

JIS

JAPANESE INDUSTRIAL STANDARD

**Heat balancing of cement
rotary kiln**

JIS R 0303 1991

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In the event of any doubt arising,
the original Standard in Japanese is to be final authority.

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Heat balancing of cement rotary kiln

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1. Scope

This Japanese Industrial Standard specifies heat balancing of rotary kiln (hereafter referred to as the "kiln") and its accessories by which Portland cement clinker is made.

Remarks 1. Applicable Standards to this Standard are shown in the following:

JIS B 8222-Heat Balancing of Boilers for Land Use

JIS K 2249-Testing Methods for Density of Crude Oil and Petroleum Products, and Petroleum Measurement Tables Based on Reference Temperature of 15°C

JIS K 2251-Crude Petroleum and Petroleum Products — Sampling

JIS K 2272-Testing Methods for Ash and Sulfated Ash of Crude Oil and Petroleum Products

JIS K 2275-Testing Methods for Water Content of Crude Oil and Petroleum Products

JIS K 2279-Testing Method for Heat of Combustion of Liquid Hydrocarbon Fuel by Bomb Calorimeter

JIS K 2541-Testing Methods for Sulfur in Crude Oil and Petroleum Products

JIS M 8813-Methods for Ultimate Analysis of Coal and Coke

JIS M 8814-Determination of Calorific Value of Coal and Coke

JIS R 5202-Method for Chemical Analysis of Portland Cement

JIS Z 8808-Methods of Measuring Dust Concentration in Fuel Gas

2. In this Standard, the units and values shown in { } are based on the traditional units, and appended for informative reference only.

2. Reference

2.1 The heat balancing shall be made based on results of not less than 24 hours consecutive normal operation of the kiln.

2.2 The heat balancing shall be performed for 1 t of Portland cement clinker (hereafter referred to as the "clinker").

2.3 The reference temperature of heat balancing shall be outside air temperature.

2.4 The heat value of fuel shall be the low heat value of it at use.

3. Items to be measured and recorded

3.1 Records concerning plant and equipment The following shall be recorded concerning the plant and equipment:

- (1) Name and location of plant
- (2) Kiln number
- (3) Manufacturing system⁽¹⁾
- (4) Size (inside diameter and full length)

- (5) Effective inside volume⁽²⁾
- (6) Kind of fuel used
- (7) Type of burner
- (8) Type and size of cooler⁽³⁾
- (9) Type of suspension preheater and number of steps and diameter of each step of cyclone
- (10) Type, number, size (inside diameter and height) and effective inside volume⁽²⁾ of calcining furnaces
- (11) Type of Repol-preheater and size (length and width) of grate
- (12) History⁽⁴⁾

Notes ⁽¹⁾ Identification of dry method (presence or absence of waste heat boiler, suspension preheater, and calcining device), semi-dry method, or wet method (presence or absence of waste heat boiler and filter).

⁽²⁾ Inside volume measured when bricks are not stuck. In the case of multitube cooler, inside volume measured to the center of the exit.

⁽³⁾ In the case of air quenching cooler, size (effective length and width) of grate; in the case of multitube cooler, number of tubes and size (diameter and length) of each tube.

⁽⁴⁾ Dates of construction and remodelling, and outline of remodelling.

3.2 Measuring items The item for measurement shall be as follows:

- (1) Measurement period (time and date) and name of measuring person(s)
- (2) Climate, atmospheric pressure, wind speed, and temperature and humidity of outside air
- (3) Clinker output
- (4) Composition and lime saturation degree of clinker
- (5) Temperatures of clinker at cooler entrance and exit
- (6) Volume of exhaust gas emanating from dry materials
- (7) Used quantity, water content, and temperature of materials
- (8) Kind, brand, composition (at use)⁽⁵⁾, heat value, temperature, and used quantity of fuel
- (9) Volumes and temperatures of primary and secondary air for burning, and static pressure of primary air
- (10) Volume, temperature, and static pressure of fluidizing air for calcining furnace
- (11) Volume, temperature, static pressure, composition and air ratio of exhaust gas at preheater exit
- (12) Volume, temperature, static pressure, composition and air ratio of exhaust gas from kiln
- (13) Volumes and temperatures of cooling air of air quenching cooler and exhaust in exhaust tube of the cooler

- (14) Quantity of dust scattering at preheater exit (or kiln exit when preheater is absent)

Note (⁵) Fuel composition (%) is as follows, according to fuel used (elements in () should be described only when element analysis is performed):

- (a) In the case of fuel oil: water, ash, sulfur, (carbon), (hydrogen), (oxygen) and (nitrogen).
- (b) In the case of coal: humidity, water content, ash, volatile matter, fixed carbon, burning sulfur, (carbon), (hydrogen), (oxygen) and (nitrogen).

4. Measuring methods

4.1 Output, composition, lime saturation degree and temperature of clinker The output, composition, lime saturation degree and temperature of clinker shall be measured as follows:

- (1) Output should be measured actually. It may also be calculated from quantities of dry materials sent in.
- (2) Composition and lime saturation degree shall be obtained as follows:
 - (a) Composition should be measured according to JIS R 5202.
 - (b) Lime saturation degree, *L. S. D.*, should be obtained from the composition of clinker according to the following formula:

$$L. S. D. = \frac{(CaO)}{2.8 (SiO_2) + 1.2 (Al_2O_3) + 0.65 (Fe_2O_3)}$$

where, (CaO) : calcium oxide in clinker (%)
 (SiO₂) : silicon dioxide in clinker (%)
 (Al₂O₃) : aluminium oxide in clinker (%)
 (Fe₂O₃) : ferric oxide in clinker (%)

- (3) The temperatures should be measured at position as near the entrance and exit of cooler as possible.

4.2 Volumes of exhaust gases emanating from dry materials (Volumes of vapor and carbon dioxide) The volumes of exhaust gases emanating from dry materials per 1 kg of clinker shall be obtained from the composition of clinker according to the following formulae.

- (1) When it is supposed that aluminium oxide (Al₂O₃) in clinker comes out from kaoline (Ka), the quantity (kg) of kaoline (Ka) is:

$$(Ka) = \frac{258}{102} \times \frac{(Al_2O_3)}{100} = 2.53 \times \frac{(Al_2O_3)}{100}$$

Further, the mass [*m*_{H₂O} (kg)] and volume [*V*_{H₂O} (m³_N)] of vapor emanating from this are obtained from the following formulae:

$$m_{H_2O} = \frac{36}{102} \times \frac{(Al_2O_3)}{100} = 0.353 \times \frac{(Al_2O_3)}{100}$$

$$V_{H_2O} = \frac{44.8}{102} \times \frac{(Al_2O_3)}{100} = 0.439 \times \frac{(Al_2O_3)}{100}$$

- (2) When it is supposed that calcium oxide (CaO) and magnesium oxide (MgO) in clinker come out from calcium carbonate (CaCO₃) (kg) and magnesium carbonate (MgCO₃) (kg), quantities of calcium carbonate and magnesium carbonate are:

$$(\text{CaCO}_3) = \frac{100}{56} \times \frac{(\text{CaO})}{100} = 1.786 \times \frac{(\text{CaO})}{100}$$

$$(\text{MgCO}_3) = \frac{84}{40} \times \frac{(\text{MgO})}{100} = 2.10 \times \frac{(\text{MgO})}{100}$$

Further, the mass [m_{CO_2} (kg)] and volume [V_{CO_2} (m³_N)] of carbon dioxide emanating from these are obtained from the following formulac:

$$m_{\text{CO}_2} = \frac{44}{56} \times \frac{(\text{CaO})}{100} \times \frac{44}{40} \times \frac{(\text{MgO})}{100}$$

$$= 0.786 \times \frac{(\text{CaO})}{100} + 1.1 \times \frac{(\text{MgO})}{100}$$

$$V_{\text{CO}_2} = \frac{22.4}{56} \times \frac{(\text{CaO})}{100} + \frac{22.4}{40} \times \frac{(\text{MgO})}{100}$$

$$= 0.40 \times \frac{(\text{CaO})}{100} + 0.56 \times \frac{(\text{MgO})}{100}$$

where, (CaO) : calcium oxide in clinker (%)

(MgO) : magnesium oxide in clinker (%)

Remarks 1. When slag is used as a part of materials, the above calculation should be performed using the quantities of (CaO) and (Al₂O₃) which are subtracted by the quantities of (CaO) and (Al₂O₃) coming from slag, as given in the following expression:

- (a) The ratio R of (CaO) coming out from lime stone to that from slag is obtained according to the following formula:

$$R = \frac{C_1 \times m_1}{C_2 \times m_2}$$

where,

C_1 : quantity of (CaO) in lime stone (%)

C_2 : quantity of (CaO) in slag (%)

m_1 : rate of lime stone compounded in raw materials (%)

m_2 : rate of slag compounded in raw materials (%)

- (b) Quantity (%) of calcium oxide [CaO] coming out from lime stone is obtained from the formula in (a) using the following formula:

$$[\text{CaO}] = (\text{CaO}) \times \frac{R}{1 + R}$$

- (c) Quantity (%) of aluminium oxide $[\text{Al}_2\text{O}_3]$ coming out from clay is obtained from the formula in (a) using the following formula:

$$[\text{Al}_2\text{O}_3] = (\text{Al}_2\text{O}_3) - (\text{CaO}) \times \frac{1}{1 + R} \times \frac{A}{C_2}$$

where,

A : quantity of aluminium oxide in slag (%)

(Al_2O_3) : quantity of aluminium oxide in clinker (%)

(CaO) : quantity of calcium oxide in clinker (%)

2. Correction of composition according to ash in fuel should be performed in conformity with the case of slag, as appropriate.
3. The m^3_{N} is the unit of volume of gas in the standard condition 0°C , 101.3 kPa {760 mmHg}.

4.3 Used quantity, water content, temperature and heat value of materials The used quantity, water content, temperature and heat value of materials shall be measured as follows:

- (1) Used quantity of dry materials Since quantity of gas emanating from 1 kg of clinker is $(m_{\text{H}_2\text{O}} + m_{\text{CO}_2})$ (kg) as calculated in 4.2, used quantity m_m (kg) of dry materials per 1 kg of clinker is obtained according to the following formula:

$$m_m = 1.0 + [m_{\text{H}_2\text{O}} + m_{\text{CO}_2}]$$

- (2) Water content and temperature of materials These values should be measured on the samples taken out from the kiln entrance, the suspension preheater or Lepol preheater entrance.
- (3) Heat value of materials The heat value of materials including flammable objects should be measured in the similar way to that given in 4.4.

4.4 Composition, heat value and used quantity of fuel The composition, heat value and used quantity of fuel shall be measured as follows:

- (1) The testing method of composition of fuel should be based on the following Japanese Industrial Standards.

Further, the sample of coal should be taken from a position as close to the injection point as possible):

- (a) JIS K 2251
- (b) JIS K 2272
- (c) JIS K 2275
- (d) JIS K 2541
- (e) JIS M 8813

- (2) The measuring method of heat value should be based on the following Japanese Industrial Standards:

- (a) JIS K 2279
- (b) JIS M 8814
- (3) Used quantity
 - (a) The used quantity of fuel oil should be measured by first measuring the volume with a positive-displacement flow meter or tank, then converting the volume into mass using the specific gravity⁽⁶⁾.
 - (b) The used quantity of coal should be expressed in mass in the state at injection.

Note ⁽⁶⁾ The specific gravity of fuel oil should be as given in JIS K 2249.

4.5 Volume and temperature of air for burning The volume and temperature of air for burning shall be measured as follows:

- (1) Volume
 - (a) The volumes of the primary air, fluidizing air for calcining furnace, and extracted air from the cooler for the calcining furnace should be measured with an orifice tester, Venturi tube, Pitot tube, or other apparatus.
 - (b) The volume of secondary air should be obtained as the difference between the volume of the primary air and the total volume of air calculated from the composition and used quantity of fuel, and the composition of the exhaust gas from the kiln.
- (2) Temperature
 - (a) The temperature of the primary air should be measured before fuel is mixed.
 - (b) The temperature of the secondary air should be measured with an aspirating pyrometer, as far as possible.

4.6 Volume, temperature, pressure, composition and air ratio of exhaust gas from preheater The volume, temperature, pressure, composition and air ratio of the exhaust gas from the preheater shall be measured as follows:

- (1) The volume should be obtained from the used quantities and compositions of materials and fuel and the composition of the exhaust gas from the preheater.
- (2) The temperature and static pressure should be measured at a position near the preheater exit.
- (3) At measuring the composition, the sample should be taken at a position as near the preheater exit as possible, and it should be analysed with an Orsat analyser.
- (4) The air ratio should be calculated from the composition of exhaust gas.

4.7 Volume, temperature, pressure, composition and air ratio of exhaust gas from kiln The volume, temperature, pressure, composition and air ratio of exhaust gas from the kiln shall be measured at the kiln exit in conformity with 4.6, as appropriate.

4.8 Volumes and temperatures of cooling air and exhaust of cooler The volumes and temperatures of the cooling air and exhaust of the cooler shall be measured in the same way as that for the primary air stated in 4.5, as appropriate.

4.9 Quantity of dust scattering at preheater or kiln exit The quantity of dust scattering at the preheater exit shall be calculated from the result of measurement of quantity of dust contained near the preheater exit according to JIS Z 8808 and the volume of exhaust gas from the preheater obtained in 4.6. In the case of a kiln without a preheater, the quantity of dust scattering at the kiln exit should be obtained by measuring the quantities of boiler dust and precipitated dust, then converting the results to the value per 1 kg of clinker.

5. Items for heat balancing and their calculations

Each item for heat balancing given at the left column of Tables 1 to 2 below shall be calculated in the way shown to its right column in the tables. Calculations shall be performed per 1 kg of clinker for convenience, but, they should be expressed per 1 t of clinker by multiplied by 10^3 . The heat balancing of the waste heat boiler should be performed according to Annex.

(1) Kiln

Table 1

Item	Calculation method
1. Thermal input $Q_1(\text{kJ}\{\text{kcal}\})$	(1) Heat of combustion of fuel $Q_a(\text{kJ}\{\text{kcal}\})$ $Q_a = m_f \times H_l$ where, m_f: used quantity of fuel per 1 kg of clinker (kg) H_l: low heat value of fuel (kJ/kg{kcal/kg}) Remarks 1. In the case of a new suspension type (hereafter referred to as the "NSP"), this should be calculated for each of the kiln and the calcining furnace. 2. Method of converting analyzed values and heat values of fuel to the ones at use time base. (1) Composition: whole water content w (%), ash contents a (%), carbon c (%), hydrogen h (%), burning sulfur s (%), nitrogen n (%), and oxygen o (%) should be converted according to the following formulae: $w = w_2 + \frac{100 - w_2}{100} \times w_1$ $a = \frac{100 - w_2}{100} \times a_1$ $c = \frac{100 - w_1}{100} \times \frac{100 - w_2}{100} c_0 = \frac{100 - w}{100} c_0$ $h = \frac{100 - w_1}{100} \times \frac{100 - w_2}{100} h_0 = \frac{100 - w}{100} h_0$ $s = \frac{100 - w_1}{100} \times \frac{100 - w_2}{100} s_0 = \frac{100 - w}{100} s_0$ $n = \frac{100 - w_1}{100} \times \frac{100 - w_2}{100} n_0 = \frac{100 - w}{100} n_0$ $o = 100 - (w + a + c + h + s + n)$ where, w_2: humidity (%) w_1: water according to industrial chemical analysis (wet basis) (%) a_1: ash according to industrial chemical analysis (wet basis) (%) c_0: carbon according to elemental analysis (dry basis) (%) h_0: hydrogen according to elemental analysis (dry basis) (%) s_0: burning sulfur according to elemental analysis (dry basis) (%) n_0: nitrogen according to elemental analysis (dry basis) (%) (2) Heat value: High heat value $H_h(\text{kJ}\{\text{kcal}\})$ and low heat value $H_l(\text{kJ}\{\text{kcal}\})$ should be converted with the following formulae: $H_h = \frac{100 - w_2}{100} H_0$ $H_l = H_h - 6(9h + w)$ where, H_0: high heat value (humidistat base) (kJ/kg{kcal/kg}) w_2: humidity (%) h: hydrogen (%) w: whole water (%)

Table 1 (Continued)

Item		Calculation method
1. Thermal input $Q_1(\text{kJ}\{\text{kcal}\})$	(1) Heat of combustion of fuel $Q_a(\text{kJ}\{\text{kcal}\})$	3. In the case of fuel oil, humidity w_2 (%) should be estimated as 0, and the composition and high heat value of fuel at use measured from the sample should be used as it is. 4. When elemental analysis is not performed for fuel oil, its carbon and hydrogen should be taken as 86 % and 12 % respectively.
	(2) Sensible heat of fuel $Q_b(\text{kJ}\{\text{kcal}\})$	$Q_b = m_f \times C_f \times (t_f - t)$ where, m_f: quantity of fuel used per 1 kg of clinker (kg) C_f: specific heat of fuel ($\text{kJ/kg}^\circ\text{C}\{\text{kcal/kg}^\circ\text{C}\}$) t_f: temperature of fuel ($^\circ\text{C}$) t: outside air temperature ($^\circ\text{C}$) Remarks 1. The C_f is $1.88 \text{ kJ/kg}^\circ\text{C}\{0.45 \text{ kcal/kg}^\circ\text{C}\}$ for fuel oil, and $1.05 \text{ kJ/kg}^\circ\text{C}\{0.25 \text{ kcal/kg}^\circ\text{C}\}$ for coal. 2. In the case of an NSP, this should be obtained for each of the kiln and the calcining furnace.
	(3) Heat of combustion of materials $Q_c(\text{kJ}\{\text{kcal}\})$	$Q_c = m_m \times H_{ml}$ where, m_m: mass of dry materials per 1 kg of clinker (kg) (should be obtained according to 4.3.) H_{ml}: low heat value of materials ($\text{kJ/kg}\{\text{kcal/kg}\}$)
	(4) Sensible heat of material $Q_d(\text{kJ}\{\text{kcal}\})$	(a) Sensible heat of dry materials $Q_{d1}(\text{kJ}\{\text{kcal}\})$ $Q_{d1} = m_m \times C_m \times (t_m - t)$ where, m_m: mass of dry materials per 1 kg of clinker (kg) (should be obtained according to 4.3.) C_m: specific heat of materials ($\text{kJ/kg}^\circ\text{C}\{\text{kcal/kg}^\circ\text{C}\}$) t_m: temperature of materials at preheater or kiln entrance ($^\circ\text{C}$) t: outside air temperature ($^\circ\text{C}$) Remarks: The C_m is $0.84 \text{ kJ/kg}^\circ\text{C}\{0.20 \text{ kcal/kg}^\circ\text{C}\}$ (b) Sensible heat of water content in materials $Q_{d2}(\text{kJ}\{\text{kcal}\})$ $Q_{d2} = m_r (t_m - t)$ where, m_r: quantity of water content in materials per 1 kg of clinker (kg) t_m: temperature of materials at preheater or kiln entrance ($^\circ\text{C}$) t: outside air temperature ($^\circ\text{C}$) Remarks 1. The m_r should be obtained according to the following formulae: (i) When water is measured on materials not added with dust: $m_r = \frac{m_m \times w_m}{100 - w_m}$ (ii) When water content is measured on materials added with dust: $m_r' = \frac{m_m \times (1 + d) \times w_m'}{100 - w_m'}$ where, m_m: mass of dry materials per 1 kg of clinker (kg) w_m: water in materials not added with dust at the preheater or kiln entrance (%) w_m': water content of materials added with dust at the preheater or kiln entrance (%) d: mixing rate of dust (ratio of quantity of dust to dry materials)

Table 1 (Continued)

Item		Calculation method
1. Thermal input Q_1 (kJ{kcal})	(4) Sensible heat of material Q_d (kJ{kcal})	2. When water content in materials is little, this may be omitted. (c) Sensible heat of materials Q_d (kJ{kcal}) $Q_d = Q_{d1} + Q_{d2}$ where, Q_{d1} : sensible heat of dry materials (kJ{kcal}) Q_{d2} : sensible heat of water content in materials (kJ{kcal})
	(5) Sensible heat of primary air Q_e (kJ{kcal})	$Q_e = A_1 \times C_a \times (t_{a1} - t)$ where, A_1 : volume of preheater primary air per 1 kg of clinker (m^3_N) C_a : specific heat of air (kJ/ $m^3_N \cdot ^\circ C$ {kcal/ $m^3_N \cdot ^\circ C$ }) t_{a1} : preheater temperature of air ($^\circ C$) t : outside air temperature ($^\circ C$) Remarks 1. This heat should be summed together only when primary air is preheated with any of the others than kiln or cooler. 2. When primary air is preheated with kiln and cooler, this should be summed together as 3. Circulating heat. 3. In the case of NSP, this should be calculated for each of kiln and calcining furnace.
	(6) Sensible heat of cooling air of coolers Q_f (kJ{kcal})	$Q_f = A_c \times C_a \times (t_{ac} - t)$ where, A_c : volume of cooling air per 1 kg of clinker (m^3_N) C_a : specific heat of air (kJ/ $m^3_N \cdot ^\circ C$ {kcal/ $m^3_N \cdot ^\circ C$ }) t_{ac} : preheating temperature of air ($^\circ C$) t : outside air temperature ($^\circ C$) Remarks 1. This heat should be summed together only when cooling air is preheated with any of the others than kiln or cooler. 2. When cooling air is preheated with kiln and cooler, this should be summed together as 3. Circulating heat.
	(7) Total thermal input Q_1 (kJ{kcal})	$Q_1 = Q_a + Q_b + Q_c + Q_d + Q_e + Q_f$ where, Q_a : heat of combustion of fuel (kJ{kcal}) Q_b : sensible heat of fuel (kJ{kcal}) Q_c : heat of combustion of materials (kJ{kcal}) Q_d : sensible heat of materials (kJ{kcal}) Q_e : sensible heat of primary air (kJ{kcal}) Q_f : sensible heat of cooling air of cooler (kJ{kcal})
2. Thermal output Q_2 (kJ{kcal})	(1) Heat for clinker burning Q_g (kJ{kcal})	(a) Sensible heat required to heat dry materials to $900^\circ C$ Q_{g1} (kJ{kcal}) $Q_{g1} = m_m \times C_m \times 900$ where, m_m : mass of dry materials per 1 kg of clinker (kg) C_m : specific heat of materials (kJ/ $kg \cdot ^\circ C$ {kcal/ $kg \cdot ^\circ C$ }) Remarks 1. Specific heat of materials should be obtained from the compounding rate of clay or slag, whose specific heats are 1.105 kJ/ $kg \cdot ^\circ C$ {0.264 kcal/ $kg \cdot ^\circ C$ } and 1.017 kJ/ $kg \cdot ^\circ C$ {0.243 kcal/ $kg \cdot ^\circ C$ } respectively. 2. This calculation should be carried out based on $0^\circ C$, because there is almost no difference whether the calculation based on ordinary temperature or $0^\circ C$. (b) Heat required for decomposition of calcium carbonate, magnesium carbonate, and kaoline Q_{g2} (kJ{kcal}) $Q_{g2} = 1674 \times (CaCO_3) + 1172 \times (MgCO_3) + 933 \times (Ka)$ $= 2989 \times (CaO) + 2461 \times (MgO) + 2361 \times (Al_2O_3)$

Table 1 (Continued)

Item	Calculation method
2. Thermal output $Q_2(\text{kJ}\{\text{kcal}\})$	(1) Heat for clinker burning $Q_g(\text{kJ}\{\text{kcal}\})$ $\begin{cases} Q_{g2} = 400 \times (\text{CaCO}_3) + 280 \times (\text{MgCO}_3) + 223 \times (\text{Ka}) \\ = 714 \times (\text{CaO}) + 588 \times (\text{MgO}) + 564 \times (\text{Al}_2\text{O}_3) \end{cases}$ where, (CaCO_3): mass of calcium carbonate per 1 kg of clinker (kg) (MgCO_3): mass of magnesium carbonate per 1 kg of clinker (kg) (Ka): mass of kaoline per 1 kg of clinker (kg) (CaO): mass of calcium oxide per 1 kg of clinker (kg) (MgO): mass of magnesium oxide per 1 kg of clinker (kg) (Al_2O_3): mass of aluminium oxide per 1 kg of clinker (kg) Remarks: This should be obtained according to 4.2 when slag is used as raw material. (c) Heat required to heat decomposed materials from 900°C to 1450°C $Q_{g3}(\text{kJ}\{\text{kcal}\})$ $Q_{g3} = 1.109 \times 1450 - 0.980 \times 900 = 726 \text{ kJ}$ $\{Q_{g3} = 0.265 \times 1450 - 0.234 \times 900 = 173 \text{ kcal}\}$ Remarks: Specific heat of decomposed materials at 900°C to 1450°C should be regarded as the same as that of clinker, and quantity of decomposed materials as the quantity of clinker. (d) Heat of product during clinkering $Q_{g4}(\text{kJ}\{\text{kcal}\})$ $Q_{g4} = 418.6 \text{ kJ}\{100 \text{ kcal}\}$ Remarks: This numerical value has been obtained from the literature by Nacken. (e) Sensible heat of carbon dioxide and steam coming out of decomposition at 900°C, $Q_{g5}(\text{kJ}\{\text{kcal}\})$ $Q_{g5} = (V_{\text{CO}_2} \times C_{\text{CO}_2} + V_{\text{H}_2\text{O}} \times C_{\text{H}_2\text{O}}) \times 3768$ $= 783 \times (\text{CaO}) + 1097 \times (\text{MgO}) + 666 \times (\text{Al}_2\text{O}_3)$ $\begin{cases} Q_{g5} = (V_{\text{CO}_2} \times C_{\text{CO}_2} + V_{\text{H}_2\text{O}} \times C_{\text{H}_2\text{O}}) \times 900 \\ = 187 \times (\text{CaO}) + 262 \times (\text{MgO}) + 159 \times (\text{Al}_2\text{O}_3) \end{cases}$ where, V_{CO_2}: volume of carbon dioxide emanating from materials per 1 kg of clinker (m^3_{N}) $V_{\text{H}_2\text{O}}$: volume of steam emanating from materials per 1 kg of clinker (m^3_{N}) C_{CO_2}: specific heat of carbon dioxide ($\text{kJ}/\text{m}^3_{\text{N}}\text{°C}\{\text{kcal}/\text{m}^3_{\text{N}}\text{°C}\}$) $C_{\text{H}_2\text{O}}$: specific heat of steam ($\text{kJ}/\text{m}^3_{\text{N}}\text{°C}\{\text{kcal}/\text{m}^3_{\text{N}}\text{°C}\}$) (CaO): quantity of calcium oxide per 1 kg of clinker (kg) (MgO): quantity of magnesium oxide per 1 kg of clinker (kg) (Al_2O_3): quantity of aluminium oxide per 1 kg of clinker (kg) Remarks: The V_{CO_2} and $V_{\text{H}_2\text{O}}$ should be obtained according to 4.2, and (CaO), (MgO) and (Al_2O_3) according to 4.1 (2). (f) Sensible heat possessed by clinker at 1450°C, $Q_{g6}(\text{kJ}\{\text{kcal}\})$ $Q_{g6} = 1.109 \times 1450 = 1608 \text{ kJ}$ $\{Q_{g6} = 0.265 \times 1450 = 384 \text{ kcal}\}$ Remarks: It is taken that average specific heat of clinker at 1450°C is $1.109 \text{ kJ}/\text{kg}^{\circ}\text{C}\{0.265 \text{ kcal}/\text{kg}^{\circ}\text{C}\}$. (g) Heat for clinker burning $Q_g(\text{kJ}\{\text{kcal}\})$ $Q_g = Q_{g1} + Q_{g2} + Q_{g3} + Q_{g4} + Q_{g5} + Q_{g6}$ where, Q_{g1}: sensible heat required to heat dry materials to 900°C ($\text{kJ}\{\text{kcal}\}$)

Table 1 (Continued)

Item	Calculation method
2. Thermal output $Q_2(\text{kJ}\{\text{kcal}\})$	(1) Heat for clinker burning $Q_g(\text{kJ}\{\text{kcal}\})$ Q_{g2} : heat required for decomposition of calcium carbonate, magnesium carbonate and kaoline (kJ{kcal}) Q_{g3} : heat required to heat decomposed materials from 900°C to 1450°C(kJ{kcal}) Q_{g4} : heat produced during clinker burning (kJ{kcal}) Q_{g5} : sensible heat of carbon dioxide and steam coming out of decomposition at 900°C(kJ{kcal}) Q_{g6} : sensible heat possessed by clinker at 1450°C (kJ{kcal}) Remarks 1. When clay is used as material, heat for clinker burning $Q_g(\text{kJ}\{\text{kcal}\})$ may be calculated according to the following formulae: $Q_g = Q_{g1} + 2206 \times (\text{CaO}) + 1365 \times (\text{MgO}) + 1695 \times (\text{Al}_2\text{O}_3) - 1302$ $\{Q_g = Q_{g1} + 527 \times (\text{CaO}) + 326 \times (\text{MgO}) + 405 \times (\text{Al}_2\text{O}_3) - 311\}$ Q_{g1} may also be as follows: $m_m = 1 + 0.353 \times (\text{Al}_2\text{O}_3) + 0.786 \times (\text{CaO}) + 1.10 \times (\text{MgO})$ When $C_m = 1.105(\text{kJ/kg}^\circ\text{C})\{C_m = 0.264(\text{kcal/kg}^\circ\text{C})\}$ $Q_{g1} = 996 + 352 \times (\text{Al}_2\text{O}_3) + 783 \times (\text{CaO}) + 1093 \times (\text{MgO})$ $\{Q_{g1} = 238 + 84 \times (\text{Al}_2\text{O}_3) + 187 \times (\text{CaO}) + 261 \times (\text{MgO})\}$ Consequently, Q_g is: $Q_g = 2047 \times (\text{Al}_2\text{O}_3) + 2989 \times (\text{CaO}) + 2457 \times (\text{MgO}) - 306$ $\{Q_g = 489 \times (\text{Al}_2\text{O}_3) + 714 \times (\text{CaO}) + 587 \times (\text{MgO}) - 73\}$ <u>Example of calculation:</u> Heat for burning per 1 kg of clinker: When the composition of clinker is as follows: $(\text{Al}_2\text{O}_3) = 5.2 \%$ $(\text{CaO}) = 65.8 \%$ $(\text{MgO}) = 1.3 \%$ $Q_g = (106 + 1967 + 32 - 306) = 1799 \text{ kJ}$ $\{Q_g = (25 + 470 + 8 - 73) = 430 \text{ kcal}\}$ 2. Reaction of clinker formation is very complicated. For example, the following reaction is expected on CaCO_3: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 + \alpha_1$ $\text{CaO} + \text{Al}_2\text{O}_3, \text{SiO}_2, \text{Fe}_2\text{O}_3 \rightarrow \text{clinker mineral} + \alpha_2$ Therefore, heat of reaction, α_1, α_2, at each temperature should be calculated and the average should be taken. However, heat of reaction at 900°C is used for convenience, considering the complication in reaction of clinker formation.
(2) Sensible heat of clinker entering into cooler $Q_h(\text{kJ}\{\text{kcal}\})$	$Q_h = C_{cl} \times (t_{cl1} - t)$ where, C_{cl} : specific heat of clinker (kJ/kg°C{kcal/kg°C}) t_{cl1} : temperature of clinker at cooler entrance (°C) t : outside air temperature (°C) Remarks: The Q_h should not be added to the total thermal output.