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APPLICATION OF AN EXHAUST SIGNAL FOR DIAGNOSING A SHIP BOILER

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Abstract

This study presents causes of faults and break-downs of ship steam boilers. The so-far used methods of their operation control based ona thermal-flow diagnostic signal have been discussed. The need to apply an exhaust signal for boiler diagnosing has been justified. A method of determining its parameters has been described. Thermal-flow clues indicating the need to start the boiler diagnosing process and an example of operational decision making based on the measured parameters of the exhaust signal (practical algorithm for a chosen boiler) has been presented. Utilitarian role of this signal in ship steam boiler operation, not only due to its pro- ecological value, has been indicated.

***Keywords:**. steam boiler, diagnostic signal, fault, emission, technical condition*

1. Introduction

Auxiliary ship boilers produce steam to feed all other receivers apart from the main power system. They are installed both on motor ships and on steam ships. Contemporary auxiliary ship boilers run solely on liquid fuels, products of petroleum distillation. Boiler fuels contain: carbon< (85-90)%, hydrogen (10 –12)%, sulphur (0.6-2)%, oxygen and nitrogen 0.5% and other impurities.

In the process of complete fuel burning, oxidation of combustible particles takes place, and as a result of an exothermic reaction the following are emitted: from carbon – CO2 (carbon dioxide), from hydrogen – H2O (water), from sulphur – SO2 (sulphur dioxide), in the gas form or as smoke. The residuals as sediments, which can be corrosive and may retard heat penetration, may partly remain in the boiler. Nitrogen and oxygen in the exhaust come from the air supplied to the furnace and also to a small extent from the fuel. [4,6,7].

When fuel burns with insufficient amount of supplied air the exhaust apart from CO2 contains also CO and unburned carbohydrates, which could be still oxidized However, burning process outside the combustion chamber is more difficult due to too low temperatures and insufficient amount of oxygen or/and insufficient amount of combustible components in the mixture.

Noxious exhaust products from auxiliary ship boilers present a real threat to maritime environment (especially when the ship is in harbours, shipyards or sailing in coastal waters) and for the boilers themselves. Exhaust from ship fuels i.e. CO, SOx and NOx have a destructive influence on the technical condition of ship boilers [1].

Some compounds from the exhaust, during operation, bring about typical destructive effects on the boiler technical condition. A characteristic one is a degradation of the technical condition of the heat exchange surface (heated) of boilers both on the side of exhaust and water. It is the consequence of corrosive processes and formation of sediments on surfaces in contact with exhaust products and with water from the boiler [1]. A specific quality of boilers as technical objects is the occurrence of faults of the same type simultaneously in several elements. There are the following, listed in the order of frequency of their appearance:

- formation of sediments impairing heat exchange and consequently the efficiency of the boiler;
- erosion, corrosion and cavitation being the result of water impurity, non-designed operation states and non-ideal construction of boiler elements;
- leakages;
- insulation faults;
- faults of oil and water pumps.

So far ship steam boilers have operated according to the scheduled-preventive (statistic) strategy, where the dates of servicing are fixed for certain points of their operation. Observation of these dates is supervised by classification societies. However, this strategy does not take into account non-scheduled servicing being the consequence of haphazard events, faults and break-downs [2].

This situation favours the application of two differing operational tactics: finding the faults and later their origins and a way to remove them.

2. Thermal-flow diagnostics in recognizing boiler faults

Sediment formation, soot on the exhaust side and scale on the water side is a particular fault which develops evolutionally and it results in a significant number of boiler faults and break-downs. Thus, an early recognition of too intensive sedimentation of exhaust products and scale is very important. It is also crucial to have reliable diagnostic methods which do not require interrupting boiler operation.

The sediments forming on heat exchange surfaces create an additional thermal resistance. It is due to low heat conductivity of oil layers, scale and exhaust sediments (in comparison to conductivity of metals). [4,6,7]. Deterioration of heat conductivity may be quantitatively determined using heat balance relations, however this method requires apart from heat measurements also measuring water fluxes which is not usually done in boiler installations.

Corrosion itself does not directly influence flow resistance in pipes, however sediments and especially impurities and scale lead to a significant increase in flow resistance. That is why it is possible to diagnose a boiler through measuring the difference in pressures [6,7]. It can be done on a ship and the stated pressure difference can be treated as a measurement of sediment formation. This method can be used to localize impurities in the air heater ducts appearing mainly on the exhaust side. For this purpose standard boiler control equipment can be used.

Detecting sediments inside and outside tubes and also on the boiler drum using the method of heat balance requires special measurement techniques. It is not a standard for ship steam boilers to measure the mass flux of exhaust gases.

To evaluate the correct functioning of an auxiliary boiler and burner, total boiler efficiency η_B defined as

$$\eta_B = \frac{\dot{m}_1 (i_1 - i_w)}{\dot{m}_{fuel} HV + \dot{m}_{air}\, i_{air\ amb}} \tag{1}$$

is used, where:

$\dot{m}_1, i_1$ – mass flux and enthalpy of overheated steam leaving the boiler

i_w – enthalpy of water feeding the boiler at the inside boiler water heater

$\dot{m}_{fuel}$ – mass flux of fuel (required) feeding the boiler

$\dot{m}_{air}, i_{air\ amb}$ – mass flux and enthalpy of atmospheric air feeding the boiler at temperature $T_{amb} = T_0$ in Fig 1,2,3

HV – fuel quality – the amount of energy emitted during complete combustion of 1 kilogram of fuel.

Boiler efficiency relation (1) can be used if only overheated steam is produced. However, as some of the steam is cooled in the cooler and the air feeding the boiler goes through an inside boiler heater, another relation (5) should be used in the boiler diagnostic model. It can be done when additional diagnostic information i.e. exhaust signal parameters are available. To measure them, in the presented boiler diagnosing, exhaust analyzer Madur Electronics GA-20 plus was used.

3. Methodology of exhaust signal parameters determination

The GA-20 *plus* is a multi-functional flow gas analyzer. Electrochemical sensors are used for the measurement of gas concentration. The instrument can be fitted with 2 or 3 of these sensors. All analyzers are fitted with O2 and CO sensors, a third gas cell may be chosen as optional when the instrument is ordered. The following description is based on an analyzer containing 3 cells, the third one being a NO sensor [5]:

– Oxygen O_2
– Carbon monoxide CO
– Nitric oxide NO
– Carbon dioxide CO_2
– Nitrogen oxides NO_x

The first three gases (O2, CO, NO) are measured directly using electrochemical cells. The remaining components are calculated. The concentrations of oxygen and carbon dioxide are shown in percentage The concentrations of the remaining gases is are shown as follows:

– volume concentration in [ppm],
– absolute mass concentration in [mg/m^3],
– mass concentration relative to the oxygen content in [mg/m^3].

In addition, the air inlet or ambient temperature and flow gas temperature are measured. Using the measured temperatures, gas concentrations and the known fuel parameters the analyzer calculates a variety of combustion parameters such as Stack Loss - SL, Efficiency - η, Excess Air - λ, Loss through Incomplete Combustion - IL.

Temperature values and also concentration of those gas elements which are detected by independent electrochemical sensors are obtained in direct measurements. The electrochemical cell indications are proportional to the volume concentration of the detected elements expressed in [ppm] (parts per million). The following quantities are obtained by means of direct measurement:

– flow gas temperature T gas and ambient temperature, expressed in [^{o}C]
– volume concentration of CO [ppm]
– volume concentration of NO [ppm]
– volume concentration of SO_2 (or any other optional cell) [ppm]
– volume concentration of O_2 [%].

3.1. Calculating the concentration of carbon dioxide

The volume concentration of carbon dioxide (expressed in [% vol]) is not obtained by direct measurement, but is calculated on the basis of measured oxygen concentration and the CO_{2max}

parameter, characteristic for a given fuel. Formula 2 shows the formula according to which the analyzer calculates the volume concentration of CO_2 [5]:

$$CO_2 = CO_{2\max}\left(1 - \frac{O_{2meas}[\%]}{20,95[\%]}\right), \tag{2}$$

where:

20,95% – volume concentration of O_2 [%] in clean air.

3.2. Calculating the concentration of nitrogen oxides NOx

In addition to nitric oxide NO, combustion gases contain also higher oxides of nitrogen (mainly NO_2). GA-20 *plus* does not have the nitrogen dioxide sensor in its basic version, only the nitric oxide sensor NO. But it is possible to calculate the NO_2 contents on the basis of the measured NO. It is generally assumed that nitric oxide NO contained in combustion gases makes up about 95% of the total amount of nitrogen oxides NO_x. GA-20 *plus* calculates the total concentration of nitrogen oxides NO_x according to the following formula:

$$NO_x[ppm] = \frac{NO[ppm]}{0,95} \tag{3}$$

The optional sensor of the GA-20 *plus* analyzer has not got the NO sensor.

3.3. Concentration of "undiluted" carbon monoxide CO_{undil}

To calculate carbon monoxide concentration in combustion gases independent of excess air with which the combustion process is conducted, the idea of "undiluted" carbon monoxide COundil was introduced (it is also called the CO concentration calculated for 0% O_2). The value of CO_{undil} is calculated according to the formula below:

.

$$CO_{undil} = CO\,\lambda \tag{4}$$

where:

CO – volume concentration CO[ppm],

λ – excess air number.

As can be seen, the concentration of "undiluted" CO is the hypothetical concentration that would have been formed if the same amount of carbon monoxide had appeared in combustion gases when burning without excess air (where λ = 1, so O_2 = 0%).

3.4. Calculating combustion parameters

Besides calculating gas component concentrations the analyzer calculates some parameters describing the combustion process. The formulas for calculating combustion parameters are empirical ones. GA-20 *plus* analyzer calculates the parameters of the combustion process according to the principles predicted by DIN standards. The most important parameter is the amount of heat convected by combustion gases to the environment – the so-called chimney loss (stack loss) SL. Chimney loss is calculated on the basis of empirical formula known as Siegert's formula [4, 5]:

$$S_L[\%] = \left(T_{gas}\left[{}^oC\right] - T_{amb}\left[{}^oC\right]\right)\left(\frac{A_1}{CO_2[\%]} + B\right) \tag{5}$$

where:

S_L – chimney loss - the percentage of heat produced in combustion process, which is convected with the combustion gases,
T_{gas} – flow gas temperature,
T_{amb} – the temperature of the boiler inlet air (it is assumed by the analyzer to be the ambient temperature)
CO_2 – the calculated (on the basis of oxygen concentration and CO2max) amount of CO_2 in combustion gases, expressed in [% vol]
A1, B – factors characteristic for a given fuel type [5].

Based on the calculated chimney loss the analyzer estimates the efficiency of the combustion process h (don't confuse it with boiler efficiency)

$$\eta = 100\% - S_L \tag{6}$$

The above formula assumes that the only quantity decreasing combustion efficiency is chimney loss. Thus, it omits incomplete combustion losses, radiation losses etc. Such a simplification is a result of the inability to measure the size of other losses with the gas analyzer. Because of this gross simplification in the formula above, it should be remembered that the efficiency calculated in this way can not be treated as precise. However, efficiency calculated like this is very convenient as a comparable parameter when regulating the furnace. The formula, though simplified, reflects precisely the tendencies of efficiency change, thus it is possible to observe whether the efficiency increases or decreases. It is sufficient information for the regulation process. It is possible to take into account the efficiency reduction caused by incomplete combustion. This loss is represented by a quantity called the loss by incomplete combustion IL. It determines the percentage of energy loss caused by the presence of flammable gases (in this case mainly CO) in the combustion gases. The loss caused by incomplete combustion is calculated on the basis of measured CO concentration in the combustion gases according to the following formula:

$$I_L = \frac{\alpha CO[\%]}{CO[\%] + CO_2[\%]} \tag{7}$$

where:
CO, CO_2 – volume concentrations of CO and CO_2 in the combustion gases,
α – the factor specific for a given fuel.

Calculating I_L enables a correction of the previously calculated (formula 6) combustion efficiency. Then the so-called corrected efficiency η^* is calculated:

$$\eta^* = \eta - I_L \tag{8}$$

The last combustion parameter calculated by GA-20 *plus* is the excess air factor l. This factor expresses how many times the amount of air supplied to the boiler is larger than the minimum amount which is necessary to burn the fuel completely. The system calculates the l factor on the basis of the known CO_{2max} value for the given fuel and the calculated concentration of CO_2 in the combustion gases using the formula:

$$\lambda = \frac{CO_{2\max}}{CO_{2mierz}} \tag{9}$$

The above formula may be transformed with the use of formula (2) into the form:

$$\lambda = \frac{20{,}95\%}{20{,}95\% - O_2[\%]} \tag{10}$$

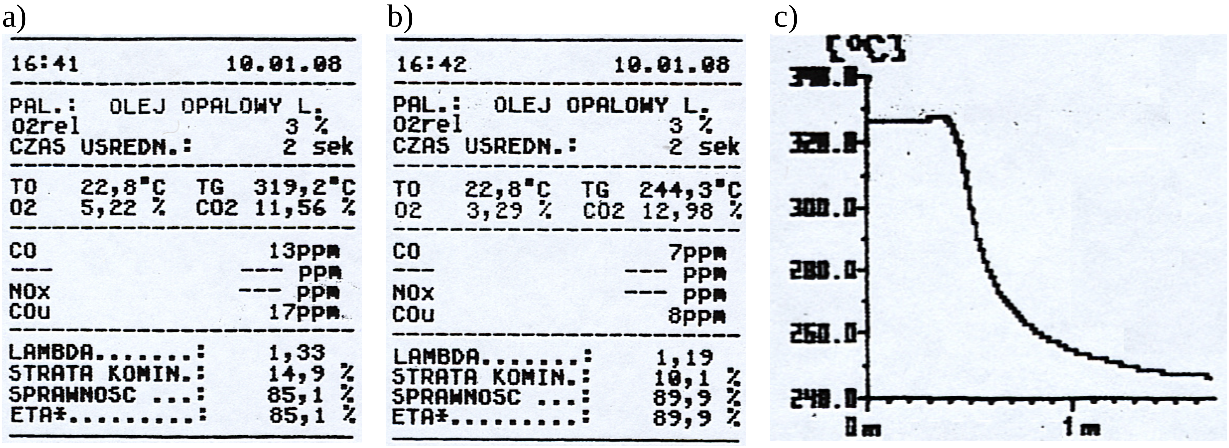
The basis for correct determination of the quantities describing the combustion process is the knowledge of fuel parameters.

4. Operational clues for starting the process of boiler diagnosis

At a voyage incorrect operation of an auxiliary boiler was stated. The analysis of the object was the quality of heat exchange in a boiler of the DJ 1250 type manufactured by Termo Trading AS [3]. Tube boiler with forced circulation installed on a container ship had the following operation parameters: operating steam pressure 0.5 MPa- set by the classificator Germanischer Lloyd for that particular boiler (maximum 0.9 MPa), temperature 180 ^{o}C, maximum steam output 1250 kg/h, heated surface 26.4 m^2. The boiler ran on L oil with the Dumphy TL burner 24 YHL did not reach the operation steam pressure (even about 0.5 MPa) and the acceptable exhaust temperature was exceeded. With the steam pressure even lower than 0.5 MPa, the boiler in a daily cycle operated in total 18-20 hours, longer than it was designed to operate in temperate climatic zone i.e.8-12 hours (it was switched on more frequently by the system of automatic regulation). At the same time excessive consumption of fuel (1.2 – 1.6 t/day) was observed, when it should have been only 0.8T/day. Steam-water installation did not show any leakages or faults. The temperature of water supplying the boiler (in the thermal box) was 75-80 ^{o}C, boiler water pH was equal to 8.3, the content of chlorides 20 ppm (all parameters were correct). On the basis of such symptoms, the boiler was stated to be unfit for further operation and the decision on the need to start diagnosing process was taken.

5.Realization of the diagnosing algorithm

Due to ambiguous symptoms of boiler faultiness additional source of diagnostic information had to be found. Besides thermal-flow parameters to check the diagnosing of the current boiler operation, exhaust signal parameters were used. Exhaust parameters are shown in Fig 1 (Fig 1a shows the situation for two operating burner nozzles, Fig 1b when only one nozzle operates, Fig 1c shows gas temperature in the outlet collector, when the second nozzle was switched off).



a)

```
16:41              10.01.08
---------------------------
PAL.:  OLEJ OPALOWY L.
O2rel                   3 %
CZAS USREDN.:         2 sek
---------------------------
TO    22,8°C  TG   319,2°C
O2    5,22 %  CO2  11,56 %
---------------------------
CO                   13ppm
---                 --- ppm
NOx                 --- ppm
COu                  17ppm
---------------------------
LAMBDA.......:       1,33
STRATA KOMIN.:       14,9 %
SPRAWNOSC ...:       85,1 %
ETA*.........:       85,1 %
```

b)

```
16:42              10.01.08
---------------------------
PAL.:  OLEJ OPALOWY L.
O2rel                   3 %
CZAS USREDN.:         2 sek
---------------------------
TO    22,8°C  TG   244,3°C
O2    3,29 %  CO2  12,98 %
---------------------------
CO                    7ppm
---                 --- ppm
NOx                 --- ppm
COu                   8ppm
---------------------------
LAMBDA.......:       1,19
STRATA KOMIN.:       10,1 %
SPRAWNOSC ...:       89,9 %
ETA*.........:       89,9 %
```

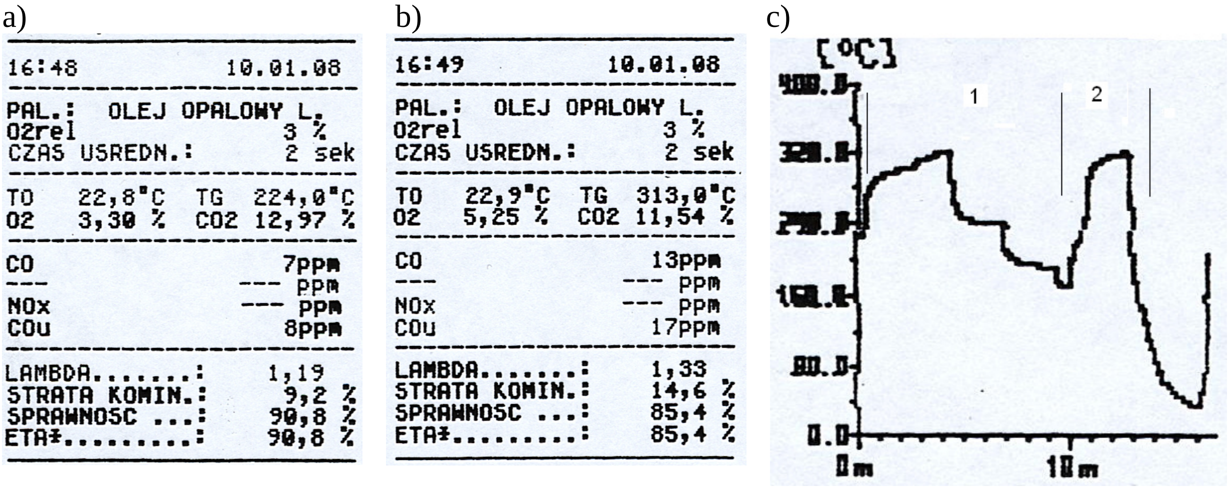
c)

Fig. 1. The results of the first boiler diagnostics:
a – with two operating burner nozzles; b –with only one nozzle; c – gas temperature in the outlet collector (when the second nozzle was switched off) TG [^{o} C] as a function of time [min.]

The presented results showed that exhaust temperature exceeded significantly the accepted values: at two operating nozzles the exhaust temperature was 319 ^{o}C, instead of the accepted 270 ^{o}C, and for one operating nozzle 244 ^{o}C instead of the accepted 180 ^{o}C [3]. The excess air coefficient λ, chimney loss and boiler efficiency were better for the operation with only one nozzle (see recordings in Fig 1). The boiler condition was considered as unfit for further operation and the diagnosing algorithm was started. Within the diagnosing process the following activities connected with fuel mixture preparation were considered necessary:

- mechanism of the air throttling valve regulator ran by a hydraulic servo was regulated (the servo is fed with fuel depending on the number of operating nozzles: one nozzle – fuel pressure at the nozzle should be equal to 0.28 MPa (but it was 0.18 MPa);two nozzles – fuel pressure at the nozzle should be equal to 0.38 MPa (but it was 0.25 MPa);
- cleanliness of the diffuser of the air supplying the boiler combustion chamber was checked, and later a second diagnostic check-up was carried out – exhaust flux parameters at the outlet collector were measured again.

The results were shown in Fig 2 (Fig 2a shows the situationwhen only one nozzle operates, Fig 2b for two operating burner nozzles, Fig 2c shows the runs of temperature changes in the automatic operation cycle-range 1 and with manual burner switching – range 2).



a)

```
16:48                10.01.08
-------------------------------
PAL.:   OLEJ OPALOWY L.
O2rel                       3 %
CZAS USREDN.:           2 sek
-------------------------------
TO     22,8°C  TG   224,0°C
O2     3,30 %  CO2  12,97 %
-------------------------------
CO                      7ppm
---                   --- ppm
NOx                   --- ppm
COu                     8ppm
-------------------------------
LAMBDA.......:        1,19
STRATA KOMIN.:         9,2 %
SPRAWNOSC ...:        90,8 %
ETA*.........:        90,8 %
```

b)

```
16:49                10.01.08
-------------------------------
PAL.:   OLEJ OPALOWY L.
O2rel                       3 %
CZAS USREDN.:           2 sek
-------------------------------
TO     22,9°C  TG   313,0°C
O2     5,25 %  CO2  11,54 %
-------------------------------
CO                     13ppm
---                   --- ppm
NOx                   --- ppm
COu                    17ppm
-------------------------------
LAMBDA.......:        1,33
STRATA KOMIN.:        14,6 %
SPRAWNOSC ...:        85,4 %
ETA*.........:        85,4 %
```

c)

Fig. 2. The results of the second boiler diagnostics after regulating the supplying fuel system, cleaning the ventilator and the diffuser of the air supplying the boiler combustion chamber

a – with one operating burner nozzle; b –with two operating nozzles; c – gas temperature in the outlet collector TG [^{o} C] : range 1 – in the automatic operation cycle, at the moment when the second nozzle was switched on and the cycle of boiler switching off by the automatic system; range 2 – manual regulation – the increase of temperature of gases as a result of manual switching on of the burner, and the decrease of temperature as a result of burner switching off

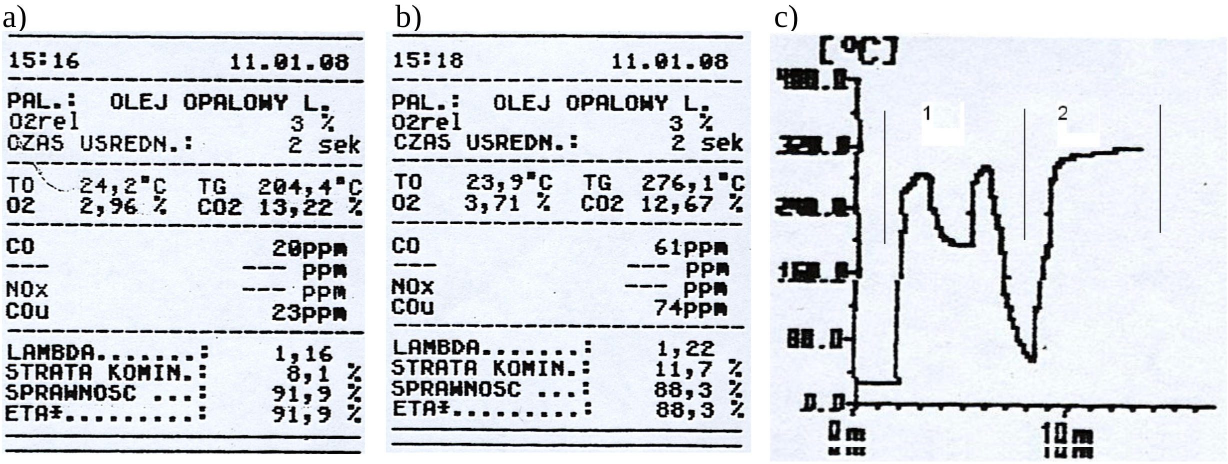
After the regulation of the supplying system, cleaning of ventilator flow ducts and the diffuser of the air feeding the boiler combustion chamber, it was stated that:

- outlet gas temperature in comparison with the first control measurements decreased only slightly by 20 K at one operating nozzle, and by 6 K at two operating nozzles,
- chimney losses also decreased only slightly, for example at one operating nozzle from10.1% to 9.2%,
- total boiler efficiency, calculated from (8) remained at approximately the same level (85.1%/85.4% at two operating nozzles, and 89.9%/90.8% at one operating nozzle)

The above indicates that after the servicing activities the burner of the boiler operates correctly, but the values of boiler efficiency, longer operation time (more frequent turning-on) and the remaining still relatively high temperatures of exhaust gases indicate deterioration of thermal conductivity of heated surfaces of the boiler.

That is why, according to the second servicing diagnosis water compartments and boiler furnace and smoke chambers were opened. A significant amounts of sediments on the surfaces of heat exchange were observed with scale on the water side and the remains of incomplete combustion of fuel (soot)on the flame side. Mechanical cleaning of fire compartment and combustion tubes was carried out, from the water side it was only washing with water under pressure without chemical treatment. After the start-up of the boiler the third diagnostics was carried out whose results are shown in Fig 3. They showed that:

– operation time of the burner in the automatic cycle decreased,
– the boiler reached a higher efficiency, closer to the designed one,
– the outlet gas temperature decreased,
– the value of the excess air coefficient decreased,
– carbon oxides content increased



a)

```
15:16                 11.01.08
PAL.:   OLEJ OPALOWY L.
O2rel                     3 %
CZAS USREDN.:           2 sek
TO    24,2°C   TG   204,4°C
O2    2,96 %   CO2  13,22 %
CO                     20ppm
---                  --- ppm
NOx                  --- ppm
COu                    23ppm
LAMBDA.......:      1,16
STRATA KOMIN.:       8,1 %
SPRAWNOSC ...:      91,9 %
ETA*.........:      91,9 %
```

b)

```
15:18                 11.01.08
PAL.:   OLEJ OPALOWY L.
O2rel                     3 %
CZAS USREDN.:           2 sek
TO    23,9°C   TG   276,1°C
O2    3,71 %   CO2  12,67 %
CO                     61ppm
---                  --- ppm
NOx                  --- ppm
COu                    74ppm
LAMBDA.......:      1,22
STRATA KOMIN.:      11,7 %
SPRAWNOSC ...:      88,3 %
ETA*.........:      88,3 %
```

c)

Fig. 3. The results of the second boiler diagnostics after cleaning the flame and smoke side and pressure washing of the water side of the boiler
a – with one operating burner nozzle; b –with two operating nozzles; c – gas temperature in the outlet collector TG [^{o} C] : range 1 – in the automatic operation cycle, at the moment when the second nozzle was switched on and the cycle of boiler switching off by the automatic system; range 2 – manual regulation – the result of manual turning on of the burner to check the increase of temperature of gases

The obtained results justified the crew’s decision to turn on the boiler o make it operate in the ship power system.

5. Conclusions and summery

In boiler operation control detection and location of faults in most cases takes place on the basis of thermal-flow diagnostic signals and thanks to visual methods. Using only these methods it is not possible to find quite a big number of faults.

The presented in this paper algorithm of ship boiler diagnosing with two diagnostic signals: thermal –flow and exhaust gases proved to be a very practical method of combining several signals for boiler diagnosing and servicing.

The process of realization of diagnostic algorithm confirmed that the cleanliness of heat exchange surfaces is reflected in different diagnostic parameters. Sediments and impurities of the boiler significantly influence the quality of heat reception, whereas the burner regulation affects the process of fuel combustion. Therefore relation (1) should be used, in the thermal-flow diagnostics and it should be verified by the results of calculations obtained from relation (5) based

on the measurements from exhaust analyzer. In the case of boiler diagnostics based on two diagnostic signals measurement possibilities can be optionally extended (in comparison to the presented ones) with the measurements of the temperature and pressure of exhaust and content of toxic compounds (e.g. nitrogen oxides) in exhaust gases.
Application of exhaust emission signal parameters for boiler diagnostics requires a particularly careful estimation of measurement and calculation precision both for the verification of thermal-flow parameters and to meet the requirements of the MARPOL Convention.

The choice of a diagnostic algorithm will always depend on the measurement availability of the boiler (its kind, construction and type) and measurement possibilities of the possessed diagnostic system.

References

[1] Adamkiewicz, A., Kołwzan K**.,** *Influence of Combustion Products on Faults in Ship Auxiliary Boilers.* Materials from the XXVIII Symposium of Ship Power Plants, Akademia Morska Gdynia, 15 – 16 listopada 2007, Gdynia 2007.
[2] Adamkiewicz A., Tomaszewski F., *Analysis Of Possibilities Of Applying Ship Boiler Maintenance Strategies With Quasidynamic Diagnostics.* 27 th International scientific conference DIAGO® 2008. Technical diagnostics of machines and Manufacturing equipment. Vysoká škola báňská - Technická univerzita Ostrava. Asociace technických diagnostiků ČR o.s., 5. - 6. February 2008, Rožnov pod Radhoštěm.
[3] Technical-operational files of a steam boiler run on liquid fuel Boiler of the *DJ 1250 type Termo Trading AS, Dunphy burner of the TL 24 YH typeL.*
[4] Kruczek S., *Boilers Construction and calculations.* Oficyna wydawnicza Politechniki Wrocławskiej. Wrocław 2001.
[5] *Flue Gas Analyzer GA-20 plus.* Operating manual 01/2003. ®MADUR Electronics. *01/2003.*
[6] Perepeczko, A., Staliński, J., *Ship boilers and steam engines*. Wydawnictwo Morskie, Gdańsk 1971.
[7] Pronobis M., Modernisation of power boilers Wydawnictwa Naukowo-Techniczne. Warszawa 2002