IS 13979 (1994): Method of calculation of efficiency of packaged steam boilers [MED 1: Boilers and Pressure Vessels]

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भारतीय मानक

पैकेजबन्द बायलरों की कार्यकुशलता परिकलन की पद्धति

Indian Standard

METHOD OF CALCULATION OF EFFICIENCY OF PACKAGED BOILERS

UDC 621·18·018 : 621·798

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Boilers Sectional Committee, HMD 1

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Boilers Sectional Committee had been approved by the Heavy Mechanical Engineering Division Council.

In the recent years, determination of the efficiency of packaged boilers has assumed great importance. Different methods are adopted for testing the performance of packaged boilers and evaluating the efficiency. The direct approach to the calculation of efficiency would be to measure the heat contained in the fuel input and to measure the heat contained in the steam output. The direct method necessitates the use of accurate instruments to measure dryness fraction and flow of steam corrected for dryness fraction. Due to lack of proper instrumentation, this method generally gives inaccurate results. Therefore, thermal efficiency is best evaluated by indirect method by calculating the total percentage losses and expressing efficiency either on the basis of Gross Calorific Value (*GCV*) or Net Calorific Value (*NCV*).

It should be clearly understood that efficiency obtained applies only to the particular load condition of the test. Even under the best conditions and when the greatest possible care is taken, it is impossible to ensure that the error of the result is less than 2 percent.

While calculating the efficiency by direct or indirect method it is necessary to clearly understand that the accuracy obtained in the indirect method is much better than that obtained in the direct method. Therefore, it is recommended that the indirect method be relied upon in preference to the direct method.

Assistance has been derived from the following standards:

BS 845 : 1972 Acceptance tests for industrial type boilers and steam generators, published by British Standards Institute.

BS 2885 : 1974 Acceptance tests on stationary steam generators of the power station type, published by British Standards Institute.

ANSI PTC 4.1 — 1974 Power test codes, steam generating units, published by the American Society of Mechanical Engineers, USA.

For acceptance tests, reference may be made to IS 8753 : 1977 'Code for acceptance tests on stationary steam generators of power station type'.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

METHOD OF CALCULATION OF EFFICIENCY OF PACKAGED BOILERS

1 SCOPE

This standard describes method of calculation of efficiency of packaged boilers by both direct and indirect methods.

1.1 For convenience, this standard has been divided into the following six sections:

Section 1 Introduction
Section 2 Method of test
Section 3 Guiding principles
Section 4 Efficiency by direct method
Section 5 Efficiency by indirect method
Section 6 Computations

1.2 Typical calculation of efficiency and maintenance of test records has been given in Annex A.

SECTION 1

2 INTRODUCTION

2.1 This standard contains instruction for testing packaged steam generating units. It is not the intent of this standard or these testing procedures to obtain data for establishing design criteria of individual parts of the overall steam generator.

2.2 Instruments and apparatus referred to herein should be studied and calibrated thoroughly because the value of the test results depends on the selection and calibration of the instruments and accuracy of the readings.

2.3 Other items of vital importance to the value of the test are the proper determination of the Gross Calorific Value (*GCV*) and other properties of the fuel used.

2.4 Advanced instrument systems, such as those using electronic devices or mass flow techniques, may be used by mutual agreement as alternate to the instruments mentioned in the standard.

SECTION 2

3 METHODS OF TEST

3.1 The purpose of this standard is to establish procedures for conducting performance tests on packaged boilers with or without superheaters to determine the efficiency.

This standard in which both direct and indirect methods are adopted applies to units burning solid fuel fired by hand, pneumatic feeders or supplied by mechanical stokers/feeders and gaseous or liquid fuel. It does not apply to dual fired or waste heat units. The standard particularly envisages boilers of small and medium capacities generally used in textile, chemical, sugar, paper and such other industries.

3.2 Definitions

For the purpose of this code, the following definitions shall apply.

3.2.1 *Heat Input*

The heat value of the fuel used by the unit during the test, based upon the gross or net calorific value as may be agreed, plus the sensible heat in fuel above ambient temperature and any heat supplied to the unit from a separate source.

3.2.2 *Heat Output*

The heat absorbed by the working fluid, steam or water.

3.2.3 *Liquid Fuels*

Petroleum fuel oils, which are burnt for generating the heat input.

3.2.4 *Packaged Boiler*

A packaged boiler is a steam or hot water boiler manufactured and supplied as a unit, ready for installation.

3.2.5 *Thermal Efficiency*

The heat output divided by the heat input.

SECTION 3

4 GUIDING PRINCIPLES

4.1 Preliminary Observation of Plant

Before conducting a test, the plant shall be observed in operation to confirm that the specified working conditions can reasonably be met.

4.2 Item on Which Agreement Shall be Reached

Before the test, the interested parties must reach agreement on the items given from **4.2.1** to **4.2.10**.

4.2.1 *General Method* — Direct or indirect.

4.2.2 Selection of the test personnel, who shall be competent, and experienced in this class of work.

4.2.3 The specific objective and the duration of the test. Observations and readings to be taken.

4.2.4 Establishment of acceptable operational conditions number of load points, and procedure to be followed during the test.

4.2.5 Supply of adequate amounts of agreed fuel and water; also the provision of adequate labour for assistance.

4.2.6 The method of obtaining fuel samples and the laboratory to make the analysis.

4.2.7 Instruments to be used, calibration of instruments, methods of measurements and equipment to be used in testing the units.

4.2.8 The allowable tolerance and limits of error in measurement and sampling.

4.2.9 The method of measuring the wetness of the steam generated, if required.

4.2.10 Corrections to be applied for deviations from design conditions for the following parameters:

a) Ambient temperature
b) Calorific value of fuel
c) Composition of fuel
d) Load conditions
e) Relative humidity
f) Feed water temperature

4.3 Acceptance Test

4.3.1 An acceptance test shall be undertaken only when the parties to the test certify that the unit is operating to their satisfaction and is, therefore, ready for test. All heat transfer surfaces, both internal and external, should be commercially clean. During the test, only the amount of cleaning shall be permitted as is necessary to maintain normal operating cleanliness.

4.3.2 More than 10 percent deviation in gross calorific value from the design value results in erroneous values and is not amenable for correcton. Therefore, in such cases, the guarantee of efficiency will be subject to a fresh agreement between the purchaser and the supplier. The variation in efficiency expected within the variation of 10 percent of gross calorific value shall be clearly spelt out beforehand.

4.3.3 Test results within $\pm$ 2 percent of the guaranteed efficiency shall be acceptable.

4.4 Preparation for Test

The entire unit shall be checked for leakage. Excessive leakage shall be corrected. During the test, the unit shall not be blown down, nor shall soot blowers be operated, other than by prior agreement. The unit under test shall be completely isolated from any water or fuel other than those passing through their respective measuring devices.

The unit under test shall be run for sufficient time to attain temperature equilibrium at test load conditions. For acceptance test, this generally requires 2 hours for packaged water tube instantaneous steam generators and 12 to 24 hours for units having appreciable amounts of refractory.

It should also be established that the water conditions are in accordance with the manufacturers' recommendations, as the condition of the feed water and of that in the boiler can affect steam wetness and thereby the accuracy of the results obtained.

If the efficiency trial is an acceptance test, before the test is started, it shall be determined whether the fuel to be fired is substantially as intended. Accurate acceptance test is dependent upon the fuel being in close agreement with the fuel for which the unit was designed. Significant deviations in fuel constituents and gross calorific value can result in appreciable deviations in heat loss and resulting efficiencies. Any departure from standard or previously specified conditions, cleanliness of heating surfaces, fuel characteristics or constancy of load shall be described clearly in the report of the test.

4.5 Test Run

4.5.1 *Preliminary Trial*

A preliminary trial shall be made for the purpose of:

a) checking the operation of all instruments.

b) training observers and other test personnel.

c) establishing proper operating condition to ensure that the requirements for the main test can be met. For the duration of the test, plant load should be controlled in such a way that the steam generator works with a steady load and with minimum fluctuation.

d) Making minor adjustments, and establishing proper combustion conditions for the particular fuel and rate of burning to be employed.

For solid fuel fired boilers, the condition and thickness of the fuel bed shall be measured and shall be as far as possible the same at the end of the test as at the start.

e) The unit shall be run for one hour before and one hour after the test duration under test conditions. Add to this the minimum duration given below and take the best readings equal to the hours specified, which shall be the test run period on which efficiency shall be computed:

1) Four hours for units fired on liquid fuels.

2) Six hours for units fired on solid fuels both with manual and mechanical stoker firing system.

The actual duration of all runs from which the final test data are derived shall be clearly stated in the test report.

4.5.2 *Frequency and Consistency of Readings*

Except for quantity measurements, the readings shall be taken at 15 minutes intervals.

Where the amount of feed water is determined from integrating instruments, a reading shall be taken every hour. If the quantities to be determined are weighed, the frequency of weighing is usually determined by the capacity of the scales, but the intervals shall be such that a total can be obtained for each hour of the test. For solid fuel, the actual quantity of fuel shall be weighed and recorded if possible every hour. Otherwise, the total weighed fuel consumed during the period of test can be recorded.

4.5.3 *Instruments and Methods of Measurement*

Instruments and methods of measurement shall be sufficiently accurate for the purposes of the test. All instruments shall comply with the applicable standards and should be checked before and if possible after the test.

Instruments should be so placed that the data recorded will be, as far as possible, a true measure of the performance of the unit under test. This is particularly important when sampling and measuring the temperature of flue gases.

4.5.4 If the parameters are stabilized and both the parties agree, then time spent on preliminary trial can be included in the test run.

SECTION 4

5 EFFICIENCY BY DIRECT METHOD

5.1 Determination of Unit Efficiency by Direct Method

This method is based on the ratio of the output to the sum of the fuel input. In this methods, inaccuracies of measurements, result in very large errors in the test results. Therefore, the indirect method is recommended for efficiency tests for acceptance.

5.2 Input Measurement

The input measurement shall be carried out according to **5.3** or **5.4** or **5.5** depending on the fuel.

5.3 Solid Fuel

5.3.1 *Quantity Measurement*

Fuel shall be weighed near the point where it is used. All loss of fuel between the point of weighment and the point of introduction to the unit shall be measured and accounted for. Weighing scales shall be calibrated prior and if possible after the trials.

Arrangement and operation of fuel weighing equipment shall preferably be such that checks can be made on consumption during each hour of run as a matter of convenience and guide.

5.3.2 *Sampling*

A representative sample of fuel shall be obtained by the following procedure.

Samples shall be collected by an experienced sampler in the presence of both parties to the agreement.

The sampling of coal for boiler test shall be from the heap utilised for trials.

Samples shall be collected at periodic intervals over the entire period of test.

Total number of samples collected shall be crushed and mixed and then 3 representative samples each of one kg shall be drawn. Two samples shall be sent to laboratory for analysis and other sealed and retained as counter sample until final results have been reviewed and declared acceptable.

5.4 Liquid Fuel

5.4.1 *Quantity Measurement*

The preference for this measurement is by means of calibrated weigh tanks. If such facilities are not available then calibrated volumetric tanks should be used.

Leakage of fuel between the point of measurement and the point of firing shall be measured and accounted for in the calculation of fuel used. All branch connections shall be blanked off. All unavoidable leakages shall be collected and accounted for.

5.4.2 *Sampling*

A drip sample shall be collected as near to the firing point as possible and analysed in laboratory previously agreed upon.

If specifically agreed in advance, gross calorific value, density at different temperatures and analysis shall be obtained from the supplier delivering the particular fuel used in test, which shall be stored in clean, empty tanks.

5.5 Gaseous Fuel

5.5.1 *Quantity Measurement*

The quantities of gaseous fuels should be measured by means of meters of the nozzle/orifice type.

The temperature and pressure at the point of volume measurement should be measured.

5.5.2 *Sampling*

Samples may be collected and agreement shall be reached on the procedure to be adopted to obtain complete analysis and true mean calorific value. For gas supplied by a statutory authority the calorific value and analysis can be obtained from those authorities.

5.6 Output Measurement

The output can be measured by measuring steam flowing out of boiler or by water going into the boiler. The steam flow measurement is generally inaccurate as the measurement of flow itself is generally dependent on the accuracy of wetness measurement. Therefore, water flow measurement is preferred.

5.7 The method of measuring output flow in connection with direct method is to measure water flow into the units as outlined below:

a) Suitable tanks and scales shall be calibrated prior to the test.

b) Volumetric tanks shall be calibrated prior to the test.

c) Water flow may be measured if agreed upon by calibrated water flow meters whose accuracy is within $\pm$ 2 percent in the range of loads measured.

d) Output steam flow to be used in the method must be obtained from feed water measurement and corrected for any addition or withdrawal of water beyond the measuring element.

e) Blowing down during test run shall be avoided. If this is not possible, the amount of heat should be determined by heat and mass balance.

f) Soot blower operation during the test run should be avoided. If this is not possible, necessary allowance should be made.

g) The drum water level should be brought back to the original level after the duration of test for finding out the water consumed.

5.8 Feed Water Temperatures

Feed water temperatures shall be measured as close to the economiser inlet and boiler inlet as possible.

Mercury in glass thermometers or resistance thermometer are acceptable for temperatures up to 400°C.

All temperature measuring devices shall be calibrated before and if possible after the test.

The heat receiving part of the instrument shall not be located in a dead pocket of the fluid, the temperature of which is subject to measurement.

5.9 Moisture in Steam

If moisture in steam at saturation temperature is to be measured it shall be with a suitable calorimeter constructed, installed and operated in a manner acceptable to both parties.

5.10 Steam and Feed Water Pressure

Pressure gauges shall be located where they will not be affected by any disturbing influences such as extremes of heat and cold or vibration and shall be located in a convenient position for reading.

Gauge connections shall be as short and direct as possible and shall have siphons.

All gauges connections shall be tight.

The gauges shall be calibrated before and if possible after the test.

SECTION 5

6 EFFICIENCY BY INDIRECT METHOD

6.1 Determination of Efficiency by Indirect Method

This method is based upon accurate and complete information which will make possible the calculations to determine all accountable losses and heat credits. The efficiency then is equal to 100 percent minus accountable losses expressed in percentage.

6.2 Data Required

Accurate data on the following items are required :

a) Temperature, pressure and quantity of any medium used for operation of the boiler.

b) Temperature of feed water entering boiler.

c) Ambient temperature.

d) Temperature of air supplied to unit for combustion.

e) Exit flue gas temperature going to stack leaving boiler/economiser/air-heater as the case may be.

f) Rate of continuous blow down, if any.

g) Flue gas analysis for CO_2.

h) Rate of fuel firing.

j) Skin temperature of the boiler surface if radiation loss is to be calculated using this value.

k) Temperature of fuel supplied at the point of entry to the unit.

m) Ultimate and proximate fuel analysis on as fired basis.

n) Combustible content in refuse from dust collector, bag filter, etc.

p) Combustible content of ash pit refuse.

q) Exposed surface area if surface radiation loss is to be independently calculated.

r) Inherent moisture and total moisture content of as fired fuel.

s) Gross calorific value and/or net calorific value of as fired fuel as required.

With the above information accurately obtained, all losses on the unit can be calculated.

6.3 Fuel Sampling and Analysis

The accuracy of the indirect method depends upon accurate sampling and evaluation of the ultimate analysis of the fuel being fired. The analysis should also break the fuel constituents into the various chemical elements which are combustible or take part in the chemical reaction in the form of ultimate analysis of the fuel. Fuel measurement and sampling is covered under **5.3**, **5.4** and **5.5**.

6.4 Refuse Sampling and Analysis

The indirect method requires the determination of heat loss due to unburnt combustibles in the refuse.

6.4.1 *Boilers Other Than Fluidised Bed Type*

6.4.1.1 In stoker fired and manually fired boilers using solid fuels, the refuse is often removed from the burning bed. Burning refuse must be quenched with water immediately upon its withdrawal from the unit.

6.4.1.2 The refuse collected from fire bed and ash chamber shall be mixed and the entire lot shall constitute the refuse available for sampling. Samples of refuse shall be collected every hour during the test. This gross sample then shall be mixed, crushed air dried and reduced to three one kg samples. Two samples shall be sent to the laboratory for analysis and the counter sample shall be retained till final results are reviewed and accepted.

6.4.2 *Fluidised Bed Boilers*

Refuse samples from an ash collecting point shall be collected, quenched, dried and mixed and 3 representative samples prepared. Two samples shall be sent for analysis and the counter sample retained till final results are reviewed and accepted. This procedure is to be followed for refuse samples from other ash collecting points also.

SECTION 6

7 COMPUTATIONS

The following computation procedures are for determining the efficiency of a unit by both the direct and indirect methods.

7.1 Efficiency by Direct Method

$$\text{Percentage efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

where

Output = Heat absorbed by the working fluid.

Input = Chemical heat in fuel. This can be expressed as *GCV* or *NCV*.

7.1.1 *Heat Output* (HO)

Heat output is equal to :

[Steam dryness fraction (SDF) × Heat absorbed per kg of steam × Actual water evaporated per hour]

+ (1 − SDF) × (Heat absorbed per kg of water × Actual water evaporated per hour)

+ (Heat absorbed per kg of water at drum pressure and temperature × Rate of blow down kg/h)

NOTES

1 In the case of superheated steam, SDF = 1 and heat absorbed by the steam should include sensible heat of super heated steam.

2 In the case of wet steam, the amount of wetness can be measured by the mutually agreed method.

7.1.2 *Heat Input* (HI) *of Fuel*

Heat input of fuel is equal to rate of fuel fired per hour multiplied by *GCV* or *NCV* as the case may be.

7.1.3 Efficiency by direct method

$$= \frac{\text{Heat output}}{\text{Heat input}} \times 100 \text{ percent}$$

This can be expressed on *GCV* or *NCV* basis.

7.2 Efficiency by Indirect Method

7.2.1 *Loss Due to Combustible in Refuse*

7.2.1.1 *Boilers other than FBC boilers*

As the refuse is pulled out from burning bed and quenched and also taken from different points, it is difficult to directly obtain the weight of refuse generated. Therefore, the quantity of refuse is to be obtained by calculations.

Heat loss due to combustible in refuse is based on

$$LR = \frac{\text{Quantity of refuse} \times \text{Calorific value of refuse}}{\text{Calorific value of fuel}} \times 100$$

which can be finally computed as

$$LR = \frac{\text{Percentage ash in fuel}}{(\text{100-Combustible matter in refuse})} \times \frac{\text{Calorific value of refuse}}{\text{Calorific value of fuel}} \times 100$$

Where *LR* can be calculated on *GCV* basis if the gross calorific value of fuel is considered and on *NCV* basis if the net calorific value of fuel is considered.

Derivation of this formula is as follows:

While calculating the efficiency of a properly tuned gaseous or liquid petroleum fired unit refuse can be considered as negligible or zero. In the case of solid fuel fired units loss due to combustibles in refuse can be found out if the quantity of refuse per kilogram of fuel fired as well as the calorific value of the refuse is known.

If

R = Quantity of refuse per kg of fuel, kg

CV_R = Calorific value of refuse, kcal/kg

A = Ash percentage in fuel by weight

R_c = Combustible percentage in refuse by weight

NCV = Net calorific value of fuel, kcal/kg

GCV = Gross calorific value of fuel, kcal/kg

LR = Loss due to combustible in refuse percentage

Then

Loss due to combustible in refuse = $R \times CV_R$ per kg of fuel.

There can be difficulties in finding out the quantity of refuse per kg of fuel fired by actual measurement. Then following assumption as given in Fig. 1 can be made.

From Fig. 1, it can be observed that the ash portion which is in the refuse

$= (100 - R_c)$ percent of the quantity of refuse.

$$= \frac{(100 - R_c)}{100} \times R \text{ kg per kg of the fuel}$$

which is equal to ($A/100$) kg per kg of fuel

$$\frac{A}{100} = \frac{(100 - R_c)}{100} \times R$$

$$R = \frac{A \times 100}{100\,(100 - R_c)} = \frac{A}{100 - R_c}$$

In other words,

$$\text{Quantity of refuse kg per kg of fuel fired} = \frac{\text{Ash percent in fuel}}{100 - \text{percentage combustible in refuse}}$$

Combustibles in ash shall be obtained by laboratory analysis of refuse.

Loss due to combustibe in refuse as a percentage of calorific value of fuel fired can be thus computed.

$$LR = R \times CV_R$$

$$= \frac{A}{(100 - R_c)} \times \frac{CV_R}{GCV \text{ or } NCV} \times 100 \text{ percent}$$

7.2.1.2 *FBC boilers*

In FBC boilers it is preferable to collect the ash at the various collecting points in measured quantities and the refuse loss calculated as given in **7.2.1.1** by obtaining the calorific value and combustible percentage as weighted average.

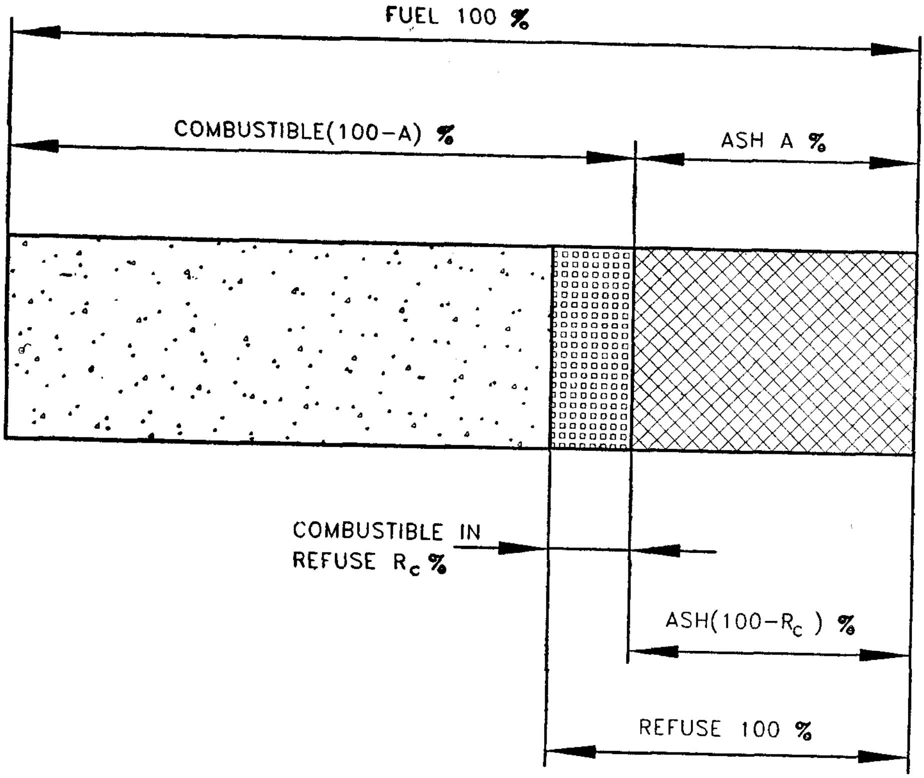

FIG. 1 COMPOSITION OF FUEL

In this case, the loss due to combustibles in fly ash should also be taken into account while calculating the loss due to combustible in refuse.

7.2.2 *Loss Due to Flue Gas (LD)*

The accountable losses on account of unabsorbed heat escaping with the flue gases can be calculated by evaluating the various components of the heat carried away through the stack. These losses can be on account of the following:

1) Dry gas loss, LD_1, and
2) Hydrogen and moisture loss, LD_2.

Thus flue gas loss $LD = LD_1 + LD_2$

7.2.2.1 *Dry gas loss*

Dry gas loss (LD_1) comprises heat lost through flue, gas of constituents other than water vapour.

Q = Dry flue gas quantity per kg of fuel, Nm^3

C_p = Specific heat of flue gas, $kcal/Nm^3$

T_S = Temperature at the outlet of last heat recovery unit, °C

T_A = Ambient temperature, °C

C_B = Carbon burnt per kg of fuel, kg

C = Carbon percentage in fuel corrected for sulphur by weight

$\% CO_2$ = Percentage carbon dioxide in flue gas (includes percent sulphur dioxide) by volume

$$\text{Dry gas loss } LD_1 = \frac{Q \times C_p \times (T_S - T_A)}{NCV \text{ or } GCV}$$

T_S and T_A are measured values. The specific heat and flue gas quantity will depend on the fuel and quantity of air used. This can be accurately got by measuring percentages of CO_2 O_2 and CO of flue gas.

In this standard we have considered evaluation by measuring CO_2 percentage of flue gas only as reasonable accuracy by this approximate method can be achieved. The logic of the calculation is as follows assuming percentage CO is negligible.

One kg of carbon produces 1·866 Nm^3 of CO_2. Let C_B be the carbon burnt per kg of fuel. Then CO_2 produced per kg of fuel would be

$$= 1{\cdot}866 \times C_B \text{ Nm}^3$$

Let volume of flue gas per kg of fuel be $= Q$

Then fraction of CO_2 per unit volume of flue gas

$$= \frac{1{\cdot}866\ C_B}{Q} \times 100$$

$$CO_2 \text{ percentage} = \frac{1{\cdot}866\ C_B}{Q} \times 100$$

$$Q = \frac{1{\cdot}866\ C_B \times 100}{\text{percentage } CO_2}$$

C_B can be evaluated by assuming all volatiles are burnt and that all carbon other than that rejected in the refuse is burnt.

C_B = Fraction of carbon in one kg of fuel – Carbon rejected in refuse per kg of fuel.

Now carbon rejected in refuse per kg of refuse

$$= \frac{\text{Calorific value of refuse}}{\text{Calorific value of carbon}}$$

Carbon rejected in refuse per kg of fuel

= (kg of refuse per kg of fuel) × (carbon in refuse per kg of refuse)

$$= \frac{R \times CV_R}{8\ 055}$$

$$C_B = \frac{C}{100} - \frac{R \times CV_R}{8\ 055}$$

$$Q = \frac{1{\cdot}866 \left(\frac{C}{100} - \frac{R \times CV_R}{8\ 055} \right)}{\text{percentage } CO_2} \times 100$$

That is

$$Q = \frac{1{\cdot}866\ C - 0{\cdot}023\ R \times CV_R}{\text{percentage } CO_2} \ \text{Nm}^3/\text{kg of fuel}$$

The correct evaluation of specific C_p would be to calculate the combined heat capacity of the component gases forming the flue gas. Various standards suggest that the value of 0·24 kcal/kg can be universally acceptable approximation. This value converted to volume basis works out to 0·33 kcal/Nm³ °C.

The value of C needs to be the equivalent carbon percentage taking the sulphur in the fuel into consideration since the measurement of CO_2 includes the quantity of SO_2.

Since SO_2 produced per kg of sulphur is approximately 3/8 times that of CO_2 produced per kg of carbon, C = Carbon (C) percent × Sulphur (S) percent.

$$\text{Dry gas loss } LD_1 = \frac{Q \times C_p \times (T_S - T_A)}{(NCV \text{ or } GCV)} \times 100$$

Substituting values of Q and R

$$LD_1 = [\ 1{\cdot}866\ (\ C + 3/8S\ ) - 0{\cdot}023\ \{\ A/(\ 100 - R_c\ )\} \times CV_R\ ] \times [\ C_p\ (\ T_S - T_A\ )/(\ NCV \text{ or } GCV\ )\ ] \times 100$$

7.2.2.2 *Loss due to hydrogen and moisture in fuel* (LD_2)

The moisture inherent in the air dried fuel evaporates, absorbs latent heat as well as sensible heat and this is lost through the stack after firing. Added to this loss on account of inherent moisture, hydrogen in fuel or burning forms water which in turn absorbs latent and sensible heat which again is lost through stack. Quantity of water formed from hydrogen is 8·936 times the quantity of hydrogen in the fuel.

If

M = Moisture percentage in fuel by weight

H = Hydrogen percentage in fuel by weight

W = Water in the flue gas, kg/kg of fuel fired

LD_2 = Hydrogen and moisture loss percentage

Now the total water content in the flue gas would be

$$W = \frac{M + 8{\cdot}936 \times H}{100} \text{ kg/kg of fuel}$$

For boilers covered by this standard, correction for free hydrogen (which is not present with oxygen in combined form) is not made as this has negligible effects on computation losses. Calculation of loss due to water vapour would be different for that on GCV and NCV basis.

a) *On GCV basis*:

Heat loss per kg of fuel = W × (Enthalpy of vapour going through stack – Enthalpy of water at T_A).

The enthalpy of water vapour going through the stack comprises the latent heat and the sensible heat including superheat.

Elaborate calculations are not required as the difference in calculated efficiency on account of this would be marginal. For calculation purpose, we can consider latent heat with 7 percent H_2O and take 0·5 kcal/kg as specific heat.

Thus heat lost per kg of fuel

$= W \times (\ 575 + 0{\cdot}5 \times T_S - T_A\ )$

percentage loss due to hydrogen and moisture in fuel LD_2

$$= \frac{W \times (\ 575 + 0{\cdot}5 \times T_S - T_A\ )}{GCV} \times 100 \text{ percent}$$

Substituting for W

$$LD_2 = \left(\frac{M + 8{\cdot}936 \times H}{100} \right) \times \left(\frac{575 + 0{\cdot}5\ T_S - T_A}{GCV} \right) \times 100 \text{ on } GCV \text{ basis}$$

b) *On NCV Basis*:

The net calorific value is obtained by deducting 540 kcal/kg of equivalent water content in one kg of fuel.

Therefore,

$$LD_2 = \frac{W \times (35 + 0{\cdot}5\ T_S - T_A)}{NCV} \times 100 \text{ percent}$$

Substituting for W

$$LD_2 = \left(\frac{M + 8{\cdot}936 \times H}{100} \right) \times \left(\frac{35 + 0{\cdot}5\ T_S - T_A}{NCV} \right) \times 100 \text{ on } NCV \text{ basis}$$

Loss due to flue gas $LD = LD_1 + LD_2$

7.2.3 *Losses Due to Radiation, Convection and Conduction* (Ls)

$$Ls_g = \frac{5\,762 \times A_1 \times (T_H - T_A)}{Q_{Ag} \times l_1} + \frac{53 \times A_2 \times Q_{Ag}}{A \times Q_{Rg} \times (l_2 + 1{\cdot}3)}$$

$$Ls_n = \frac{5\,762 \times A_1 \times (T_H - T_A)}{Q_{An} \times l_1} + \frac{53 \times A_2 \times Q_{An}}{A \times Q_{Rn} \times (l_2 + 1{\cdot}3)}$$

where

A = Total external surface area of boiler = $A_1 + A_2$ – m^2

A_1 = Water or steam backed external surface of boiler – m^2

A_2 = Gas backed external surface area of boiler – m^2

T_H = Steam or water temperature at boiler pressure – °C

T_A = Ambient temperature – °C

Q_{Ag} = Actual rate of heat input to the boiler during test based on gross calorific value of fuel – kcal/h

Q_{An} = Actual rate of heat input to the boiler during test based on net calorific value of fuel – kcal/h

Q_{Rg} = Rate of heat input at rated output of boiler based on gross calorific value of fuel – kcal/h

Q_{Rn} = Rate oi heat input at rated output of boiler based on net calorific value of fuel – kcal/h

l_1 = Thickness of insulation having a thermal conductivity of 0·043 kcal/m-h-°C on water or steam backed surface – mm

l_2 = Thickness of insulation having a thermal conductivity of 0·043 kcal/m-h-°C on gas backed surface – mm.

If insulation other than material having a thermal conductivity of 0·043 kcal/m-h-C° is used, the insulation thickness l_1 and l_3 should be multiplied by a factor of 0·043/k, where, k is the thermal conductivity.

The radiation, convection and conduction losses from a boiler depend upon its design and construction and are small as a proportion of the total losses. Therefore, the values given in Table 1 will often suffice.

Characteristics of common types of boiler are shown in Table 1 together with typical radiation, convection and conduction losses at rated output. Where the types of boiler can generally be recognised but one characteristic varies from that shown in the table, the relevant losses may be interpolated. However, where the type cannot readily be recognised, the losses should be calculated as per the expressions given above. The percentage radiation, convection and conduction losses at outputs other than the rated output can be assumed to be in inverse proportion to the ratio of the actual fuel input to the fuel input at the rated output.

7.2.4 *Other Losses*

7.2.4.1 Sensible heat loss (LSH) in refuse can be calculated by actual measurement of bulk temperature of refuse assuming specific heat as 0·16 kcal/kg °C. Alternatively, this sensible heat loss can be assumed to be a maximum of 0·5 percent considering 30 percent ash at 500°C for coal refuse. For other fuels lower values can be considered. For gaseous and liquid petroleum fuels this loss would be negligible and can be taken as zero.

7.2.4.2 Unmeasured losses (*LV*) can also be on account of unburnt gases such as *CO* and on heat lost in cooling water, etc.

For this standard unmeasured losses *LV* can be approximated between 0·1 to 0·3 percent depending upon type of equipment and fuel.

Table 1 Typical Radiation, Convection and Conduction Losses from Water Tube and Shell Boilers

(*Clause* (7.2.3)

Boiler Type	Design Details	Total Loss[1] at Rated Output Based on Gross Calorific Value, Percent
A	Water-tube and multi-tubular shell boilers with rated outputs of 8 tonnes per hour F & A 100°C and above	0·3
B	Water-tube and multi-tubular shell boilers with rated outputs of 3 tonnes per hour F and A 100°C and above but less than 8 tonnes per hour F and A 100°C	0·5
C	Water-tube and multi-tubular shell boilers with rated outputs below 3 tonnes per hour F and A 100°C	1·0
D	Brickset and dry back multi-tubular and brickhearth boilers	1·5
E	Brickset water-tube boilers with water walls	2·0
F	Brickset water-tube boilers without water walls	2·5
G	Brickset Lancashire and Cornish boilers	4·0

[1]Radiation, covection and conduction losses are combined to give the total loss as a percentage of the heat input, under stable test conditions and at the rated output.

7.2.5 Efficiency (indirect method) = 100 − Total losses. This can be expressed either on *GCV* or *NCV* basis.

ANNEX A

(*Clause* 1.2)

TYPICAL CALCULATION OF EFFICIENCY AND MAINTENANCE OF TEST RECORDS

EFFICIENCY — TRIAL

CLIENT'S NAME	:	
	:	
	:	
	:	
BOILER MODEL	:	
	:	
	:	
	:	
DATE OF TRIAL	:	
	:	
CONDUCTED BY	:	
	:	
CODE	:	INDIAN STANDARD

EFFICIENCY — CALCULATION

A. LINE DATA

a)	Boiler make		:		
b)	Boiler type		:		
c)	Boiler model & serial No.		:		
d)	Capacity	kg/h	:		
		kcal/h	:		
e)	Pressure	kg/cm^{2}g	:		
f)	Type of heat recovery unit		:		
g)	Fuel		:		
h)	Firing method		:		
j)	Is heat recovery system provided Ans Y or N		:	(Y/N)	
k)	Is dust collector after heat recovery system Ans Y or N		:	(Y/N)	
m)	Is only one ash discharging outlet provided Ans Y or N		:	(Y/N)	
n)	Is bag filter after heat recovery system Ans Y or N		:	(Y/N)	

B. OBSERVED DATA

Sl No.	*Parameters*	*Unit*	*Value*
(1)	Steam pressure in boiler	kg/cm^2 g	
(2)	Steam or water temperature at boiler pressure	°C	
(3)	Feedwater temperature at boiler inlet	°C	
(4)	Feedwater temperature at heat reco. system	°C	
(5)	Feedwater temperature at tank inlet	°C	
(6)	Ambient temperature	°C	
(7)	Temperature of air for combustion after air preheater (if provided)	°C	
(8)	Average flue gas temperature leaving boiler	°C	
(9)	Average flue gas temperature leaving the last heat recovery unit of the boiler	°C	
(10)	Actual water evaporated	kg/h	
(11)	Rate of continuous blow down	kg/h	
(12)	Average carbon-dioxide in flue gas	percent	
(13)	Actual rate of fuel firing	kg/h	
(14)	Fuel firing at rated load	kg/h	
(15)	Steam quality (Dryness fraction)	Fraction	
(16)	Quantity of refuse discharged from boiler furnace	kg/h	
(17)	Temp. of refuse discharged from boiler furnace	°C	
(18)	Quantity of refuse discharged from heat recovery system.	kg/h	
(19)	Temperature of refuse discharged from heat recovery system	°C	
(20)	Quantity of refuse discharged from dust collector	kg/h	
(21)	Temperature of refuse discharged from dust collector	°C	
(22)	Quantity of refuse discharged from bag filter or precipitator	kg/h	
(23)	Temperature of refuse discharged from bag filter or precipitator	°C	
(24)			

C. SYSTEM DATA

Sl No.	*Parameters*	*Unit*	*Value*
(25)	Water or steam backed external surface of the boiler	m^2	
(26)	Gas backed external surface of the boiler	m^2	
(27)	Specific heat of flue gas	kcal/Nm^3°C	
(28)	Thickness of insulation having a thermal conductivity of 0·043 kcal/m – h – °C on water or steam backed surface	mm	
(29)	Thickness of insulation having a thermal conductivity of 0·043 kcal/m – h – °C on gas backed surface	mm	
(30)	Fuel size	mm	

D. CONSTANT QUANTITIES

Sl No.	*Parameters*	*Unit*	*Value*
(31)	Enthalpy of steam at boiler pressure	kcal/kg	
(32)	Enthalpy of water entering boiler	kcal/kg	
(33)	Enthalpy of water entering feedwater tank	kcal/kg	
(34)	Enthalpy of water entering economiser (if provided)	kcal/kg	
(35)	Enthalpy of boiler water at working pressure	kcal/kg	
(36)	Heat absorbed per kg of steam in boiler [(31)-(32)]	kcal/kg	
(37)	Heat absorbed per kg of steam in boiler and economiser [(31)-(34)]	kcal/kg	
(38)	Heat absorbed per kg of water in boiler [(35)-(32)] [without economiser]	kcal/kg	
(39)	Heat absorbed per kg of water in boiler [(35)-(34)] [with economiser]	kcal/kg	
(40)			

E. FUEL AND REFUSE ANALYSIS

Sl No.	*Parameters*	*Unit*	*Value*
(41)	Moisture	percent	
(42)	Ash	percent	
(43)	Volatiles	percent	
(44)	Fixed carbon	percent	
(45)	Mineral matter	percent	
(46)	Carbon	percent	
(47)	Hydrogen	percent	
(48)	Nitrogen	percent	
(49)	Sulphur	percent	
(50)	Oxygen	percent	
(51)	Gross calorific value [*GCV*]	kcal/kg	
(52)	Net calorific value [*NCV*]	kcal/kg	
(53)	Average combustible matter in refuse	percent	
(54)	Average calorific value of refuse	kcal/kg	
(55)	Calorific value of refuse from boiler furnace	kcal/kg	
(56)	Calorific value of refuse from heat recovery system	kcal/kg	
(57)	Calorific value of refuse from dust collector	kcal/kg	
(58)	Calorific value of refuse from bag filter or precipitator	kcal/kg	
(59)	Combustible matter in refuse from boiler furnace	percent	
(60)	Combustible matter in refuse from heat recovery system	percent	
(61)	Combustible matter in refuse from dust collector	percent	
(62)	Combustible matter in refuse from bag filter or precipitator	percent	

F. CALCULATIONS

I. INDIRECT METHOD :

1 *LOSS DUE TO COMBUSTIBLES IN REFUSE (LR)*

NOTE — (53) and (54) to be calculated in case of boilers with more than one discharging outlet. For other boilers (53) and (54) can be obtained from Laboratory Report.

(53) = Average combustible matter in refuse percent

$$= \frac{(16)\times(59)+(18)\times(60)+(20)\times(61)+(22)\times(62)}{(16)+(18)+(20)+(22)}$$

= percent

(54) = Average calorific value of refuse kcal/kg

$$= \frac{(16)\times(55)+(18)\times(56)+(20)\times(57)+(22)\times(58)}{(16)+(18)+(20)+(22)}$$

= kcal/kg

LOSS DUE TO COMBUSTIBLES IN REFUSE [*LR*]
ON *GCV* BASIS

$$LR = \frac{(42)}{[100-(53)]} \times \frac{(54)}{(51)} \times 100$$

LR = percent

ON *NCV* BASIS

$$LR = \frac{(42)}{[100-(53)]} \times \frac{(54)}{(52)} \times 100$$

LR = percent

2 *LOSS DUE TO FLUE GASES (LD)*

ON *GCV* BASIS

$LD_1 = A \times B \times 100$ where

$$A = \left| \frac{[\,1{\cdot}866\,[\,(46)+3/8\,(49)\,]-0{\cdot}023\left[\frac{(42)}{[100-(53)]}\right]\times(54)\,]}{(12)} \right|$$

$$B = \left[\frac{[\,(27)\times[\,(9)-(6)\,]}{(51)}\right]$$

LD_1 = percent

$$LD_2 = \frac{[\,(41)+8{\cdot}936\,(47)\,]}{100} \times \frac{[\,575+0{\cdot}5\times(9)-(6)\,]}{(51)} \times 100$$

LD_2 = percent

LOSS DUE TO FLUE GAS LD = $LD_1 + LD_2$

$LD = LD_1 + LD_2$

LD = percent

ON *NCV* BASIS

$LD_1 = A \times B \times 100$ where

$$A = \left| \frac{[\,1{\cdot}866\,[\,(46)+3/8\,(49)\,]-0{\cdot}023\left[\dfrac{(42)}{[\,100-(53)\,]}\right]\times(54)]}{(12)} \right|$$

$$B = \left[\frac{[\,(27)\times[\,(9)-(6)\,]}{(52)} \right]$$

LD_1 = percent

$$LD_2 = \frac{[\,(41)+8{\cdot}936\,(47)\,]}{100} \times \frac{[\,35+0{\cdot}5\times(9)-(6)\,]}{(52)} \times 100$$

LD_2 = percent

LOSS DUE TO FLUE GAS $LD = LD_1 + LD_2$

$LD = LD_1 + LD_2$

LD = percent

3 *LOSSES DUE TO RADIATION, CONVECTION AND CONDUCTION* (*LS*)

ON *GCV* BASIS

$$LS = \frac{5\,762\times(25)\times[\,(2)-(6)\,]}{(13)\times(51)\times(28)} + \frac{53\times(26)\times(13)\times(51)}{[\,(25)+(26)\,]\times(14)\times(51)\times[\,(29)+1{\cdot}3]}$$

= percent

ON *NCV* BASIS

$$LS = \frac{5\,762\times(25)\times[\,(2)-(6)\,]}{(13)\times(52)\times(28)} + \frac{53\times(26)\times(13)\times(52)}{[\,(25)+(26)\,]\times(14)\times(52)\times[\,(29)+1{\cdot}3\,]}$$

= percent

---

4 *SENSIBLE HEAT LOSS THROUGH REFUSE* (*LSH*)

A) FROM BOILER FURNACE (A)

$LSH_1 = (16)\times 0{\cdot}16 \times [\,(17)-(6)\,]$ kcal/h

LSH_1 = kcal/h

B) FROM HEAT RECOVERY SYSTEM OUTLET

$LSH_2 = (18)\times 0{\cdot}16 \times [\,(19)-(6)\,]$ (B)

LSH_2 = kcal/h

C) FROM DUST COLLECTOR (C)

(40)=(9) if dust collector is after the Heat Recovery System otherwise (21)°C.

$LSH_3 = (20)\times 0{\cdot}16 \times [\,(40)-(6)\,]$

LSH_3 = kcal/h

D) FROM BAG FILTER (D)

(24)=(9) if bag filter is after the Heat Recovery System otherwise (23)°C.

$LSH_4 = (22)\times 0{\cdot}16 \times [\,(24)-(6)\,]$ kcal/h

LSH_4 = kcal/h

ON *GCV* BASIS

$$LSH = \frac{LSH_1+LSH_2+LSH_3+LSH_4}{(51)\times(13)} \times 100$$

LSH = percent

ON *NCV* BASIS

$$LSH = \frac{LSH_1+LSH_2+LSH_3+LSH_4}{(52)\times(13)} \times 100$$

LSH = percent

---

5 *TOTAL UNMEASURED LOSSES* (*LV*)

LV = 0·1 to 0·3 percent

ASSUMED LV VALUE = percent

II. BY DIRECT METHOD:

1 *HEAT OUTPUT* (*HO*)

$$HO = [(15) \times [(36) \text{ or } (37)] + (10)] + [[1 - (15)] \times [(38) \text{ or } (39)] \times (10)] + [[(38) \times (11)] \text{ or } [(39) \times (11)]$$

HO = kcal/h

2 *HEAT INPUT* (*HI*)

ON GCV BASIS

HI = (13) × (51)

HI = kcal/h

ON NCV BASIS

HI = (13) × (52)

HI = kcal/h

EFFICIENCY BY DIRECT METHOD

$$= \frac{\text{HEAT OUTPUT}}{\text{HEAT INPUT}} \times 100 \text{ percent}$$

= percent on GCV basis

= percent on NCV basis

RESULTS

EFFICIENCY BY INDIRECT METHOD

HEAT LOSS DATA	% ON *GCV*	% ON *NVC*
LOSS DUE TO COMBUSTIBLE IN REFUSE. (*LR*)		
LOSS DUE TO FLUE GAS (*LD*)		
LOSSES DUE TO RADIATION, CONVECTION, CONDUCTION (*LS*)		
LOSS DUE TO SENSIBLE HEAT LOST THROUGH REFUSE (*LSH*)		
UNMEASURED LOSSES (*LV*)		
TOTAL LOSSES %		

EFFICIENCY = 100 − TOTAL LOSSES
On *GCV* basis percent
On *NCV* basis percent

EFFICIENCY		METHOD ——>	DIRECT	INDIRECT
On *GCV* basis	percent		________	________
On *LCV* basis	percent		________	________

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