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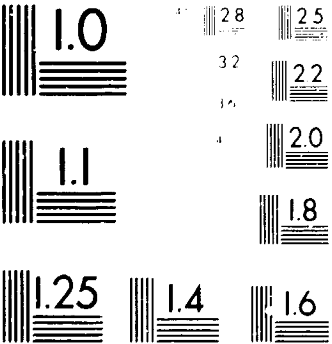

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HEAT DIAGNOSES MADE ON TUNNEL KILNS AND ON BELT DRIER

Basic Information*

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ABSTRACT

The publication deals with the diagnostic measurements of heat consuming units in the ceramic industry from the point of view of their operation, adjustment and energy conservation.

Two examples of diagnosis accomplished by means of a diagnostic mobile unit are presented - one diagnosis of a tunnel kiln for firing wall tiles, the other of a belt drier for washed kaolin. Technical parameters of the equipment are briefly described in both cases including the objectives of measurements. Diagnostic methods used and apparatuses applied during the measurements, testing results and their evaluation are presented. Recommendations on technical and operational measures to be taken to improve the conditions of material thermal treatment and to achieve energy conservation are worked out on the basis of the testing results. They form an inseparable part of each technical report on diagnostic measurements. Expected contributions which would be acquired by the realization of the recommendations are mentioned, too.

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INTRODUCTION

To meet the requirements of the developing countries for information on practical performance of diagnostic measurements, the UNIDO-Czechoslovakia Joint Programme in Pilsen elaborated this publication giving an example of two diagnoses. A lot of equipments in ceramic plants in the developing and least developed countries operate under conditions which are quite different from the optimal ones and consequently, the reject occurrence is high, quality of products is low and also energy conservation is too high.

Diagnostic measurements give a detailed information about the operation of the respective equipment measured and thus provide the system of energy management with the data necessary for decision making with regard to the modernization of the equipment. On the basis of the data obtained, a study is worked out. Within this study, conclusions and recommendations are presented to assist the producer in operational adjustment, production intensification, quality improvement, reduction of reject occurrence and in energy conservation measures.

The activities performed during the measurements comprise three fundamental stages:

- statement of the thermal unit operation conditions, performance of objective tests and functional measurements
- evaluation of the tests and measurements
- working out proposals on technical, energetical, operational and organizational measures or recommendations on a complete reconstruction

There are two basic types of diagnostic measurements focused either on the technological process optimization or on energy conservation.

Nevertheless, the complex measurements, e.g. combination of technological and energetical types, are most advisable for the purpose of energy management. The complex measurements provide the team of experts with complete information about the unit. Thus they can prepare an objective and complex statement for the user of the heat consuming unit, draft all suitable and recommendable adjustments and necessary changes which are to be realized with a view to the perfect and efficient service of the unit.

The most important data, investigated during the diagnostic measurements, are as follows:

- course of thermal treatment
- temperature distribution in the inner space of the kiln (drier)
- relative humidity of the drying medium in the drier
- heat balance of the unit
- combustion gases analysis
- fuel consumption and heating value fluctuation

I. TUNNEL KILN FOR FIRING WALL TILES

1. Technical Parameters

	Project	Reality
Type:	semimuffled tunnel kiln	
In operation since:	1976	
Fired product:	biscuit wall tiles 150 x 150 mm	
Internal dimensions:	l x w x h : 120.80 x 1.16 x 1.30 m	
Firing temperature:	1060°C	
Fuel:	town gas calorific value = 14455 kJm^{-3}	
Number of burners:	58 (29 on each side)	
Number of kiln cars in the kiln:	68	
Output (m^2 per year):	1 870 000	1 618 000
Setting on one kiln car:	160 m^2	160 m^2
Firing cycle:	51 hours	59 hours
Reject:		7.1 %
Specific heat consumption:	3 720 $kJkg^{-1}$	4 465 $kJkg^{-1}$ /+

/+ Average value during one month preceding the measurements

The diagnostic measurement was accomplished in 1982.As far as that time, the kiln had worked without interruption and the reject occurrence decreased from the initial value of about 10% down to 7.1% at the time of measurements. During the measurements, the kiln operated under stabile conditions, e.g. uniform kiln car advance and no interruption in its operation.

2. Objective of Measurement

The producer operates two other kilns of a similar type for bisque firing of wall tiles with a considerably lower reject (3.8 and 4.1%). Also specific consumption of the kiln is almost 20% higher than the projected one while the firing cycle is longer and output lower than the projected parameters. To improve this situation, the producer ordered diagnostic measurements of the kiln with the following requirements:

- improvement of firing conditions to reduce the reject occurrence
- reduction of specific consumption
- increased output

3. Diagnostic Method and Applied Apparatuses

To fulfil' the target of measurements, the following data were determined:

- firing curve and temperature distribution in the cross-section of the kiln
- combustion gases analyses
- pressure curve
- fuel consumption
- fuel quality (composition and calorific value)
- heat balance of the kiln

To investigate the firing conditions, a measuring kiln car wa used equipped with four jacketted thermocouples Ni - NiCr (see Figure 1). The positions of measuring points were chosen with regard to the symetrical reject occurrence on the left and right sides of the kiln and higher concentration of reject in the lower part of the setting. The thermocouples were put through the drilled-out lining of the kiln car. They were connected with a recorder by a compensating lead wire which was strained through the inspection tunnel under the kiln (see Figure 2). The kiln atmosphere samples were taken through the sight holes of the kiln and analyzed by means of analysers - Infralyt (CO_2) and Permolyt (O_2) (see Figure 3).

The kiln atmosphere pressure was measured through the sight holes by a precise micromanometer with changeable response.

The town gas consumption was measured by an installed calibrated gas meter. The composition of gas and its average calorific value were determined in a laboratory. The gas quality fluctuation was checked by a Wobbe's number meter. The air and combustion gases flow velocity was measured either by anemometers (suckings of fans) or by a Pitot's tube and micromanometers (pipelines). The surface temperatures were measured by a digital contact thermometer with Ni - NiCr sensors. As for the heat balance, attention was paid to the heat losses which could be deprived of or, at least, reduced by a new adjustment of the kiln. Therefore, neither the thermal loss tnrough the brickwork nor technological loss wer determined.

4. Testing Results

Parameters of gas

Consumption of town gas in respective days of measurement and its average consumption presents Table 1. Average gas composition during the time of testing shows Table 2. The heating value fluctuation expressed by percentage of average Wobbe's number value is presented in Table 3.

Firing conditions

Firing curves measured in four measuring points in the kiln cross-section presents Figure 4. The pressure curve of the kiln atmosphere, CO_2 and O_2 concentration are shown in Table 4 and Figure 5. Table 5 presents the theoretical need of oxygen and amount of combustion products in dependence on the gas composition.

Theoretical need of oxygen for firing 1 m^3 of gas is 0.7660 m^3. This amount of oxygen in the air is accompanied by nitrogen:

$$0.7660 \times \frac{79}{21} = 2.8816 \ m^3$$

Theoretical need of firing air for firing 1 m^3 of gas:

$$V_{at} = 0.7660 + 2.8816 = 3.6476 \ m^3$$

Theoretical volume of dry combustion products formed by firing 1 m^3 of gas:

$$V_{dt} = 2.8816 + 0.0220 + 0.481 = 3.3846 \ m^3$$

Theoretical volume of wet combustion products:

$$V_{we} = 3.3846 + 0.9370 = 4.3216 \ m^3$$

Real volume of combustion products

It had to be determined indirect from the concentration of CO_2 in stack draught. This concentration fluctuated to a minimum extent during the time of measurement and the average value was 2.45%.

The real amount of dry combustion products can be determined from the CO_2 theoretical content devided by the real one:

$$V_{dr} = \frac{0.481}{2.45} \times 100 = 19.6326 \text{ m}^3 \text{ per } 1\text{m}^3 \text{ of gas}$$

The air excess coefficient for this amount of combustion products:

$$n = \frac{V_{dr} - (CO_2 + N_2 \text{ in combustion products})}{V_{at}} =$$

$$= \frac{19.6326 - 0.481 - 0.022}{3.6476} = 5.24$$

Heat balance

Heat input by fired gas:

$$\dot{Q}_g = \dot{V}_g \times H_g = \frac{580.2}{3600} \times 14184 = 2\ 286 \text{ kW}$$

$\dot{V}_g$ ..... gas consumption ($m^3\ s^{-1}$)

H_g ..... calorific value of the gas ($kJ\ m^{-3}$)

Heat loss by the air from the cooling zone

The warm air is piped from the cooling zone through the piping of circular cross-section with the diameter 1.0 m. The air flow velocity was calculated from dynamic pressure measured by Pitot`s tube and precise manometer in two mutually perpendicular diameters. The average air flow velocity:

$v_a = 5.05 \text{ m s}^{-1}$

Static pressure of air: 22 Pa

Temperature: $t_{ac} = 138\ ^{o}C$

Specific mass: 0.795 kg m^{-3}

Quantity of air, draught from the cooling zone, recalculated for normal conditions:

$\dot{v}_{ac} = 2.63 \text{ m}^3 \text{ s}^{-1}$

Heat loss:

$\dot{Q}_{ac} = \dot{V}_{ac} \times C_{ac} \times (t_{ac} - 20) = 2.63 \times 1.306 \times 118 = 405.3 \text{ kW}$

C_{ac} - specific heat of air (kJ m^{-3} K^{-1})

t_{ac} - temperature of air (^{o}C)

Flue loss

The real amount of wet combustion products:

$V_{wr} = V_{dr} + V_{H_2O} = 19.6326 + 0.937 = 20.5696 \text{ m}^3$ per 1 m^3 gas

$\dot{V}_{wr} = V_{wr}$ x gas cons. per second = $3.315 \text{ m}^3 \text{ s}^{-1}$

temperature of comb. products: $t_{cp} = 226\ ^{o}C$

Flue loss: $\dot{Q}_f = \dot{V}_{wr} \times c_{cp} \times /t_{cp} - 20/ = 3.315 \times 1.313 \times 206 =$

$= 896.5 \text{ kW}$

c_{cp} - specific heat of comb. products (kJ m^{-3} K^{-1})

t_{cp} - temperature of comb. products (^{o}C)

Accumulated heat

The loss by heat accumulated in products and in kiln cars was calculated from average temperature, specific heat and material flow of respective material. The temperature was measured in the upper, central and lower parts of the setting on the surface as well as inside the setting. The temperature of kiln car lining and the temperature of iron boggie was measured in four different points. Three cars per day were measured this way. The average temperatures of individual materials were used for calculations.

Heat flow by the heat accumulated in setting:

$$\dot{Q}_{as} = \dot{m}_s \times c_s \times (t_s - 20) = 0.513 \times 0.791 \times 145.0 = 58.8 \text{ kW}$$

$\dot{m}_s$ ..... material flow of setting (kg s^{-1})

c_s ..... specific heat of setting (kJ kg^{-1} K^{-1})

t_s ..... average temperature of setting (^oC)

Heat flow by the heat accumulated in kiln car lining:

$$\dot{Q}_{al} = \dot{m}_l \times c_l \times (t_l - 20) = 0.375 \times 0.893 \times 116 = 38.8 \text{ kW}$$

$\dot{m}_l$ ..... material flow of kiln car lining (kg s^{-1})

c_l ..... specific heat of kiln car lining (kJ kg^{-1} K^{-1})

t_l ..... average temperature of kiln car lining (^oC)

Heat flow by the heat accumulated in kiln car iron boggie:

$$\dot{Q}_{ab} = \dot{m}_b \times c_b \times (t_b - 20) = 0.119 \times 0.476 \times 89 = 5.0 \text{ kW}$$

$\dot{m}_b$ ..... material flow of iron boggie (kg s^{-1})

c_b ..... specific heat of iron (kJ kg^{-1} K^{-1})

t_b ..... average temperature of iron boggie (^oC)

Total loss by accumulated heat:

$$\dot{Q}_{at} = \dot{Q}_{as} + \dot{Q}_{al} + \dot{Q}_{ab} = 58.8 + 38.8 + 5.0 = 102.6 \text{ kW}$$

Review of Heat Balance

	kW	%
Heat input	2 286	100
Loss by cooling air	405.3	17.72
Flue loss	896.5	39.20
Loss by accumulated heat	102.6	4.49
Other losses (technological, through brickwork, by leakage, to foundations, etc.)	881.6	38.59

Graphically is the heat balance expressed in Figure 6.

Specific consumption of the kiln:

Output	0.513	$kg\ s^{-1}$
Heat input	2 286	kW
Specific consumption of heat for firing 1 kg of products:	4 456	$kJ\ kg^{-1}$

5. Evaluation of Testing Results

Firing conditions

The temperature difference between the lower and upper part of the setting in the preheating zone is considerably high and goes above 150°C. Temperature equalization causes too high temperature gradient in the lower part of cross--section, interval of 500 - 750 °C where the fired material is sensitive to temperature changes due to $\alpha - \beta$ quartz transformation. This temperature rise causes a part of cracks in fired tiles. The firing curve in the upper part of the setting is favourable.

The temperature is very well equalized in the cross-section in the firing zone.

The course of cooling can be improved by a rapid temperature drop from the firing temperature to 700°C. The fired body shows high thermal shock resistance in this interval and the measure enables to slow down the temperature decline from 600 to 500°C. Cooling under 450°C should be rapid again to lower the outlet temperature and thus the loss by accumulated heat.

Pressure conditions

The underpressure at the beginning of the preheating zone amountsto - 20 Pa. Together with overpressure of 11 Pa at the end of the preheating zone, it causes a too rapid flow of combustion gases which does not enable the proper heat transfer between the combustion products and the heated material.

The kiln is equipped with a system of openings to the stack draught in the first eight sections. The openings are located in two levels, one of them being at the level of kiln car platforms, the other by 0.6 m higher. 25% of outlets are opened in lower level 50% of them in higher one.

The maximum overpressure of 11 Pa is rather high and sets in in a considerably long part of the kiln. It causes the penetration of the kiln atmosphere to the inspection tunnel and increases the loss by leakage.

Kiln atmosphere

The CO_2 and O_2 concentrations prove proper adjustment of burners in firing and preheating zones. The rapid decline of CO_2 concentration at the beginning of the kiln and low CO_2 concentration in stack draught show the infiltration of air into the kiln due to high underpressure in the preheating zone.

Gas quality and consumption

The differences of Wobbe`s number did not exceed ± 3% of average value (see Table 3). Short changes - within several hours - are compensated by thermal inertia of kiln brickwork and no change in temperature can be registered. Longer changes - one day or more - cause the drift of the kiln to change the firing curve. In such a case, the input of the kiln must compensate the change in calorific value. In this example, the gas quality declined which was reflected by increased consumption (see Table 1).

Heat balance

The flue loss is considerably high (39.2% of the input) due to relatively high temperature and great volume of combustion products. The possibilities of its reduction are presented in the part of "Recommendations".

The loss by cooling air (17.72%) corresponds to that of other similar kilns. This hot air is utilized in driers of pressed products.

The brickwork of the cooling zone is intensively cooled by a vertical duct from which the hot air escapes to the ambient. This system increases the loss through brickwork and limits the utilization of hot air in a technological process.

The loss by accumulated heat in fired tiles and in kiln cars (4.5%) can be partly reduced by lowering the outlet temperature.

The rest of the input (38.59%) is spent on the losses on chemo-physical changes in the fired material (technological loss), losses through lining, by leakage, to foundations, etc.

The specific consumption - 4 456 kJ kg^{-1} - exceeds the projected value - 3 720 kJ kg^{-1} - by 19.8%. It is caused partly by lower actual output than projected, partly by the adjustment of the kiln.

6. Recommendations

Firing conditions

a) To improve the temperature distribution in the cross-section of the preheating zone, it is necessary to increase the heat transfer from the kiln atmosphere to tiles, especially in the lower part of the kiln. This can be reached by closing several outlets to stack draught in the upper level and opening some of them in the lower level. Finally, about 20% of openings in the upper level and 35 - 40% in the lower level should be opened.

b) The high rapidity of cooling immediately after the firing zone can be reached by the adjustment of cooling fans to higher output.

c) To slow down the temperature decline from 600 to 500°C by complete closing of the cooling system in corresponding part of the kiln.

Pressure conditions

Pressure conditions will be improved by measures para a) and b) in the recommendations on firing conditions.

Heat balance

a) A partial closing of stack draught outlets will lower the amount of combustion gases and their temperature in the stack draught and thus the flue loss as well as the penetration of cold air into the preheating zone will be reduced.

b) A higher output of cooling fans will partly lower the overpressure in the firing zone and the penetration of the kiln atmosphere into the inspection tunnel will be reduced.

c) To improve the cooling in the last part of the kiln, it is necessary to increase the output of exit air lock. Lower temperature of tiles and kiln cars leaving the kiln will lower the loss of accumulated heat.

d) The part of heated air from the cooling zone obtained by the increased output of cooling fans should be used in the entrance air lock for preheating tiles.

The principle to be strictly observed during the kiln adjustment: Only one change should be realized and only after the response and when the new stabilized operation of the kiln is reached a new change can be accomplished. Thus the effect of each change can be registered.

Table 1 Consumption of town gas

Day of measurement	Consumption /m^3/	m^3 h^{-1}	% of average value
1	13 571	565.5	97.5
2	13 795	574.8	99.1
3	13 962	581.8	100.3
4	14 174	590.6	101.8
5	14 117	588.2	101.4

The average consumption during the time of measurement:
580.2 m^3 h^{-1}

Table 2 Average composition of town gas

Component	%
H_2	50.30
CO	14.90
CH_4	21.11
C_nH_m	0.59
CO_2	10.88
N_2	2.22

This composition corresponds to the calorific value:
1 4 184 kJ m^{-3}

Table 3 <u>Gas Wobbe`s number fluctuation</u>

Day	Time	% of average value
1	6.oo	102.4
	12.oo	102.3
	18.oo	101.9
	24.oo	102.8
2	6.oo	101.3
	12.oo	100.5
	18.oo	100.7
	24.oo	100.9
3	6.oo	99.9
	12.oo	100.1
	18.oo	99.6
	24.oo	99.4
4	6.oo	99.0
	12.oo	98.1
	18.oo	97.8
	24.oo	98.1
5	6.oo	98.4
	12.oo	99.8
	18.oo	98.3
	24.oo	98.8

Table 4 Pressure conditions, CO_2 and O_2 concentrations

Section No.	Pressure /Pa/	CO_2 /%/	O_2 /%/
5	- 20.3	3.3	17.0
10	- 17.2	5.1	11.8
15	- 12.5	5.8	10.6
20	- 2.4	7.8	7.2
25	8.0	9.2	4.8
29	11.1	10.5	3.2
33	11.2	12.1	0.4
36	11.4	12.5	0.1
39	10.9	12.9	0.0
42	9.9	11.3	1.5
45	8.6	9.7	4.8
49	6.8	4.3	13.6
53	6.4	2.1	18.4
57	7.8	0.0	20.8

Table 5 Theoretical need of oxygen and amount of combustion products

Comp.	Volume $/m^3/$ in $1m^3$ of gas	Need of O_2 $/m^3/$	Combustion products $/m^3/$		
			CO_2	H_2O	N_2
H_2	0.503	0.2515	-	0.503	-
CO	0.149	0.0745	0.149	-	-
CH_4	0.211	0.4220	0.221	0.422	-
C_nH_m	0.006	0.0180	0.012	0.012	-
CO_2	0.109	-	0.109	-	-
N_2	0.022	-	-	-	0.022
Total	1.000	0.7660	0.481	0.937	0.022

II. BELT DRIER FOR WASHED KAOLIN

1. Technical Parameters

Type:	conveyor drier with forced circulation
Put into operation:	1974
Dried material:	washed kaolin
Drying medium:	hot air from heat exchanger
Output:	4 610 kg h^{-1} of dry substance
Inlet humidity:	28 % /+
Outlet humidity:	10 % /+
Specific consumption:	max. 4180 kJ kg^{-1} of evaporated water /+

/+ Projected values.

Heat exchanger:

Heat input:	2 585 kW
Heat useful output:	2 020 kW
Amount of heated air:	5.83 m^3 s^{-1}
Air outlet temperature:	max. 330^{o}C, permanently 280^{o}C

Fuel:

Fuel oil "S"	42 300 kJ kg^{-1}
Critical air consumption:	11 m^3 kg^{-1}
Dry combustion products:	10.31 m^3 kg^{-1}
Wet combustion products:	11.65 m^3 kg^{-1}
CO_2 max. :	15.6 %

The measurement was conducted under stable conditions, the drier operated without interruptions.

2. Objective of Measurement

The drier operated with a higher specific consumption than projected. Therefore, the recommendations were focused on the drying process improvement and energy conservation. The measurement proper determined the drying process economy and specific heat consumption.

3. Diagnostic Method and Applied Apparatuses

Oil consumption

An installed operation meter was applied for the determination of oil consumption.

Power output of driers

The technological line does not include weighing the processed material. Therefore, the calculation was based on the mass and number of filterpressed kaolin cakes. An average mass of dried cakes - 67.49 kg was taken into account. Humidities of the taken samples were determined in a laboratory. The samples were taken after 2-hour period. The temperature and moisture content of the drying medium were measured by a probe in the level of the surface of kaolin layer on the belt. The probe was sent together with dried kaolin through the drier and data were recorded continually by a recorder. The air flow velocity was measured by anemometers and by a Pitot`s tube with micromanometers. Combustion products of the heat exchanger were analyzed by CO_2 and O_2 analyzers.

4. Testing Results

Temperature and relative moisture content of the drying medium on the level of dried material are presented in Table 6, graphically in Figure 7 together with the scheme of the drier. Table 7 presents the review of the following values:

- output - measured by the mass of moist kaolin at the entry of the drier
- fuel oil consumption
- relative moisture content of kaolin samples taken at the entry and exit of the drier
- temperature of kaolin samples
- CO_2 and O_2 concentrations in combustion products of the heat exchanger
- temperature of combustion products
- temperature of exhausted air from the drier (two exhausts)
- quantity of exhausted air (recalculated normal conditions)
- flow rate of primary air for the burner of the heat exchanger

Survey of selected parameters of the drier calculated from the measured values is presented in Table 8.

Example of calculations

Mass of dry matter:

$$M_{dm} = M_{ml} \times \left(1 - \frac{W_1}{100}\right) = 9.42 \times \left(1 - \frac{30.9}{100}\right) = 6.51\ \mathrm{t\ h^{-1}}$$

M_{ml} - mass of entering material

W_1 - entry moisture content

Mass of evaporated water:

$$M_{we} = M_{ml} \times \frac{W_1 - W_2}{100 - W_2} = 9.42 \times \frac{30.9 - 13.7}{100 - 13.7} = 1.88\ \mathrm{t\ h^{-1}}$$

W_2 - exit moisture content

Mass of residual water:

$$M_{wr} = M_{ml} - M_{dm} - M_{we} = 9.42 - 6.51 - 1.88 = 1.03 \text{ t h}^{-1}$$

Volume of dry air in exhaust:

$$V_{da} = V_{ma} - V_v = 7.14 - \frac{1880}{3600} \times \frac{22.4}{18} = 6.49 \text{ m}^3 \text{ s}^{-1}$$

V_{ma} - volume of moist air

V_v - volume of water vapour

Air for burner:

$$V_a = K \times S \times \bar{V}_a \times \frac{273}{273+t} \times \frac{p_b}{p_n} = 0.95 \times 0.108 \times 8.91 \times$$

$$\times \frac{273}{293} \times \frac{98.6}{101.3} = 0.829 \text{ m}^3 \text{ s}^{-1}$$

S - surface of the sucking opening

$\bar{V}_a$ - average velocity of air flow

t - temperature of air

p_b - barometric pressure

p_n - normal barometric pressure

K - correction coefficient for switching off the thermo-regulation

Excess air coefficient:

$$n = \frac{\%\ CO_2 \text{ max.}}{\%\ CO_2} = \frac{15.6}{11.1} = 1.41$$

Quantity of combustion products:

$$V_m = \frac{M_Q}{3600} \times / V_{mt} + V_{at} \times (n-1)/ = \frac{190.7}{3600} \times /11.65 + 11 \times$$

$$\times (1.41-1)/ = 0.856 \text{ m}^3 \text{ s}^{-1}$$

M_o - consumption of oil (kg h^{-1})

V_{mt} - theoretical volume of moist combustion products (m^3 kg^{-1})

V_{at} - theoretical volume of air (m^3 kg^{-1})

Heat balance

Heat input by burning oil:

$$Q_o = H_o \times M_o \times \frac{1}{3600} = 42\ 300 \times \frac{190.7}{3\ 600} = 2\ 241 \text{ kW}$$

H_o - heating value of oil (kJ kg^{-1})

M_o - consumption of oil

Heat output for evaporation of water:

Heat necessary for evaporation of 1 kg of water:

$q_{we} = 2\ 638$ kJ

Heat output necessary for water evaporation:

$$Q_{we} = M_{we} \times q_{we} \times \frac{1}{3600} = 1880 \times \frac{2\ 638}{3\ 600} = 1\ 378 \text{ kW}$$

Flue loss

$$Q_{cp} = c_{cp} \times V_{cp} \times (t_{cp} - 20) = 1.425 \times 0.856 \times 268 = 327 \text{ kW}$$

c_{cp} - specific heat of combustion products (kJ m^{-3} K^{-1})

V_{cp} - volume of combustion products (m^3 s^{-1})

t_{cp} - temperature of combustion products (°C)

Loss by exhausted air:

Exhaust No. 1

$$Q_{a1} = c_a \times V_{a1} \times (t_a - 20) = 1.318 \times 3.62 \times 40.2 = 192 \text{ kW}$$

Exhaust No. 2

$Q_{a2} = 194$ kW

Total:

$Q_a = Q_{a1} + Q_{a2} = 386$ kW

c_a - specific heat of air (kJ m^{-3} k^{-1})

t_a - temperature of exhausted air (°C)

Heat loss by accumulated heat:

By heat accumulated in dry matter:

$$Q_d = \frac{M_{dm}}{3600} \times c_m \times (t_{ex} - 20) = \frac{6 \times 510}{3600} \times 0.87 \times 7.6 = 12 \text{ kW}$$

c_m - specific heat of dry matter (kJ kg^{-1} K^{-1})

t_{ex} - exit temperature of kaolin

By residual water:

$$Q_{wr} = \frac{M_{wr}}{3600} \times c_w \times (t_{ex} - 20) = \frac{1030}{3600} \times 4.187 \times 7.6 = 9 \text{ kW}$$

c_w - specific heat of water

Review of heat balance

	kW	%
Heat input by burning oil	2 241	100
Heat output for evaporation of water	1 378	61.49
Flue loss	327	14.59
Loss by exhausted air	192	8.57
Loss by accumulated heat	21	0.94
Other losses (radiation, leakage, etc.)	323	14.41

The heat balance is expressed graphically in Figure 8.

Specific consumption (kJ per 1 kg evaporated water) 4 291 kJ kg^{-1}

5. Evaluation of Testing Results

Drying conditions

They are presented in Figure 1. The relative moisture content varies from 15 to 40% along the length of the active drying zone while the temperature attains about 90°C. This temperature differs considerably in comparison with the operation measurement by permanently installed thermometers which measure the temperature about 40 cm above the kaolin layer.

Operation parameters

The output of the drier is higher by 41% than the designed (see Table 3). This is the main reason why the required outlet humidity of kaolin (10% of water content) is not achieved. Also the decisive influence of inlet humidity at the entry into the noodle making machine is evident. With the inlet humidity up to 30.5%, short noodles showing a disturbed surface are produced. These noodles have a considerably larger surface for water evaporation and the belt of the drier is covered evenly. The relative humidity of exhausted air from the drier is relatively low (48%). It means that the parameters of the drying medium (temperature, relative humidity and flow velocity) are not optimum for the required output. Also the application of a perforated sheet for the conveyor belt does not enable optimum air flow through the layer of kaolin. The wire-woven belt is more advantageous from the point of view of air permeability. The overloading of equipment affects also evidently the quality of drying. The average output during six months preceding the measurements was 20% above the projected value.

Heat balance

In the heat balance, the useful heat for water evaporation represents more than 61%. The flue loss (14.59%) is lower than projected (22%). This favourable state is achieved by the optimum setting of firing conditions. The loss by exhausted air from the drier is low (8.57%) due to the relatively low temperature of exhausted air. Nevertheless, it can be lowered by a better utilization of drying medium.

The heat balance obtained by the diagnostic measurements is relatively favourable due to the uniform operation of the drier during testing. The frequent interruptions in its operation deteriorate the production economy.

Specific consumption

The specific consumption 4 291 kJ kg^{-1} obtained by measurements is only higher by 2.7% than projected. It is caused partly by the above-mentioned optimum operation conditions during testing, partly by drying to higher final relative humidity than projected. The specific heat consumption is in the uninterrupted operation only the function of dosing and inlet humidity of the dried material.

6. Recommendations and Expected Contributions

a) The supply of hot air to the drying space should be changed to bring the hot air as close as possible to circulation fans. By taking this measure, the temperature of the drying medium will be increased by approximately 10°C and drying efficiency will also be higher.

b) All interruptions in operation should be limited as much as possible, especially by regularly feeding kaolin into the drier to avoid the operation of empty drier.

c) Recorders should be installed to record outlet temperatures of the drying medium. In this way, each halt of the belt and the duration of standstill would be reliably registered.

d) The inlet humidity of inputs of the drier should be lower than 30.5%. To meet this requirement, filterpresses should be adjusted accordingly.

e) The outlet temperature of combustion products over 280°C makes possible to apply an additional heat exchanger to utilize this waste heat. The application of this heat for drying would save up to 20 tonnes of heating oil per year.

Table 6 **Temperature and relative moisture content of drying medium**

Section	Operation measurement /°C/	Temperature /°C/	Relative moisture content /%/
2		52	50.5
4	84	74	26.2
6		77	22.3
8	88	79	20.8
10		84	19.7
12		92	17.3
14	121	90	18.0
16		91	18.1
18		92	17.5
20	105	93	16.4
22		92	16.0
24		90	14.3
26	87	76	25.2
28		49	44.1
30		-	-

Table 7 Review of measured values

Time /h/	Output /t/	Oil consumption /kg/	Moisture content /%/ entry	Moisture content /%/ exit	Temperature of material /°C/ entry	Temperature of material /°C/ exit	Combustion products /%/ CO_2	Combustion products /%/ O_2	Temperature of combustion products /°C/
7.00			33.2	13.5	18.6	26.2			
8.00							11.1	5.0	288
9.00			30.4	15.2					
10.00									
11.00			30.0	12.2			11.3	4.9	285
12.00					19.0	28.6			
13.00			30.6	12.1					
14.00							11.0	5.0	291
15.00			30.8	14.2					
16.00									
17.00	94.241	1907.4	30.5	14.9	18.8	28.0	10.9	5.4	289
Ø	9.424 $t\ h^{-1}$	190.7 $kg\ h^{-1}$	30.9	13.7	18.8	27.6	11.1	5.1	288

Table 7 Review of measured values - continuation

Time /h/	Temperature of exhausted air /°C/		Quantity of exhausted air $/m^3\ s^{-1}/$		Primary air flow rate $/m\ s^{-1})$
	exhaust 1	exhaust 2	exhaust 1	exhaust 2	
7.00					8.85
8.00	62	65	3.55	3.46	
9.00					
10.00	61	63			
11.00					
12.00	58	60	3.68	3.61	
13.00					8.97
14.00	59	58			
15.00					
16.00	61	63	3.63	3.48	
17.00					
Ø	60.2	61.8	3.62	3.52	8.91

Table 8 Survey of selected parameters of the drier

Output - moist material	(t h^{-1})	9.42
dry matter	(t h^{-1})	6.51
Evaporated water	(t h^{-1})	1.88
Residual water	(t h^{-1})	1.03
Consumption of oil	(kg h^{-1})	190.7
Quantity of air for burner	(m^3 s^{-1})	0.829
Excess air coefficient		1.41
Quantity of combustion products	(m^3 s^{-1})	0.856
Quantity of medium in exhaust	(m^3 s^{-1})	7.14
Quantity of dry air in exhaust	(m^3 s^{-1})	6.49
Relative moisture content in exhaust	(%)	48

III. FINAL NOTE

The presented publication was elaborated by the UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries in Pilsen to show the ceramic manufacturers in the developing and least developed countries the potentiality of economizing the operation of heat consuming units in the silicate industries by means of diagnostic measurements. Positive results achieved by these measurements were palpable. Depending on the operating conditions of respective heat consuming units, their specific heat consumption can be reduced down by 5 to 70% after taking the recommended remedial measures. The mostly result in the reduction of reject occurrence, production intensification and better quality of outputs. According to the Czechoslovak experience of last years, the application of the specialized diagnostic units has proved to be the most effective method of performing the diagnostic measurements.

This paper gives two examples of the most frequent diagnostic analyses in ceramic industry - the diagnoses of a kiln and of a drier.

The UNIDO-Czechoslovakia Joint Programme in Pilsen is ready to mediate further assistance in the field of energy conservation to the developing and least developed countries (advisory missions of experts, application of the diagnostic mobile unit owned by the Research Institute for Ceramics, Refractories and Raw Materials in Pilsen, assistance in construction of diagnostic mobile units, etc.)

IV. REFERENCES

J. P. Hartnett, W. M. Rohsenow, Handbook of Heat Transfer, New York, 1973

M. Nový, Diagnostics, UNIDO-Czechoslovakia Joint Programme, Pilsen, 1981

M. Nový, Diagnostic Mobile Unit UNIDO-Czechoslovakia Joint Programme, Pilsen, 1983

Research Institute for Ceramics, Refractories and Raw Materials in Pilsen, Technical Reports on Diagnostic Measurements, 1980 - 1983

ANNEX

List of Figures

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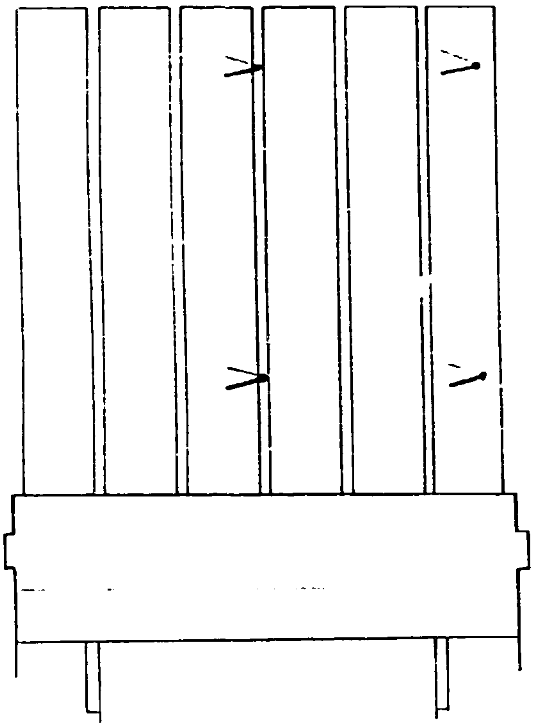
Figure 1: Measuring Kiln Car



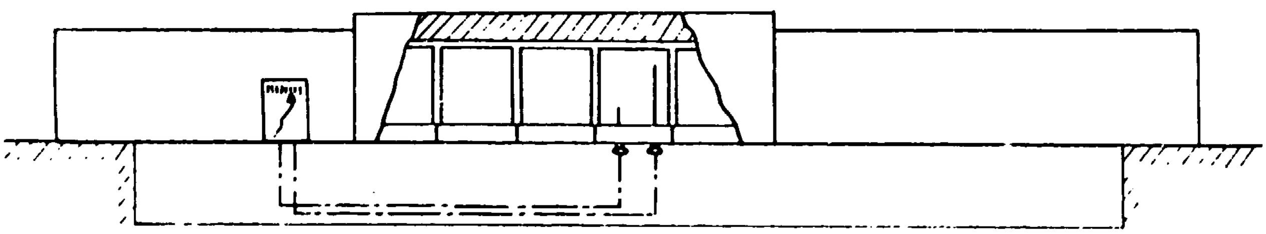


Figure 2: Measurement of Firing Curves

Figure 3: **Measurement of CO_2 and O_2 Concentrations**

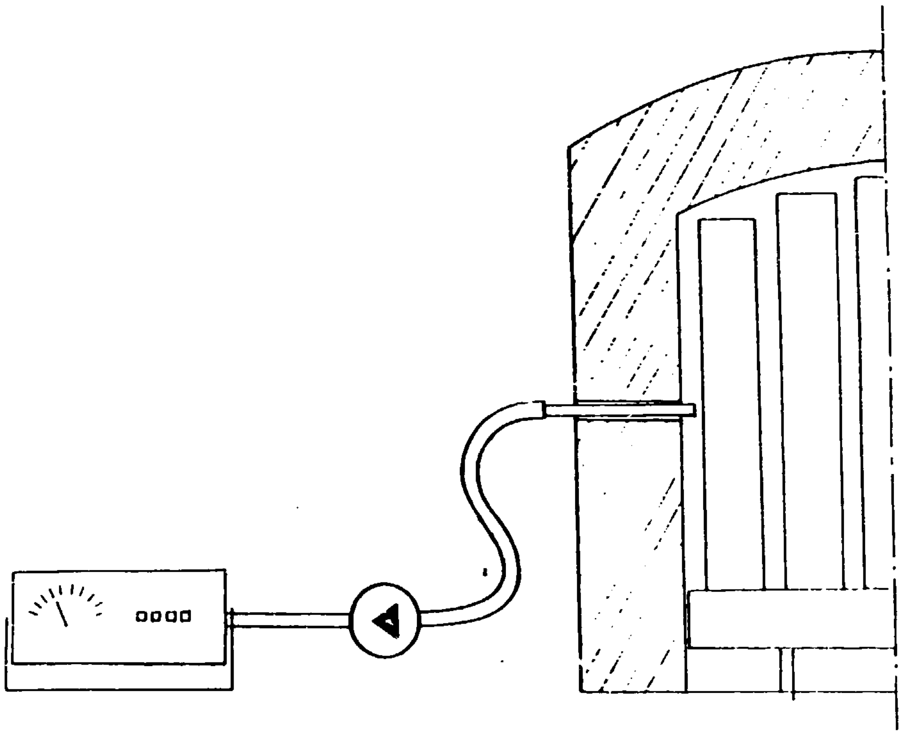


Figure 4: Firing Curves

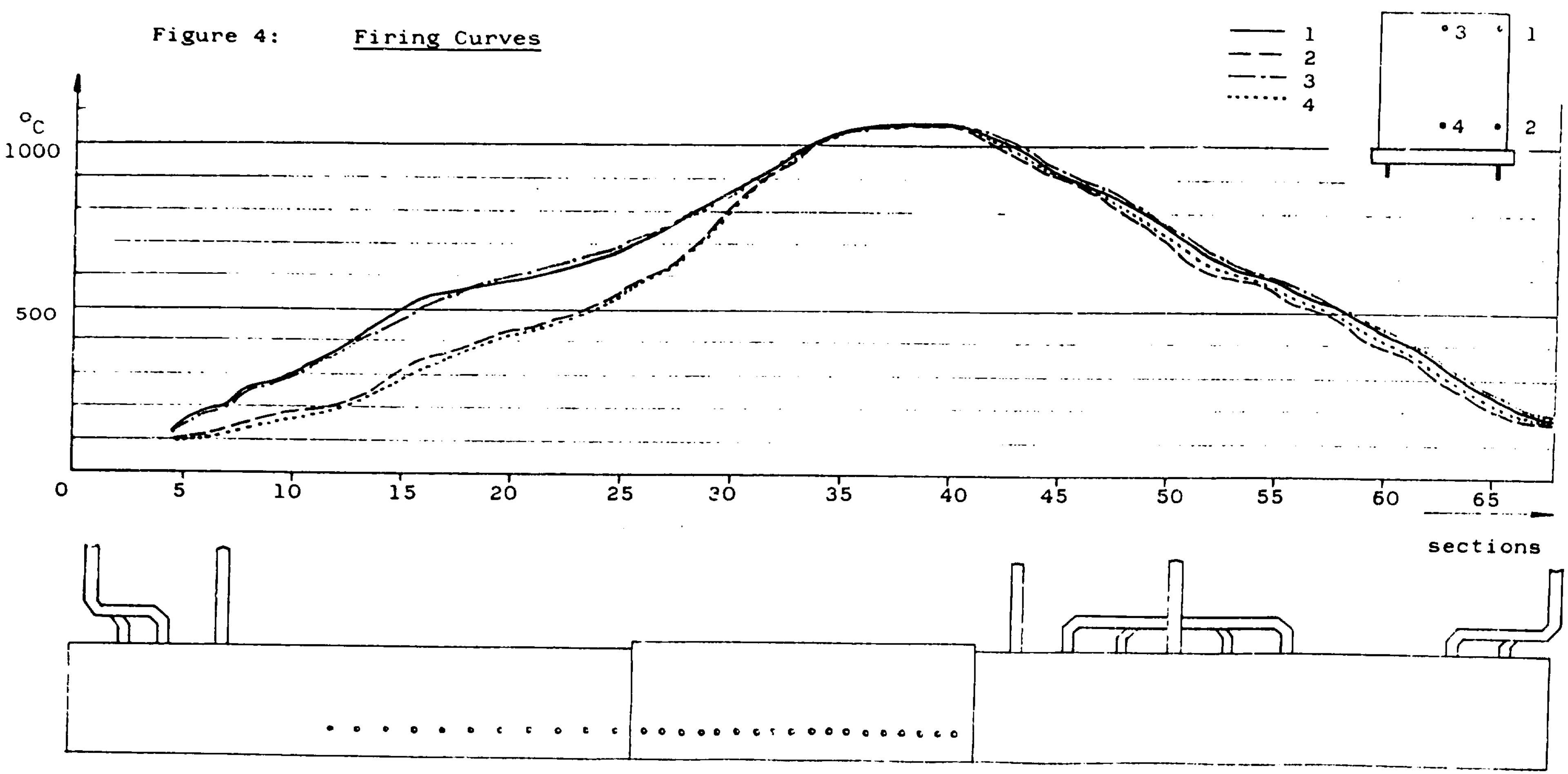


Figure 5: Pressure Curve , CO_2 and O_2 Concentrations

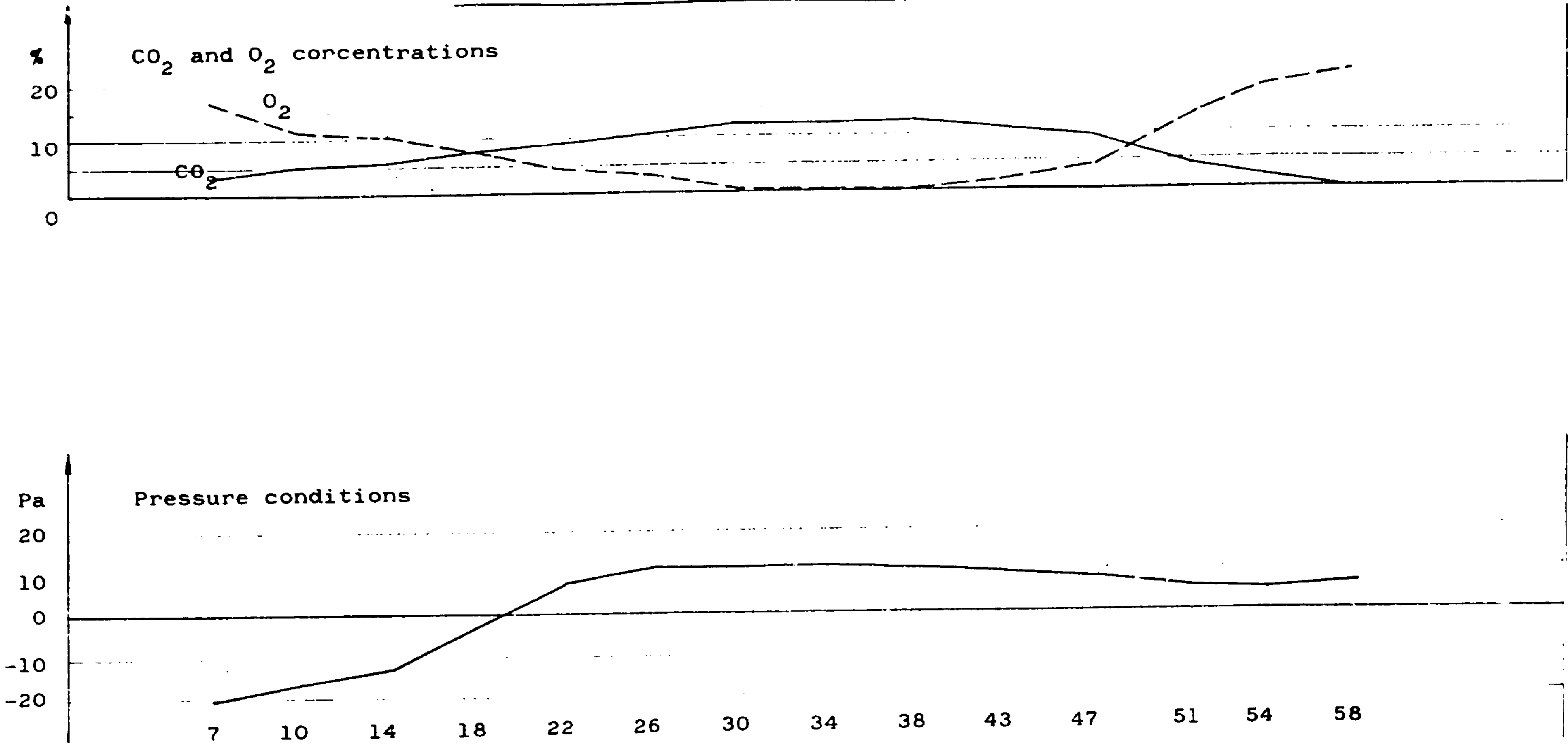
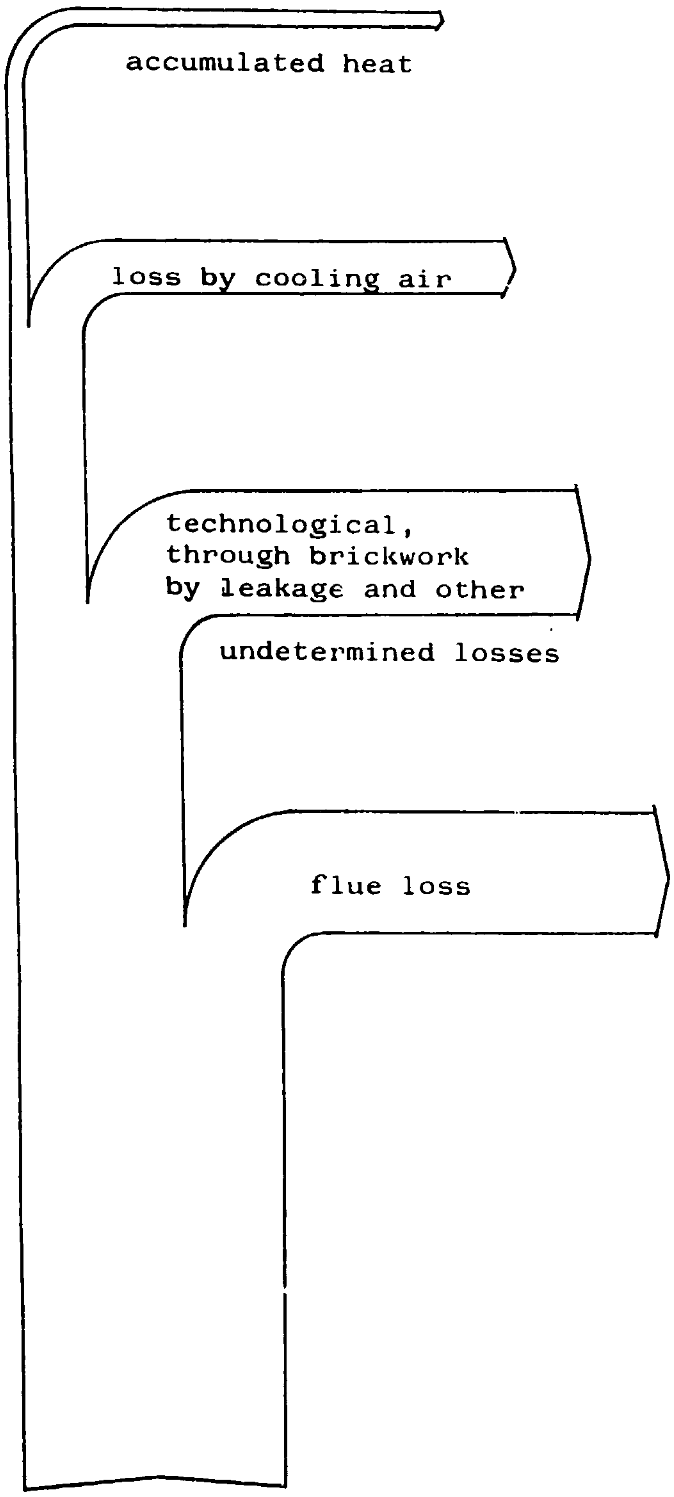


Figure 6: Heat Balance of the Kiln



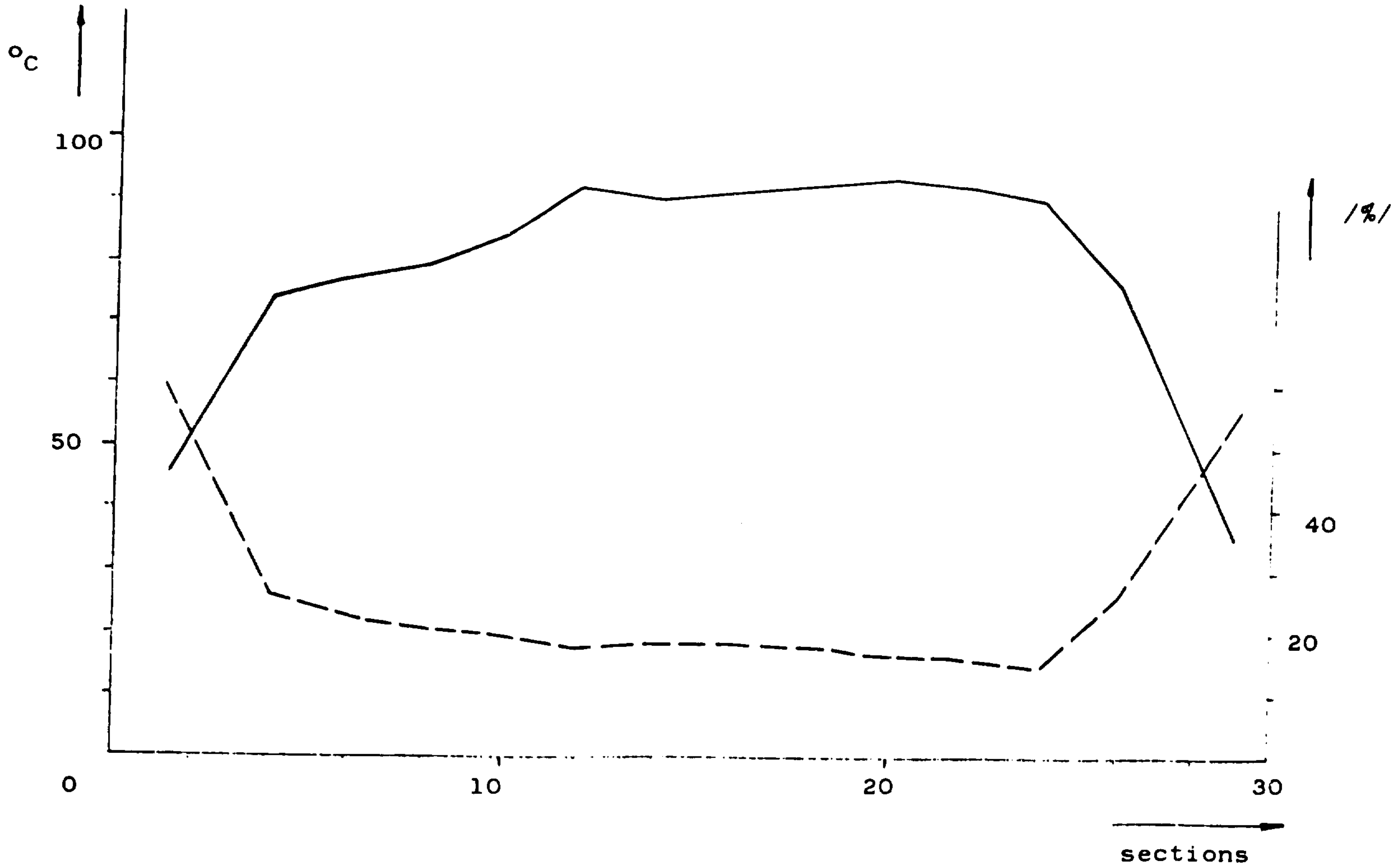


Figure 7: Temperature and Relative Moisture Content of Drying Medium

Figure 8: Heat Balance of the Drier