OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

→ Marie Dietrich
→ Pembleton

UNIDO-Czechoslovakia Joint Programme
for International Co-operation in the Field of Ceramics,
Building Materials and Non-metallic Minerals Based Industries
Pilsen, Czechoslovakia

Distr.
LIMITED

JP/199/84
October 1984
ORIGINAL: English

14714

MOBILE DIAGNOSTIC UNIT (energy saving) FOR DEVELOPING COUNTRIES

by: M. Nový

Special Consultant: Z.A. Engelthaler

The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

cf. 12886

ABSTRACT

Mobile Diagnostic Unit /MDU/ serves as an effective means of technical data collection through diagnostic measurements of the heat consuming equipment in production plants.

The evaluation of measured data by a team of specialists results in recommendations on operation optimization to reach energy savings, production intensification, quality improvement and reject reduction.

The interest of numerous developing countries, such as India, Turkey, Libya, Egypt, Brazil and Iran in the MDU operation evoked the preparation of this paper in which the essential information about the MDU equipment and measurement procedures is presented. It also informs of the MDU crew and contributions from the realized recommendations which are worked out by the the experts on the basis of test results. A list of selected suppliers of measuring equipment completes the publication.

TABLE OF CONTENTS

---...---

I. INTRODUCTION

Diagnostics of heat consuming equipment represent an important item in the scheme of energy management. Providing the experts with an objective information about energy consumptions and course of thermal treatment in the respective equipment, diagnostics enable to construct conclusions and recommendations on the improvements in its operation.

Mobile diagnostic units used for many years by the experts of the Research Institute for Ceramics, Refractories and Raw Materials in Pilsen have proved to be an effective means of data colletion and evaluation. These units were designed and assembled by the experts and mechanics of the Institute. Their utilization brings about large contributions in the quality and intensification of production and in energy conservation in production plants.

The UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries in Pilsen is ready to satisfy the requests from developing countries concerning technical information, technical assistance and know-how transfer to assist thus the developing countries in the construction and utilization of their own mobile diagnostic units and in energy management programmes.

The decreased specific energy consumptions reached by the application of energy management system bring about competitive prices of products and enable the entrepreneurs to expand the production in conditions of a limited availability of energy sources.

The equipment of MDU complies with the application not only in the ceramic industry for which it was originally designed but with the application in other industries, such as glass, metallurgy and textile industries. Nevertheless, the instrumentation is regularly supplemented in dependence on the development of apparatuses available on the world market which will facilitate the application of MDU.

II. DIAGNOSTIC METHODS - PRINCIPLES AND PROCEDURES

The diagnostic measurement provides the team of experts with objective and detailed data about the thermal unit operation. The sets of values obtained under common working conditions being completed with the information about the technological parameters of the production unit and fuel consumed are evaluated in an energy conservation study. This study agrees with the user of the heat consuming unit as an indispensable basis for his further technical, operational and organizational measures and steps to improve the production parameters.

There are two types of diagnostic measurements, either focused on the technological process optimization or on the energy conservation. Nevertheless, the complex measurements, e.g. combination of the technological and energetical types of measurements, are the most advisable for the purpose of energy management. The complex measurements provide the team of experts with the complete information about the unit. Thus they can prepare to the user of the heat consuming unit the objective and complex statement and draft all suitable and recommendable adjustments and changes which are to be realized for the perfect and effective service of the unit.

Regardless of the type of measurements (energetical or technological), the activities performed during the measurements comprise three fundamental stages:

- statement of thermal unit operation conditions, performance of objective tests and functional measurements,

- evaluation of tests and measurements,

- working out proposals for technical, energetical and operational and organization arrangements or recommendations on heat balance or reconstruction purposes.

Technological Measurement

The technological type of measurement after its evaluation forms the essential basis for working out proposals of arrangements in the field of thermal technological process optimization. The essential information in this case is the course of thermal treatment of the ware and the temperature distribution in the cross-section of the unit. These data are expressed graphically by firing curves, measured in several points in the cross-section (Figure 1). The measuring points must be located so that the measured temperatures give the sufficient information about the temperature distribution in the cross-section of the unit. The measurement must inform about the temperature differences in the horizontal as well as in vertical directions and about the differences between the inner part and surface of the setting.

For the firing curve investigation in a tunnel kiln, a measuring kiln car is used (Figure 2). The kiln car lining is drilled through and thermocouples are pushed through the holes and fixed in the measuring positions. Cold junctions of the thermocouples are fixed under the steel boggie of the measuring kiln car. They are connected with a recorder or a data logger through the inspection tunnel of the kiln. While the measuring kiln car proceeds through the kiln, temperatures in the measuring points are measured and recorded. Thus the firing curve and temperature distribution in the cross-section of the kiln are obtained (Figure 1). Besides the firing curve, the pressure of the kiln atmosphere is measured and combustion gases analyses are done as well.

A drier being tested; the most important data are as follows:

- *course of temperature*
- *course of the dew point*
- *drying medium flow velocity*

A probe, measuring the drying medium dew point, is sent through the drier together with the dried material to investigate the drying conditions (Figure 3). This probe consists of a temperature resistance sensor and of a dew point sensor. The drying curve resultates from this measurement. The drying medium flow velocity is measured either by anemometers or by Pitot' s tubes.

All the technical data gathered by measurements together with the information about the location of regulating elements at the unit, conditions of the heating system, level of combustion processes, heat transfer in the unit and the amount and quality of production are evaluated using a computer.

The real firing (drying) curve obtained by measurements is then compared with the optimal one of the unit at this phase of work. The recommendations on the adjustment of regulating elements are worked out to minimize the difference between the real and optimal firing (drying) curves. Thus the optimal thermal treatment of fired (dried) material is reached. This interference with the adjustment usually causes the production intensification and quality improvement.

Energetical Measurement

The most important information for energy consumption minimization is the heat balance of the tested equipment. It includes all items of heat energy entering and leaving the unit and shows the possibilities of energy conservation.

The most significant items of heat balance of a kiln are as follows:

heat input

- *is determined from the calorific value and amount of the fuel consumed*

$$P = M \cdot H \quad /kW/$$

M ... amount of fuel consumed $/kg.s^{-1}/$

H ... calorific value of the fuel $/kJ.kg^{-1}/$

To reach a better precision of the heat input determination and to check the results obtained by the direct method, the indirect method is used very frequently. The heat input is calculated from the combustion gases analyses and from the amount of combustion gases drawn from the unit by this method.

A small portion of the heat energy entering the unit is formed by specific heat of the fuel (usually 1 to 2%).

flue loss

- *is determined from the volume, temperature and specific heat of combustion gases*

$$P_l = V \cdot t \cdot c \quad /kW/$$

V ... volume of combustion gases $/m^3 s^{-1}/$

t ... temperature of combustion gases $/K/$

c ... specific heat of combustion gases $/kJ\ m^{-3} K^{-1}/$

The volume of combustion gases is calculated from the flow velocity and the cross-sectional area of the duct. The flue loss is the necessary phenomenon of a firing process. It cannot be lowered under a certain limit ensuring proper pressure conditions in the kiln.

The flue loss of a tunnel kiln with opened fire forms usually about 25% from the input.

loss by heat conduction of brickwork

- *for continually operating kilns it can be derived from the kiln atmosphere temperature, heat conductivity of brickwork, surface area of lining and temperature of the ambient*

$$P_2 = k \cdot \Delta t \cdot S \quad /kW/$$

k	...	heat transfer coefficient	$/kJ\ s^{-1}\ K^{-1}\ m^{-2}/$
Δt	...	temperature difference between inner and ambient temperature	$/K/$
S	...	lining area	$/m^2/$

The loss by heat conductivity of lining forms usually about 15 from the input of a continually operating kilns with the classical type of lining (e.g.combination of fireclay and red bricks) and less than 10% from the input of a kiln insulated by up-to-date insulating materials (e.g. light-weight refractories and fibres).

loss by heat accumulated in kiln cars

- *to ascertain this loss, the average temperature of the kiln car lining and average temperature of iron boggie must be determined from several measurements. The loss by accumulated heat is than calculated from the average temperature and specific heat of material.*

$$P_3 = M \cdot t \cdot c \quad /kW/$$

M	...	mass flow of material	$/kg\ s^{-1}/$
t	...	average temperature of material	$/K/$
c	...	specific heat of material	$/kJ\ kg^{-1}K^{-1}/$

The loss by heat accumulated in kiln cars forms about 3% from the input of a kiln with properly adjusted cooling zone.

loss by heat accumulated in ware

- the process is similar to that of kiln cars. This loss forms about 5% from the input.

loss by heat conduction of foundations

- this loss is very difficult to ascertain due to the complicated conditions of heat conduction. The item of heat conduction of foundations in the heat balance is usually lower than 5 - 10% from the thermal unit heat input. Therefore, this loss is usually comprehended in the so called undeterminable losses together with the loss by leakage and that through the inspection tunnel. All these losses form about 15% from the thermal unit heat input.

Technological loss

- comprehends all losses for physical and chemical transformations in the material of ware. It alternates from 3 to about 25% from the thermal unit heat input according to the type and composition of the fired material. The amount of heat necessary for endothermic reactions can be determined by laboratory tests of a ceramic body.

loss by heated air draught from the cooling zone

- is calculated from the amount of heated air multiplicated by its temperature and specific heat

$$P_4 = V \cdot t \cdot c \qquad /kW/$$

V ...	amount of heated air	/m^3 s^{-1}/
t ...	temperature of air	/K/
c ...	specific heat of air	/kJ m^{-3} K^{-1}/

To determine the amount of heated air, the average air flow velocity must be multiplicated by the cross-sectional area of the duct.

Despite of the use of heated air from the cooling zone in the technological process (e.g. for drying or preheating of the material), for the purpose of heat balance, this heat is considered as a loss. This item of the heat balance of a tunnel kiln amounts from 20 to 35%.

production of kiln

- *the knowledge of this value is necessary for the purpose of the specific energy consumption determination. The energy consumed during the measuring period devided by the production volume during this period forms this important index enabling the comparison of various kilns mutually, from the operation economy point of view.*

The other tests, performed during the energetical measurement:

combustion gases analyses

The samples of the kiln atmosphere for the purpose of the combustion gases analyses are taken through the sight holes of the kiln. The economy of combustion is determined by these analyses. The air excess coefficient is calculated from the portion of CO_2 *in the combustion products and expresses the excess of burning air above the theoretical volume. The fuel consumption of a kiln can be calculated from the portion of* CO_2 *in the combustion products, from the amount of these products and from the theoretical portion of* CO_2 *in the combustion products.*

stack draught

A sufficient value of the stack draught enables the operation of a kiln in optimal pressure conditions.

The drier being the object of testing, following values must be determined:

- *heat input*
- *heat losses*
  - *by efficiency of heat exchanger*
  - *flue loss*
  - *by exhausted drying medium from drier*
  - *by heat conduction of brickwork*
  - *by heat accumulated in dried material*
  - *by heat accumulated in residual water*
- *production of drier*
- *combustion gases analyses*
- *relative moisture content of exhausted drying medium*
- *relative moisture content of entering material*
- *relative moisture content of dried material*

III. MDU ADVANTAGES AND CONTRIBUTIONS

The advantageous arrangement of measuring instruments and of an evaluation centre in a mobile diagnostic unit brings about an effective and operational utilization of the equipment in different production plants. The partial evaluation of measurements on the spot minimizes undesirable production conditions. The contributions reached by the realization of proposed recommendations are direct and indirect ones:

Direct Contributions

Energy conservation

realized by

- adjustment of burning conditions (adjustment of optimal air excess, adjustment of the outlet temperature of burners, etc.)
- adjustment of pressure conditions (reduction of too high pressure in the firing zone brings about reduced penetration of kiln atmosphere to inspection tunnel)
- adjustment of firing curve (if the temperature in some part of the kiln is higher than necessary, its reduction brings about lower losses by conduction of brickwork)
- adjustment of entrance and exit air locks, etc.

Quality improvement and rejects decreasing

accomplished usually by

- firing curve optimization
- temperature equalization in the cross-section (by the use of mixing fans, by pressure curve adjustment, by setting optimization, etc.)

Output increase

can be realized by:

- optimalization of setting(with optimal heat transfer to and from the fired material)

- temperature equalization in the cross-section of the unit, firing curve optimalization (it enables in some cases to shorten the firing cycle and thus increase the output)

Substitution for fuel used

Detailed knowledge of material thermal treatment gained by the diagnostic measurement enables a successful substitution for the fuel used, together with the second measurement, serving for optimal adjustment of the unit, firing the new fuel.

Indirect Contributions

Besides the direct contributions, an indirect profit can also be gained. A detailed technical information about the heat consuming unit serves as the basis for

- constructional improvements
- decision about the stage of modernization
- recommendations on waste heat utilization (utilization of the heat escaping from the cooling zone, by combustion products, etc.)

IV. MEASURING EQUIPMENT OF MDU

A Temperature Measurements

Apparatus - sensor	range
Resistance Pt thermocouples	up to 600°C
Mercury thermocouples	up to 450°C
Ni-NiCr thermocouples in protective ceramic tubes	up to 1200°C
Ni-NiCr flexible jacketted thermocouples	up to 1200°C
Pt-PtRh thermocouples	up to 1400°C permanently, peaks up to 1600°C
PtRh6-PtRh30 thermocouples	up to 1600°C permanently, peaks up to 1800°C
Digital thermometer Ni-NiCr for both atmospheric and surface temperature contact measurements	up to 1200°C
Radiometer Thermopoint for surface temperature measurements	-30 - 1100°C
Total radiating pyrometers	150 - 2000°C

B Gas Flow Measurements

Apparatus	range	piece
Mechanical anemometer	0 - 15 $m.s^{-1}$	2
Mechanical-electrical anemometer with two ranges	0 - 5 $m.s^{-1}$ 0 - 30 $m.s^{-1}$	2
Set of Pitot's tubes with direct indication of gas flow velocity	length from 0.5 to 2 m	4

C Pressure Measurements

Apparatus	range	piece
Digital micromanometer with additional direct indication of gas flow velocity with 3 ranges	0 - 120 Pa; 0 - 14 m.s^{-1} 0 - 500 Pa; 0 - 28 m.s^{-1} 0 - 2500 Pa	1
Micromanometer with changeable sensitivity	maximum 0 - 2 450 Pa	2
Set of precise manometers	- 100 kPa - 0.5 MPa	5
Annubar balance with recorder and changeable sensitivity	maximum - 200 - 200 Pa	1

D Dew Point Measurements

Apparatus	range	piece
Digital relative humidity measuring instrument with temperature indication	5 - 98% rel. hum. 0 - 70^{o}C	1
Dew point measuring set "Feutron" consisting of three probes and one plotting recorder, each probe measures the temperature of dry thermometer and the temperature of wet thermometer	0 - 100% rel. hum. 0 - 150^{o}C	2

E Combustion Gases Analyses

Apparatus	range	piece
Transportable analyzer "Infralyt" with two ranges for CO_2 content	0 - 10% 0 - 20%	2

for CO content	0 - 2.5% 0 - 5%	1
for SO_2 content	0 - 0.5% 0 - 1.0%	1
Analyzer "Permolyt" for O_2 content	0 - 10% 0 - 25%	1

F Gas Quality Measurements

Apparatus	range	piece
Wobbe's number meter with built-in recorder	Wobbe's number of generator gas, town gas, natural gas and propan	1

G Recording and Evaluation

Apparatus	range	piece
Digital data logger with built-in printer and automatic timing	6 inputs for Ni-NiCr thermocouples 6 inputs for Pt-PtRh thermocouples 6 mV inputs	1
Compensation recorder, writing width 250 mm	12 inputs for Ni-NiCr thermo-couples or Pt-PtRh thermocouples or mV - changeable by range modules	3
Small computer with built-in thermal printer for 21 digits and 16 digits display, stored programme system with 1024 steps in main routine and two levels of subroutines of the capacity 1024 steps each. External storage of the programme on magnetic cards.		

H <u>Accessories</u>

Filters for gas cleaning

Calibrating gas for analyzers and Wobbe' s number meter

Cables

Compensating lead wires

PVC pipes

Set of tools

Protective aids

Communication set - three pieces of short-wave transceivers

V. MDU CREW

The crew of the MDU consists of the following experts and technicians:

A Team Leader - expert on energy management experienced in production technology

B Expert on thermal processes and waste heat utilization

C Expert on measuring methods

D Expert on technical calculations and measurement evaluation

E Mechanician and driver of MDU

On the basis of the data obtained by the measurement proper, the experts prepare an energy conservation study with the recommendations on possible improvements in the spheres of energy conservation, rationalization of firing processes, rejects reduction and quality control.

VI. LIST OF SELECTED SUPPLIERS OF EQUIPMENT

AMR Holzkirchen, FRG	temperature measurements, relative humidity measurements, losses through the brickwork, gas flow velocity, recorders, data loggers
AIRFLOW Rheinbach, FRG	gas flow velocity, pressure measurements, relative humidity measurements, temperature measurements,
AGA Infrared Systems, Danderyd, Sweden	temperature measurements, thermovision systems
Ari Industries, Farnborough, Great Britain	thermocouples, resistance thermometers
BBC Brown Boveri, FRG	electric multimeters, recorders
Comark Electronics Ltd. Rustington, Great Britain	temperature data loggers,
Hewlett Packard, Palo Alto, USA	data loggers, computers
Honeywell Inc. Phoenix, Arizona, USA	recorders, multichannel recorders, flow measurements
Keithley Instruments, Inc. Cleveland, Ohio,USA	digital thermometers
Neotronics Ltd.,Takeley, Great Britain	electronic digital micromanometers, combustion gases analyzers
Phillips Eindhoven, the Netherlands	temperature measurements, humidity measurements, gas analyzers, recorders
Servomex Ltd., Crowborough, Sussex, Great Britain	O_2 analyzers

Testoterm KG, Lenzkirch, FRG	*temperature measurements, gas flow velocity, humidity measurements, pressure measurements, flue gases analyzers*
Takeda Riken Co., Ltd. Tokyo 176, Japan	*data loggers, recorders, computing data loggers*
Taylor Ltd., Great Britain	*analyzers*
Ultrakust, Ruhmannsfelden, FRG	*temperature measurements, gas flow velocity, recorders and data loggers, relative humidity measurements*
VDO Mess-und Regeltechnik GmbH, Hannover, FRG	*recorders*
VEB Junkalor Dessau, GDR	*gas analyzers, pressure measurements, Wobbe's number*
VEB Thermometerwerk, Geraberg, GDR	*thermocouples*
Wilhelm Lambrecht, GmbH, Göttingen, FRG	*gas flow velocity*

VII. FINAL NOTE

The diagnostic measurements of heat consuming equipments have an indispensable position in the system of energy management. They help to solve energy problems which become ever more the limiting factors of further industrial development in both the industrialized and developing countries.

Knowledge and experience gained within the Trust of Czechoslovak Ceramic Works with the application of mobile diagnostic units of the Research Institute for Ceramics, Refractories and Raw Materials in Pilsen have showed a high effect brought about. Annual contributions reach up to 55 TJ of heat energy which represents 1380 tonnes of fuel oil.

The UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries in Pilsen elaborated this paper as an initial information for the developing countries intending to construct and utilize their own mobile diagnostic units.

VIII. REFERENCES

Engelthaler Z.A., Nový M. - Energy Management in Ceramic Industry - lecture and publication, Czechoslovak Ceramic Works, Prague, 1982

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

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

Nový M. - Diagnostic Mobile Unit, UNIDO-Czechoslovakia Joint Programme, Pilsen, 1982

Nový M. - Waste Heat Utilization in Ceramic Industry, Stavivo 2/82, Prague, 1982

Nový M. - Heat Diagnoses Made on Tunnel Kiln and on Belt Drier, UNIDO/IO.572, January 1984

Wang F.Y. - Ceramic Fabrication Processes, New York, 1976

Research Institute for Ceramics, Refractories and Raw Materials, Pilsen - technical reports on diagnostic measurements, Pilsen 1980 - 1984

ANNEX

List of Figures

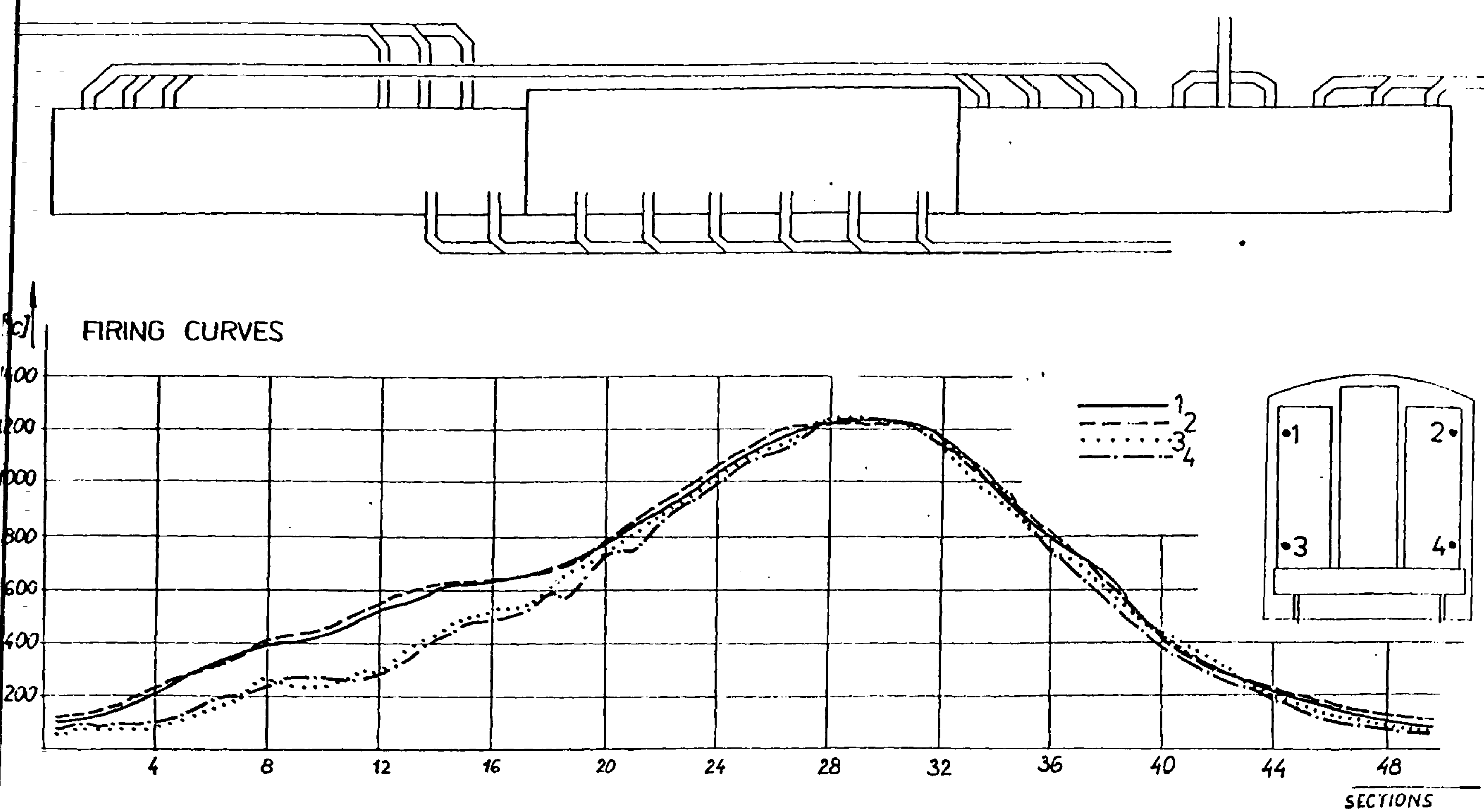

Figure 1: <u>Firing Curves of a Tunnel Kiln</u>

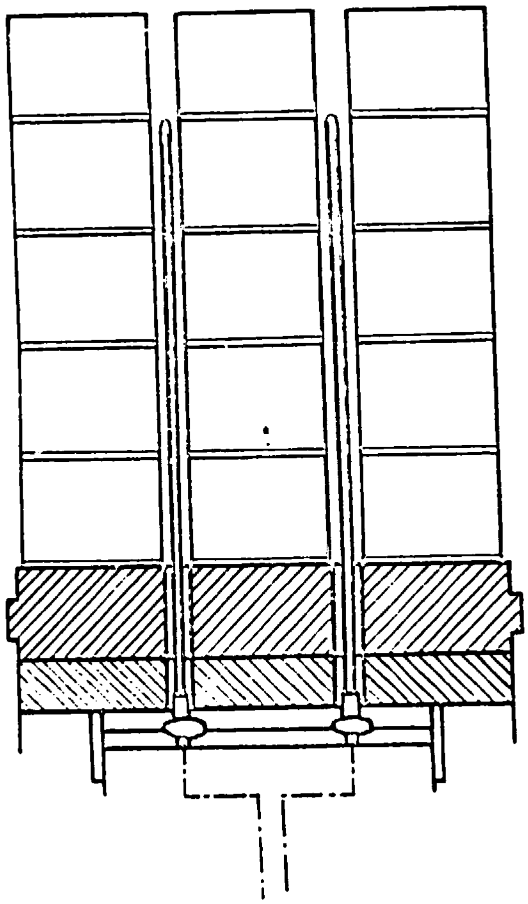

Figure 2: *Measuring Kiln Car*