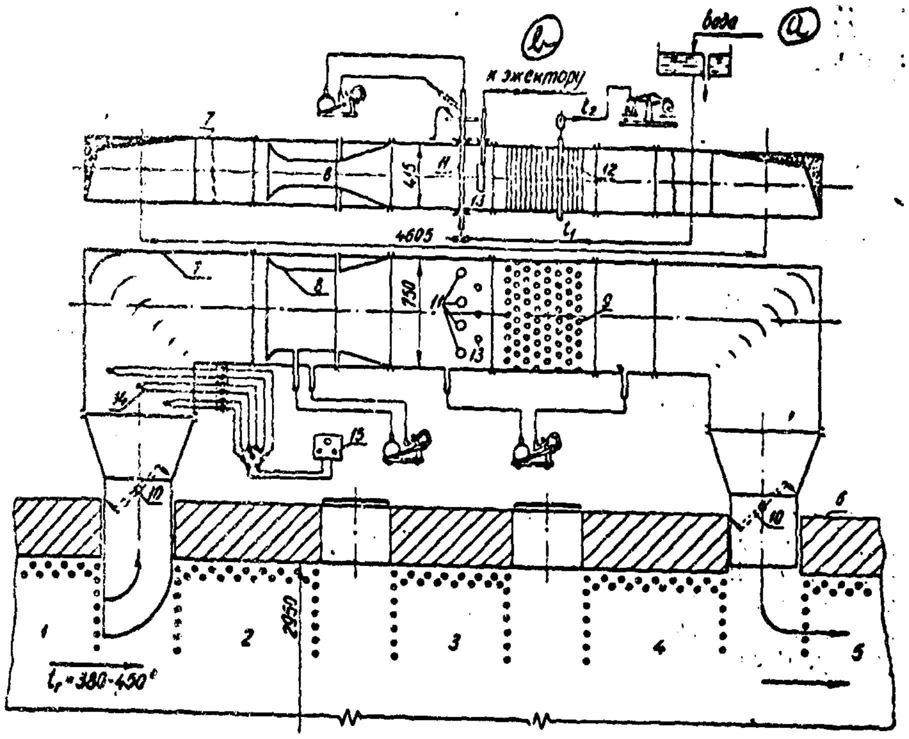

Figure 2. Diagram of the experimental unit.
1 — 4 - evaporation pipe clusters of the boiler; 5 - economizer; 6 - boiler lining; 7 - aerodynamic tube; 8 - measuring nozzle; 9 - test pipe cluster; 10 - baffle plates; 11 - pneumometric tube; 12 - tube-calorimeter; 13 - tube for take-off of dust; 14 - thermocouples; 15 - potentiometer.
Key: (a) water; (b) to ejector.

The aerodynamic tube is in contact with the waste-heat boiler through hatches which are located on the first and last blocks of the boiler evaporating coils.

Corner ducts of the tube are equipped with carefully made directing vanes. On the outer side the tube is covered with a layer of insulation.

The temperature of gases in the unit fluctuated in the interval from 380°C down to 45°C.

The tests were carried out at various values for the rate of gas flow within the limits of change of the Re criterion from 2 500 to 8 000. Measurement of the rate of gas flow was carried out with the help of a measuring nozzle (attachment), the convergent portion of the inlet collector of which has the form of a constricted jet. The nozzle has openings for the release of total and static pressures. The difference of these pressures, equal to the dynamic pressure in the constricted section of the nozzle, was fixed with the help of a MFU micromanometer.

For measuring the aerodynamic resistance of the test unit, in the side walls of the tube before the cluster and beyond it we welded on sleeves with openings with a diameter of $d = 2$ mm and to which a micromanometer of the same type was attached. Measurement of temperature of gases was done with copper-constantan thermocouples. Water calorimeters (Figure 3) were used for determination of heat receiving by tubes of the cluster and the coefficient of heat transfer. The amount of water passing through the calorimeter was estimated by the gravimetric method. The temperature of incoming and outgoing water was measured by mercury thermometers mounted in special cases.

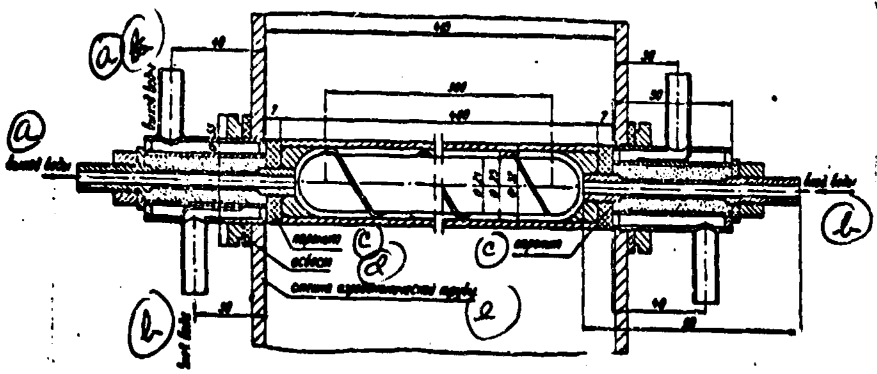

Figure 3. Water calorimeter.

Key: (a) outflow of water; (b) intake of water; (c) paranite; (d) asbestos; (e) wall of aerodynamic tube.

For increasing the coefficient of heat emission from the wall to the water (α_2) passing through the calorimeter its straight through section was selected sufficiently small.

Here the values of α_2 comprised more than 2 000 Cal/m^2 hr degree.

The calorimeters were established in the 1st and 6th rows of the pipe cluster, i.e., in those places where there was thermal and hydrodynamic stabilization of flow.

Heat perception of the calorimeter was determined from the expression

$$Q = D(t_2 - t_1) \text{Cal/hr},$$

where D - hourly flow rate of water passing through the calorimeter; t_1 and t_2 - correspondingly the temperature of the water at the intake and outlet of the calorimeter.

For determination of the coefficient of heat transfer we used the conventional formula

$$K = \frac{Q}{H \cdot \Delta t_{av}} \quad \text{Cal/m}^2\text{hr degrees},$$

where H - surface of heat perception of calorimeter in m^2;
Δt_{av} - average temperature pressure between gas and the water passing through the calorimeter in degrees.

As a special analysis showed, the coefficient of heat transfer k differed little from the coefficient of emission α_1 from the gas flow to the surface of the tube. In our case the decrease of k due to external contamination of the pipes was compensated by an additional supply of heat by means of emission to the calorimeter from the dust-laden gas flow and pipes surrounding the calorimeter. In connection with what was said above it will subsequently be taken that $k \approx \alpha_1$.

Results of Investigation

For the purpose of a comparison of data obtained in the experimental unit during washing of a pipe cluster with hot flue gases, we conducted a scavenging by cold air of the checkered cluster with spacings of $S_1 = 2.6d$ ar $S_2 = 2d$ in a laboratory aerodynamic tube. A description of this unit was given in work [2]. In these tests hot water with a temperature of 85 — 95°C was fed into the water calorimeter. At the same time measurements were made of the aerodynamic resistance of the column.

The results of the tests in this tube are presented in Figure 4. On these same charts are plotted the curves, constructed according to the formulas of Academy member Mikheyev [3]

$$Nu_l = 0{,}41 \cdot Re_l^{0{,}6} Pr_l^{0{,}33} \left(\frac{Pr_l}{Pr_w}\right)^{0{,}25};$$

$$Eu_l = (10{,}8 + 6{,}8 \cdot Z)\, Re_l^{-0{,}28}$$

and the formulas of the VTI—TsKTI [4] and [5].

$$Nu_l = 0{,}295 \cdot C_z \cdot Re_l^{0{,}6} \left(\frac{S_1 - d}{S_2 - d}\right)^{0{,}25};$$

$$Eu_l = 1{,}93\,(z + 1) \sqrt{\frac{1 - \frac{d}{S_2}}{\frac{S_1}{d} - 1}}\; Re_l^{-0{,}25}$$

In addition, Figure 4 shows the test curves characterizing heat emission and aerodynamic resistance of a checkered cluster with spacings of $S_1 = 2.63d$, $S_2 = 2d$ and $d = 19$ mm /2/. In tests with this cluster a steam-electric calorimeter was used. From a comparison of the curves shown in Figure 4 it can be seen that the test data obtained during scavenging of this cluster with a water calorimeter are close to the data cited in /2/.

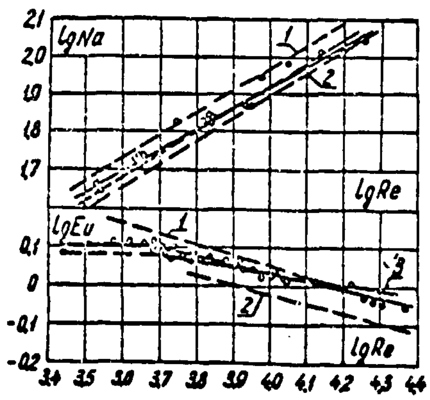

Figure 4. Thermal emission and aerodynamic resistance of a seven-row checkered cluster with spacings of $S_1 = 2.6d$, $S_2 = 2d$ and $d = 32$ mm in tests carried out in an aerodynamic tube.
1 - based on formulas of M. A. Mikheyev; 2 - based on formulas of VTI; 3 - for a cluster with spacings $S_1 = 2.63d$, $S_2 = 2d$ and $d = 19$ mm.

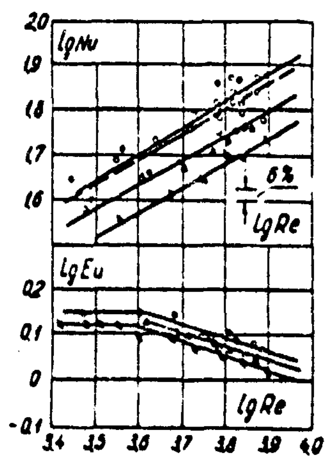

Figure 5. Heat emission and aerodynamic resistance of an 8-row checkered cluster with spacings $S_1 = 2.6d$; $S_2 = 2d$. O - clean tubes; ● - after 15 hours of work; X - after 7th day of work; 1 - heat emission during scavenging in an aerodynamic tube; ▲ after 2 days of work.

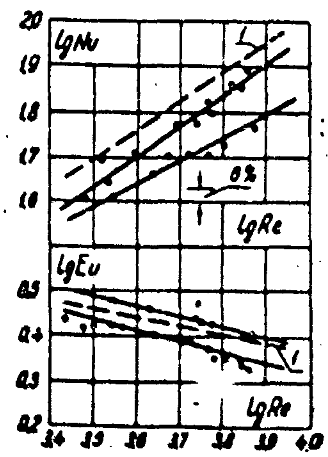

Figure 6. Heat emission and aerodynamic resistance of an 8-row checkered cluster with spacings $S_1 = 2.6d$; $S_2 = 2d$. O - clean tubes; ● - polluted tubes; 1 - for cluster with spacings $S_1 = 2.63d$; $S_2 = d$ and $d = 19$ mm during scavenging in an aerodynamic tube.

The results of the experimental investigation of heat transfer and aerodynamic resistance of clean and polluted pipe clusters with a checkered and an unstaggered distribution of pipes in a test gas conduit are presented in logarithmic coordinates in the form of dependences $Nu_f = (Re_f)$ and $Eu_f = \varphi(Re_f)$ in figures 5, 6, and 7.

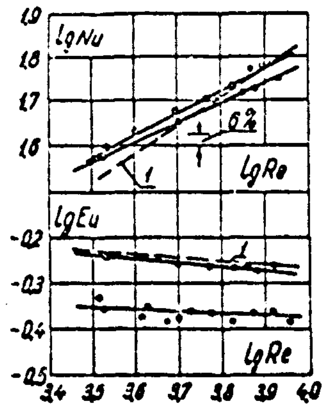

Figure 7. Heat emission and aerodynamic resistance of a 7-row unstaggered cluster with spacings $S_1 = 2.6d$; $S_2 = 2d$. O - clean tubes; ● - polluted tubes; 1 - based on formulas of VTI.

It is necessary to note that the term "clean" tubes is conditional, i.e., in the period of establishing the required regimen of work of the test gas conduit the tube cluster was subjected to pollution. This circumstance was taken into consideration during the processing of data by means of introduction of the necessary corrections during determination of the coefficient of heat emission.

The analysis of the test data for the checkered cluster with a longitudinal spacing S_2 2d (Figure 5) shows that depending on the duration of work of the cluster in a dust-laden flow of gas there is an increase in the contamination of the tubes, which leads to a sharp lowering of heat transfer. Lowering of aerodynamic resistance of the pipe cluster with an increase of contamination is explained by the fact that contaminated tubes acquire a more streamlined form.

The investigation of the checkered cluster with spacing $S_2 = d$, which according to the terminology of the VTI belongs to the type of self-blow out clusters (in the case of friable deposits), was undertaken for the purpose of exposing the peculiarities of its operation during contamination with charge dust.

It follows from Figure 6 that a lessening of the longitudinal spacing of the checkered cluster does not promote a lessening of contamination. Aerodynamic resistance of this cluster with an increase of pollution is lowered, bu based on absolute value turns out to be more considerable in comparison with the previous cluster. For a comparative evaluation we also studied a cluster with an unstaggered distribution of tubes ($S_1 = 2.6d$; $S_2 = 2d$).

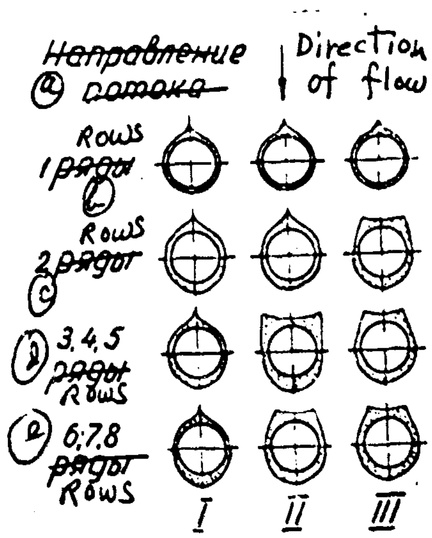

Figure 8. Nature of deposits on pipe clusters. 1 - checkered distribution of tubes $S_1/d = 2.6$; $S_2/d = 2$; II - checkered distribution of tubes $S_1|d = 2.6$; $S_2|d = 1$. III - unstaggered distribution of tubes $S_1|d = 2.6$; $S_2|d = 2$.

It is necessary to note that the tests on heat emission for this cluster, the results of which are presented in Figure 7, were conducted for technical reasons only with weakly contaminated pipes. In regard to tests on aerodynamic resistance, then they were relative to strongly contaminated clusters.

Tests with an unstaggered cluster showed that in the practically encountered range of change in the Re criterium, in a thermal respect during a dust-laden gas flow it yields to the checkered cluster.

Characteristics of contamination of tubes of the investigated clusters are illustrated in Figure 8.

The largest deposits on tubes of the checkered cluster with $S_2 = 2d$ take place on the frontal sector of the tubes, where thick (structurally) "crests" are formed. The heights of these have a tendency for growth.

In a checkered cluster with S_2 d the nature of the deposits is different. The pipes of the first and second rows of this cluster are contaminated in the same manner as pipes from the cluster with $S_2 = 2d$. On tubes of subsequent rows on the frontal sector the contaminations form two "crests" as a result of peculiarities of the aerodynamic flow in the inter-tube space of the cluster with a small longitudinal spacing. The nature of deposits on tubes of the first row of an unstaggered cluster is no different from that for checkered clusters. Beginning with the second row deposits are distributed in approximately the same manner as in a checkered cluster with $S_2 = d$. In structure the deposits are close to thick, but not cemented.

Conclusions

1. During washing of pipe clusters with clean pipes by a gas flow which is dust-laden with charge priming, heat emission by means of convection and aerodynamic resistance based on its value remain the same as in the case of a non-dust-laden flow.

2. Pipe clusters under conditions of work with dust-laden gas flow are subjected to considerable contamination, which is accompanied by a lessening of the coefficient of heat transfer. As a measure of contamination the pipes become more streamlined, as a result of which the aerodynamic resistance of the clusters in reduced.

3. Deposits on the pipe clusters have a tendency for progressive growth with an increase in the duration of operation of the cluster. Tests did not reveal any thermal and hydrodynamic stabilization setting in, in cases of friable deposits, even after several hours of operation of the cluster.

4. Changes in the geometrical characteristics of clusters with thick deposits did not lead to a decrease of contamination.

Literature

1. N. V. Kuznetsov and L. Z. Shcherbakov, Ash Contamination of Heating Surfaces. Teploenergetika, No 1, 1954.
2. F. P. Kazakevich, Heat Emission of Transversely Streamlined Pipe Clusters at Small Values of the Re Criterium, Teploenergetika, No 4, 1955.
3. M. A. Mikheyev, Bases of Heat Transfer, Gosenergoizdat, 1956.
4. Thermal Calculation of Boiler Units (norm method); under the editorial supervision of A. M. Gurvich and N.V. Kuznetsov, Gosenergoizdat, 1957.
5. N. V. Kuznetsov, A. Z. Shcherbakov, and Ye. Ya. Titova, New Calculation Formulas for Aerodynamic Resistance of Transversely Streamlined Pipe Clusters. Teploenergetika, No 9, 1954.