

TESTING BOILERS AND DETERMINING THERMAL EFFICIENCY

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ABSTRACT

The purpose of testing the boilers is to verify the guarantees presented by the manufacturer or, as the case may be, by the repairer and it is carried out in the following cases:

- on the occasion of the homologation of a prototype, in order to move to the series production; the purpose of the test is to confirm the parameters that are established by this project, respectively to finalize these parameters;*
- when a boiler is put into operation for the first time, with the purpose of checking the parameters established by the project for the respective type-series, on the occasion of the homologation of the prototype and guaranteed for compliance by the construction or installation company;*
- after carrying out a repair that had the effect of changing one or more parameters, with the aim of confirming and, respectively, finalizing the new parameters established by the repair project.*

KEYWORDS: boilers, operating regimes, quality, heat agent, combustion process

1. INTRODUCTION

The most important characteristic that is determined during the test is the yield.

As a rule, the notion of efficiency, without any other specification, refers to the "gross efficiency" of the boiler, which refers to the whole of the boiler, including auxiliary services (mills, grates, fans, etc.). To obtain the "net yield" it is necessary to subtract the thermal equivalent of the energy consumed by the auxiliary services (for the operation of mobile grills, coal mills, fans, etc.)

To determine the yield, two methods can be used, namely:

- the "direct" method, in which a complete heat balance is established; in that balance is involved, on the one hand, the amount of heat contained in the fuel and air that, in the mixture, burn in the hearth, and on the other hand, the heat stored in the water and steam in the boiler;

- the "indirect" method, in which all the heat losses during the combustion process must be determined by measurement.

The two methods of determining yield are equivalent.

The choice of method depends on the possibility to perform the measurements with a certain degree of precision so that the results obtained are valid.

2. BOILER PREPARATION FOR TESTING

In order to carry out the test, the boiler must be subjected to a thorough check-out, paying particular attention to the heating surfaces, which must be in good and clean condition, in order not to influence the circulation of the water-steam fluid and, respectively, the heat exchange; also, the tightness of the firebox, gas lines, air heater and economizer will be checked.

Before proceeding to the actual tests, the boiler must be put into operation and examined from the point of view of the possibility of achieving and maintaining the technical conditions provided for the test. On this occasion, the following will be checked mainly: the steam flow at the main tap, the steam pressure at the superheater outlet, feed water temperature at the

boiler entrance, steam temperature at the superheater exit, ambient air temperature (from the boiler room), preheated air temperature.

The boiler under test must be isolated from sources of fuel or water that have not been measured; it must also be secured against any loss of water or steam which could influence the test results.

In order to start the measurements, it is necessary for the installations to operate for a certain period of time, different from one boiler to another, so as to achieve a balance of temperatures and combustion, under the conditions of the test loads.

During operation, the following conditions are recommended for the test load:

- the steam flow should not vary by more than $\pm 3\%$ compared to the value provided for the test;

- the extreme values for the steam pressure must not differ between them by more than 6% compared to the value provided for the test;

- the extreme values of the difference between the temperature of the combustion gases at the exit from the boiler and the ambient temperature must not differ by more than 6% from the temperature of the combustion gases at the exit, provided for the test.

During the test, the boiler must not be purged and the ash extinguishing installation must not be put into operation; if such operations are preliminarily necessary, measures will be taken to ensure their determination as accurately as possible (quantity, duration, time at which they were carried out and boiler parameters at those times).

3. TECHNICAL CONDITIONS FOR PERFORMING THE TEST

The actual test must be preceded by another test, during which at least the following operations will be performed:

- checking the proper functioning of all measuring and control devices;

- checking and, if necessary, adjusting the combustion plant so that the combustion is as complete as possible;

- verification of the knowledge of the operating personnel and the operators who will be used to carry out the tests.

In order to obtain valid results, it is necessary that at the beginning and end of the test (the actual test period) practically equal values are measured in terms of: combustion conditions, excess air, feed water flow, fuel flow, pressure of steam, water level in the

drum, steam flow.

If the "direct" method is used to determine the yield, it is necessary that the operation of the grate, for boilers equipped with grates, as well as the state and amount of fuel be the same at the beginning and end of the test.

The duration of the test is different from one boiler to another, depending on the construction type of the boiler and the type of fuel and combustion plant.

If, during the test, there are variations in the steam flow rate and pressure, as well as in the temperature of the combustion gases at the boiler outlet, greater than the previously mentioned values, the test will be considered unsuccessful.

4. THERMAL EFFICIENCY CALCULATION

In general, the gross efficiency is determined during the boiler testing, because it more conclusively expresses the degree of use of the fuel.

The direct efficiency determination method is applied in the most cases encountered in boiler tests and consists in calculating the ratio between the useful heat contained in the steam produced and in the evacuated purge and the heat introduced into the boiler.

The expression for calculating the thermal efficiency is:

$$\eta = \frac{D_{si}(i_{si} - i_{aa}) + D_p(i_{sat} - i_{aa})}{BQ + B_{comb} + BG_{inj}(i_{inj} - 600)} \cdot 100 \quad [\%] \quad (1)$$

For boilers that produce saturated steam, the efficiency calculation relationship is:

$$\eta = \frac{D_{ab}[i_{sat} - i_{aa} + \lambda(i^* - i_{sat})] + D_p(i_{sat} - i_{aa})}{BQ + B_{comb} + BG_{inj}(i_{inj} - 600)} \cdot 100 \quad [\%] \quad (2)$$

The indirect method of determining efficiency is used in cases where steam and fuel flows cannot be accurately measured or as a check on efficiency determined by the direct method.

The calculation relationship of the yield by the indirect method is:

$$\eta = 100 - \sum_i \quad [\%] \quad (3)$$

The thermal efficiency depends on the load of the boiler. The normal slope of the yield curve is characterized by three zones (figure 1).

Zone I is between D_{min} and $0.8 D_n$; The efficiency in this range increases with the boiler load. This increase is more pronounced in the

case of fuels burned on grills, but slightly accentuated in medium and high flow boilers.

Zone II is located around the nominal flow rate (0.8 DN) of the boiler.

The yield shows a maximum which in large boilers is extended over a larger range of load variation (the curve is flattened). This maximum is pronounced in small boilers that use solid fuel.

Zone III includes the range between the normal and nominal flow rates (Dn) of the boiler.

Thus, the field of limit deviations in which the yield values are found is obtained and a diagram similar to the one represented in the figure below is drawn (figure 1).

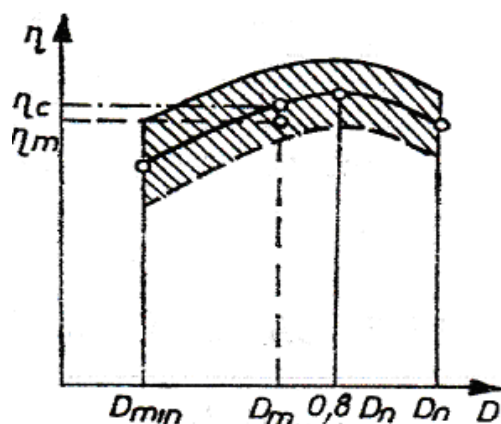


Fig. 1. The field of validity of the yield.

In operation, a time interval is considered for which the average load D_m and, respectively, the yield η_m are calculated. This yield will have to be within the validity limits of η_c ; in this case, the installation can be considered to have been operated under economic operating conditions.

If the value of η_m is not in the calculated validity range, the dispersions of the different indices are compared, in order to determine the causes that generated an uneconomical operation.

5. MEASURING DEVICES AND METHODS

To test a boiler, it is necessary to determine the following: the amount of heat consumed, the amount of useful heat, heat losses and the amount of energy consumed by auxiliary services.

The measuring devices used must be, by construction, of a certain precision class, so that the measurement deviations fall within limits that do not influence the test results; they must be verified in accordance with the provisions of the technical prescriptions in the field.

It is recommended to measure

temperatures with the following types of devices:

- mercury thermometers in a glass tube, with a graduated scale;

- thermocouples connected to a potentiometer of appropriate precision;

- thermoresistives connected to a Wheatstone bridge.

The measurement method must be chosen in such a way that heat transfers other than those between the measured fluid and the apparatus used for this purpose are minimized; if this is not possible, at the end of the test it is necessary to make the appropriate corrections.

When using thermometers, it is recommended to observe the following rules:

- the assembly will be carried out in such a way that the sensitive element is as close as possible to the axis of the pipe through which the fluid whose temperature must be measured circulates;

- in the case of fluids under pressure, the thermometers will be mounted in protective tubes, which must meet the following conditions: the inner diameter and wall thickness must be minimal, they must be well cleaned inside before inserting the thermometers, they must be cooled by filling with the quantity of liquid, in cases where high temperatures are measured;

- the thermometer rod must protrude as little as possible from the medium whose temperature is being measured; the temperature of the emerging mercury column must be measured in order to finally make the necessary corrections.

In the case of using thermocouples, it is necessary to place them in the gas paths in such a way that they are perpendicular to the direction of gas flow; if necessary, protective screens against the cold surfaces of the gas paths shall be used.

In general, in the case of pipelines or gas lines with large sections, it is recommended to perform, at first, a few probing measurements at different points of the section, in order to establish the most representative measurement point.

The measurement of pressures will be carried out with manometers of various types, except for those with a membrane, which are contraindicated. In order to make correct measurements, it is necessary to take into account the following rules:

- the scale of the pressure gauges must allow reading a pressure variation of 1% at a point;

- before and after use, the monuments must be checked under the temperature and pressure conditions specific to the test, using a standard manometer for this purpose;

- for mounting the manometers, the shortest possible connections will be used, and the placement will be done in such a way that they are not subject to vibrations and temperatures

higher than 600C;

- the assembly will be carried out by means of a siphon tube to ensure steam condensation; the number of turns of the siphon tube will be as small as possible, in order to minimize measurement errors, as a result of the influence of the water column that is created in the siphon;

- connection to the siphon tube will be made through a three-way valve, to ensure the cleaning of the pipes by blowing, as well as to check the zero point of the manometer;

To measure air or gas pressure, manometers and micromanometers with liquid will be used; to ensure correct measurements, the pressure tap must be taken in such a way that only the static pressure is measured, and there must be a perfect seal between the pressure tap and the device.

Flow measurement will be done by using charts, venturi tubes, meters, actual weighing or tanks whose capacity is known and verified beforehand.

The steam flow measurement must be done under conditions where the water level in the drum, at the beginning and at the end of the measurement, is practically constant; if this is not possible, the necessary corrections must be made.

It is forbidden to leak water or steam during the test (at pumps, flanges, drain seals, safety valves, etc.); if this is not possible, the respective losses must be measured in order to make the necessary corrections. Sampling of combustion gases for analysis is done, after they exit from the last heating surface of the boiler, as well as at other points of the gas paths, such as at the end of the hearth (to check the combustion conditions), as needed.

The purpose of the sampling is to determine the volume of carbon dioxide, oxygen, and carbon monoxide in the combustion gases (in percentage). As devices, the most widely used are chemical analyzers, based on the principle of selective absorption (for example, the ORSAT device) and electrical analyzers, based on measuring the thermal conductivity of flue gases and air.

Sampling can be done either from one point, if through preliminary analyzes it is concluded that it is representative in terms of gas composition, or from several points.

The gas inlets must be made of temperature-resistant materials; in the case of high temperatures, such as at the end of the firebox, water-cooled sockets are used. The connection between the outlet and the device is made by rubber tubes, which must be tested for proper tightness both before and after the analyses.

6. CONCLUSIONS

In this area, the yield drops rapidly with the load, as a result of the boiler's demand to reach the nominal flow rate.

In order to be able to compare the operation of a boiler in operation, with the values obtained during the homologation tests, it is necessary to establish the validity limits of the yield obtained during these tests. When determining these limits, account must be taken of the working conditions and the nature of the factors that influence the operation of the plant in operation.

A method for calculating the field of validity is presented in the specialized literature; this takes into account the limit deviation and vapor dispersions of the string of measurements of the parameters that determine the yield.

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