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BUREAU OF INDIAN STANDARDS

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भारतीय मानक **मसौदा**

औद्योगिक बॉयलरों के स्वीकार्यता परीक्षण — रीति संहिता

(आई एस 13980 का *प्रथम पुनरीक्षण*)

DRAFT *Indian Standard*

ACCEPTANCE TESTS ON INDUSTRIAL BOILERS — CODE OF PRACTICE

(*First Revision of* IS 13980)

ICS 23.020.30; 27.060.30

Boilers and Pressure Vessels Sectional Committee, MED 01	**Last date for receipt of comments: 26 Feb 2025**

FOREWORD

(*Formal clause will be added later*)

This code covers instructions for testing hot water boilers, steam boiler of industrial or commercial type. These units are defined as combination of equipment for liberating heat from conventional fuels and transferring the heat thus made available to the working fluids. For the purpose of this code such a unit will include fuel burning equipment, furnace, boiler with or without super heater, economizer and air heater, it is not the intent of this code to obtain data for establishing design criterion or individual equipment of the unit.

This standard was first published in 1995. The first revision has been taken up with a view to incorporating the modifications found necessary as a result of experience gained in the use of this standard. Also, the standard has been brought into latest style and format of Indian Standard and references to Indian Standard wherever applicable have been updated.

The instruments and apparatus referred to herein should be studies thoroughly because the value of the test results depends on the selection and application of the instruments, their calibration and the accuracy of the readings.

The higher heat value and analysis of the fuel used should be determined in accordance with relevant Indian Standards or in absence of any such standards prior agreement on determination of these to be arrived at between the parties concerned.

The code is intended as a guide for conducting tests on hot water boilers and steam boiler of industrial or commercial type, but it could not possibly detail a test applicable to every variation in the design of boiler.

Where this code does not adequately cover the equipment under test the parties concerned may mutually agree to follow procedures which will satisfy the intent of this code.

Advance instruments systems such as those using electronic devices or mass flow techniques may be used by mutual agreement as alternates to the recommendations set herein.

In reporting the result of a test or analysis made in accordance with this standard, is to be rounded off, it shall be done in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Draft *Indian Standard*

ACCEPTANCE TESTS ON INDUSTRIAL BOILERS — CODE OF PRACTICE

(*First Revision*)

SECTION 1 GENERAL

1 SCOPE

1.1 Purpose

The purpose of this code is to establish procedures for conducting acceptance tests on industrial steam generating units and hot water boilers of the water tube type with capabilities larger than 25 tonnes F&A 100 °C of steam per hour, generally as envisaged in Fig. 1. The standard applies to units burning solid fuels fired by hand or by mechanical stokers or pulverized fuel firing equipment as well as liquid or gaseous fuel. It does not apply to packaged boilers which are, to a large extent, shop assembled. It also does not apply to dual fired or waste heat units which require a more specialized form of dry and wet gas heat loss measurement. The code lays the procedure to determine:

a) Gross thermal efficiency;
b) Rating of the units; and
c) Other relating operating parameters such as steam temperature and control range.

NOTE — F & A means the amount of steam generated from water at 100 °C to saturated steam at 100 °C.

1.2 Methods of Testing

Instructions are given for two acceptable methods of testing steam boilers to determine efficiency. One method is the direct measurement of input and output, hereinafter referred to as the input-output method. The other method is the direct measurement of heat losses and is hereinafter referred to as the heat loss method. The method followed in conducting the test shall be clearly defined in the report. The generating units shall preferably be tested by heat loss method, as the errors involved are too large to control in large installation by input-output method.

1.2.1 The input-output method requires the accurate measurement of the quantity and high heat value of the fuel, heat credits and the heat absorbed by the working fluid or fluids.

1.2.2 The heat loss method requires the determination of losses, heat credit and ultimate analysis and high heat value of the fuel. To establish the capacity at which the losses occur it is necessary to measure either the input or output.

1.2.3 Throughout this code input is defined as high heat value of the fuel plus the heat added from other sources such as sensible heat in fuel and air, heat atomizing steam, as applicable.

1.2.4 The output is defined as the heat absorbed by the working fluid or fluids.

1.3 Capacity

Rating of steam boilers is defined as the evaporation in kg of steam per hour delivered at defined operating parameters at which the efficiency is guaranteed or kW absorbed by the working fluid or fluids. Rating of hot water heaters is defined on the heat absorbed by water and the heat of any steam that may be generated (kW).

1.4 Efficiency

The efficiency of steam boiler determined within the scope of this code is the gross thermal efficiency and is defined as the ratio of heat absorbed by the working fluid or fluids to the heat input as defined in **1.2.3**. This definition disregards the equivalent heat in the power required by the auxiliary apparatus external to the envelope (*see* Fig. 1).

1.4.1 Efficiency for the two methods is expressed by the following equations:

a) Input-Output Method

$$\text{Efficiency (percent)} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{\text{Heat absorbed by working fluid or fluids}}{\text{Heat in fuel} + \text{Heat credits}} \times 100$$

b) Heat Loss Method

$$\text{Efficiency (percent)} = 100 - \frac{\text{Heat losses}}{\text{Heat in fuel+Heat credits}} \times 100$$

1.5 Abbreviated Efficiency Test

It is recognized that for acceptance testing of small heating and industrial steam boiler a simplified test is the only practical approach. An abbreviated efficiency test considered only the major losses, and the chemical heat in the fuel as input. Although the abbreviated tests procedure ignores the minor losses, and the heat credits, the test procedures for obtaining the major items will be the same as specified, for the sizes of boiler units and therefore, the contents of this code should be read and understood prior to running a simplified efficiency test. Where heat losses are to be adjusted to compensate for variations in fuel, or changes in inlet air temperature, as would be done in verifying an efficiency guarantee, the procedure given in Section 7 for collection of standard or guarantee conditions of the code should be followed. Figure 2 gives relationship between input, output, heat credits and losses.

1.6 Fuels

Both the heat loss and the input-output method of this code apply to boiler units operating with either solid, liquid or gaseous fuels.

1.6.1 This code will apply only when tests are run using a single fuel.

1.6.2 Where tests have to be made using a combination of fuels, it will be necessary to establish test procedure and calculations based on guiding principles and general intent of this code.

1.7 Test Reports

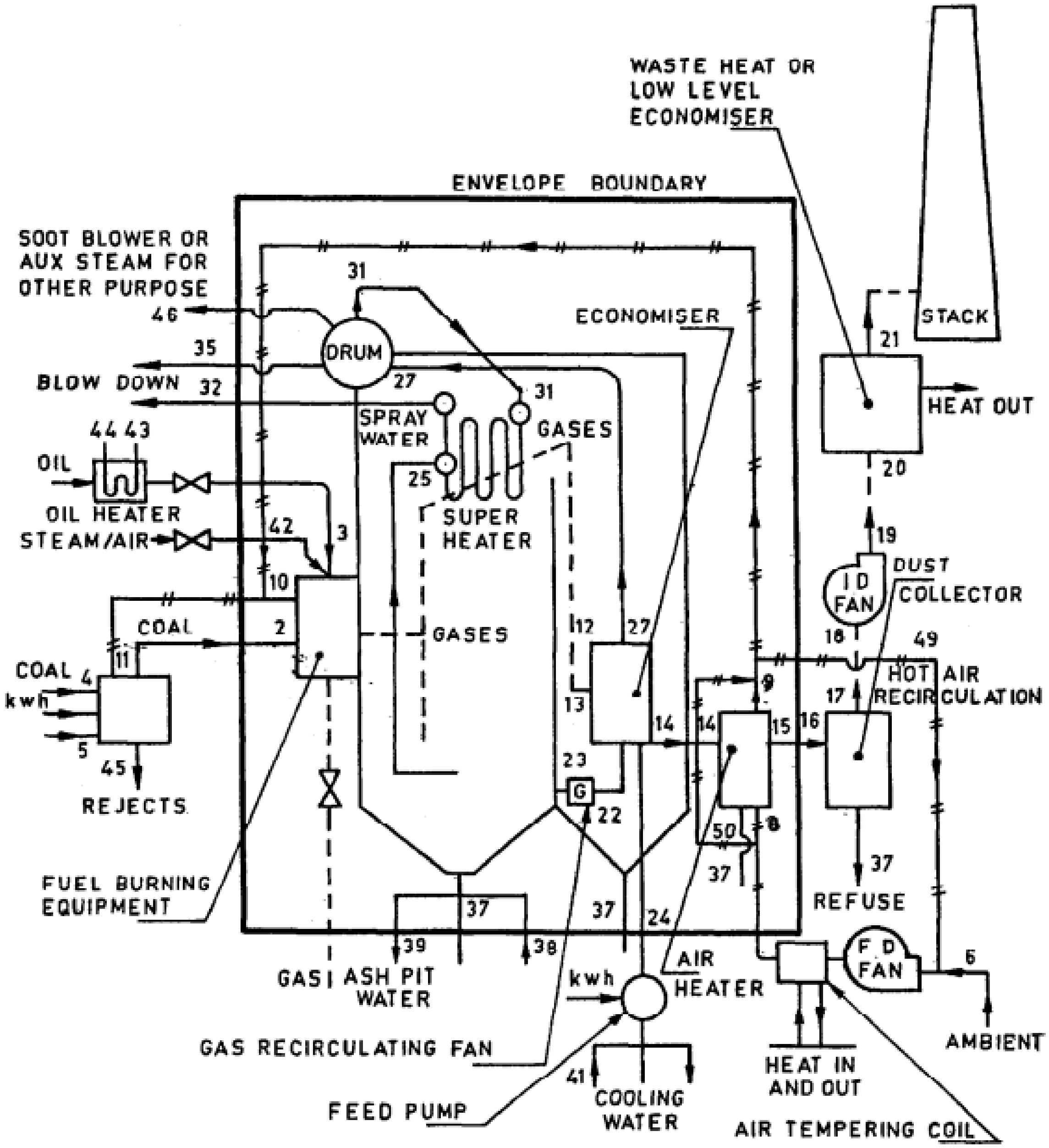
A typical summary sheet for abbreviated efficiency test, and other parameters are given in this section.

2 REFERENCES

The standard listed below contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below:

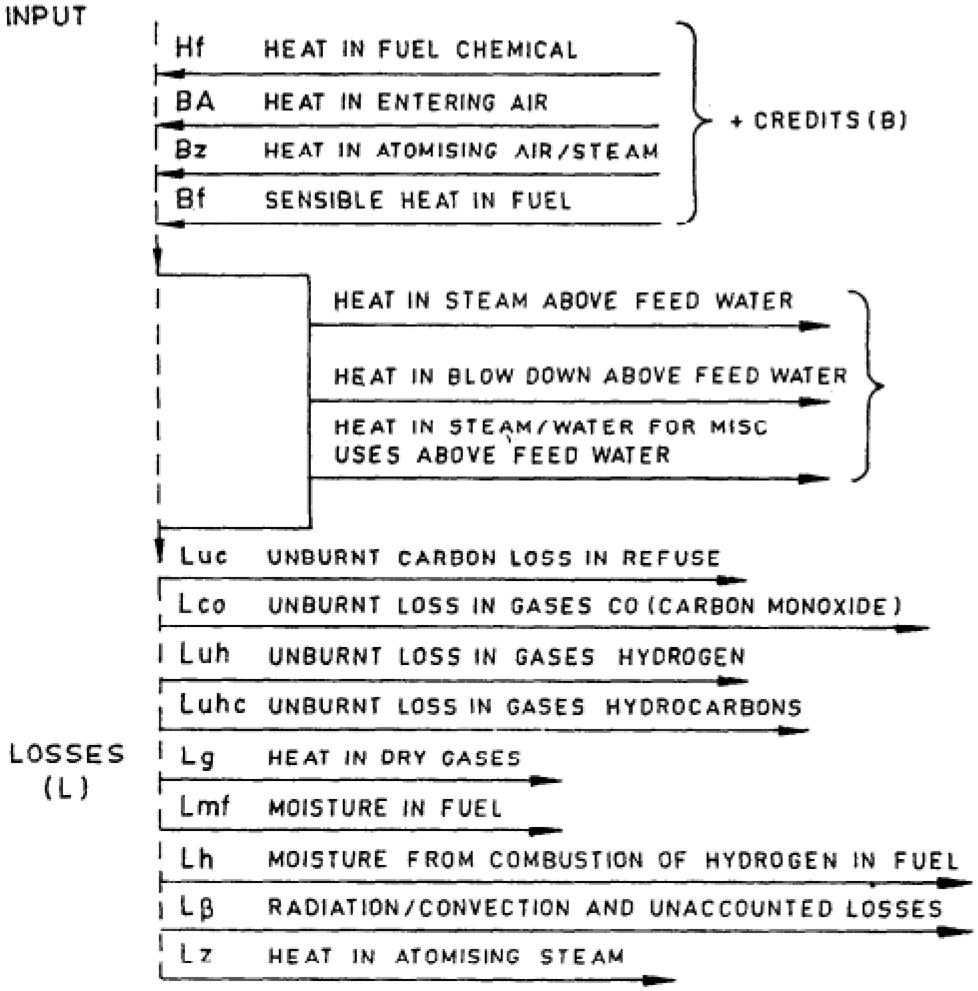
IS No.	*Title*
IS 436 (Part l/Sec1) : 2024	Methods for sampling of coal and coke Part 1 Sampling of coal Section 1 Manual sampling (*second revision)*
IS 1350	
(Part 1) : 1984	Methods of test for coal and coke : Part 1 proximate analysis (*second revision)*
(Part 2) : 2022/ISO 1928 : 2020	Method of test for coal and coke : Part 2 determination of gross calorific value (*third revision)*
(Part 3) : 2022/ISO 334 : 2020	Methods of test for coal and coke : Part 3 determination of total sulphur — Eschka method (*second revision)*
(Part 4/Sec 1) : 2024	Coal and coke — Methods of test : Part 4 Ultimate analysis Section 1 Determination of carbon and hydrogen (*second revision)*
(Part 4/Sec 2) : 1975	Methods of test for coal and coke : Part 4 Ultimate analysis Section 2 Determination of nitrogen (*first revision*)
(Part 5) : 2017	Methods of test for coal and coke : Part 5 Determination of special impurities (carbon present as carbonate, chlorine and phosphorus) (*second revision*)
IS 1447 (Part 1) : 2021	Methods of sampling of petroleum and its products Part 1 Manual sampling (*second revision*)
IS 1448 and parts	Methods of test for petroleum and its products

IS 3624 : 1987	Pressure and vacuum gauges (*second revision*)
SP 26 : 2021	Steam Tables in SI Units (*third revision*)



NOTE — The location numbers given in this figure refers to various clauses in the text.

FIG. 1 STEAM BOILER



Gross Thermal Efficiency (Percent) = $\eta_g \ \% = \frac{Output}{Input} \times 100 = \frac{Input-L}{Hf+B} \times 100$

Heat Balance Hf + B = Output + L

= $\eta_g \ \% = \left(1 - \frac{L}{Hf+B}\right) \times 100$

FIG. 2 HEAT BALANCE OF STEAM BOILER

SUMMARY SHEET FOR ABBREVIATED EFFICIENCY TEST

TEST NO.	BOILER NO.		DATE	
OWNER	LOCATION			
CONDUCTED BY	DURATION			
BOILER MAKE AND TYPE	TEST-RATING			
STOKER TYPE AND SIZE				
PULVERIZER TYPE AND SIZE			BURNERS, TYPE AND SIZE	
FUEL USED	MINE	STATE	COUNTRY	SIZE AS FIRED

Pressure and Temperatures

Item No.	*Description*	*Unit*	*Observation*
1.	Steam pressure in drum	MPa or bar	
2.	Steam pressure at super heater outlet	MPa or bar	
3.	Steam temperature at super heater outlet/water temperature at heater outlet[1)]	°C	
4.	Feed temperature entering (Economizer) (Boiler)/Water heater[1)]	°C	
5.	Steam quality dryness fraction or moisture	ppm	
6.	Air temperature around boiler (Ambient)	°C	
7.	Temperature of air entering the unit (This is the reference temperature)	°C	
8.	Temperature of fuel	°C	
9.	Temperature of gas leaving boiler/Economizer / Air heater/ Water heater[1)]	°C	

[1)] For water heaters only.

Unit Quantities

10.	Enthalpy of saturated liquid	kcal/kg or kJ/kg	
11.	Enthalpy of steam (superheated/saturated)/Water[1)]	kcal/kg or kJ/kg	

12.	Enthalpy of feed water to boiler/ Economizer/Water heater[1)]	kcal/kg or kJ/kg	
13.	Heat absolute/kg of steam/water[1)] (Item 11 – Item 12)	kcal/kg or kJ/kg	
14.	Blow down	kg/s	
15.	Heat absolute/kg of blow (Item 10 – Item 12 or Item 11 – Item 12)[1)]	kcal/kg or kJ/kg	
16.	Dry refuse (ash pit and fly ash)/kg fuel fired	kg/kg	
17.	Heat value/kg of refuse (weighted average)	kcal/kg or kJ/kg	
18.	Rate of feed	kg/s	
19.	Rate of evaporation/output[1)] (Item 18–Item 14)	kg/s	
20.	Rate of fuel firing (as fired weight)	kg/s	
21.	Total heat input Item 20 × Items 34, 45 or 55	kcal/or kJ/s	
22.	Heat output in blowdown Item 14 × Item 15	kcal/or kJ/s	
23.	Total heat output = (Item 19 × Item 13)+Item 22	kcal/or kJ/s	
24.	Dry kg/kg of fuel fired	kg/kg	

Flue Gas Analysis (Boiler/Economizer/Air heater Outlet)

25.	CO_2	% by volume	
26.	CO	% by volume	
27.	O_2	% by volume	
28.	N_2 (by difference)	% by volume	
29.	Excess air	%	

Fuel Data Coal as Fired (Proximate Analysis)

30.	Moisture	% by volume	
31.	Ash	% by volume	
32.	Volatile matter	% by volume	
33.	Fixed carbon (by difference) TOTAL	% by volume 100%	
34.	Higher heat value (as fired)	kcal/kg or kJ/kg	
35.	Ash softening temperature in semi-reducing atmosphere	°C	

Coal or Oil as Fired (Ultimate Analysis)

36.	Carbon	% by volume	
37.	Hydrogen	% by volume	
38.	Oxygen	% by volume	
39.	Nitrogen	% by volume	
40.	Sulphur	% by volume	
41.	Ash	% by volume	
42.	Moisture	% by volume	
	TOTAL	%	

1) For water heaters only.
2) Not required for efficiency test.

Item No.	*Description*	*Unit*	*Observation*
43.	Flash point 1)	°C	
44.	Specific gravity degree API 1)	Degree API	
45.	Valve (as fired)	kcal/kg or kJ/kg	

Gas

46.	C (Carbon monoxide)	% by volume	
47.	CH_4 (Methane)	% by volume	
48.	C_nH_{2n}	% by volume	
49.	C_nH_{2n-2}	% by volume	
50.	H_2S	% by volume	
51.	H_2	% by volume	
52.	O_2	% by volume	
53.	CO_2	% by volume	
54.	N_2 (by difference)	% by volume	
55.	Valve (as fired)	kcal/kg or kJ/kg	
56.	Efficiency of the unit (percent) Input-Output method	$\frac{\text{Item 23}}{\text{Item 21}} \times 100$	

Efficiency by Heat Loss Method

	Unit	*Unit*
	kcal/kg or kJ/kg A.F. Fuel	% of A.F Fuel

57.	Heat loss due to dry gases		
58.	Heat loss due to moisture in fuel		
59.	Heat loss due to water from combustion of hydrogen		
60.	Heat loss due to combustion in fuel		
[2]61.	Heat loss due to radiation and unmeasured losses		
62.	Total losses		
63.	Gross thermal efficiency (100 – Item 62)		

[1] Not required for efficiency test.
[2] To be agreed before test.

Boiler Test Code

Calculation Sheets for Abbreviated Efficiency Test

<table>
<tr><td colspan="2"><i>Owner</i></td><td><i>Test No.</i></td><td><i>Boiler No.</i></td><td><i>Date</i></td></tr>
<tr><td>Item No. Referred Earlier</td><td>Description</td><td colspan="3">Method of Calculation</td></tr>
<tr><td>16.</td><td>Dry refuse/kg fuel fired</td><td colspan="3">$$\frac{\%\ \text{Ash in coal as fired}}{100 - \%\ \text{combustibles in refuse sample}}$$
(NOTE — If flue dust and ash pit refuse differ materially in combustible content, they should be estimated separate. see Section 7)</td></tr>
<tr><td></td><td>Carbon equivalent in dry refuse/kg of fuel as fired (say item 16A)</td><td colspan="3">$$\frac{\text{Item 16} \times \text{Item 17}}{8\ 078} (\text{kcal/kg})$$
$$\frac{\text{Item 16} \times \text{Item 17}}{33\ 820} (\text{kJ/kg})$$</td></tr>
<tr><td>24.</td><td>kg dry gas/kg of fuel as fired</td><td colspan="3">$$= \frac{11\ \text{CO2}+8\text{O2}+7(\text{N2}+\text{CO})}{3\ (\text{CO2}+\text{CO})} \times (\text{kg Carbon} \frac{\text{burned}}{\text{kg}}\ \text{of fuel as fired} + \frac{S}{2.67})$$
$$= \frac{11 \times \text{Item 25} + 8 \times \text{Item 27} + 7\ (\text{Item 28} + \text{Item 26})}{3 \times (\text{Item 25} + \text{Item 36})}$$
$$\times \left(\frac{Item\ 36 - Item\ 16A}{100} + \frac{Item\ 40}{2.67} \right)$$</td></tr>
<tr><td>29.</td><td>Excess air</td><td colspan="3"></td></tr>
</table>

		$= 100\times\frac{\text{O2}-\frac{\text{CO}}{2}}{0.268\ 2\ \text{N2}-(\text{O2}-\frac{\text{CO}}{2})}$ $= 100\times \frac{\text{Item 27}-\text{Item}\frac{26}{2}}{0.268\ 2\ (\text{Item 28})-(\text{Item 27}-\text{Item}\frac{26}{2})}$
57.	Heat due to dry gases/kg fuel as fired Expressed as percent of higher heat value	kg Dry gas/kg of fuel fired× C_p (Item 9 – Item 7) = Item 24 × 0.24 × (Item 9 – Item 7) in kcal or Item 24 × 100 (Item 9 – Item 7) kJ $\frac{\text{Item 57}}{\text{Item 34 or 45}} \times 100$
58.	Heat loss due to moisture in fuel/kg of fuel fired Expressed as percent of higher heat value	Kg H_2O/kg fuel as fired × [Enthalpy of vapour at 0.07 kg/cm^2 absolute temperature of gas (tg) leaving unit) – (Enthalpy of liquid at T_{fuel})] = $\frac{\text{Item 42}}{100} \times \left[\left(\text{Enthalpy of vapour at 0.07}\frac{\text{kg}}{\text{cm}^2}\text{ absolute temperature as in Item 9}\right) - (\text{Enthalpy of liquid at temp. Item 8})\right]$ $= \frac{\text{Item 58}}{\text{Item 34 or 45}} \times 100$
59.	Heat loss due to water from combination of hydrogen/kg of fuel as fired Expressed as percent of higher heat value	$\frac{\text{H}_2}{100}\text{ fuel as fired } \times 9 \times \left[\text{Enthalpy of vapour at 0.07}\frac{\text{kg}}{\text{cm}^2}\text{ absolute, temperature of gas}\right) - (\text{Enthalpy of liquid at T fuel})$ $= \frac{\text{Item 37}\times 9}{100} \times [\left(\text{Enthalpy of vapour at 0.07}\frac{\text{kg}}{\text{cm}^2}\text{absolute, temperature as in Item 9}\right) - (\text{Enthalpy of liquid at temperature, Item in 8})$ $= \frac{\text{Item 59}}{\text{Item 34 or 45}} \times 100 = \cdots$
60.	Heat loss due to combustible in refuse/kg of fuel as	$\frac{\text{Item 16} \times \text{Item 17}}{\text{Item 34}} \times 100 = \ldots\ldots$

	fired. Expressed as percent of higher heat value of fuel	
61.	Heat loss due to radiation and unmeasured losses	
62.	Total losses	
63.	Gross thermal efficiency	100 – Item 62

SECTION 2

SYMBOLS AND THEIR DESCRIPTIONS

3 SYMBOLS

A list of symbols for use in the computation is included in this section. The chemical symbols are also used in some cases as subscripts.

3.1 With so many quantities and points of reference involved, it has been found impractical to restrict the Code to the use of single subscripts. Where both letter and numerical subscripts are used, the numerical one is given second; for example W_{se32}. This symbol means "W" for kilograms, "s" for steam, "*e*" for elapsed time and "W_{se32}" then should be read kilograms of steam per hour at location 32 in Fig. 1 (Super heater outlet).

3.2 Numerical Subscripts

The diagram of a steam boiler unit, shown in is intended to serve as a key to numerical subscripts employed throughout this code to indicate the location to which reference is made. Many large installations will have all of the apparatus shown. Small industrial and commercial installations will be less elaborate. Even though the apparatus may not be in exactly the same relative position, it is believed that the numerical identification shown on this line diagram will prove applicable and helpful.

3.2.1 In the case of chemical symbols, the numerical subscripts refer to the number of atoms and not to the key diagram. The standard chemical symbols are used throughout this code and are so well known that it is considered unnecessary to enumerate all of them.

3.3 Symbols and Description

Symbol	*Description*	*Unit*
A	Air	—
A'	Dry air	—
A.F.	As fired	—
API gr	Gravity of the fuel based on the API scale	deg API
A^{θ}	Theoretical quantity of air required for complete combustion of the fuel	kg per kg of kF.2) fuel
A_X	Excess air is the actual quantity of air used minus the theoretical air required divided by the theoretical air, and expressed as a percentage	Percent
a	Ash content of the fuel	kcal/kJ
B	Heat credits added to the steam generator in the form of sensible heat	kcal or kJ/s
B_{Ae}	Sensible heat supplied by the entering air (rate)	kcal or kJ/s
$B_{A'e}$	Sensible heat supplied by the dry entering air (rate)	kcal or kJ/s
B_e	Heat credits added to the steam generator in the form of sensible heat (rate)	kcal or kJ/s
B_{fe}	Sensible heat supplied with fuel (rate)	kcal or kJ/s
$\underline{B}_{mAe}$	Heat supplied from the moisture entering with the inlet air (rate)	kcal or kJ/s
B_{ze}	Heat supplied by the atomizing steam (rate)	kcal or kJ/s
b	Burned	—
C	Weight of carbon per kg of "as fired" fuel — (laboratory analysis)	kg/kg of A.F.
C_b	Weight of carbon burned per kg of "as fired" fuel	Percent
CO	Percent carbon monoxide per volume of dry flue gas. Determined by flue gas analysis	Percent
CO_2	Percent carbon dioxide per volume of dry flue gas. Determined by flue gas analysis	Percent
CO_{2HC}	The weight of carbon dioxide formed from burning the hydrocarbon in the dry flue gas	kg/kg of dry gas
c	Specific heat	kcal/kg°C or kJ/kg°C
c_p	Specific heat at constant pressure	kcal/kg°C or kJ/kg°C
$c_{pA'}$	Mean specific heat of dry air at constant pressure	kcal/kg°C or kJ/kg°C
c_{pf}	Means constant pressure specific heat of the inlet fuel determined for temperature difference between fuel inlet temperature and reference temperature	kcal/kg°C or kJ/kg°C
c_{pG}	Mean specific heat of the flue gas	kcal/kg°C or kJ/kg°C
c_{ps}	Specific heat of steam	kcal/kg°C or kJ/kg°C
D	Standard or guarantee	—

Symbol	*Description*	*Unit*
d	Fuel gas refuse (dust)	—
d'	Dry flue gas refuse (dust)	—
E	Energy	kcal or kJ
e	Elapsed time	h or s
f	Fuel	—
G	Fuel gas	—
G'	Dry flue gas	—
g	Gross	—
H	Weight of hydrogen exclusive of that in moisture per kg of "as fired" fuel (laboratory analysis)	kg/kg of A.F. fuel
H_2	Hydrogen content of the flue gas (laboratory analysis)	m^3/m^3 of the dry gas
HC	Percent hydrocarbons per volume of dry flue gas (laboratory analysis)	Percent
$H_{d'p'}$	High-heat value of total dry refuse (laboratory analysis)	kcal/kg of refuse of kJ/kg of refuse
H_{fp}	High-heat value of the fuel at constant pressure,	kcal/kg or kJ/kg
H_{fv}	High-heat value of the fuel at constant volume	kcal/kg or kJ/kg
H_f	High-heat value (chemical heat) of the fuel on the "as fired" basis (laboratory analysis)	kcal/kg or kJ/kg
H'_f	High-heat value (chemical heat) of the fuel on a dry basis (laboratory analysis)	kcal/kg or kJ/kg
H_r	High-heat value (chemical heat) of the pulverizer rejects (laboratory analysis)	kcal/kg or kJ/kg
h	Enthalpy	kcal/kg or kJ/kg
H_{RW}	Reference enthalpy of entering moisture. It is the enthalpy of the liquid at the reference temperature.	kcal/kg or kJ/kg
h_{Rv}	Reference enthalpy of entering vapour. It is the enthalpy of the saturated vapour at the reference temperature	kcal/kg or kJ/kg
h_s	Enthalpy of steam	kcal/kg or kJ/kg
h_v	Enthalpy of the vapour	kcal/kg or kJ/kg
h_w	Enthalpy of the liquid	kcal/kg or kJ/kg
i	Isentropic process	—
K	Heat content per cubic metre of dry flue gas (laboratory analysis)	$kcal/m^3$ of dry gas or kJ/m^3 of dry gas
k_{Wh}	Electrical energy	Kwh or W/s
L	Heat loss from the steam generator which could have been added to the working fluid	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_{CO}	Heat loss due to the formation of carbon monoxide	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
$L_{G'}$	Heat loss due to heat in dry flue gas	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_η	Heat loss due to moisture from burning hydrogen	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel

Symbol	*Description*	*Unit*
L_{mA}	Heat loss due to moisture in the combustion air	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_{mf}	Heat loss due to moisture in the "as fired" fuel	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_p	Heat loss due to radiation to ash pit, sensible heat in slag and, if applicable, latent heat of fusion of slag	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_r	Heat loss due to heat in pulverizer rejects	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_{UC}	Heat loss due to unburned carbon	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_{UH}	Heat loss due to unburned hydrogen	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_{UHC}	Heat loss due to unburned hydrocarbons	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
L_β	Heat loss due to radiation and convection	kcal/kg of A.F. fuel or kJ/kg of A.F. fuel
M	Molecular weight of any substance	kg/mole
M_{HC}	Molecular weight of hydrocarbons	kg/mole
m	Moisture content	Percent by weight
mf	Moisture in fuel	kg of water per kg of A.F fuel
m_p	Moisture in pit refuse	kg of water per kg or pit refuse
N	Weight of nitrogen per kg of "as fired" fuel (laboratory analysis)	kg of water per kg or pit refuse
N_2	Percent nitrogen per volume of dry fuel gas. Determined by subtracting the sum of the measured quantities CO_2 , O_2 and CO from 100	Percent
n	Net	—
O	Weight of oxygen per kg of "as fired" fuel (laboratory analysis)	kg per kg of A.F. fuel
O_2	Percent oxygen per volume of dry flue gas. Determined by flue gas analysis	Percent
P	Pressure	—
P_A	Atmospheric pressure	kgf/cm^2 or Mpa
P_f	Pressure of gaseous fuel at the primary measuring element	kgf/cm^2 or Mpa
P_{mA}	The partial pressure or vapour pressure of the moisture in the air	kgf/cm^2 or Mpa
P_{mG}	The partial pressure or vapour pressure of the moisture in the flue gas	kgf/cm^2 or Mpa
P_s	Pressure of the steam measured at the point indicated by the appropriate numerical subscript (Fig. 1)	kgf/cm^2 or Mpa
P_w	Pressure of the water measured at the point indicated by the subscript number (Fig. 1)	kgf/cm^2 or Mpa
P	Ash pit refuse	

Symbol	*Description*	*Unit*
p	Ash pit	
p'	Dry pit refuse	Kg
Q_{fe}	Quantity of gaseous fuel fired (rate) — based on 1.033 kg/cm^2 and 20°C	M^3/h or m^3/s
R	Reference	
R_u	Universal gas constant (1 545)	—
r	Pulverizer rejects	kg
S	Weight of Sulphur per kg of "as fired" fuel (laboratory analysis)	kg/kg of A.F. fuel
SO_2	Percent Sulphur dioxide per volume of dry flue gas (laboratory analysis)	Percent
s	Steam	—
T	Temperature Kelvin	K
t	Temperature degree Celsius	° C
t_{RA}	Reference air temperature is the basic temperature to which sensible heat losses and credits are compared for efficiency computations	° C
t_A	Temperature of air	° C
t_f	Temperature of fuel	° C
t_G	Temperature of fuel gas	° C
t_s	Temperature of steam	° C
t_w	Temperature of the water	° C
U	Unburned	—
V	Volume of any substance — substance indicated by subscript	m^3
v	Vapour	—
W	Weight	kg
W_A	Weight of moist air supplied per kg of "as fired" fuel	Kg/kg of A.F. fuel
$W_{A'}$	Weight of dry air supplied per kg of "as fired" fuel	Kg/kg of A.F. fuel
W_{Ae}	Weight of air supplied (rate)	Kg/h or kg/s
$W_{A'e}$	Weight of dry air supplied (rate)	Kg/h or kg/s
$W_{G'}$	The weight of dry gas leaving unit per kg of "as fired" fuel	Kg/kg of A.F. fuel
$W_{d'p'}$	Weight of dry refuse per kg of "as fired" fuel	Kg/kg of A.F. fuel
$W_{d'p'e}$	Weight of dry refuse collected (rate)	Kg/h or kg/s
W_{fe}	Weight of fuel fired (rate) either solid or liquid	Kg/h or kg/s
$W_{G'}N_2$	Weight of nitrogen in dry gas per kg of "as fired" fuel	Kg/kg
$W_{mA'}$	Weight of moisture per kg of dry air	Kg/kg or dry air
W_{se}	Weight of steam per hour flowing at any location identified by appropriate numerical subscript	Kg/kg or kg/s
W_{wc}	Weight of water (rate)	Kg/h or kg/s
W_z	Weight of atomizing steam per kg of "as fired" fuel	Kg/kg of A.F. fuel
w	Water	—
X	Excess	—
x	Auaxiliary	—

Symbol	*Description*	*Unit*
z	Atomizing steam	—
B	Radiation and convection	—
γ	Gas specific weight at 20°C and 1.033 kg/cm^2	Kg/m3 of gas
δ	Corrected	—
η	Efficiency	Percent
η_g	Gross efficiency	Percent
θ	Theoretical	—
ψ	The number of pound moles of zany substance - substance indicated by subscript	—
'(prime)	Dry	—
Δ	Change	—

NOTE —

1 API gravity from the relative density in accordance with the following formula:

$$Deg\ API = \frac{141.5}{\text{Relative density } 15.6° \text{ C}/15.6° \text{ C}} - 131.5$$

2 A.F. = “as fired”

3.4 Test and Run

Throughout this Code the word “test” is applied only to the entire investigation, and the word “run” to a subdivision. A run consists of a complete set of observations made for a period of time with one or more of the independent variables maintained virtually constant.

SECTION 3

GUIDING PRINCIPLES

4 ITEMS ON WHICH AGREEMENT SHALL BE REACHED

4.1 In order to achieve the objectives of the test the interested parties must reach agreement on the following pertinent items:

a) Gross thermal efficiency determination (*see* **1.4**);
    i) General method — Heat loss or input-output;
    ii) Heat credits to be measured;
    iii) Heat credits to be assigned where not measured;
    iv) Heat losses to be measured;
    v) Heat losses to be assigned where not measured; and
    vi) Permissible deviation in efficiency between duplicate runs.

b) Rating or Output (*see* **1.5**);
c) Allocation of responsibility for all performance and operating conditions which affect the test;

d) Selection of test personnel to conduct the test;
e) Establishment of acceptable operational conditions, number of load points, duration of runs, basis of rejection of runs and procedures to be followed during the test;
f) Cleanliness of unit initially and how this is to be maintained during the test (*see* **4.4.2**);
g) Actual air leakage to be allowed, if any, initially or during the test;
h) The fuel to be fired, the method of obtaining fuel samples and the laboratory to make the analysis;
j) Observations and readings to be taken to comply with the object or objectives of the test;
k) This test code supplements on instruments and apparatus to be used, calibration of instruments and methods of measurements, when applicable;
m) Tolerances and limits of error in measurement and sampling;
n) Distribution of fuel refuse quantities between various collection points and methods of sampling; and
p) Corrections to be made for deviations from specified operating conditions.

4.2 Selection of Personnel

To insure obtaining reliable results, all personnel participating in the test shall be fully qualified to perform their particular function.

4.3 Tolerances and Limits of Error

This Code does not include consideration of overall tolerances or margins on performance guarantees. The test results shall be reported as computed from test observations, with proper corrections for calibrations. However, following guidelines are provided:

a) For units smaller than 15 × 10^6 kJ/h output or approximately 5 t/h steam generation; and
  i) For solid fuel
    1) Input output method ± 3.5 percent
    2) Heat loss method ± 3.0 percent

  ii) For liquid and gaseous fuel
    1) Input output method ± 2.5 percent
    2) Heat loss method ± 2.0 percent

b) For units larger than 15 × 10^6 kJ/h output or approximately 5 t/h steam generation.
  i) For solid fuel
    1) Input output method ± 3 percent
    2) Heat loss method ± 2.5 percent

  ii) For liquid and gaseous fuel
    1) Input output method ± Percent
    2) Heat loss method ± 1.5 percent

4.3.1 Allowances for errors of measurement and sampling are permissible provided they are agreed upon in advance by the parties to the test and clearly stated in the test report. The limits of probable error on calculated steam generator efficiency shall be taken as the square root of the sum of the squares of the individual effects on efficiency.

4.3.2 Whenever allowances for probable errors of measurement and sampling are to be taken into consideration, the reported test results shall be qualified by the statement that the error in the results may be considered not to exceed a given plus or minus percentage, this value having been determined in accordance with the foregoing method for computing limits of probable error.

4.3.3 The following table is included as a guide to show the effect on efficiency of measurement errors exclusive of sampling errors. The measurement error range in the table is not intended to be authoritative but conforms approximately with experience. The values in the table are not intended to be used in any calculation of test results.

4.3.4 *Input-Output Method*

Sl No. (1)	*Measurement* (2)	*Measurement Error, Percent* (3)	*Error in Calculated Steam Generator Efficiency, Percent* (4)
i)	Weigh tanks (calibrated scales)	± 0.10	± 0.10
ii)	Volumetric tanks (calibrated)	±0.25	±0.25
iii)	Calibrated flow nozzle or orifice including manometer	±0.35	±0.35
iv)	Calibrated flow nozzle or orifice including recorder	±0.55l	±0.55
v)	Coal Scales — Batch or dump (calibrated)	±0.25	±0.25
vi)	Uncalibrated flow nozzle or orifice including manometer	±1.25	±1.25
vii)	Uncalibrated flow nozzle or orifice including recorder	±1.60	±1.60
viii)	Fuel heating value		
	a) Coal	±0.50	±0.50
	b) Gas and oil	±0.35	±0.35
ix)	Superheater outlet temperature (calibrated measuring device)	±0.25	±0.15
x)	Superheater outlet pressure (calibrated measuring device)	±1.00	0
xi)	Feedwater temperature (calibrated measuring device)	±0.25	±0.10

4.3.5 *Heat Loss Method*

Sl No.	*Measurement*	*Measurement Error , Percent*	*Error in Calculated Steam Generator Efficiency , Percent*

(1)	(2)	(3)	(4)
i)	Heating value		
	a) Coal	±0.50	±0.03
	b) Gas and oil	±0.35	±0.02
ii)	Orsat analysis	±0.30	±0.30
iii)	Exit gas temperature (calibated measuring device)	±0.50	±0.02
iv)	Inlet air temperature (calibrated measuring)	±0.50	0
v)	Ultimate analysis of coal		
	a) Carbon	± 1.00	±0.10
	b) Hydrogen	± 1.00	±0.10
vi)	Fuel moisture	±1.00	0

4.4 Acceptance Test

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. Especially in the case of fuel burning equipment, adjustments and changes are sometimes necessary to obtain optimum performance. The acceptance test should be started as soon as the unit is in satisfactory condition for test, provided the load and other governing factors are suitable.

4.4.1 Parties to the test may designate a person to direct the test and to serve as arbiter in the event of disputes as to the accuracy of observations, conditions or methods of operation.

4.4.2 All heat transfer surfaces, both internal and external, should be commercially clean (normal operating cleanliness) before starting the test (*see* **4.1.6**). During the test, only the amount of cleaning shall be permitted as is necessary to maintain normal operating cleanliness.

4.4.3 After a preliminary run has been made, it may be declared and acceptance run if agreed to and provided that all the requirements of a regular run have been met.

4.5 Preparation for All Tests

4.5.1 The entire steam generating unit shall be checked for leakage. Air heater internal leakage shall also be checked. Excessive leakage shall be corrected.

4.5.2 Before the test is started, it shall be determined whether the fuel to be fired is substantially as intended. The obtaining of a reliable, accurate efficiency test of the purpose of equipment acceptance is dependent upon the fuel being in close agreement with the fuel for which the steam generating unit was designed. Significant deviations of fuel constituents and high heating value can result in appreciable inaccuracies in heat loss calculations and resulting efficiencies. The magnitude of deviation that is tolerable is difficult to establish, but it should be recognized that fuel analysis variation producing changes in high heating value in the order of 10 percent can alter final calculated efficiency in the order of 1 percent.

4.5.3 Any departures from standard or previously specified conditions in physical state of equipment, cleanliness of heating surfaces, fuel characteristics, or constancy of load, shall be described clearly in the report of the test. If deviations of operating conditions of fuel characteristics do occur, appropriate adjustments to calculated results shall be applied in accordance with provisions in Section 7 for corrections to standard or guarantee conditions, recognizing that this will not produce the precise results to be obtained by testing with a fuel that would not require such calculation adjustments.

4.6 Purpose of Preliminary Run

The purpose of preliminary run is as follows:

a) Checking the operation of all instruments;
b) Training the observers and other test personnel; and
c) Making minor adjustments, the needs for which were not evident during the preparation for the test, and establishing proper combustion conditions for the particular fuel and rate of burning to the employed.

4.7 Starting and Stopping

Combustion conditions, rate of feeding fuel (also quantity of fuel on great if stoker fired), rate of feeding water, water level in drum (if of drum type), excess air and all controllable temperatures and pressures shall be, as nearly as possible, the same at the end of the run as at the beginning. These, and any other conditions in which variations might affect the results of the test, shall be essentially reached and held as constant as possible. There must be reasonable assurance that the temperature of the refractories of the setting and all other parts of the equipment have reached equilibrium before the run is started. The time required to attain stabilization or equilibrium with respect to temperatures will vary widely with the design of the unit and character of materials in the setting. For acceptance tests this generally requires not less than 12 hours for brick set boilers and boilers containing appreciable amount of refractory a minimum of 24 hours is required; for instantaneous steam generators, on the other hand, 1 hour will usually be sufficient.

4.7.1 In some instances it may be necessary to terminate a run prematurely because of inability to maintain one or more of the operating conditions at the desired value.

4.7.2 In order to attain the desired operating conditions when solid fuel is fired by stokers, it is essential that major cleaning and conditioning of the fuel bed shall be accomplished some length of time before the run starts and again the same length of time before the run is completed. Minor occasional normal cleaning of the fuel bed may be permitted during the run. Rate of burning or feeding fuel after the initial cleaning of fires shall be kept at that rate which is to prevail during the run. The fuel bed depth shall be the same at the beginning and end of the run. The ash pit shall be emptied either just after the initial and final cleaning and conditioning of the fuel the weight of refuse corresponds to theweigh1 of coal burned.

4.7.3 In the case of runs to determine the maximum output at which the unit can be operated for a short period, the run should be stared as soon as the maximum output is reached and continued until conditions necessitate terminating the run.

4.8 Duration of Runs

4.8.1 When determination the efficiency of coal fired units, using pulverized coal or crushed coal as in the case of cyclone firing, the runs should be preferably of not less than four hours duration. This duration is satisfactory even for tests conducted by the input-output method provided a unit system of pulverizes or crushers is used, and the fuel weighed as it is fed to the pulverizes or crushers. For those stations having a centralized fuel preparation plant, it may be impractical to weigh the fuel fed to any one unit, in which case the loss method should be used.

4.8.2 When determining the efficiency of a stoker fired steam generating unit by input-output, the runs should be preferably of six hours duration. However, in the case of continuous ash discharge stokers, if conditions make it advisable, the length of a run may be reduced, but not to less than six hours. The longer the duration of the runs the less will be the possibility of significant error due to estimating the difference in amount of unburned fuel on the grate .at the beginning and end of the run.

4.8.3 When determination the efficiency of steam boilers fired with liquid or gaseous fuels, the runs should preferably be of not less than four hours duration.

4.8.4 The duration of runs to determine the maximum short period output, when the efficiency is not to be shall be determined by agreement of the parties to the test.

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

4.9 Frequency and Consistency of Readings

Except for quantity measurements, the readings shall be taken at 1.5 min intervals. If, however, there are fluctuations, the readings shall be taken at such frequency as may be necessary to determine the average.

4.9.1 Where the amount of fuel or 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. The time shall be recorded when each hopper of coal or each tank of feed water is dumped. When indicating flow meters or manometers are used with venturitubes, flow nozzles or orifice plates for subsequently determining quantity measurements, the flow indicating element shall be read at five minute intervals or more frequently when deemed necessary.

4.10 Rejection of Runs

Should serious inconsistencies in the observed data be detected during a run or during the computation of the results, the run shall be rejected completely or in part if the effected part is at the beginning or at the end of the run. A run that has been rejected shall be repeated, if necessary to attain the objectives of the test.

4.11 Records and Test Reports

All observations, measurements and instrument readings necessary for the objective of the test shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record.

4.12 Instruments and Methods of Measurement

The necessary instruments and procedures for making measurements shall be as per the relevant Indian Standards.

SECTION 4

EFFICIENCY BY INPUT-OUTPUT METHOD

5.1 Determination of Steam Boiler Efficiency by Input-output Method

This method is based on the ratio of the output, to the sum of the fuel input plus heat credits. It requires accurate measurement of the quantity and high-heat value of the fuel and the heat absorbed by the steam generator.

5.2 Input Measurement

The following paragraphs describe the methods of determining the steam generator input. These methods shall be used when evaluating the steam generator by the input-output method.

5.3 Solid Fuel-Quantity Measurement

Fuel shall be weighed near the point where it is to be used. All loss of fuel between the, point of weighing and the point of introduction to the steam generating unit shall be measured and accounted for. The weighing scales shall be calibrated prior to and after the test. Experience indicate a possible measurement error within 0.25 percent in the range of loads weighed. Checks and calibrations shall be made in accordance with relevant Indian Standards.

5.3.1 Arrangement and operation of fuel weighing equipment shall be such that checks can be made on consumption during each hour of the run as a matter of convenience and guide. Only the totals, however, are to be used in the final calculations.

5.4 Solid Fuel Sampling

A representative sample of fuel shall be obtained in accordance with IS 436 (Part l/Sec 1).

5.4.1 The sampling of solid fuel for analysis and calorific value shall be carried out in accordance with IS 436 (Part l/Sec 1) or as mutually agreed upon by the parties concerned.

5.4.2 The special sample for moisture determination shall be separated from the general sample, quickly placed in a non-corrosive air tight container and sealed immediately. This sample for moisture shall not be quartered or crushed prior to moisture determination in the laboratory. Every effort shall be made to avoid loss of moisture due to strong drafts at the point of sampling (such as may occur at a pulverizer feeder for example).

5.5 Solid Fuel Analysis and High-Heat Value

Analysis of fuel and determination of high heat value shall be made in accordance with relevant parts of IS 1350.

5.6 Liquid Fuel-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. Experience indicates the former to have a possible measurement error within ± 0.10 percent and the latter within ± 0.25 percent. Calibrations and handling of the tanks during tests should be such as to obtain these accuracies. Positive displacement meters may be used if carefully calibrated under conditions simulating those existing during the test in regard to grade of fuel temperature, pressure, rate of flow and meter location. Calibrated meter accuracy must be within ± 0.50 percent.

5.6.1 Leakage of fuel between point of measurement and point of firing shall be measured and accounted for in the flow calibration. Branch connections on the fuel piping shall be either blanked off or provided with double valves and suitable telltale drains for detecting leakage. Leakage from valve stuffing boxes shall be prevented. Any unavoidable leakage from pump stuffing boxes, or elsewhere, shall be collected and accounted for. Where an oil return system from the burners is used, both supply and return flows shall be measured by calibrated meters.

5.6.2 Practice and precautions relative to the use of weigh tanks and volumetric tanks for liquid fuel measurement shall be those stated in **5.14** and **5.15**.

5.7 Liquid Fuel Sampling

Are presentative sample of fuel shall be obtained in accordance with IS 1447 (Part 1).

5.8 Liquid Fuel Analysis and High-Heat Value

Fuel analysis, high-heat value, density and viscosity determination shall be made in accordance with relevant part of IS 1448.

5.9 Gaseous Fuel Quantity Measurement

The quantities of gaseous fuels shall be measured by means of meters of the nozzle, orifice plate or pite static tube type.

5.9.1 If fluctuations in flow are present, due to reciprocating devices or other source of pulsation, the difference between the indicated maximum and minimum flow rates shall be minimized and must be made to be less than ±5 percent of the average flow, by the introduction of a cushion chamber, surge chamber, or other means of absorbing the pulsations between the source of pulsation and the primary device, before measurement is considered acceptable.

5.9.2 Pressure of the gaseous fuel at point of volume determination and at other required points shall be measured by a suitable thermometer or pressure gauge. Temperature shall be measured with liquid-in-glass thermometers.

5.10 Gaseous Fuel Sampling

If composition of fuel gas is expected to remain constant, samples of gas may be taken at regular intervals or continuously; if the composition is expected to vary for example gas from and intermittent gas producing process agreement should be reached on the procedure to be adopted to obtain complete analysis and type weighed mean calorific value.

5.11 Gaseous Fuel Analysis and High-Heat Value

Fuel analysis and high-heat value determination shall be made in accordance with the Test code for gaseous fuels standard methods of test for calorific value of gaseous fuels by the water-flow calorimeter as per agreement between the manufacturer and the purchaser.

5.12 Heat Credits

Heat credits are sensible heats added to the steam generator envelope Fig. 1 and are listed in Fig. 2. Heats of each are determined by a quantity measurement multiplied by an enthalpy difference, or by the conversion to thermal units if an electrical energy measurement.

5.13 Output Measurement

The method of measuring output flow in connection with the input-output method is to measure the water flow into the unit as outlined in **5.14** and **5.15**. These are the only accepted test measurements of output flow.

5.14 Weigh Tanks

Suitable tanks and scale shall be calibrated prior to and after the test and caused to weigh to a possible measurement error within + 0.10 percent in the range of loads weighed. The weight of water used must be corrected for any steam or condensate entering or leaving the cycle, after the weigh point. A heat balance diagram shall be prepared to reveal additional sources of supply, if any, to the feed water circuit.

5.14.1 Design, construction, calibration and operation of weighing tanks shall be as per agreement between the manufacturer and the purchaser.

5.15 Volumetric Tanks

Volumetric tanks shall be calibrated prior to and after the test and caused to measure a possible measurement error within + 0.25 percent in the range of loads measured.

5.15.1 Volumetric tanks shall be calibrated with weighed increments of water at a constant temperature and measurement accuracy of ± 1 °C. In the use of volumetric tanks, density corrections shall be made for water temperature differences during testing and calibration. Corrections shall also be made for the change in thermal expansion of the tanks metal.

5.15.2 The precautions given in **5.14** shall be observed wherever they apply to volumetric tanks.

5.15.3 Design, construction, calibration and operation of volumetric tanks shall be as per agreement between the manufacturer and the purchaser.

5.16 Venturitube, Flow Nozzle or Thin Plate Orifice

Water quantity may be measured by venturitube, flow nozzle or thin plate orifice. Measuring devices including manometers shall be calibrated prior to and after the test and caused to measure to an accuracy within 40.35 percent in the range of loads measured.

5.16.1 The design, construction, calibration and use of flow measuring elements, as well as their location and installation in the pipe lines and the installation of the connecting piping system between the primary element and the manometer shall be as per agreement between the manufacturer and the purchaser. All computations of flow rate from the observed differentials, pressures and temperatures shall be recorded.

5.16.2 Venturi tube, nozzle or orifice selected shall be such that the differential pressure at any test output as shown by the manometer is at least 125 mm of manometric liquid.

5.16.3 If fluctuations in flow are present, due to reciprocating devices or other source of pulsation, the difference between the indicated maximum and minimum flow rates shall be reduced to not more than ± 5 percent of the average flow by the introduction of a cushion chamber, surge chamber or other means of absorbing the pulsations between the source of pulsation and the primary device, before measurement is considered acceptable.

5.16.4 Differential pressure at the primary metering element shall be measured by two complete manometer systems which shall agree within ± 0.2 percent of each other.

5.17 Flow Measurement of Steam

Output steam flow to be used in the input-output method must be obtained from feed water measurement as described in **5.14**, **5.15** and **5.16.**

5.17.1 The design, construction, calibration and use of flow nozzles and orifices as well as their location and installation in the pipe lines and the installation of the connecting piping system between the primary element and the manometer shall be as per agreement between the manufacturer and the purchaser. All computations of flow rate from the observed differential pressures, pressures and temperatures shall be made in accordance with **5.14**, **5.15** and **5.16**.

5.17.2 Differential pressures at the primary metering element shall be measured by a direct reading manometer system.

5.18 Precautions and Corrections Relating to Output Quantity Measurements

All leakage which may affect test results shall be eliminated. If not eliminated, it -must be measured and accounted for. Errors due to steam or water entering or leaving the equipment under test, through connecting piping, shall be prevented by blanking off such connections or by providing open telltale drains between double valves to give visible assurance that no flow exists.

5.18.1 Water content of all locations where water can accumulate between point of measurement and the boiler, such as surge tanks, feed water heaters and receiving tanks to which measuring tanks discharge, shall be recorded at the start and conclusion of the run and proper allowances made.

5.18.2 Blowing down during a run shall preferably be avoided. If this is not possible, the amount of heat can be determined by heat balance around the blow down heat recovery system. Corrections shall be made for any steam and water which are sampled for the determination of solids or for chemical analysis.

5.18.3 Soot blower operation during a run should either be avoided or allowance made.

5.19 Steam and Feed Water Temperatures

Saturated steam temperature may be measured at any point in the steam line where convenient but as close to the saturated steam outlet as possible. The temperature of superheated steam shall be measured as close to the super heater outlets as possible to minimize error from heat loss. Feedwater temperatures shall be measured as close to the economizer inlet and boiler inlet as possible. Steam and feedwater temperatures which are of primary importance shall each be taken at two different points as close together as practical and the mean of the two readings after corrections to each shall be the temperature of the fluid. Discrepancies between the two corrected readings exceeding 0.25 percent for steam and 0.50 percent for water shall be investigated.

5.19.1 Mercury-in-glass thermometers, resistance thermometers or thermocouples are acceptable for temperatures up to 350 °C at or above 350 °C either resistance thermometers or thermocouples shall be used.

5.19.2 All temperature measuring devices shall be calibrated before and after tests. When employing mercury-in-glass thermometers, proper allowance shall be made for difference between thermometer steam temperature during calibration and test.

5.19.3 The following precautions shall be observed in the use of temperature measuring devices.

5.19.3.1 All temperature measuring instruments and wells shall be constructed, installed, and the instruments calibrated and operated as per agreement between the manufacturer and the purchaser.

5.19.3.2 Temperature measuring devices shall be installed so that they will not be affected by radiation or conduction.

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

5.20 Moisture in Steam

Moisture in steam at saturation temperature in connection with output determination shall be measured with a suitable calorimeter constructed, installed and operated in the acceptable to both parties.

5.21 Steam and Feedwater Pressures

Pressure gauges shall be located where they will not be affected by any disturbing influences such as extremes of heat and cold and vibration and shall be located in convenient positions for reading. While calibrated Bourdon test gauges or deadweight gauges may be used, the use of the latter is preferred.

5.21.1 Gauge connections shall be as short and direct as possible.

5.21.2 Gauges shall be protected with syphons or their equivalent. Convolutions of syphons shall be as few in number as possible, consistent with gauge remaining cool, because of their tendency to introduce errors due to unbalanced water columns in the convolutions.

5.21.3 All gauge connections shall be tight.

5.21.4 Pressure connections shall be located and installed with extreme care in order to avoid errors due to impact and eddies. Pressure gauge pulsations shall not be dampened by throttling the connection to the gauge or by the use of commercial gauge dampers, but a volume chamber may be employed. The arrangement may be considered satisfactory if the maximum and minimum values of the instantaneous pressure do not differ by more than 2.0 percent from the mean value. Bourdon test gauges shall be calibrated, installed and used in accordance with IS 3624. These gauges shall be calibrated before and after the test and at intervals of not more than one week if the test is extended beyond that period.

SECTION 5

EFFICIENCY BY HEAT LOSS METIIOD

6 DEFINITION AND DATA

6.1 Steam Boiler Efficiency by Heat Loss 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 a quotient expressed in percent. The quotient is made up of the sum of all accountable losses as the numerator, and heat in the fuel plus heat credits, as the denominator. The capacity at which the unit is to be tested may be based upon either water flow measurement in accordance with **5.14**, **5.15** and **5.16** or steam flow measurement in accordance with **5.17**.

6.2 Data Required

Accurate data on the following items are required.

6.2.1 Fuel Analysis

6.2.2 Flue gas composition or analysis for CO_2, O_2, CO and other gaseous combustibles.

6.2.3 Flue gas temperature determined as result of a velocity and temperature traverse of the cross sectional area.

6.2.4 Temperature of air supplied to unit for combustion.

6.2.5 Combustible content and quality of dust carried by exit gases.

6.2.6 Combustible content and respective quantities in dust collector hoppers and all miscellaneous hoppers.

6.2.7 Combustible content and quantity of ash pit refuse.

6.2.8 Temperature of fuel supplied at point entering unit.

6.2.9 Humidity of air supplied for combustion.

6.2.10 With the above information accurately obtained, all losses on the unit can be calculated in terms of percent of the sum of the high-heat value of the “as fired” fuel plus heat credits. Equations for calculating all losses and credits are given in Section 7.

6.3 Fuel Sampling and Analysis

The accuracy of the heat loss method depends upon an accurate sample and ultimate analysis of the fuel being fired. The analysis should break the fuel constituents into the various chemical elements which are combustible or take part in the chemical reaction. These elements are determined in percent by weight or percent by volume of the “as fired” fuel. Refer to **5.4**, **5.5**, **5.7, 5.8** and **5.10**.

6.4 Flue Gas Sampling and Analysis

6.4.1 *Sampling Location*

Orsat analysis of the flue gases at the exit of the steam generator is required. This will be at locations 15, 14 or 12 (*see* Fig. 1) depending upon the equipment which comprises the steam generator. Frequently analyses are required at other points. There may be considerable variation in flue gas analysis over the cross section of the gas passage due to stratification and air infiltration. The best practical method of obtaining representative results is to divide the cross section of the gas passage into equal areas and to take velocity measurements and simultaneous gas samples from the centers of these component areas. A weighted average can then be calculated, taking into consideration the gas temperature, **6.8** as well as the velocity. The number and arrangement of the equal areas will depend on the size and configuration of the gas passage. The areas shall be approximately square and the sampling points shall be not more than one metre apart, and a total of not less than four points shall be used. In round ducts, test points shall be located on two traverses along axes normal to each other. It is recognized that there may be cases in which the gas velocity is so low that velocity measurements would be impractical. In such cases an arithmetic average rather than a weighted average should be employed. Where accuracy is not impaired, an aspirator and suitable apparatus for obtaining a composite sample from several sampling points may be employed. With the exception of the area sampling instruction above, all of the procedures are to be in accordance with recommendations of flue and exhaust gas analyses.

6.5 Sampling Lines

Sampling tubes shall be made of material which shall not contaminate the sample by the temperatures encountered. For sampling high temperature flue gas, such as in a furnace suitable water cooled samplers must be employed. Sampling lines shall-be as short and straight as possible, shall be accessible for cleaning and blowing out, shall slope in the direction of the flow, shall be suitably drained and shall be maintained tight.

6.6 Method of Analysis

Apparatus and method of analysis to be employed are dependent upon the type of fuel burned and upon the purpose of the test. Design, construction and operation of the apparatus and preparation of the reagents shall be in accordance with agreement between the manufacturer and the purchaser.

6.6.1 An analysis should be made to verify presence or absence of gaseous combustibles. If combustibles are found and cannot be eliminated by adjustment to the fuel burning equipment, the hydrogen and hydrocarbons shall be measured and the loss there from calculated as covered in Section 6.

6.6.2 For hydrogen and hydrocarbon analyses, it is necessary to obtain representative field samples of the gases for submission to a qualified laboratory.

6.7 Precautions

Proper steps shall be taken to prevent leakage to or from gas analyzing apparatus and sampling lines, to avoid contamination and exhaustion of reagents, to provide fresh reagents when needed, to keep manifolds clear of reagents, to avoid errors due to physical solubility of gases in reagents and confining liquids, to avoid personal injury by contact with reagents, to allow for burette error and drainage time to avoid, change of sample temperature during analysis, to keep apparatus clean, to minimize personal errors by employing careful operators who are given adequate information on common sources of error, to provide operators with adequate light and reasonable comfort, to verify, results by checking against theoretical, and in all other ways, to assure that recorded data are correct and their degree of precision known. Sampling should be continuous when possible. Because all gases, especially SO_2 and CO_2, are soluble to some extent in water, the water in the levelling bottle shall be saturated with sample gas before talking any readings.

6.7.1 Detailed precautions pertaining to flue and exhaust gas analysis may be followed.

6.8 Flue Gas and Air Temperature Measurement

6.8.1 *Outlet the Gas Temperature* — Flue gas temperature measurement at the exit of the steam generator is required. This will be at locations 15, 14 or 12, Fig. 1 depending upon the equipment which comprises the steam generator.

This may certain instances be measured at other points such as at the inlet and discharge of air or gas recirculating fans.

6.8.2 Gas temperatures must be taken at the same sampling points as used for flue gas sampling (*see* **6.4**) to minimize the effect of gas temperature stratification.

6.8.3 If a preliminary survey of flue gas flow (*see* **6.4**), indicates severe stratification, it is recommended that the temperature measurements at individual locations in the duct cross section be weighted in proportion to the gas flow at the corresponding locations and an average of the weighted temperatures be used as representing the gas temperature at that cross section.

6.8.4 The selection, design, construction, calibration, installation and operation of temperature measuring instruments shall be as per agreement between the manufacturer and the purchaser.

6.9 Air and Recirculated Flue Gas Temperature

The same general methods and the same precautions given in 5.8 shall apply to the determination of temperatures of primary air, secondary air, recirculated air or flue gas and temperature of air entering and leaving the air heater.

6.10 Flue Gas and Air Weight

6.10.1 *Weight Determination*

Flue gas quantity shall be determined by calculation from fuel analysis and flue gas composition. Calculation procedure for gas weight per heat unit of fuel is given in **7.3.2.2**. Similarly, air quantities shall be calculated as per **7.2.7.1**.

6.10.2 In some instances it is desirable to know flue gas or air quantities other than total for the unit, such as recirculated flue gas, primary air, secondary air, etc. These may be calculated by heat balances, by differences or may be measured if they cannot be calculated.

6.10.3 Appropriate methods of measurement for flue gas and air quantity testing purpose shall be used. Where continual knowledge of such flows is required, flow nozzles, venturi or thin plate orifices can be installed.

6.11 Refuse

6.11.1 *Quantity Measurement*— The heat loss method of this Code requires the determination of heat loss due to unburned combustible in the refuse. It is also necessary in the input-output method if the test is to be checked by a heat balance. From the viewpoint of testing, the most difficult part of this determination is the accurate measurement of all the refuse discharged or removal from the unit.

In some installations it may be impractical or even impossible to collect and weigh all the refuse. When this is the case, it becomes necessary to estimate any undetermined amounts of refuse by volumetric measurement or a refuse balance difference. Care should be exercised to include all the refuse discharged or removed from the unit and to exclude any refuse which is returned to the unit for further combustion. In order to be sure that the refuse collected is in proper relation to the weight of ash in the coal burned, the collection must take into account the time required for the refuse to pass from the furnace to the point of discharge, as discussed in **4.7**. This may be especially important in stoker fired units.

6.11.2 The refuse collected at various points in the unit shall be weighed separately and preferably in the dry state, although any burning refuse must be quenched with water immediately upon its withdrawal from the unit. The moisture content of the refuse shall be determined by laboratory analysis. Flue dust collected at all points in the steam generating unit ahead of the samples taken from the gas stream, shall be collected, weighed, sampled and analyzed separately. The amount and combustible content of the fly ash carried in suspension by the flue gas shall be determined in accordance with **6.13** to **6.19** inclusive.

6.12 Sampling

Refuse sampling is subject to large errors and every precaution shall be taken to insure as representative sample as possible.

6.12.1 Soot, siftings, cinders and dust separator refuse collected in hoppers shall each be reduced by successive quartering to obtain two 10 kg samples in each location. Where the total collection is less than 15 kg for the duration of the test, the quantity shall be equally divided to constitute the two required samples. One sample shall be sent to the laboratory for analysis and the other sample shall be retained as a duplicate until final results of the tests have been reviewed and declared acceptable.

6.12.2 In the cast of furnace bottom refuse either from a stoker fired or dry bottom pulverized fuel fired unit a gross sample of approximately 500 kg shall be taken in equal increments of approximately 25 kg from each tonne of refuse. Care shall be exercised to obtain proper proportions of coarse and fine refuse in each increment. If the total amount of furnace-bottom refuse is less than 500 kg then the entire amount of refuse shall constitute the gross sample. The gross sample shall be crushed and reduced to two 10 kg samples. One sample shall be sent to the laboratory for analysis and the other shall be retained as a duplicate until final results have been reviewed and declared acceptable.

6.12.3 The reduction of the gross samples to laboratory size shall proceed as rapidly as possible to prevent undue loss of moisture by evaporation and the two laboratory size samples shall be placed and sealed in airtight containers.

6.13 Analysis

Refuse samples shall be analyzed for moisture, combustible content and heat value of the combustible be taken as 33 820 kJ/kg.

6.13.1 For moisture determination, the refuse shall be crushed, if necessary, in a jaw crusher to pass through a 4-mesh sieve, spread over suitable galvanized iron pans, and dried at a temperature in the range of 105 °C to 110 °C in an air drying oven until the weight loss per hour is not more than 0.1 percent of the weight of the sample. Care shall be used, when drying samples of fine material such as refuse from soot hoppers and precipitators, to regulate the flow of air through the drying over to a velocity which will not pick up and carry away any of the sample.

6.14 Dust Sampling and Analysis

The general principles of sampling apply of tests made to determine the dust analysis and concentration in flue gas as well as to occasional tests for fineness of coal and for properties of suspended materials in gaseous fuel to burners. Dust samples are obtained by inserting one or more sampling tubes into and facing the gas stream in question, drawing off the measured quantity of the gas at such a rate that the velocity of the gas entering the mouth of the sampling tube is the same as the velocity of the main body of gas at that point in the cross section of the duct and collecting all the dust carried by this quantity of gas.

6.14.1 All apparatus and test procedure for dust separating apparatus and determining dust concentration in a gas stream, shall be as per agreement between the manufacturer and the purchaser.

6.15 Design of Dust Sampling Apparatus

The design of sampling apparatus shall be in accordance with the agreement between the manufacturer and the purchaser.

6.15.1 The volume of gas drawn through the sampling tube shall be measured by a displacement gas meter of known accuracy, by an orifice or flow nozzle, or by some other acceptable means such as a pitot tube suitably incorporated in the sampling tube.

6.15.2 Separation of dust from the gas sample shall be by suitable filters of ceramic or paper thimble or cloth bag type, by one of these in conjunction with a cyclone separator or by other acceptable sample collecting apparatus.

6.15.3 It is usually necessary to draw the gas sample through the sampling tube, separator and metering apparatus. For this purpose, air, water and steam operated aspirators and motor driven pumps and blowers, such as employed in vacuum cleaners, are suitable. In general, use of the blower is limited to types of collecting sample apparatus having relatively low resistance.

6.15.4 In, cases where normal temperature of the apparatus is below the dew point of the gas samples, precipitation of moisture shall be prevented by suitable insulation known or by heating the apparatus.

6.16 Dust Sampling Points

A careful preliminary survey shall be made to show the variation in dust concentration over the cross section of the duct as a guide in determining the number and location of sampling points necessary to obtain the required accuracy. Points of sampling should be located in a long straight run of duct, preferably vertical rather than horizontal, not more than one metre apart and a total of not less than four points. In round ducts, test points should be located on two traverses along axes normal to each other.

6.17 Dust Sampling Tubes

Since the number of sampling points necessary to attain the required accuracy will probably exceed the number of samplers it is practical to employ, the sampling tubes should be so designed that they can be moved to sample each required point.

6.18 Method of Determining Proper Rate of Gas Plow Through Dust Sampler

Proper sampling rates at each sampling point shall be determined by a pitot tube or its equivalent. Where duct velocities are determined by pitot tube and the gas at the sample metering device is at a temperature or pressure appreciably different from that in the duct, proper allowances shall be made. In some instances, a traverse of the duct with a thermocouple is necessary.

6.19 Dust Sampling Precaution

Sampling should be continued throughout the duration of the run. Filters shall be changed when necessary, with the least possible loss of time correction. Correction shall be made for time lost while changing filters.

6.19.1 Sampling shall begin immediately after inserting the sampling tube in the duct. The stopping of sampling and the removal of the sampling tube shall likewise be as nearly simultaneous as possible.

6.19.2 When a sampling tube is moved from point to point to obtain an average, the duration of exposure shall be the same at all points and the sampling rate shall be regulated to correspond with the duct velocities at the individual points. The mouth of the sampling tube shall always point in the upstream direction.

6.19.3 Great care must be exercised to collect all the dust drawn into the sampling tube. This often requires that the piping between the sampling mouth and the dust separating device be cleaned with a weighed swab and the dust so collected accounted for. The sample and its container must be thoroughly dried before weighing.

6.19.4 Before use, filter bags, thimbles and other parts in which dust for the sample may collect shall be thoroughly dried and accurately weighed. This weight and that of any swabs or other cleaning media constitute a tare weight in the calculation.

6.20 Moisture in Combustion Air

The moisture carried by combustion air must be taken into consideration when calculating the efficiency by the heat loss method. This moisture may be determined with the aid of a sling-type psychrometer or similar device. From the dry-and wet-bulb thermometer readings taken from the psychrometer at the observed barometric pressure, the absolute or specific humidity (kg of moisture per kg of dry air) can be determined either from the chart published for humidity determinations, or from psychrometic tables.

6.20.1 The dry and wet bulb temperatures may be determined at the atmospheric air inlet to the system. This is possible since the desired quantity is kilograms of moisture per kilograms of dry air for combustion. Since the specific humidity does not change with heat addition unless there is moisture addition, the air moisture crossing the envelope, (*see* Fig. l), is the same as that measured at the air inlet.

6.21 Surface Radiation and Convection

The approximate radiation heat loss shall be derived by the use of the chart included in Section 6 (*see* Fig. 8).

SECTION 6

COMPUTATIONS

7.1 Computation of Efficiency

The following computation procedures are for determining the gross thermal efficiency of a steam boiler by both the input-output and the heat loss methods for the actual operating conditions of the tests. Where a comparison is to be made between test efficiency and a standard or guaranteed efficiency, adjustments should be made in computations for deviation of test conditions from the standard or guaranteed conditions for certain heat credits and heat losses. Each computation subject to adjustment is so noted in the following section and the procedure for adjusting is as described in **7.4** to **7.6**.

7.2 Efficiency by Input-Output Method

$$\text{Efficiency } \eta_{\mathrm{g}} = \frac{\mathrm{Output}}{\mathrm{Input}}$$

$$\eta_g = \left[\frac{W_{se31}\,(h_{s32} - h_{w24}) + W_{wc25}\,(h_{s32} - h_{w25}) + W_{wc35}\,(h_{w35} - h_{w24})}{H_f \times W_{fe} + B_e}\right] \times 100$$

NOTE —Auxiliary steam usages are not indicated in the above equation, but wherever they occur, their heats are additive in the numerator.

where,

n_{g} = percent gross efficiency.

7.2.1 $W_{se31} = \frac{\text{kg steam}}{\text{h}}$ or $\frac{\text{kg steam}}{\text{s}}$ = Steam flow entering superheater.

7.2.2 $h_s32 = \frac{\text{kcal}}{\text{kg steam}}$ or $\frac{\text{kJ}}{\text{kg steam}}$ = Enthalpy of steam at superheater outlet.

7.2.3 hw_{24}, hw_{25}, hw_{35} = $\frac{\text{kcal}}{\text{kg water}}$ or $\frac{\text{kJ}}{\text{kg water}}$

Enthalpy of feedwater entering unit.
Enthalpy of superheater spray water.
Enthalpy of blowdown.

7.2.4 Wwe_{25}, Wwe_{35} = $\frac{\text{kg water}}{\text{h}}$ or $\frac{\text{kg water}}{\text{s}}$
= Superheater spray water flow, blowdown flow.

7.2.5 $H_f = \frac{\text{kcal}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F.fuel}}$

= Heating value of fuel to be obtained by laboratory analysis and adjusted to an "as fired" basis from laboratory determination of moisture in fuel. For gaseous fuels, the use of continuous recording calorimeter is permitted.

7.2.5.1 Adjustment for moisture will be as follows:

$$H_f = H_{f'} \times \frac{100-\text{mf}}{100}$$

where,

$H_{f'}$ = High heat value of the fuel on a dry basis

$= \frac{\text{kcal}}{\text{kg fuel (dry basis)}}$ or $\frac{\text{kJ}}{\text{kg fuel (dry basis)}}$

= Laboratory determination by fuel analysis on a dry basis.

m_f = Percent moisture in fuel as determined by analysis of moisture sample.

7.2.5.2 When the heating value is determined at constant volume (*see* **5.5** and **5.8**) it must be converted to a constant pressure value as follows:

$$H_{fp} = H_{fv} + 146.77\ \text{H kcal/kg}$$
$$= H_{fv} + 614.51\ \text{H kJ/kg}$$

7.2.5.3 *See* Section 7 for complete derivation of above formula for conversion of high-heat value at constant volume as obtained with the bomb calorimeter to the high-heat value at constant pressure.

7.2.6 W_{fe}

$$= \frac{\text{kg A.F.fuel}}{\text{h}} = \left(\text{or } \frac{\text{kg A. F.fuel}}{\text{s}}\right) = \text{measured fuel rate}$$

If solid or liquid fuels are used the weight is determined by direct measurement. If gaseous fuel is used, the measured volume must be converted to a weight basis as follows:

7.2.6.1 $W_{fe} = Q_{fe} \times \gamma f$

where,

$W_{fe} = \frac{\text{kg A.F. fuel}}{\text{h}}$ or $\frac{\text{kg A.F.fuel}}{\text{s}}$ = measured fuel rate.
$Q_{fe} = \frac{\text{m}^3}{\text{h}}$ or $\frac{\text{m}^3}{\text{s}}$ = Quantity of gaseous fuel fired.
$\gamma f = \frac{\text{kg}}{\text{m}^3}$ = Fuel gas specific weight at the primary measuring element, to be corrected to 20 °C.

7.2.7 $B_e = \frac{\text{kcal}}{\text{h}}$ or $\frac{\text{kJ}}{\text{s}}$ = Total heat credit and is defined as those amounts of heat added to the envelope of the steam generator other than the chemical heat in the fuel "as fired"

$$B_e = B_{Ae} + B_{ze} + B_{fe}$$

7.2.7.1 $B_{Ae} = \frac{\text{kcal}}{\text{h}}$ (*or* kJ/s) = Heat supplied by entering air from such sources as steam air heaters.
$B_{Ae} = (W_{A'} - W_{A'5}) \times W_{fe} \times C_{pA'}\,[t_{A7,A8} - t_{RA}] + W_{A'5}\, W_{fe} \times c_{pA'}\,[t_{A'5} - t_{RA}]$

where,
$W_{A'} = \frac{\text{kg}}{\text{kg A.F.fuel}}$ = weight of dry air per kg of "as fired"fuel

$W_{A'} = \frac{WG'N2-N}{0.768\ 5}$
where,

$W_{G'N2} = \frac{\text{kg nitrogen in dry gas}}{\text{kg A.F.fuel}} = \frac{\text{kg dry gas}}{\text{kg A.F.fuel}} \times \frac{\text{kg nitrogen in dry gas}}{\text{kg dry gas}}$
$W_{G'N2} = \frac{W_{G'} \times 28.02\ N_2}{44.01 CO_2 + 32.00\ O_2 + 28.02\ N_2 + 28.01\ CO}$
$W_{G'} = \frac{kg}{kg\ A.F.fuel} = kf\ of\ dry\ gas\ per\ kg\ of$ "as fired" $fuel$

$$W_{G'} = \frac{44.01 CO_2 + 32.00\ O_2 + 28.02\ N_2 + 28.01\ CO}{12.01\ (CO_2 + CO)} \left(C_b + \frac{S}{2.67}\right)$$

$$W_{G'N2} = \frac{28.02 N_2 - N}{12.01\ (CO2 + CO)} \left(Cb + \frac{S}{2.67}\right)$$

$$W_{A'} = \frac{W_{G'N2} - N}{0.7685}$$

For complete fundamental derivation, *see* Section 7.

The proceeding formula is based on molecular weights accurate to four significant figures, but it is not to be implied that the weight of dry air has this degree of accuracy. The four digit molecular weights are used to hold errors from calculation procedure to a minimum.

CO_2, O_2 and CO = percent by volume of dry flue gas. (Location 12,14 or 15, Fig. 1.) N_2 being determined by subtracting the total of CO_2, O_2 and CO from 100 percent.

$C_b = C\frac{Wd'p'\times Hd'p'}{\text{Heat value of 1 kg of carbon}}$

where,

C_b - $\frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg of the carbon burned per kg of "as fired" fuel.

C = $\frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg carbon as firedfuel by laboratory analysis.

$W_{d'p'}$ = $\frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg of total dry refuse per kg of "as fired" fuel (*see* **7.3.2.1**)

$H_{d'p}$' = $\frac{\text{kg}}{\text{kg dry refuse}}$ = Heat value for total dry refuse from laboratory determination.

$$\frac{8\ 078\ \text{kcal}}{\text{kg}} = \frac{33\ 820\ \text{kj}}{\text{kg}} = \text{Heat value of 1 kg of carbon as it occurs in refuse.}$$

S = $\frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg sulfur per kg of "as fired"fuel as determined for laboratory analysis.

N = $\frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg of nitrogen per kg of "as fired"fuel.

For computation of the theoretical and excess air, the equations are given in Section 7.

$W_{fc} = \frac{\text{A.F.fuel}}{\text{h}}$ = fuel rate as determined by weighing procedures outlined in Section 5.

$C_{pA'}$ = Mean specific heat of dry air inlet temperature, as obtained from curve sheet. (*see* Fig. 3). It is determined from the instantaneous values over the range between inlet air temperature and the reference temperatures.

t_{A7} or t_{A8} = F = Inlet air temperature. If the unite is equipped with a steam or water coil air heater before the main air heater and it is supplied with heat from a source external to the unit being tested (as defined by Fig. 1), the inlet air temperature tA8 shall be measured in the air steam after this heater and in this case the heat added to the inlet air is heat credit. If the coil above or recirculated hot air is being supplied by heat direct form the unit being tested, inlet air temperature tA7 shall be measured in the air steam ahead of the heater and there is no heat credit.

t_{RA} = F = Reference air temperature. This is the base temperature to which sensible heat losses and credits are compared for efficiency computations. When heat is added to the combustion air before the forced draft fan, corrections must be made to the measured temperature at location 7 on Fig. 1. Where adjustment is to be made for deviation from standard or guarantee conditions (*see* **7.4.1**).

7.2.7.2 B_{ze}= $\frac{\text{kcal}}{\text{h}}$ or $\frac{\text{kJ}}{\text{S}}$ = Heat supplied by atomizing steam when the source is external to the unit being tested.

$$B_{ze} = W_{ze} \times (h_{z42} - h_{Rv})$$

where,

$W_{ze} = \frac{\text{kg}}{\text{h}}$ or $\frac{\text{kJ}}{\text{S}}$ = Metered atomizing steam flow.
h_{z42} = Enthalpy of atomizing steam at pressure and temperature at metering point.
h_{Rv} = Enthalpy of saturated vapour at reference temperature.

7.2.7.3 $B_{fe} = \frac{\text{kcal}}{\text{h}}$ or $\frac{\text{kJ}}{\text{S}}$ = Heat supplied by sensible heat in fuel.

$$B_{fe} = W_{fe} \times C_{pf}(t_{f1}, 3, 4 - t_{RA})$$

where,

$W_{fe} = \frac{\text{kg A.F.fuel}}{\text{h}}$ or $\frac{\text{kJ A.F.fuel}}{\text{S}}$ = Measured fuel rate

$C_{pf} = \frac{\text{kcal}}{\text{kg °C}}$ or $= \frac{\text{kJ}}{\text{kg °C}}$ = Mean specific heat of fuel. Use 0.3 kcal/kg °C or 1.256 kJ/kg °C for coal (*see* Fig. 4 for fuel oil, *See* Fig. 5 for gas). It is determined form the instantaneous values over the range between inlet fuel temperature and the reference temperature.

If liquid fuel is heated by a source external to the unit being tested, the inlet temperature shall be measured after this heater, but if heated directly from the unit being tested temperature shall be measured before the heater.

t_{f1}, t_{f3}, t_{f4} = Fuel inlet temperature.
t_{RA} = Reference air temperature.

7.2.8 The foregoing heat credits are to be summarized into total heat credits and used as the value of B_e in the equation in **7.2** for solving for gross efficiency by the input-output method.

7.3 Efficiency by Heat Loss Method

$$\eta_g = 100 - \frac{L}{Hf+B} \times 100$$

7.3.1

η_g = Percent = Gross efficiency

7.3.2

$L = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Total heat loss from the steam generator.
$L = L^*_{UC} + L_{G'} + L_{mf} + L_{CO + LUHC} + L^*_d + L^*_r + L_{UH}$

*A fuel rate is used in the calculation of these losses.

7.3.2.1

$L_{\text{UC}} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}} =$ Heat loss due to unburned carbon in total dry fuel.

$L_{\text{UC}} = W_{\text{d'p'}} \times H_{\text{d'p'}}$

where,

$$W_{\text{d'p'}} = \frac{Wd'p'e}{W_{fe}}$$

where,

$$W_{\text{d'p'}} = \frac{kg}{kg\ A.F.fuel} - \text{kg of total dry refuse per kg of "as fired" fuel.}$$

Where refuse rate at various collection points, such as ashpit, dust collector and boiler hoppers is not actually determined it may be estimated (*see* **4.1.13**).

$W_{\text{d'p'e}} = \frac{\text{kg}}{\text{h}}$ or $\frac{\text{kg}}{\text{s}} =$ kg of total dry fuel.

$W_{\text{fe}} = = \frac{\text{kg A.F.fuel}}{\text{h}}$ or $\frac{\text{kg A.F.fule}}{\text{s}} =$ Measured fuel rate.

If fuel rate is not measured, the expected rate for the test may be used, and considered sufficiently accurate for this calculation. Iteration will be required for more accurate results.

$H_{\text{d'p'}} = \frac{\text{kcal}}{\text{kg dry refuse}}$ or $\frac{\text{kJ}}{\text{kg dry refuse}} =$ (Laboratory dertermination of percent combustible) ×
$(8\ 078 \frac{\text{kcal}}{\text{kg}}$ or $33\ 820$ kJ/kg)
or
$H_{\text{d'p'}} = \frac{\text{kcal}}{\text{kg dry refuse}}$ or $\frac{\text{kJ}}{\text{kg dry refuse}} =$ Laboratory determination of heating value.

If it is possible and desirable to measure the refuse collection rate at all collection points, then the following calculation procedure will be used to determine unburned carbon loss.

$L_{\text{UC}} = \frac{\text{kcal}}{\text{kg A.F. fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F. fuel}} = a + b + c + d + e$

a) kcal/kg or kJ/kg in ash pit

$$= \frac{\text{kg dry refuse in ash pit}}{\text{kg A.F.fuel}} \left(\frac{\text{kcal or kJ}}{\text{kg ash pit refuse}}\right)$$

b) kcal/kg (or kJ/kg) in boiler hopper

$$= \frac{\text{kg dry refuse in ash pit}}{\text{kg A.F.fuel}} \left(\frac{\text{kcal or kJ}}{\text{kg boiler hopper refuse}}\right)$$

c) kcal/kg (or kJ/kg) in economiser hopper

$$= \frac{\text{kg dry refuse in economiser hopper}}{\text{kg A.F.fuel}} \left(\frac{\text{kcal or kJ}}{\text{kg hopper refuse}}\right)$$

d) kcal/kg or kJ/kg air heater hopper

$$= \frac{\text{kg dry refuse in air heater hopper}}{\text{kg A.F.fuel}} \left(\frac{\text{kcal or kJ}}{\text{kg air heater hopper refuse}}\right)$$

e) kcal/kg or kJ/kg in dust collector hopper

$$= \frac{\text{kg dry refuse in dust collector hopper}}{\text{kg A.F.fuel}} \times \text{or} \left(\frac{\text{kcal or kJ}}{\text{kg collector refuse}}\right)$$

If the flue dust is sampled prior to all collection points with the exception of the ashpit, and all parties agree ashpit combustibles negligible, flue dust rate may be estimated or determined by dust concentration measurement. Then the loss due to unburned combustible will become

$$L_{\text{UCd}} = \frac{\text{kcal}}{\text{kgA. F. fuel}} \text{ or } \frac{\text{kJ}}{\text{kgA. F. fuel}} = \text{ Heat loss due to unburned carbon in flue dust}$$

$$L_{\text{UCd}} = \text{w}_{\text{d}'} \times \text{H}_{\text{d}'}$$

where,

$$W_{d'} = \frac{\text{kg}}{\text{kg A} \cdot \text{F. fuel}} = \text{ kilograms of dry flue dust per kilogram of "as fired" fuel}$$

$$H_{d'} = \frac{\text{kcal}}{\text{kg of dust}} = (\text{ or kJ/kg of dust}) \text{ heat value of flue dust}$$

Unburnt combustible loss in Heat-Loss method can also be determined analytically. The mathematical analysis is derived without regard to the type of solid-fuel-burning system employed; this analysis can be applied to any such system burning fuels ranging from cellulose and lignite to anthracite coal. The method is described in Section 7.

7.3.2.2

$$L_{\text{G}'} = \frac{\text{kcal loss}}{\text{kgA} \cdot \text{F} \cdot \text{ fuel}} \text{ or } \frac{\text{kJ loss}}{\text{kg A.F. fuel}} = \text{ Heat-loss due to heat in dry flue gas}$$

$$L_{\text{G}'} = \text{W}_{\text{G}} \times \text{c}_{\text{pG}'}(\text{t}_{\text{G}} - \text{t}_{\text{RA}})$$

where,

$$W_{G'} = \frac{\text{kg}}{\text{kgA. F. fuel}} = \text{kg of dry gas per kg of "as fired" fuel}$$

$$W_{G'} = \frac{44.01\text{CO}_2 + 32.00\text{O}_2 + 28.02\ \text{N}_2 + 28.01\text{CO}}{12.01(\text{CO}_2 + \text{CO})} \times \left[\text{Cb} + \frac{\text{S}}{2.67}\right]$$

$C_{pG'} = \frac{\text{kcal}}{\text{kg°C}}$ (or kJ/kg °C) = Mean specific heat of the dry flue gas as obtained from curves on Fig. 7. It is determined from the instantaneous values over the range between gas temperature leaving the unit and the reference temperature.

t_G = Gas temperature leaving the unit, such as t_{G12}, t_{G14}, or t_{G15}. If this temperature is to be corrected because of deviation from standard or guarantee air heater inlet air temperature (*see* **7.5.2**).

t_{RA} = Reference air temperature. If this temperature is to be corrected because of deviation from standard or guarantee inlet air temperature (*see* **7.4.1**).

7.3.2.3

$L_{mf} = \frac{\text{kcal loss}}{\text{kg A.F. fuel}}$ *or* $\frac{\text{kJ}}{\text{kg A.F. fuel}}$

= Heat loss due to moisture in the “as fired” fuel.

$L_{mf} = m_f\ (h_{12,\,14,\,15} - h_{Rw})$

where,

$m_f = \frac{\text{kcal loss}}{\text{kg A.F. fuel}}$ = kg moisture per kg of “as fired” fuel by laboratory analysis.

$h_{12,\,14,\,15}$ = Enthalpy of vapour at 0.07 kgf/cm^2 absolute gas temperature $t_{G12,\,14,\,15}$ to be taken from steam tables.

h_{Rw} = Enthalpy of saturated liquid at t_{RA} is used for solid and liquid fuels. Where moisture loss is to be adjusted for deviation from standard or guarantee conditions (*see* **7.5.4**)

7.3.2.4

$L_H = \frac{\text{kcal loss}}{\text{kg A.F. fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F. fuel}}$ = Heat loss due to moisture from burning of hydrogen.

$L_H = 8.936 \times \text{H}\ (h_{12,\,14,\,15} - h_{Rw})$

where,

8.936 = 8.936 kg of water produced from burning one kg of hydrogen

H = $\frac{\text{kg}}{\text{kg A.F. fuel}}$ = kg of hydrogen exclusive of that in moisture in as fired fuel by laboratory analysis.

Remaining items shall be identical with **7.3.2.3** where hydrogen loss is to be adjusted for deviation from standard or guaranteed conditions (*see* **7.5.4**).

NOTE — If gas analysis shows unburnt hydrogen, this loss is to be adjusted suitably.

7.3.2.5

$L_z = \frac{\text{kcal loss}}{\text{kg A.F. fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F. fuel}}$
= Heat loss due to heat in atomizing steam.
$L_z = \frac{\text{Wze}}{\text{Wfe}} (h_{12,\,14,\,15} - h_{Rw})$

where,
$W_{ze} = \frac{\text{kg}}{\text{h}} \left(\text{or} \frac{\text{kg}}{\text{s}}\right)$ kilograms of metered or estimated atomizing steam as agreee to by all parties.

$W_{fe} = \frac{\text{kg A.F.fuel}}{\text{h}}$ or $\frac{\text{kg A.F.fuel}}{\text{s}}$ = Measured fuel rate as in $\mathbf{7.3.2.3}$.

$h_{12,\,14,\,15} = \frac{\text{kcal}}{\text{kg steam}}$ or $\frac{\text{kJ}}{\text{kg steam}}$ will be identical with $\mathbf{7.3.2.3}$.

$h_{Rv} = \frac{\text{kcal}}{\text{kg H2O}}$ $(\text{or kJ/kg } H_2O)$ = Enthalpy of saturated vapour at reference temperature t_{RA} (*see* **7.2.2.3**)

7.3.2.6

$L_{CO} = \frac{\text{kcal loss}}{\text{kg A.F. fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F. fuel}}$ = Heat loss due to formation of carbon monoxide.
Where it is established that CO is present and cannot be eliminated by operating adjustments.
$L_{CO} = \left(\frac{CO}{CO_2+CO}\right) \times (\text{Heat generated by burning 1 kg of carbon in CO to } CO_2) \times C_b$

where,

CO and CO_2 percent by volume of flue gas.

5 644 kcal (or 23632.12 kJ) = Heat generated burning 1 kg of carbon in CO to CO_2 and represents the difference between the burning carbon as it occurs in fuel to CO_2 (8078 kcal or 33820 kJ) and burning carbon as it occurs in fuel to CO (2433.33 kcal or 10187.88 kJ), that is (8078 – 2433.33) or (33820 – 10187.88)
= 5644.67 kcal or 23632.12 kJ

$C_b = \frac{\text{kg}}{\text{kg A.F.fuel}}$ = Kilograms of carbon burned per kilogram of "as fired" fuel.

7.3.2.7

$L_{\mathrm{UHC}} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F.fuel}}$ = Heat loss due to unburned hydrogen.

Where it is established that unburned hydrogen is resent and cannot be eliminated by separating adjustments.

$$L_{\mathrm{UH}} = \frac{\frac{\text{H2 (in m}^3)}{\text{m}^3\text{ of dry gas}} \times W_{G'} \times 2838.21}{\text{Flue gas specific weight}}\ \text{kcal/kg}$$

where,

$\frac{\text{H2 (in m}^3)}{\text{m}^3\text{ of dry gas}}$ = laboratory determination of H_2 content of flue gas (*see* **6.6**)

$W_{G'} = \frac{\text{kg}}{\text{kg A.F.fuel}}$ = kilograms of dry gas per kilogram of "as fired" fuel as determined in **7.2.7.1**

2 838.21 = kcal/m^3 of hydrogen at one atmosphere and 20 °C.

Flue gas specific weight at 20 °C and atmospheric pressure.

$$= 0.352\,6\left[\frac{CO_2}{19.268} + \frac{O_2}{26.499} + \frac{CO}{30.263} + \frac{N_2}{30.263} + \frac{SO_2}{13.235} + \frac{H_2}{420.063} + \frac{\frac{HC}{847.98}}{M\mathrm{HC}}\right]$$

Where,
CO_2, O_2, CO, etc. = Percent = Percent by volume constituents as determined by laboratory analysis of flue gas.
M_{HC} = molecular weight of hydrocarbon in flue gas.

For derivation of flue gas specific weight (*see* Section 7).

7.3.2.8

$L_{\mathrm{UHC}} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F.fuel}}$ = Heat loss due to unburned hydrocarbons.

Where it is established that unburned hydrocarbons (UHC) are present and cannot be eliminated by operating adjustments:

$$L_{\mathrm{UH}} = \frac{\frac{\text{UHC (in m}^3)}{\text{m}^3\text{ dry gas}} \times W_{G'} \times K_{\mathrm{UHC}}}{100 \times \text{flue gas specific weight}}\ \text{kcal/kg}$$

where,

$\frac{\text{UHC (in m}^3)}{\text{m}^3\text{ dry gas}}$ = Laboratory determination of flue gas constituents as in **6.6**.

$W_{G'} = \frac{\text{kg}}{\text{kg A.F.fuel}}$ = kg of dry gas per kg of as fired fuel, as determined in **7.2.7.1**.

K_{UHC} = kcal/m^3 (or kJ/m^3) of unburned hydrocarbons as determined by laboratory analysis at 20 °C and atmospheric pressure.

For gas specific weight at 20°C and 1.033 kg/cm^2 absolute.

NOTE — If unburnt hydrogen carbon exists the dry gas loss and moisture loss from combustion of hydrogen be adjusted suitably.

7.3.2.9

L_β = Loss due to surface radiation and convection.

This loss may be obtained from radiation loss chart (*see* Fig. 8) and correction for air velocities. *See* Fig. 9 by taking the radiation loss percent and multiplying it by the chemical heat in one kg of "as fired" fuel (H_f). Alternatively, the loss may be as agreed to by the parties concerned.

7.3.2.10 *Summarising losses*

$$L = L_{UC} + L_{G'} + L_{mf} + L_H + L_z + L_{CO} + L_{UH} + L_{UHC} + L_\beta$$

where,

$L = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Total heat losses (*see* **7.3.2**)

$L_{UC} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to unburned carbon in refuse (*see* **7.3.2.1**)

$L_{G'} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to heat in dry flue gas (*see* **7.3.2.2**)

$L_{mf} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to moisture in the "as fired" fuel (*see* **7.3.2.3**)

$L_H = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to moisture from burning of hydrogen (*see* **7.3.2.4**)

$L_z = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to heat in atomizing steam (*see* **7.3.2.5**)

$L_{CO} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to formation of carbon monoxide (*see* **7.3.2.6**)

$L_{UH} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to unburned hydrocarbons (*see* **7.3.2.7**)

$L_{UHC} = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to unburned hydrocarbons (*see* **7.3.2.8**)

$L_\beta = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Heat loss due to surface radiation and convection (*see* **7.3.2.9**)

7.3.3

$H_f = \frac{\text{kcal loss}}{\text{kg A.F.fuel}}$ *or* $\frac{\text{kJ loss}}{\text{kg A.F.fuel}}$ = Chemical heat in fuel to be obtained as in **7.2.5.1**.

7.3.4

$B = \frac{\text{kcal credit}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ credit}}{\text{kg A.F.fuel}}$ = Total heat credits per k of “as fired” fuel added to the steam generator in the form of sensible heat.

$B = \frac{B_{Ae}+B_{ze}+B_{fe}}{Wfe}$

where,

$B_{Ae} = \frac{\text{kcal credit}}{\text{h}}$ or $\frac{\text{kJ credit}}{\text{s}} = \text{Heat credit supplied by entering air } (\textit{see } \mathbf{7.2.7.1}).$

$B_{ze} = \frac{\text{kcal credit}}{\text{h}}$ or $\frac{\text{kJ credit}}{\text{s}} = \text{Heat credit supplied by at missing steam } (\textit{see } \mathbf{7.7.2.2}).$

$B_{ze} = \frac{\text{kcal credit}}{\text{h}}$ or $\frac{\text{kJ credit}}{\text{s}} = \text{supplied by sensible heat in fuel } (\textit{see } \mathbf{7.2.7.3}).$

$W_{fe} = \frac{\text{kg A.F.fuel}}{\text{h}}$ or $\frac{\text{kg A.F.fuel}}{\text{s}} = \text{Measured fuel rate as in } \mathbf{7.3.2.1}$

For a more accurate calculation of gross steam boiler efficiency, the gross efficiency obtained from the initial calculation can be used as the basis for determining a refined fuel rate. When this value is substituted in formulas for determining heat losses and credits, a more accurate calculated gross efficiency is obtained.

7.4 Corrections to Standard or Guaranteed Condition Corrections to Heat Credits

7.4.1 Corrections to the heat credits, “heat supplied by entering air” and “heat supplied by sensible heat in fuel” for change from test reference air temperature (*see* **7.2.7.1**) to a standard or guaranteed-air inlet temperature are made by substituting the standard or guaranteed temperature for the test reference temperature in the heat credit formulae.

7.4.2 Corrections to the heat credits, “heat supplied by atomizing steam” for changes from test reference air temperature to a standard or guaranteed temperature air inlet temperature are made by substituting the enthalpy corresponding to the standard or guaranteed temperature for the enthalpy corresponding to the test reference temperature in the heat credit formulae.

7.5 Corrections to Heat Losses

Corrections to heat losses, besides including a correction for changes from the test reference air temperature to standard or guaranteed air inlet temperature as in the treatment of heat credit corrections must also include, when an air heater is used, a correction for the change in gas exit temperature resulting from the above change in air inlet temperature. The corrected gas outlet temperature is as follows:

$$t_{G15}{}^{\delta} = \frac{t_{AB}{}^{D}\,(tG_{14} - tG_{15}) + tG14\,(tG_{15} - t_{AB})}{(tG_{14} - t_{AB})}$$

where,

$t_{G15}{}^{\delta}$ = Corrected air heater exit gas temperature.
$t_{AB}{}^{D}$ = Standard or guaranteed air heater inlet air temperature.
t_{G14} = Air heater inlet gas test temperature.
t_{G15} = Air heater exit gas test temperature.
t_{AB} = Air heater inlet air test temperature.

A further minor correction caused by leakage difference between test and standard of guaranteed temperature is to be applied.

7.5.2 Corrections to the heat losses, “Dry gas loss” for changes from test reference air temperature to a standard or guaranteed air inlet temperature are made by substituting the standard or guaranteed temperature for the test reference air temperature and also by substituting the corrected gas exit temperature for the test gas exist temperature in the heat loss formulae.

7.5.3 Corrections to the heat losses, “Heat loss due to moisture in fuel” and “Heat loss due to atomizing steam” for changes from the test reference air temperature to a standard or guaranteed air inlet temperature are made by substituting the appropriate enthalpy corresponding to the standard or guaranteed air inlet temperature for the enthalpy corresponding to the test reference air temperature, and also by substituting the enthalpy corresponding to the corrected gas exit temperature for the enthalpy corresponding to the test gas exit temperature in the heat loss formulae. The “appropriate” inlet enthalpy referred to above relates to the state of the entering moisture (liquid or vapour).

7.5.4 Corrections to the heat losses “Heat loss due to moisture in fuel” and “Heat loss due to hydrogen in fuel” for changes of moisture and hydrogen content from the test fuel to the fuel used for the standard or guaranteed computations, are made by substituting the weight of moisture or hydrogen per kg of fuel in the standard or guaranteed fuel for the weight of moisture or hydrogen per kg of fuel, of the test fuel, in the heat loss formula.

7.5.5 Other heat losses listed in the computations are not considered in these corrections paragraphs either because they do not apply or the magnitude of the correction is usually insignificant.

7.6 The corrected steam generator efficiency resulting from the preceding adjustments of credits and losses to standard or guarantee conditions can then be compared with the standard or guaranteed conditions, respectively.

SECTION 7

ANNEX

8.1 Derivation of the Weight of Dry Air

The following is the derivation of the equation for computing the weight of dry air per pound of "as fired" fuel (*see* **7.2.7.1**) In this derivation the assumption is made that whatever sulphur is present in the fuel is burned to sulphur dioxide. This is no1 entirely true, a fraction may be horned to sulphur trioxide and another fraction could form oxides with the ash. In addition some of the sulphur may be in the form of sulphides or sulphates and unavailable for combustion. However, the treatment presented here appears to be the best for general usage. An additional minor assumption made is that all the sulphur dioxide sampled is removed in the Orsat by the carbon dioxide reagent.

Kilograms of dry gas per mole of dry gas =

$$44.01\,\frac{(\mathrm{CO_2})}{100} + 28.01\,\frac{(\mathrm{CO})}{100} + 32.00\,\frac{(\mathrm{O_2})}{100} + 28.02\,\frac{(\mathrm{N_2})}{100}$$

Kilograms of equivalent carbon burned per mol of dry gas $= 12.01\,\frac{(\mathrm{CO_2}+\mathrm{CO})}{100}$

In order to use this equation the weight of carbon burned per kg of "as fired" fuel must be adjusted for the sulphur dioxide absorbed in the or sat aside. To reduce the sulphur in the fuel to its carbon equivalent, multiply the sulphur in the fuel by$\left[\frac{12.01}{32.07}\right]$

Molecular weight:

C = 12.01
S = 32.07

Than the equivalent carbon burned is $\mathrm{C}_b + \frac{\mathrm{S}}{2.67}$

The weight of dry gas per kg of "as fired" fuel is obtained as follows:
WG'

$$W_G' = \frac{\text{kg dry gas}}{\text{mol dry gas}} \times \frac{1}{\frac{\text{kg carbon}}{\text{mol dry gas}}} \times \frac{\text{kg carbon}}{\text{kgA. F fuel}} = \frac{\text{kg dry gas}}{\text{kgA. F. fuel}}$$

$$W_{\mathrm{G}'} = \frac{44.01(\mathrm{CO_2}) + 28.01(\mathrm{CO}) + 32.00(\mathrm{O_2}) + 28.02(\mathrm{N_2})}{12.01(\mathrm{CO_2}+\mathrm{CO})}\left(\mathrm{C}_b + \frac{\mathrm{S}}{2.67}\right)$$

Kilogram of nitrogen per mol of dry gas $= 28.02\,\frac{(\mathrm{N_2})}{100}$

$W_{NG'} = \frac{1}{\frac{\text{kg dry gas}}{\text{mol dry gas}}} \times \frac{\text{kg nitrogen}}{\text{mol dry gas}}$ = kg of nitrogen in the dry gas per kg of dry gas.

$$W_{\mathrm{N}G'} = \frac{28.02(\mathrm{N_2})}{44.01(\mathrm{CO_2}) + 28.01(\mathrm{CO}) + 32.00(\mathrm{O_2}) + 28.02(\mathrm{N_2})}$$

Kilogram of nitrogen in the dry gas per kg of dry gas multiplied by kilogram of dry gas per kilogram of “as fired” fuel = $W_{\mathrm{NG'}}$ × $W_{\mathrm{G'}}$ = kilogram of nitrogen in the dry gas per kg of “as fired fuel” fuel = $W_{G'N_2}$

Therefore

$$W_{G'\mathrm{N_2}} = \frac{28.02(\mathrm{N_2})}{44.01\ (\mathrm{CO2}) + 28.01\ (CO) + 32.00\ (O2) + 28.02\ (N2)} \times \frac{44.01(\mathrm{CO_2}) + 28.01(\mathrm{CO}) + 32.00(\mathrm{O_2}) + 28.02(\mathrm{N_2})}{12.01(\mathrm{CO_2} + \mathrm{CO})}\left(\mathrm{C}_b + \frac{\mathrm{S}}{2.67}\right)$$

$$W_{G'\mathrm{N_2}} = \frac{28.02(\mathrm{N_2})}{12.01(\mathrm{CO_2} + \mathrm{CO})}\left(\mathrm{C}_b + \frac{\mathrm{S}}{2.67}\right)$$

W_A' = kg of dry air per kg of “as fired” fuel
N = kg of nitrogen per kg of “as fired” fuel — (From laboratory analysis of the fuel)

$$W_A' = \frac{W_{G'\mathrm{N_2}} - \mathrm{N}}{0.7685}$$

0.768 5 = the kg of nitrogen per kg of standard air (*see* International Critical Tables — Vol. I). The complete equation for the weight of dry air per kg of “as fired” fuel is equal to:

$$W_A' = \frac{\frac{28.02(\mathrm{N_2}) \times \left(\mathrm{C}_b + \frac{\mathrm{S}}{2.67}\right)}{12.01(\mathrm{CO_2} + \mathrm{CO})}}{0.7685}$$

8.2 Computation of Theoretical and Excess Air

For those interested in calculating theoretical and excess air the following formulae are useful:

Theoretical air:

$A'_\theta = 11.51\mathrm{C} + 34.30\left(H - \frac{O}{7.937}\right) + 4.335\ \mathrm{S}$
$A'_\theta = \frac{\text{kg of dry air}}{\text{kg A.F.fuel}}$ = Theoretical dry air in kg required to completely burn a kg of “as fired” fuel

$\mathrm{C} = \frac{\text{kg carbon}}{\text{kg A.F.fuel}}$ (From laboratory analysis of the fuel)

$\mathrm{H} = \frac{\text{kg hydrogen}}{\text{kg A.F.fuel}}$ (From laboratory analysis of the fuel)

$O = \frac{\text{kg oxygen}}{\text{kg A.F.fuel}}$ (From laboratory analysis of the fuel)

$S = \frac{\text{kg sulphur}}{\text{kg A.F.fuel}}$ (From laboratory analysis of the fuel)

All constants are based on molecular weights.

Excess air:

$$A'_s = \frac{W_{A'\theta} - A'_\theta}{A'_\theta} \times 100$$

A'_s = percent excess air

$W_{A'} = \frac{\text{kg of dry air}}{\text{kg A.F. fuel}} = \text{Weight of dry air per kg of "as fired" fuel}$

$A'_\theta = \frac{\text{kg of dry air}}{\text{kg A.F. fuel}}$ = kg of dry air theoretically required to completely burn a kg of “as fired” fuel

8.3 Derivation of Flue Gas Specific Weight

The following derivation of flue gas specific weight at 20°C and 1.033 kg/cm^2 (*see* **7.3.2.7**) is based on the assumption that the flue gas conforms to the ideal gas law:

$$PV = \psi R_u T$$

where,

$P = \frac{\text{kg}}{\text{m}^2}$ = absolute pressure

V = m^3 = volume

Ψ = number of kg moles

$R_u = \frac{847.98}{\text{kg mole, °K}}$ = Universal gas constant

T = °K = Temperature Kelvin.

Multiplying both sides by the molecular weight M

$\therefore \quad MPV = M\,\psi\, MR_uT$

But $M\,\psi = W$ = kg of gas

$MPV = WR_uT$

$MP = \frac{W}{V} R_u T$

Specific weight of gas = $\gamma = \frac{W}{V}$

$$\therefore MP = \gamma R_u T$$
$$\gamma = \frac{P}{T} \times \frac{M}{R_u}$$

At standard conditions:

$$\mathrm{P} = 1.033\ \mathrm{kg\ per\ cm^2} \times 104 \frac{\mathrm{cm^2}}{\mathrm{m^2}} = 1.033 \times 104 \frac{\mathrm{kg}}{\mathrm{m^2}}$$
$$\mathrm{T} = 20^{\circ}\mathrm{C} + 273 = 293\ \mathrm{K}$$
$$\frac{\mathrm{P}}{\mathrm{T}} = \frac{1.033 \times 10^4}{293}$$

Therefore:

$$\gamma = 35.26 \frac{M}{R_{\mathrm{u}}}$$

$$\gamma = \frac{35.26}{100}\left[\frac{(\mathrm{CO_2} \times \mathrm{M_{CO_2}}) + (\mathrm{O_2} \times \mathrm{M_{O_2}}) + (\mathrm{N_2} \times \mathrm{M_{N_2}}) + (\mathrm{CO} \times \mathrm{M_{CO}}) + (\mathrm{SO_2} \times \mathrm{M_{SO_2}}) \pm (\mathrm{H_2} \times \mathrm{M_{H_2}}) + (\mathrm{HC} \times \mathrm{M_{HC}})}{847.98}\right]$$

$$\gamma = 0.3526\left[\frac{\frac{\mathrm{CO_2}}{847.98}}{44.01} + \frac{\frac{\mathrm{O_2}}{847.98}}{32.00} + \frac{\frac{\mathrm{N_2}}{847.98}}{28.02} + \frac{\frac{\mathrm{CO}}{247.98}}{28.01} + \frac{\frac{\mathrm{SO_2}}{847.98}}{64.07} + \frac{\frac{\mathrm{H_2}}{847.98}}{2.016} + \frac{\frac{\mathrm{HC}}{847.98}}{\mathrm{M_{HC}}}\right]$$

$$\gamma = 0.3526\left[\frac{\mathrm{CO_2}}{19.268} + \frac{\mathrm{O_2}}{26.499} + \frac{\mathrm{N_2}}{30.263} + \frac{\mathrm{CO}}{30.274} + \frac{\mathrm{SO_2}}{13.235} + \frac{\mathrm{H_2}}{420.0625} + \frac{\frac{\mathrm{HC}}{847.97}}{\mathrm{M_{HC}}}\right]$$

8.4 Heating Value of Carbon as it Occurs in Refuse

Heat value of carbon to be used in estimating the heat loss due to combustible in the refuse in boiler heat balance varies approximately from 8 000 to 8 111 kcal/kg (33 494.4 to 33 959.6 kJ/kg) mainly due to the form in which the carbon is present. For the purpose of consistent accuracy, the value of 8 078 kcal/kg (33 820 kJ/kg) has been used throughout this Code.

8.5 Radiation and Convection Losses

This is the only significant loss, the computation of which is not based on test measurements. Therefore, this loss is estimated using the curves given in Fig. 8.

8.5.1 In order that this curve may be improved in accuracy in future years, users of this Code are encouraged to take radiation and convection loss readings on acceptance tests and from these compute the loss and report the results to the statutory authority and committee on steam boilers, giving a detailed description of the unit in regard to exposure, wind velocities, type of wall construction, method of testing, etc. In conducting such tests, the following method is suggested for obtaining test data and computing the loss.

8.5.2 Determine this loss through the steam generator walls, roof, bottom, air heater, ducts, piping and any other exposed surfaces by installing at the centre of every ten square metre of area a pair of thermocouples in a block of insulation of known conductivity. With the temperature gradient measured by the thermocouples, the known distance between thermocouples and the conductivity of the insulation compute the radiation and conductivity loss for each 10 m^2. The sum of these losses for each 10 m^2 divided by the steam generator heat input rate will be the radiation and convection loss for the unit.

8.6 Conversion of Heating Value from Constant Volume to Constant Pressure

The formula for the conversion of the high-heat value at constant pressure is based on the first law of thermodynamics and the general energy equations. In a heating value determination there is no thermodynamic work performed nor kinetic change, therefore, the heating value at constant volume is the change in internal energy between the reactants and products. Similarly, and for the same reasons, the heating value at constant pressure is the change in enthalpy between the reactants and products. This being the situation the general energy equation relating the constant routine, heating value with the constant pressure heating value is as follows:

$$H_{fp} = H_{fu} + \frac{\Delta PV}{778.2}$$

Assuming the perfect gas law can be applied to the gaseous constituents of the reactions:

$$\frac{\Delta PV}{\mathrm{J}} = \frac{\Delta_{\psi} R_u T}{\mathrm{J}}$$

where

J = Mechanical equivalent of heat, and

H_{fp} = $H_{fv} + \frac{\Delta_{\psi} R_u T}{\mathrm{J}}$

where

$H_{\mathrm{fp}} = \frac{\mathrm{kcal}}{\mathrm{kg\ A.F.fuel}}$ or $\frac{\mathrm{kJ}}{\mathrm{kg\ A.F.fuel}} = \mathrm{High-heat\ value\ of\ fuel\ at\ constant\ pressure}$

$H_{fv} = \frac{\text{kcal}}{\text{kg A.F.fuel}}$ or $\frac{\text{kJ}}{\text{kg A.F.fuel}} = \text{High} - \text{heat value of fuel at constant volume}$

$\Delta\psi$ = Change in the number of kg moles of gaseous products when compared to the kg moles of gaseous reactants. Only the number of gaseous moles are of importance because the volume occupied by a mole of liquid or solid material is so small that it is insignificant and the perfect gas law does not apply to these fractions.

$R_u = \frac{847.98\ \text{m-kg}}{\text{kg mol K}}$ or $= \frac{8.314\,3 \times 10^{-3}\text{kJ}}{\text{mol deg}}$

T = 298.6 K. This is the absolute value of the standard calorimeter temperature.

427 m-kg = 1 kcal = Mechanical equivalent of heat.

Determination of the change in the number of moles caused by the combustion reactions of solid or liquid fuels.

Sl No. (1)	*Reactants* (2)	*Products* (3)
i)	C (solid) or + O_2 (gas) (liquid)	CO_2 (gas)
ii)	N (solid) or (liquid)	N_2 (gas)
iii)	H (solid) or + ½ O_2 (gas) (liquid)	H_2O (liquid)
iv)	S (solid) or + O_2 (gas) (liquid)	SO_2 (gas)

$\left.\begin{array}{c}\text{O}\\\text{A}\\\text{M}\end{array}\right|$ in combined state as reactants, therefore, they cannot enter reaction except for occasional rare constituents.

The carbon (C) reaction has no change in the number of gaseous moles from reactants to products, therefore, no correction required.

The nitrogen (N) reaction, assuming it is released as a gas in the products and reacted as a solid or liquid, increases by one (l) mole per mole of nitrogen reactant. This causes a PV change and requires an adjustment between the high-heat value at constant pressure and volume.

Hydrogen as a liquid or solid portion of a compound is released and units with oxygen to form water which is condensed to a liquid. Therefore, the net effect of the reaction is a decrease of half a mole of product for each mole of hydrogen exclusive of that in the fuel moisture.

Solid sulphur reacts with a mole of oxygen to form a mole of sulphur dioxide in the products. There is no net change in gaseous constituents, therefore, no correction required.

All oxygen in the fuel is assumed to be in the combined state. The compounds envisioned are water and metallic oxides in the ash. In the foregoing forms the oxygen in the fuel will not react and appears unchanged in the products and no correction is required. Similar reasoning applied to the ash and moisture in the fuel proves no need for a correction on their behalf.

$$\Delta\psi = \frac{-\mathrm{N}}{28.016} + \frac{1}{2}\,\frac{\mathrm{H}}{2.016}$$

Note the sign convection — Where there is an increase in the mole volume, work is done on the surroundings and results in a negative sign.

$\mathrm{N} = \frac{\mathrm{kg}}{\mathrm{kg\ A.F.fuel}}$ = kg of nitrogen per kg of “as fired” fuel

$28.016 = \mathrm{kg}\,\frac{\mathrm{kg}}{\mathrm{mole}}$ = kg of nitrogen per kg mole of nitrogen

$\mathrm{H} = \frac{\mathrm{kg}}{\mathrm{kg\ A.F.fuel}}$ = kg of hydrogen exclusive of that in the moisture per kg of “as fired” fuel

$2.016 = \frac{\mathrm{kg}}{\mathrm{mole}}$ = kg of hydrogen per kg mole of hydrogen.

Substituting into the general equation:

$$H_{\mathrm{fp}} = \mathrm{H}_{\mathrm{fv}} + \left(\frac{-\mathrm{N}}{28.016} + \frac{\mathrm{H}}{4.032}\right)\frac{R_{\mathrm{u}}T}{427}$$

Substituting for R_{u} and assuming a standard calorimeter temperature of 25 ° C this reduces to:

$$H_{\mathrm{fp}} = H_{\mathrm{fv}} + \left(\frac{-N}{28.016} + \frac{H}{4.032}\right)\frac{591.79\ \mathrm{kcal}}{\mathrm{kg\ of\ A.F.fuel}}$$

or

$$H_{\mathrm{fp}} = H_{\mathrm{fv}} + \left(\frac{-N}{28.016} + \frac{H}{4.032}\right)\frac{2\,477.71\ \mathrm{kJ}}{\mathrm{kg\ of\ A.F.fuel}}$$

The nitrogen in liquid and solid fuel is less than 2 percent by weight, therefore, the nitrogen correction is less than 0.422 kcal per kg of fuel or 1.765 kJ per kg of fuel. This correction is only required if the nitrogen is in the solid or liquid form in the fuel and is released as a gas during combustion. If it is an entrapped gas initially or forms an ash compound during combustion, no correction is required. In considering these various contingencies, it was decided to neglect the nitrogen correction and the formula as found in **7.2.5.2** and given here reduces to the following results:

$H_{fp} = H_{fv} + 146.77\ \mathrm{H}$ kcal/kg

or $H_{fp} = H_{fv} + 614.51\ \mathrm{H}$ kJ/k

8.7 Method of Determining Combustible Loss for a Solid Fuel Burning System

The analysis is based on the accepted principle as given in **8.7.1**, **8.7.2** and **8.7.3**.

8.7.1 Ash content as determined from the proximate or ultimate analysis of the fuel, fed to a furnace must be accounted for.

8.7.2 The ash entering a component or system of components per unit time, must be equal to the ash leaving the same component or system of components for the same unit of time.

8.7.3 Ash has combustible matter associated with it to some degree.

8.7.4 The following nomenclature is being used only for the purpose of computation of combustible losses for solid fuel burning system:

AB = Ash from boiler hoppers kg/h.
AD = Ash from dust collector hoppers (that is *AEC*)
AE = Ash from economizer hoppers.
AH = Ash from air heater hoppers.
AEB = Ash entering boiler.
AEC = Ash entering dust collector.
AEE = Ash entering economizer.
AF = Ash to furnace.
AEH = Ash entering air heater.
AG = Ash from furnace bottom.
AS = Ash to stack.
C = Percent solid combustible loss.
CB = Combustible associated with ash from boiler hopper.
CD = Combustible associated with ash from dust collector hoppers.
CE, CH = Combustibles associated with ash from economizer and/or air heater hoppers.
CEB = Combustibles associated with ash entering boiler.
CEC = Combustible associated with ash entering dust collector.
CEE = Combustibles associated with ash entering economizer and/or air heater.
CG = Combustibles associated with ash from furnace bottom.
CS = Combustibles associated with ash to stack.
RB = Refuse in boiler hoppers.
RD =Refuse in dust collector hoppers.
RE =Refuse from economizer hoppers.
RH =Refuse from air heater hoppers.
REB = Refuse entering boiler.
REC = Refuse entering dust collector.
REE = Refuse entering economizer.
RG = Refuse in ash pit.
RS = Refuse to stack.

8.7.5 In this analysis, percentage of ash that enters the furnace or removed as bottom ash shall be determined. The ratio *AG*/*AF* varies from fuel to fuel and type of firing. Part of this variation is accounted for in the fuel sizing and rank of the fuel. Another major factor contributing to the variation is allowable grate heat release rate. This ratio of AG/AF for various fuel ranks and create heat release rates are given in Fig. 11, Fig. 12, Fig. 13, and Fig. 14.

8.7.6 Ash distribution through each component of the system shall be found out. Due to **8.7.3**, the total refuse may be found from the following expression:

$$R = \frac{\text{Ash (100) kg/h}}{100 - \text{percentage combustible}}$$

The some of ash and the combustible shall be calculated (*see* **8.7.2**), which will be equal to the refuse a teach point of entering or leaving a system or system component.

8.7.7 The percentage combustible loss shall be calculated from the following expression:

$$\text{C} = \frac{(C_1+C_2+C_3 \ldots\ldots Cn)\times HHV}{\text{Total fuel fired} \times Hf \; (see \text{ Section 2})}$$

Where,
C_1,C_2……C_n = Combustible leaving each system/component
HHV = High-heat value
= 8 078 kcal/kg or 33 820 kJ/kg

8.7.8 *Illustration of Analysis*

The analysis given in **8.7.1** to **8.7.7** has been illustrated in the following example considering reinjection only from boiler hopper.

8.7.8.1 The following information's are known:

a) Firing equipment : Continuous ash discharge spreader stocker
b) Fuel : High volatile 'B'
c) *HHV* : 5 555.56 kcal/kg or 23 260 kJ/kg (as fired)
d) Ash : 20% (as fired)
e) Grate heat release rate : 1 627 476 kcal/h m^2 or 0.189 kJ/cm_2
f) Total steam output : 45 361.76 kg/h (from integrator reading)
g) Heat added to steam : 611 kcal/kg (or 2 558.6 kJ/kg)
h) Steam generating efficiency : 85% (for initial calculations assumed from design data)
j) Stack dust loading : 1.26 kg/10^6 (kcal input or 0.3 kg/10^6) kJ input (For initial calculations assumed from design data)
k) Percent combustible in
    1) Ash pit. Refuse : 5
    2) Boiler hopper : 35
    3) Economizer hopper : 45
    4) Dust collector hopper : 40
    5) Stack refuse : 35

To determine solid combustible loss, when cinder re-injection is only from boiler hoppers.

Calculations

Total heat input $= \frac{(45\ 361.76)\times(611)}{(0.85)}$

$= 32.6 \times 10^6$ kcal/h

Total fuel input $= F$

$= \frac{32.6 \times 10^6}{5\ 555.56}$

$= 5\ 868.00$ kg/h

Total ash to furnace $= AF$

$= (5\ 868)\ (0.20)$

$= 1\ 173.6$ kg/h

From Fig. No. 11.

$AG/AF = 0.70$

$AG = (0.70)\ (1\ 173.6)$

$= 821.60$ kg/h

Defining the system by the dotted line as shown in Fig. 10.

It is assumed that:

$AB = 0.10\ AEB$. For single pass boilers.

$AB = 0.20\ AEB$. For multi pass boilers.

$AE = 0.20\ AEE$. For economizer and air heater hoppers with 180” gas turns.

$AF + AB = AG + AEB$ (*see* **8.7.4**)

$AF + 0.1\ AEB = AG + AEB$ (Since $AB = 0.1\ AEB$)

$AF - AG = 0.9\ AEB$

$AEB = \frac{AF-AG}{0.9} = \frac{(1\ 173.6)-(821.6)}{0.9}$

$AEB = 391.1$kg/h

$AB = 39.1$ kg/h

$AEE = AEB - AB = 391.1 - 39.1$

$AEE = 352$ kg/h

$AE = 352(0.2) = 70.4$

$AEC = 352-70.4 = 281.6$

Total refuse to stack $= RS = (1.26)\ (32.60) = 41.00$ kg/h

Percent combustible in stack refuse: 35% (given).

Total ash in stack refuse:

$AS = (41.00)\ (0.65) = 26.65$ kg/h

$AF = AG + AE + AD + AS$
$AD = 1\,173.6 - 821.6 - 70.4 - 26.65 = 254.95$ kg/h

Combustibles:

Combustible in stack refuse, CS = $RS - AS$.

$CS = (41.00) - (26.65) = 14.35$ kg/h

Combustible in dust collector hoppers:

Percentage combustible in dust collector hoppers: 40% (given)

Percentage ash in dust collector hoppers: 100 - 40 = 60%

Total refuse in dust collector hopper, $RD = \frac{254.95}{0.60}$

$RD = 424.9$ kg/h

Combustible in dust collector hopper, CD = RD -AD.

$CD = 424.9 - 254.95$
$CD = 169.95$ kg/h

Combustible in economiser hoppers:

Percentage combustible in economiser hoppers: 45% (given)

Percentage ash in economiser hoppers: 100 - 45 = 55%

Total refuse in economiser hopper : RE = $\frac{70.4}{0.55}$
$RE = 128.0$ kg/h

Combustible in economiser hoppers, $CE = RE - AE$

$CE = 128.0 - 70.4$
$CE = 57.6$ kg/h

Combustible in ash pit:

Percentage combustible in refuse: 5% (given.)

Percentage ash in ash pit refuse: 100 - 5 = 95%

Total refuse in ash pit, $RG = \frac{821.6}{0.95}$

RG = 864.8 kg/h

Combustible in ash pit refuse = $CG = RG – AG$

CG = 864.8 - 821.6
CG = 43.2 kg/h

Solid combustible loss of unit =

$$C = \frac{(CG + CE + CD + CS)(8\ 078)(100)}{(5\ 868)(5\ 555.56)}$$

$$CG + CE + CD + CS = 43.20 + 57.6 + 169.95 + 14.35$$

= 285.1 kg/h

Percent solid combustible loss, C

$$= \frac{(285.1)(8\ 078)(100)}{(5\ 868)\ (5\ 555.56)}$$
= 7.06 %

Following the same procedure percent solid combustible loss C can be worked out in other cases, such as cinder being circulated from economiser hoppers and dust collector hoppers.

8.7.8.2 The same technique can also be adopted for '*Bagasse* Fired' Boilers as follows:

a) Firing equipment — Continuous ash discharge spreader stoker;
b) Fuel — *Bagasse*;
c) *HHV* — 2 266.7 kcal/kg or 9 489.00 K;
d) Ash — l.56 %;
e) Grate heat release rate — 1627 476 kcal or 0.189 kJ/cm^2–sec;
f) Total steam output — 30 000 kg/J (from integrator readings);
g) Heat added to steam — 611 kcal/kg or 2 558.6 kJ/kg;
h) Steam generating efficiency — 64%;
j) Percent combustible (Given):

1) Ash pit refuse	:	5%
2) Boiler hopper	:	55%
3) Air heater hoppers	:	65%
4) Dust collector hoppers	:	65%
5) Stack refuse	:	55%

To determine solid combustible loss when there is no cinder re-injection from any hopper.

Calculations

Total heat input = $\frac{(30\ 000)(611)}{(0.64)}$
= 28.64 × 10^6 kcal/h
Total fuel input, F = $\frac{28.64 \times 10^6}{2266.7}$
= 12 635.1 kg/h
Total ash to furnace, AF = (12 635.1) (0.015 6)
= 197.1 kg/h

From Fig. 14.

$$\begin{aligned} AG/AF &= 0.61 \\ AG &= (0.61)(197.1) \\ &= 120.24 \text{ kg/h} \end{aligned}$$

Assuming
$AB = 0.10AEB$; for single pass boilers.
$AB = 0.20AEB$; for multi pass boilers.
$AH = 0.20AEH$, for air heater hoppers with 180° Gas Turns.
Defining the system as shown in Fig. 10 (A)

$AEB = AF - AG$

= 197.1– 120.24

= 76.86 kg/h

AB = (0.2) (AEB)

= (0.2) (76.86)

= 15.36 kg/h

$AEH = AEB - AB$

= 76.86 – 15.37

= 61.49 kg/h

AH= (0.1) (AEH)

= (0.1) (61.49)

= 6.149 kg/h

$AEC = AEH - AH$

= 61.49 – 6.149

= 55.34 kg/h

Assuming efficiency of dust collector $= 80\%$
that is $\frac{RD}{REC} = 0.8$
For dust collector

$$REC - RD = RS$$

But $RS = \frac{\frac{(AS)}{(100-55)}}{(100)}$
(Since percentage burnable in stack refuse is 55)

$$RS = \frac{AS}{0.45}$$
$$= \frac{\mathrm{A}EC - AD}{0.45}$$

Therefore $(RD/0.8) - (RD) = \frac{(AEC-AD)}{(0.45)}$
or
$$RD = 8.89(AEC - AD)$$

But $RD = \frac{\frac{AD}{(100-65)}}{(100)}$
(Since percentage burnable discharge from dust collector hoppers is 65.)

$$= \frac{AD}{0.35}$$

Therefore $\frac{AD}{0.35} = 8.89$ (AEC-AD)
Or

$$AD = 0.757AEC$$

or

$$AD = (0.757)(55.34)$$
$$= 41.88 \text{ kg/h}$$

and

$$AS = AEC - AD$$
$$= (55.34) - (41.88)$$
$$= 13.46 \text{ kg/h}$$

Combustibles :

Combustible in stack refuse : $CS = RS - AS$

$$RS = \frac{AS}{\frac{(100-55)}{100}}$$ (% combustibles to the stack is 55%)

$$= AS/0.45$$
$$= 13.46/0.45$$
$$= 29.91 \text{ kg/h}$$

Therefore:

$$CS = 29.91 - 13.46$$
$$CS = 16.45 \text{ kg/h}$$

Combustible in dust collector hoppers :

Percentage combustible in dust collector hoppers = 65% (Given)

$$CD = RD - AD$$

$$= \frac{AD}{(100-65)}$$
$$= \frac{AD}{0.35} - AD$$

or $CD = \frac{(41.88)}{(0.35)} - (41.88)$

$$CD = 77.78 \text{ kg/h}$$

Combustible in air heater hoppers:

Percentage combustible in air heater hopper 65%

$$CH = RH - AH$$
$$= \frac{\frac{(AH)}{(100-65)}}{100} - AH$$

$\therefore$ $CH = (6.149/0.35) - 6.149$

or, $CH = 11.42 \text{ kg/h}$

Combustible in boiler hoppers:

Percentage combustible in boiler hoppers = 55 %

CB= *RB*-*AB*

$$= \frac{\frac{AB}{(100-55)}}{100} - AB$$

$$= \frac{15.37}{(0.45)} - 15.37$$

CB = 18.79 kg/h

Combustible in ash pit:

Percentage combustible in refuse = 5 % (Given)

$$CG = RG - AG$$

$$= \frac{\frac{(AG)}{(100-5)}}{100} - AG$$

$$= \frac{(120.24)}{0.95} - (120.24)$$

$$CG = 6.33 \text{ kg/h}$$

Solid combustible loss of unit:

$$C = \frac{(CG + CB + CH + CD + CS)(8078)(100)}{(12635.1)(2266.7)}$$

$$CG + CB + CH + CD + CS = 6.33 + 18.79 + 11.42 + 77.78 + 16.45$$

$$= 130.77 \text{ kg/h}$$

Percent solid combustible loss:

$$C = \frac{(130.77)(8078)(100)}{(12635.1)(2266.7)}$$

$$= 3.69\%$$

It is common practice with all types of solid fuel burning systems, except pulverised coal, to resort to some sort of fly ash re-injection from one or more of the system hoppers in order to reduce the solid combustible loss. When re-inject fly ash is extended from the boiler and economiser hoppers to the dust collector hoppers, the purpose for which dust collect is installed shall be completely defected. The recirculated load shall be taken extremely high and it will be impossible to satisfy the stack dust load requirement. Besides, high erosion will take place in the economiser, dust collector, boiler, tubes and I.D. Fan.

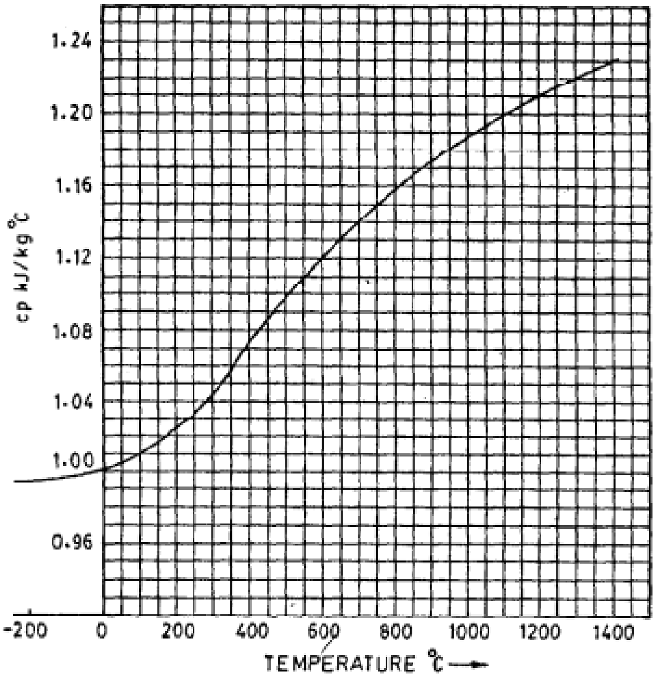


FIG. 3 INSTANTANEOUS SPECIFIC HEAT OF AIR

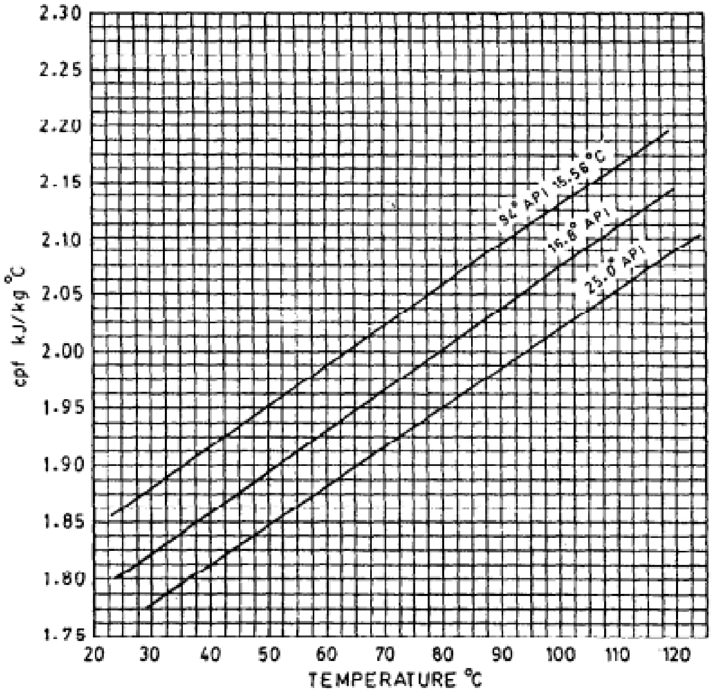


FIG. 4 INSTANTANEOUS SPECIFIC HEAT OF FUEL OIL 1 ATM

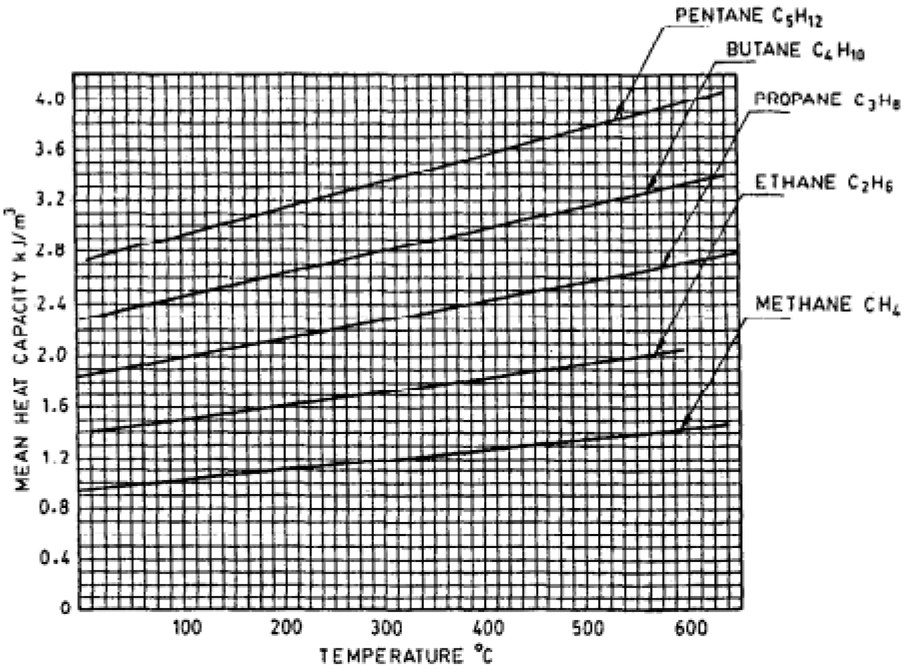


FIG. 5 INSTANTANEOUS SPECIFIC HEAT OF FUEL GAS

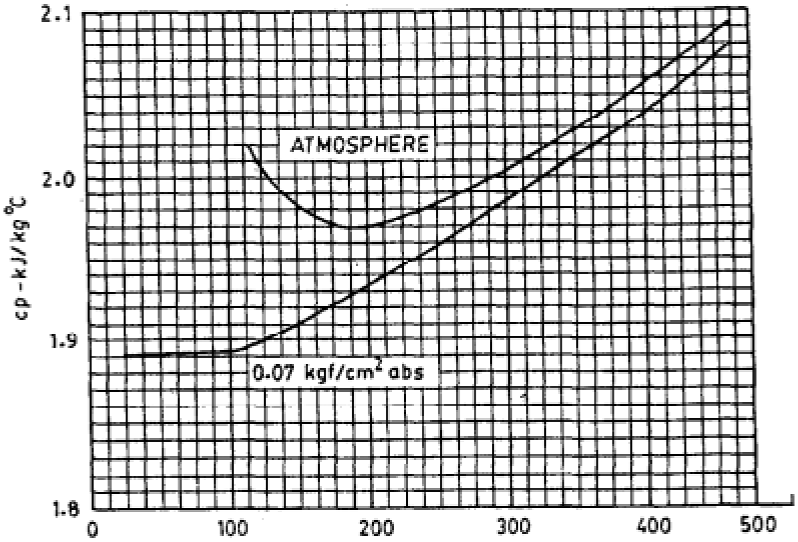


FIG. 6 INSTANTANEOUS SPECIFIC HEAT OF STEAM

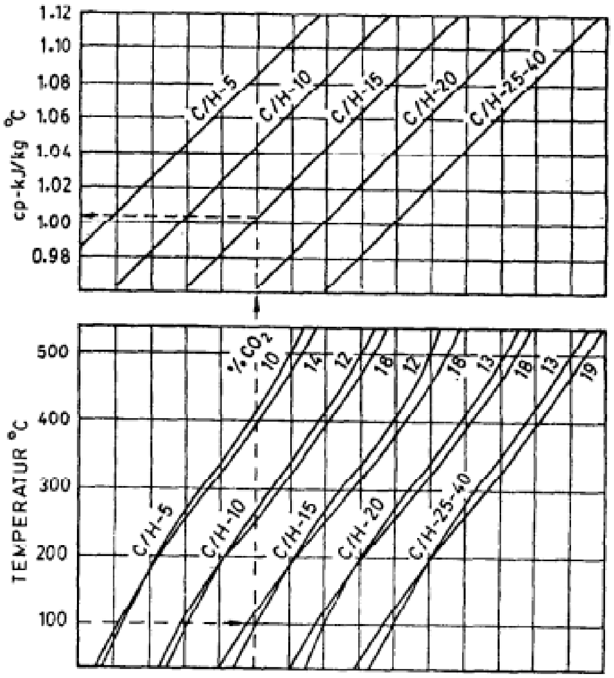


FIG. 7 INSTANTANEOUS SPECIFIC HEAT OF DRY FUEL GAS FOR CARBON HYDROGEN RATIO (FUEL) 5-40

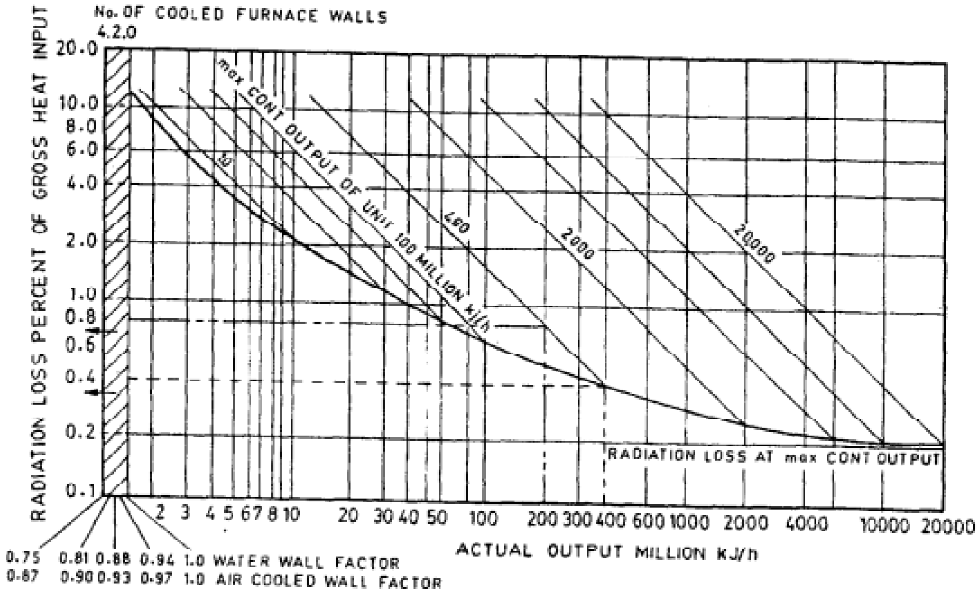


FIG. 8 STANDARD RADIATION LOSS CHART

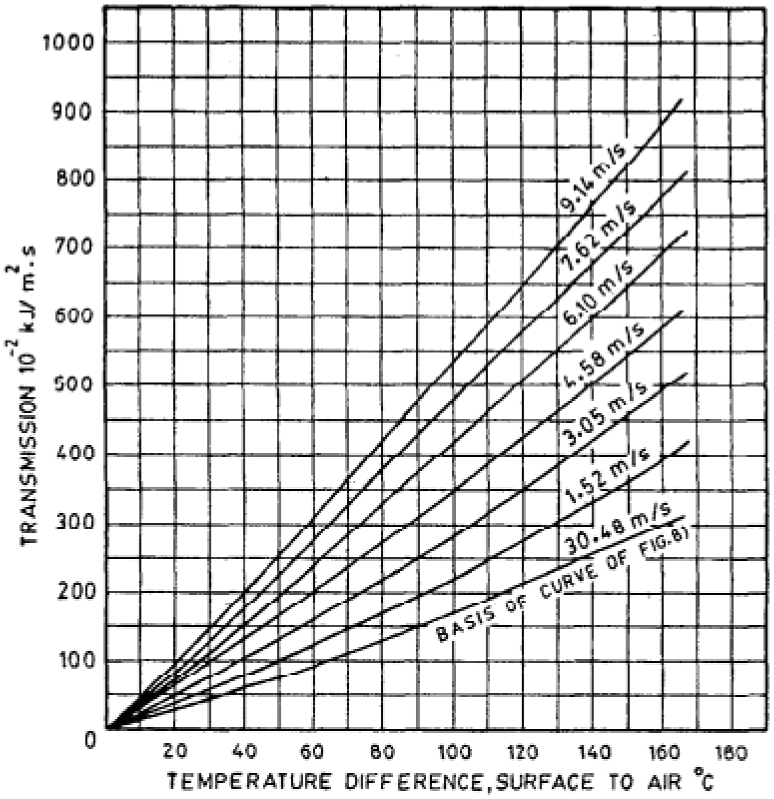


FIG. 9 SURFACE TRANSMISSION FOR VARIOUS AIR VELOCITIES BASED ON EMISSIVITY OF 0.95 AND AIR TEMPERATURE OF 21°C

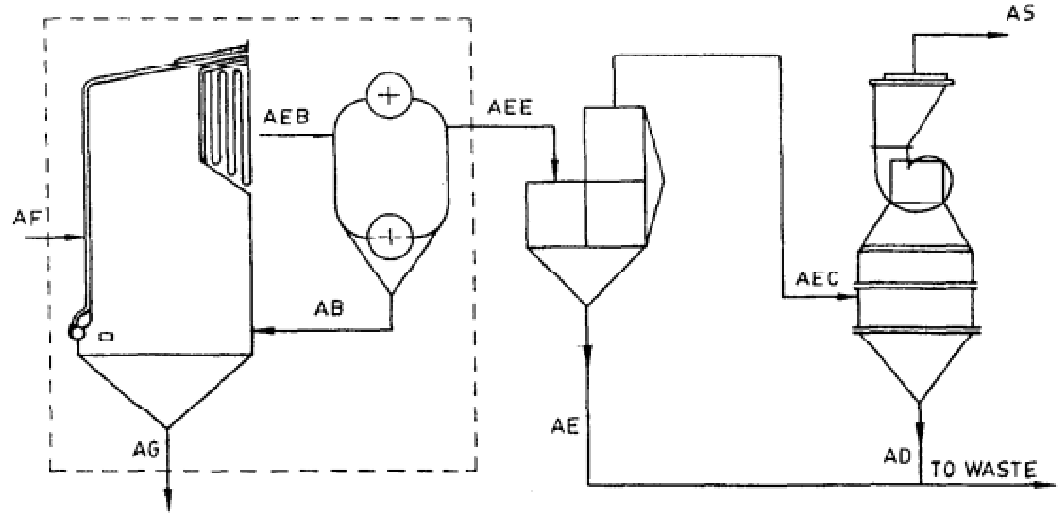


FIG. 10 ASH BALANCE — REINJECTION FROM BOILER HOPPERS

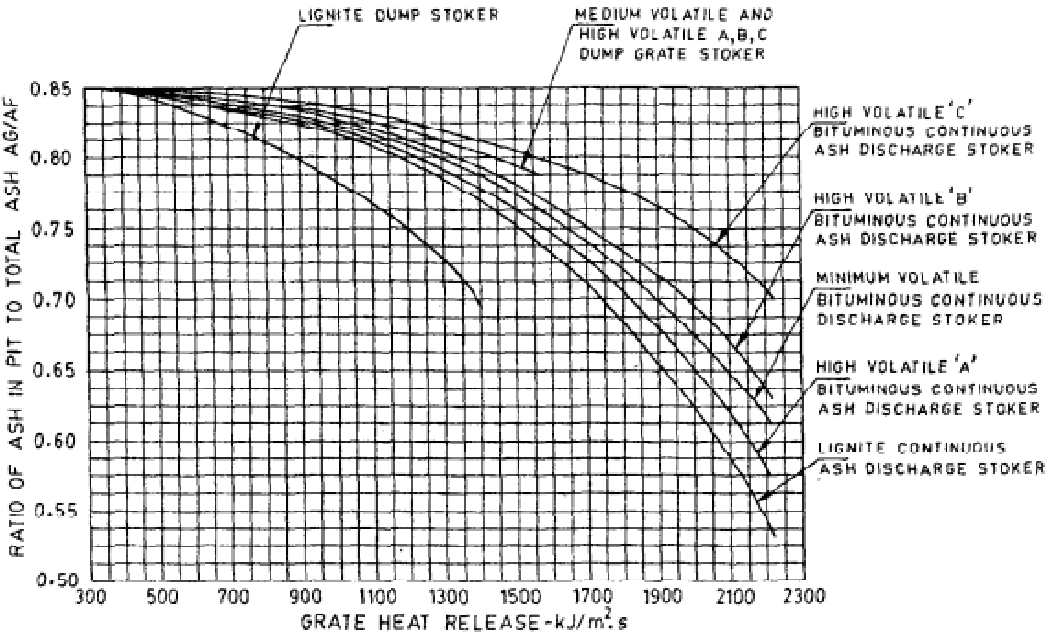


FIG. 11 RATIO OF ASH IN PIT TO TOTAL ASH (AG/AF) VERSUS HEAT RELEASE FOR COAL-FIRED, LOW-SET SPREADER, DUMP GRATE, AND CONTINUOUS DISCHARGE STOKERS WITH PARTIAL REINJECTION

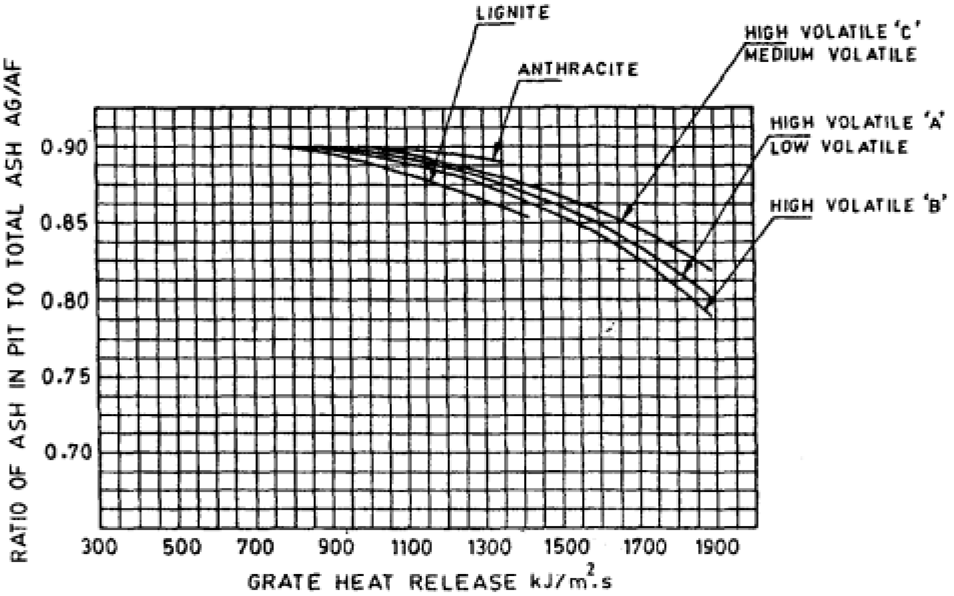


FIG. 12 RATIO OF ASH IN PIT TO TOTAL ASH (AG/AF) VERSUS HEAT RELEASE FOR TRAVELLING GRATE STOKERS WITH PARTIAL REINJECTION

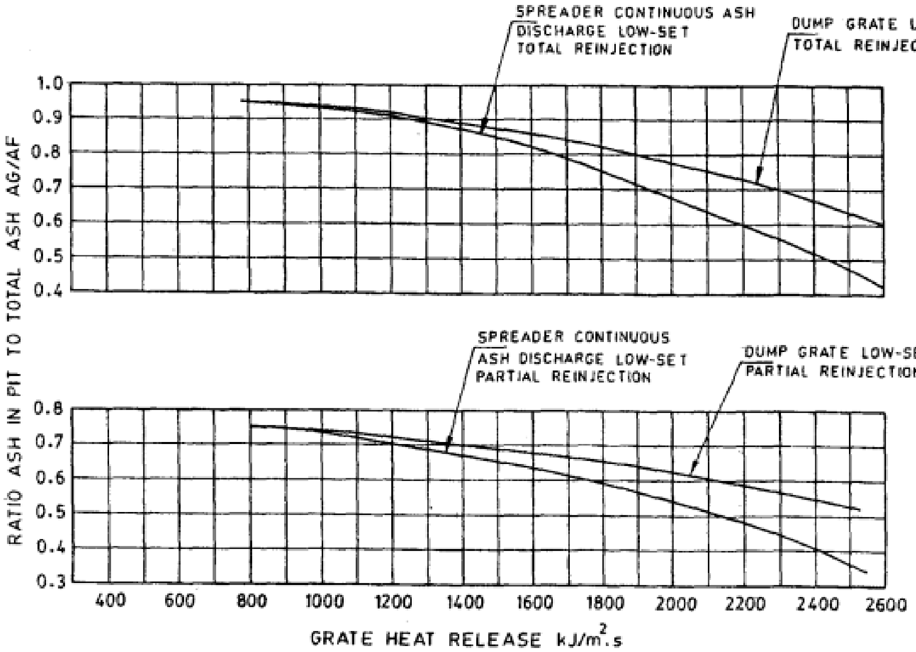


Fig. 13 Ratio of Ash in Pit to Total Ash (AG/AF) Versus Heat Release for Wood Burning Continuous Discharge and Dump Grate Low-Set Spreader Stokers

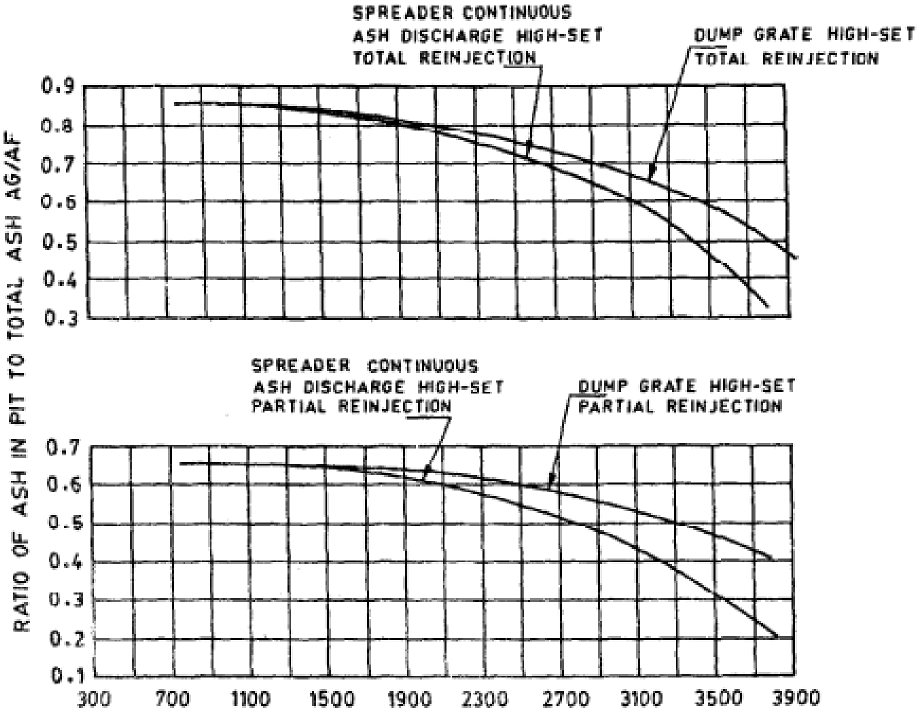


Fig. 14 Ratio of Ash in Pit to Total Ash (AG/AF) Versus Heat Release for Wood Burning Continuous Discharge and Dump Grate High-Set Spreader Stokers