COKE PLANT PROCESS CONTROL

by

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1. INTRODUCTION

At the present time, the coke-maker is faced with a number of constraints. Primarily, he must produce, in as regular a fashion as possible, coke of excellent quality, responding to the requirements of the blast furnace operators. This priority duty must be achieved, whilst taking care particularly to minimise energy costs and ensure maximum battery service life.

These different objectives can only be attained by applying constant and effective control of the coking process.

Many programmes of work have been carried out worldwide, aimed at improving coke-oven control (1-18).

Since 1977, C.R.M. has also been involved in research into means for improving coke-oven control. We have developed, in collaboration with our affiliated plants, an efficient control system. The principal elements and sensors used in this system have been at first worked out and tested in different coke oven plants and progressively installed at the coke plant of COCKERILL-SAMBRE - Marchienne.

2. PHILOSOPHY ADOPTED BY C.R.M.

Figure 1 shows, in schematic fashion, the control system put forward by C.R.M. for ensuring the overall regulation of a coke-oven battery.

2.1. Basic principle

The basic principle involves adjusting the thermal input to the real requirements of the coke ovens, by altering the heating pause time at reversals, when a rich gas is used for heating, or, if a lean gas is used, the calorific value of the heating gas.

2.2. Preliminary stabilisation

In order to regularise the operation of a coke-oven battery at a given production rate, it is necessary to stabilise, as far as is possible, all of the factors which can have an effect on the process.

It is therefore, above all, necessary to use a heating gas of which the calorific value does not change in an unprompted fashion. It is also necessary to control and stabilise the composition of the coal blend, and as far as possible also its humidity and the weight charged.

In spite of this, there still exist certain variations which it is advisable to allow for, by means of control loops acting in feed-forward on the heat input.

2.3. Final adjustment

Not all of the disturbing factors can be detected and controlled, but can, for all that, have a significant effect on the process. It is therefore necessary to compensate for these effects, by means of feed-back control loops in the system.

Above all, it is necessary to take care to maintain the mean temperature of the battery at a constant level. This temperature is measured by means of thermocouples installed at the top of different heating flues in the battery.

If the mean temperature thus measured deviates from the set point value, a regulator adjusts the heat supply so as to correct this deviation.

The temperature drop of the distillation gas in the ascension pipes permits the detection of the coking end-point. On the basis of related indications from a number of ascension pipes, it is possible to check that the coke is, in general, discharged when it is correctly carbonised. If necessary, a control loop alters the set point value for the mean battery temperature, so that the coke is correctly carbonised within the time allowed.

A battery of gas analysers (for CO, CO_2 and O_2), situated on the waste gas circuit, at the regenerators' outlet, allows to check whether the heating gas has been completely burned with a minimum of excess air. If required, a control loop adjusts the draught at the stack.

Finally, by measuring the surface temperature of the coke cake during pushing, it is possible to detect inhomogeneous heating and to come to an informed decision on the corrective actions to be carried out manually on the heating system (cleaning of burners, "rodding" of diaphragms, etc...).

We will hereafter examine in greater detail the techniques used to implement these different controls.

3. CONTROL OF THE THERMAL LEVEL OF THE BATTERY

3.1. Objectives

The constant maintenance of an appropriate thermal level of the battery is of prime importance. It ensures the production, within the time available, of coke of good quality, whilst avoiding untoward overheating :

- It the mean temperature of the battery is too low, the quality of the coke decreases. Moreover, it may cause problems and increased pollution during pushing.

- If the mean temperature is too high, the energy balance is adversely affected and the service life of the ovens may be reduced.

3.2. Measurement system

C.R.M. has developed a temperature probe consisting of a Pt/Pt-Rh thermocouple, protected by an alumina sheath, inserted into an outer silica sheath (fig. 2), which is totally compatible with the refractory brickwork and resistant to thermal shock, whilst the inner sheath protects the platinum from any attack by the silica. These probes have been installed at the top of a number of flues in a coke-oven battery, to measure the flue gas temperature.

Initially, these thermocouples were placed in the axis of the hairpin, as illustrated in figure 3. This location is relatively easy, if anticipated when the battery is under construction, since previously-pierced bricks can be used. However, the installation of thermocouples of this type into an existing battery necessitates drilling holes in the battery roof.

In order to avoid such drilling, which, in spite of everything, is a delicate operation, we decided, in a second stage, to introduce the temperature probes through the inspection holes usually provided at the top of the heating flues (fig. 4).

3.3. Results

Figure 5 allows comparison of the evolution, with time, of the classical temperature measured on a brick at the bottom of the flue, using an optical pyrometer, with that measured by a thermocouple in the top of the corresponding hairpin. Each point on the diagram refers to a 20-minute period corresponding to one phase of the reversing cycle. For the temperature measured classically at the bottom of the flue, we have taken into consideration the mean value of two measurements carried out in the down-coming flue, 5 and 15 minutes, respectively, after inversion. With respect to the thermocouple at the top of the hairpin, we considered the mean value from ten individual measurements, recorded at invervals of 2 minutes.

These two temperatures present parallel trends and they are affected in similar fashion by pushing and charging operations, relative to the two ovens surrounding the heating wall concerned by these temperature measurements.

It should be observed that the flue gas temperature measured at the top of the hairpin is about 110°C lower than that measured on the brick at the bottom of the flue. Figure 6 shows, nevertheless, that the two temperatures are closely correlated (r = 0.84).

In a second stage, we compared the temperatures measured in the flue gases by two thermocouples sited respectively on the axis of the hairpin (fig. 3) and, just to its side, in the classical inspection hole (fig. 4). We compared the mean values measured during each inversion phase, over a complete carbonisation cycle. Figure 7 shows that the two measurements are totally equivalent, since they correlate perfectly ($r = 0.995$, $\sigma_r = 1.4°C$).

It can be concluded, therefore, that the mean value indicated by several probes, measuring the flue gas temperature at the top of several correctly-chosen flues, constitutes a valid measure of the thermal level of the battery.

This technique is reliable. The commercial temperature probes initially used had inadequate service life - about three months. For this reason, C.R.M. developed a temperature probe better suited to the requirements (see section 3.2). These new probes have been in place more than a year and are still in service.

The technique offers the great benefit to a continuous measurement, labour-free, whereas the classical measurement, carried out at the bottom of the flue with an optical pyrometer, requires a specific labour input and provides a measurement which is essentially discontinuous and, in part, subjective.

4. CONTROL OF THE DEGREE OF CARBONISATION

4.1. Objectives

The control of the degree of coke carbonisation is essential, to ensure production, within the time available, of high quality coke.

- If the coke is pushed whilst incompletely coked, its quality can be adversely affected. This can also lead to difficulties during pushing and increase the pollution level.

If the charge is overcoked, a part of the energy consumed is, in effect, wasted.

4.2. Measurement system

A number of the ascension pipes of a coke-oven battery were each equipped with two thermocouples, in order to measure the distillation-gas temperature, at the base and the top, respectively (fig. 8). The thermocouples are 1.7 m apart and are of the Chromel/Alumel type, protected by a heat-resistant steel sheath.

The temperature difference measured between the two thermocouples exhibits a characteristic trend (fig. 9) which can be related to the state of progress of the carbonisation process :

- In the first hours after charging, the coal gives off a significant amount of gas. The residence time of these gases in the ascension pipe is limited and, as a result, they undergo a slight temperature decrease.

- After a certain time, which depends on the thermal level of the battery, the oven geometry and the characteristics of the charge, the amount of gas distilled decreases, its residence time in the ascension pipe and, consequently, the temperature difference increase.

- When the coke is completely cured, distillation gas is no longer produced. If the coke is retained in the oven above this time, the temperature difference observed between the two thermocouples becomes high but no longer variable.

It is logical to assume that the time corresponding to the completion of coking lies within the steeply-rising portion of the temperature drop curve.

4.3. Results

During a period of relatively stable operation of the battery, we carried out a measurement campaign in which the coking time for a number of ovens was intentionally varied.

The coke produced in the various test ovens was isolated after quenching, then carefully sampled before complete characterisation.

Figure 10 shows the results obtained on the basis of the I 10 index as a measure of the degree of carbonisation. It is shown that, under the test conditions, this index no longer changes after 15 hours. It becomes therefore possible to localise the corresponding point on the temperature drop curve of the distillation gas. One can see that this characteristic point is effectively located in the steeply-rising portion of the curve.

We are pursuing our tests at different temperature levels, in order to determine with an even greater accuracy the coking end point. We will then be able to use this measurement on a routine basis to check whether the charge is pushed when completely coked. If this is not the case, the set point value of the thermal level of the battery will be adjusted in a suitable manner.

5. CONTROL OF HEATING-GAS COMBUSTION

5.1. Objectives

In order to obtain a low heat consumption, it is necessary to ensure a complete combustion of the underfiring gas without using a too great excess of air :

- If there is insufficient excess air, part of the heating gas will be rejected, unburnt, through the stack, constituting a loss of energy.

- If the volume of excess air is too high, the heating gas will be completely burnt, however the heat losses in the off-gas increase and the energy balance will again be adversely affected.

5.2. Measurement system

The waste gases are sampled at the outlet of the regenerators and relayed by piping to a battery of CO, CO_2 and O_2 analysers.

A system of pneumatic valves, controlled by a microprocessor, permits cyclic analysis of the waste gases from the various regenerators (fig. 11).

The analysis results are processed and stored in a computer.

5.3. Results

By means of this technique, we have for example been able to establish that, in a given case, some heating walls operated with an over-excess of air, the oxygen content of the waste gas sometimes reaching 10 %, whilst others operated correctly, i.e. without producing unburnt gas (waste gas CO contents below 200 ppm) and with a relatively satisfactory excess-air content (waste gas oxygen content of 5 %). This was due to inefficient partition of air between the various heating walls. This anomaly could be corrected and now all of the heating walls operate with minimum excess air.

The mean data relating to different heating walls are periodically compared, to reveal any possible anomaly in a given heating wall.

The mean value of the analyses of the heating walls overall is used to control the draught at the stack, so as to ensure constant full combustion of the heating gas, with minimal excess air.

6. CONTROL OF HOMOGENEITY OF HEATING

6.1. Objectives

It is essential to ensure uniform heating throughout all of the ovens. Inhomogeneity of heating can, in effect, result in :

1) variable coke quality, with possible problems during pushing and increased pollution ;

2) excessive energy consumption, since, in order to avoid weakly coked zones, it will be necessary to accept overcoking of the hottest zones, which can also lead to graphitisation ;

3) generation of thermal stresses in the refractories, and hence a reduction in the service life of the battery.

6.2. Measurement system

In order to control the uniformity of temperature in the heating walls, C.R.M. has proceeded from the concept that all inhomogeneity in heating at a given flue is reflected necessarily in the temperature attained by the corresponding surface of the coke cake at the end of carbonisation. In this way, the COTHERM system, shown in principle in figure 12, was conceived.

The system operates as follows :

- During pushing, three infra-red pyrometers installed on the coke-guide measure the surface temperature of the coke cake at three different levels.
- Data are pre-processed and temporarily stored by a microprocessor mounted on the coke-guide.
- After the oven is pushed, the data are transmitted by a carrier signal to a main computer in the control room.
- This computer processes and stores the data.
- The principal results are displayed on a colour monitor and printed out.

6.3. Results

The COTHERM system can be used to control uniformity of heating in a given oven, at three levels of measurement (fig. 13).

Using the temperature profiles measured at a given level during the most recent push of each oven, one can establish a thermal map, showing, in coded form, the temperature distribution of the various flues in the battery (fig. 14). Although, for purposes of publication, we have used a black-and-white code, the thermal maps are, in practice, printed out using a colour code, which makes it very easy to locate the hottest and coldest flues.

By utilising the mean recorded temperature for each flue, over several successive pushes, the system permits the easy detection of flues which exhibit a persistent anomaly. Figure 15, obtained by consideration of the thermal profiles during eight successive pushes of each oven clearly shows that heating walls 1 to 6 are running too cold whereas heating wall 17 is too hot. It can also be noted that flue 16 in heating wall 12 is too cold. This is confirmed in figure 16, which shows four successive individual profiles for oven 12.

Based on these various diagrams, the operator can make a reasoned judgment with respect to corrective actions such as cleaning of burners, "rodding" of diaphragms, etc...

The system can also reveal evidence of vertical heterogeneity, since temperature measurements are carried out at three different levels. For each flue, it is in fact possible to calculate an index of vertical heterogeneity, with the aid of the following expression :

$$HI_f = \sqrt{\frac{\sum_{i=1}^{3} (T_i - \overline{T})^2}{3}}$$

with :

HI_f = vertical heterogeneity index for flue f (°C),

T_i = temperature of flue f measured at level i (°C),

$\overline{T}$ = mean temperature of flue f (°C).

Figure 17 shows, as an example, the vertical heterogeneity index for the different flues of a particular oven. It will be seen that flues 3 and 20 to 23 of this oven exhibit the most serious vertical heterogeneities.

Here also, the use of data relating to several successive pushes of each oven allows better detection of persistent vertical inhomogeneity and facilitates the formulation of the appropriate decision.

7. COMPLEMENTARY CONTROLS

In order to assist the coke-maker to make a more-objective judgment, with respect to proper operation of his batteries, the control system also provides tables and diagrams which give, for each oven, the coking time, type of heating gas and the weight of coal charged (fig. 18).

8. CONCLUSION

In collaboration with its affiliated plants, C.R.M. has developed an effective control system for the operation of coke-ovens.

First of all, this system permits the regulation of the thermal level of the battery. Moreover, it allows control of the degree of coke carbonisation and, also, the efficiency of the underfiring. Finally, it facilitates the detection of possible heterogeneities of heating and reasoned judgments as to corrective actions.

This system has been progressively installed in the Marchienne coke plant of COCKERILL-SAMBRE and is now in the process of being installed in other Belgian coke plants.

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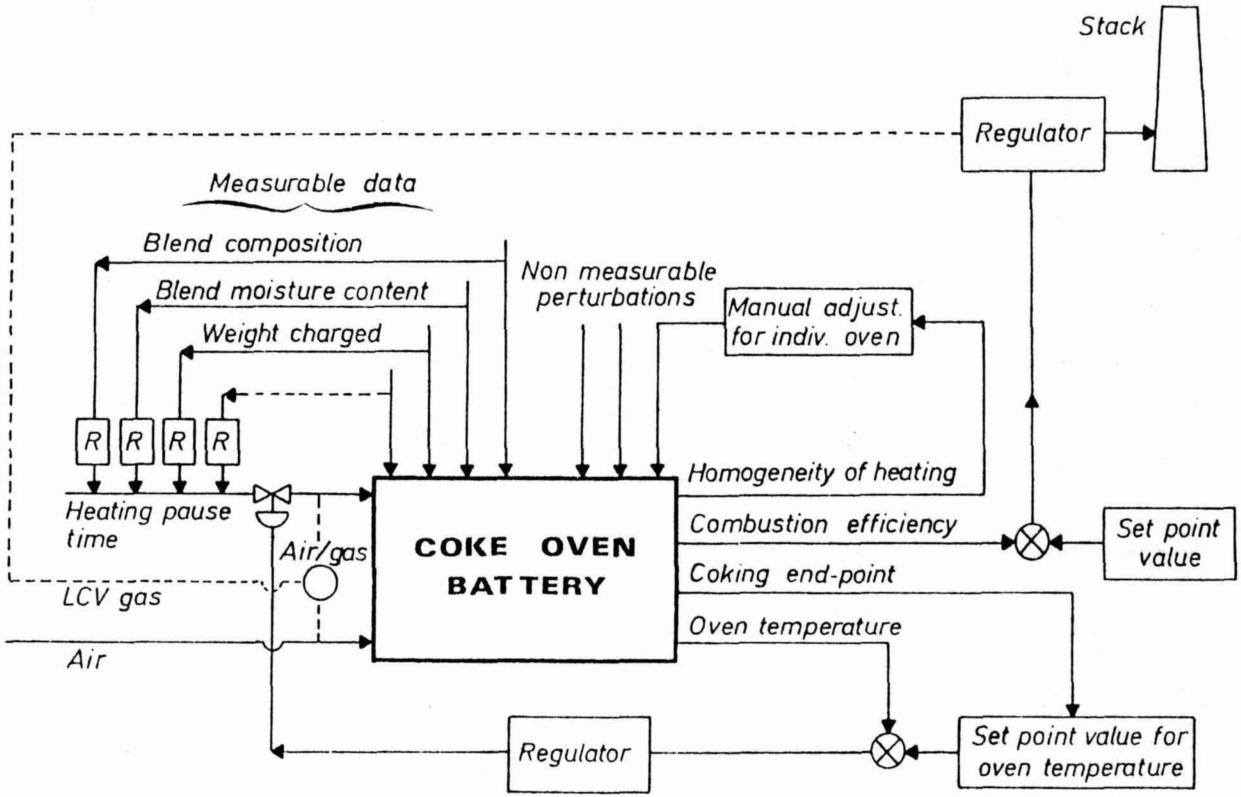

Fig. 1 Schematic representation of CRM system for coke oven control

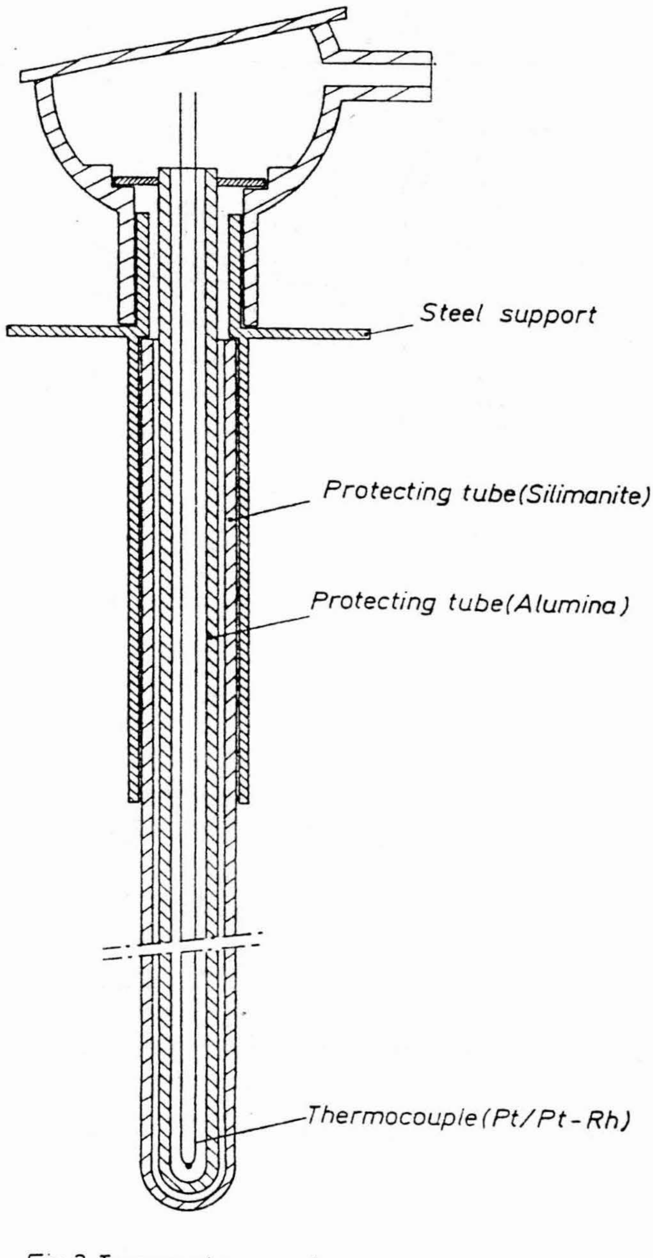

Fig.2 Temperature probe

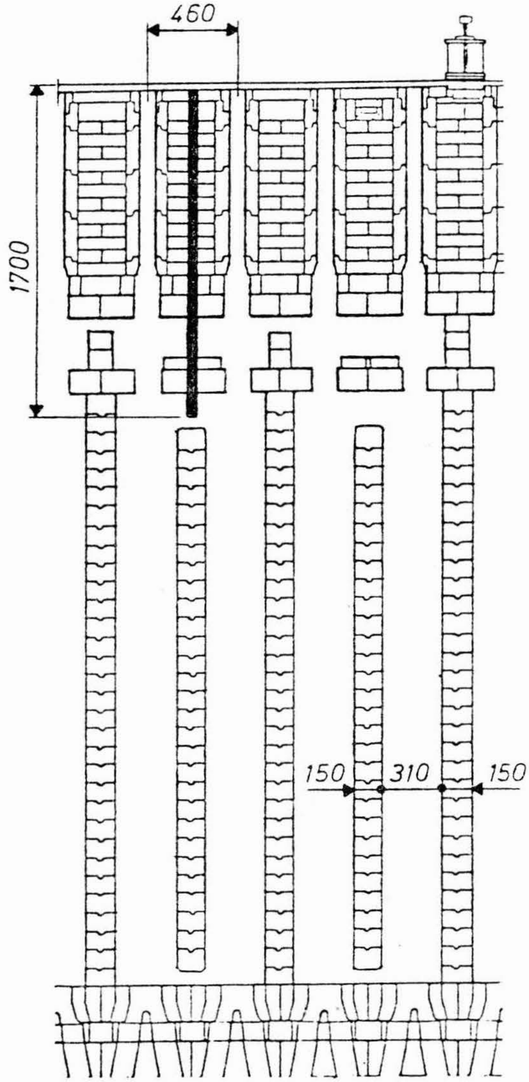

Fig.3 Thermocouple position in the hairpin

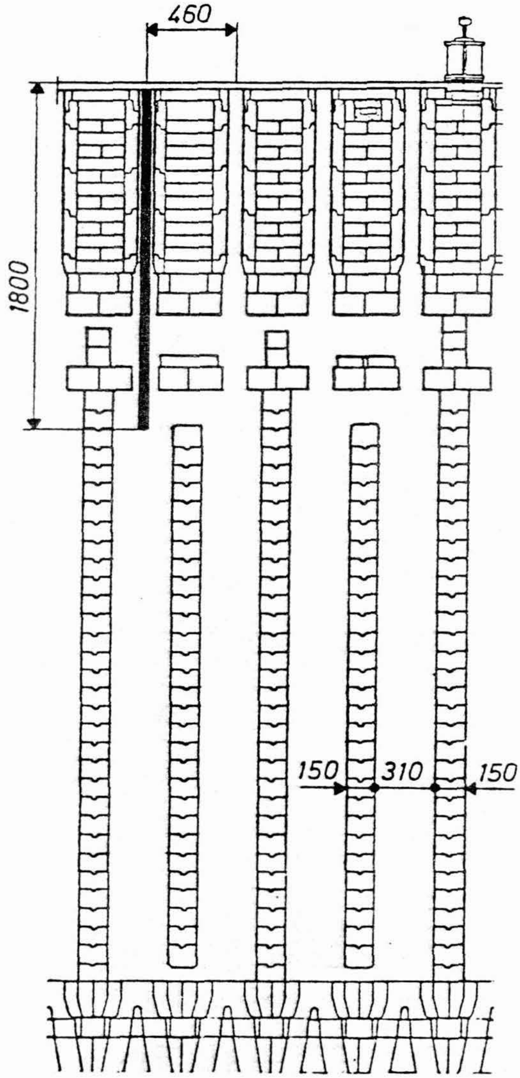

Fig.4 Thermocouple position at the top of the heating flue

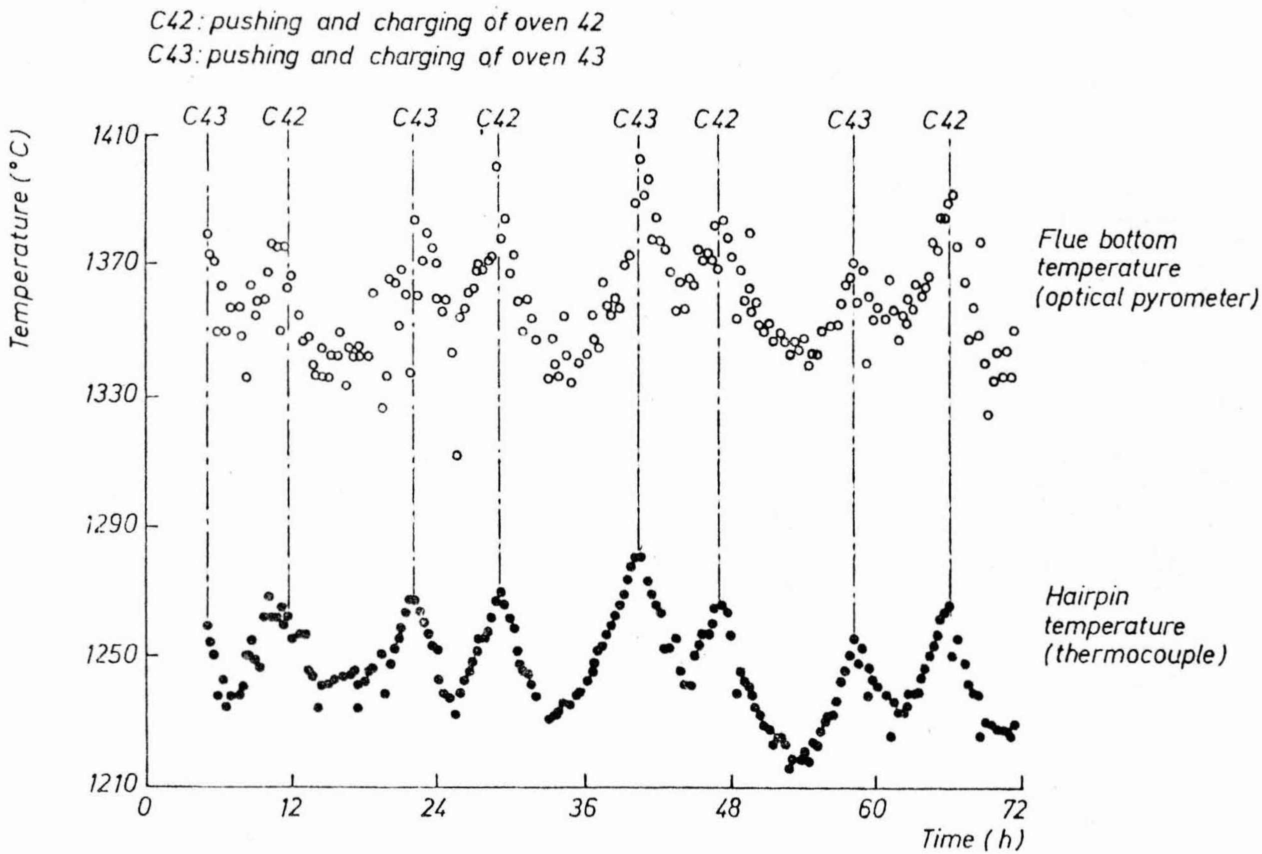

Fig.5 Flue temperature evolution

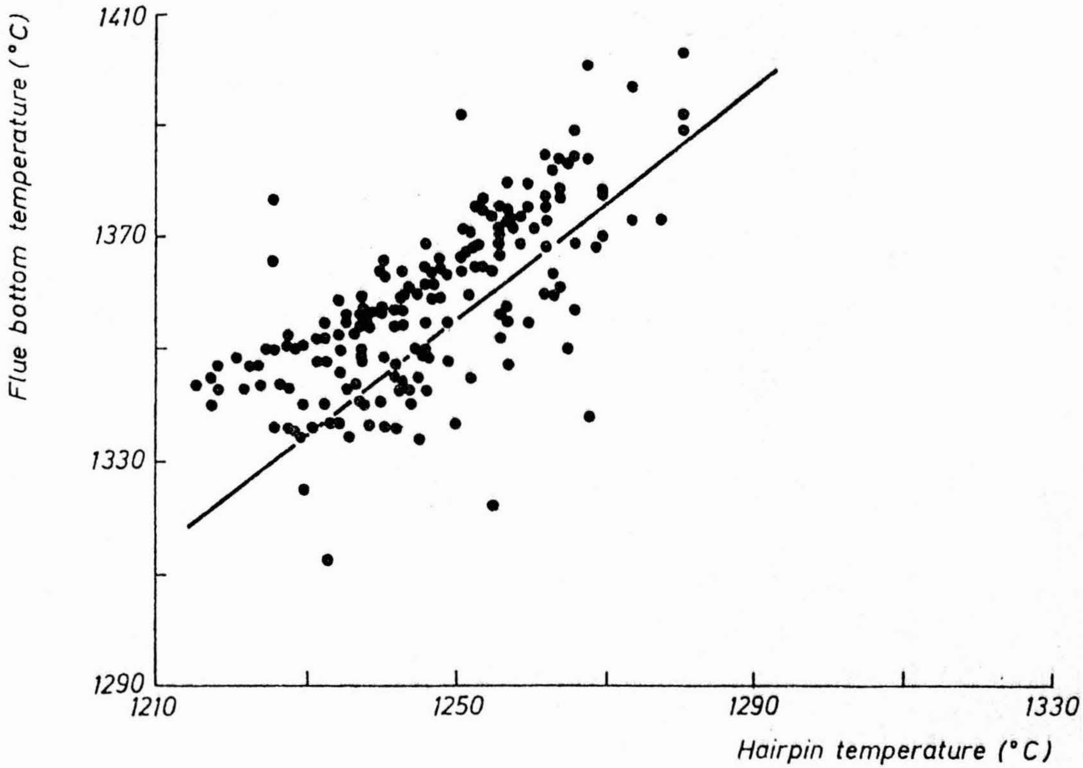

Fig.6 Correlation between hairpin and flue bottom temperatures

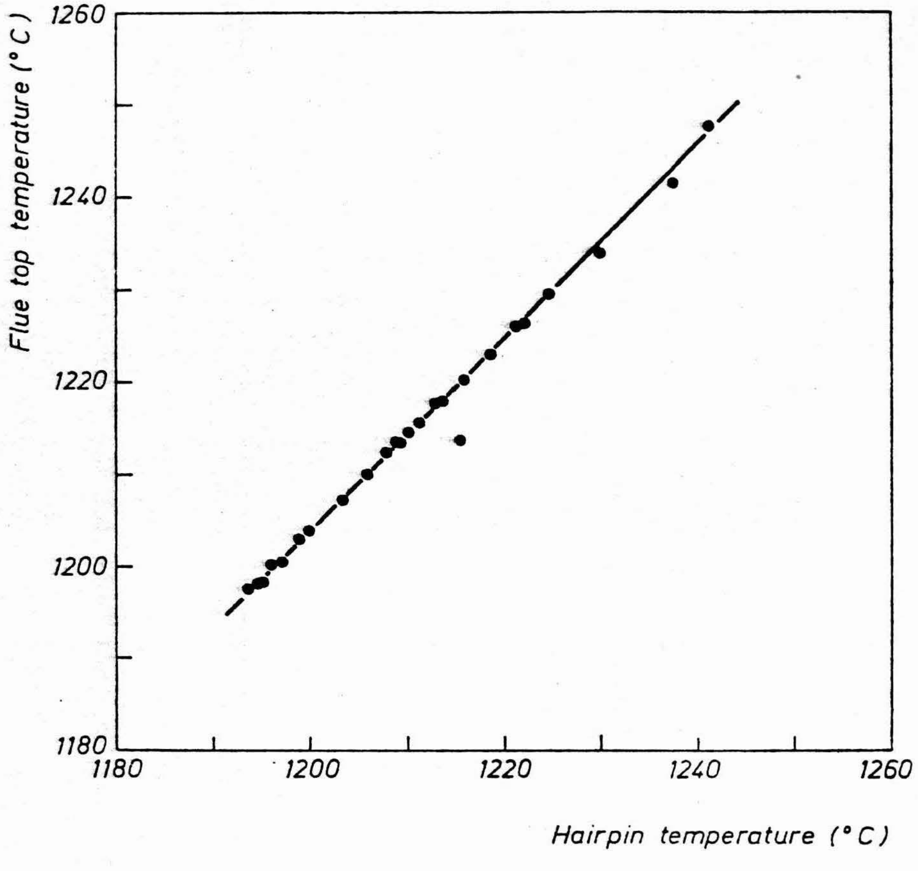

Fig.7 Correlation between hairpin and flue top temperatures

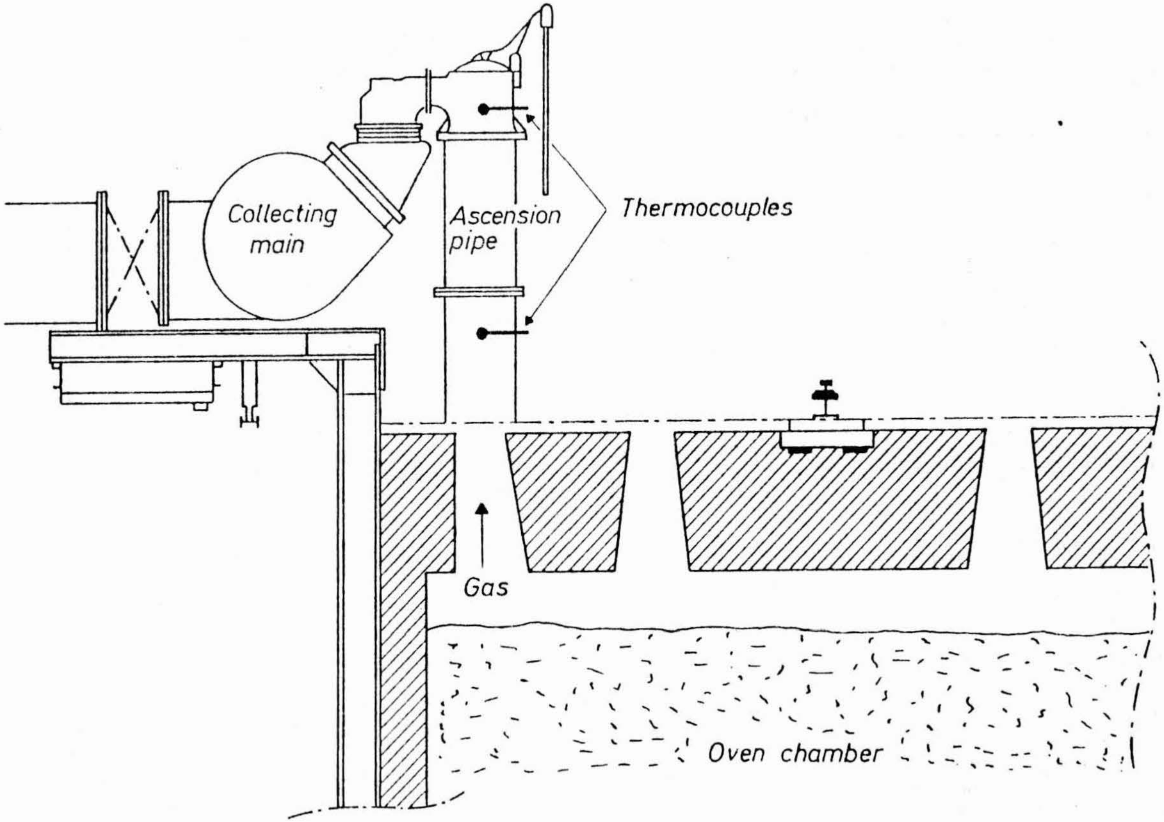

Fig.8 Thermocouples' position in the ascension pipe

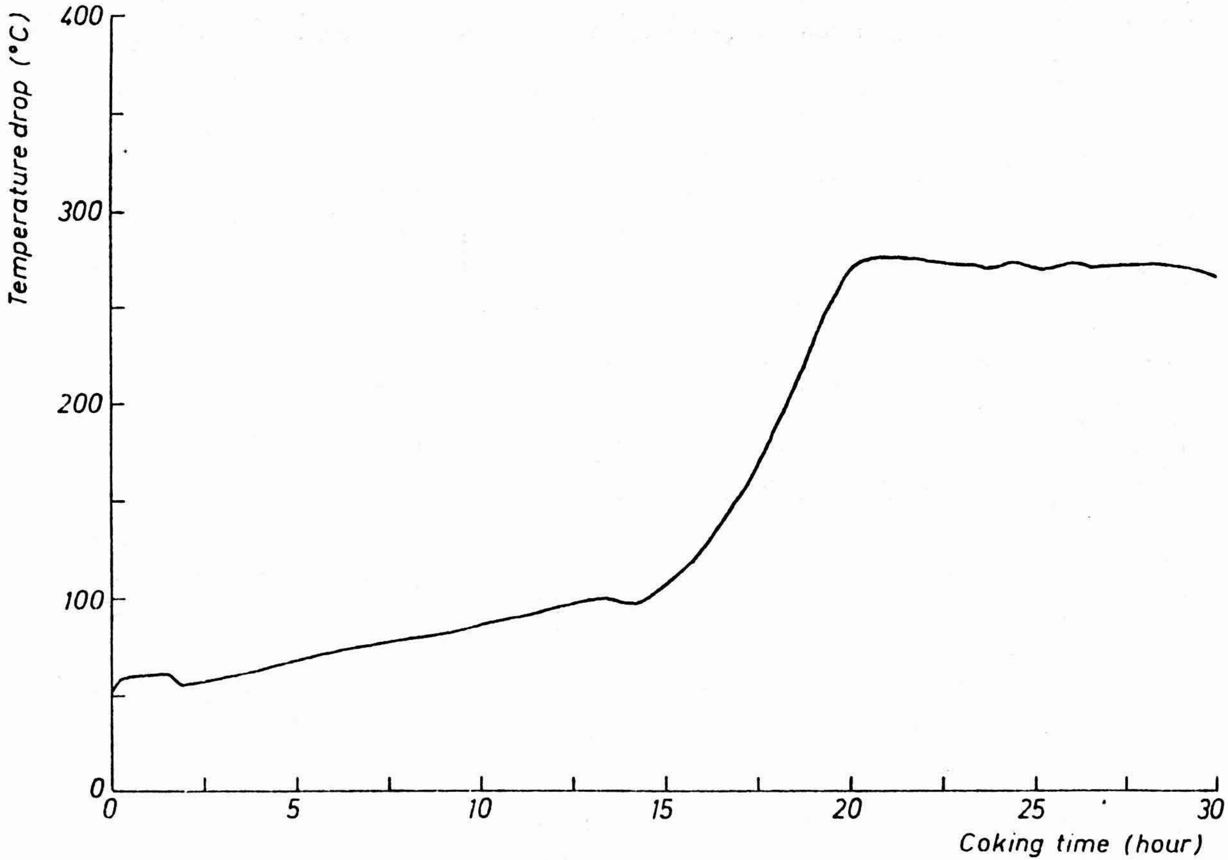

Fig.9 Gas temperature drop in the ascension pipe during carbonization process

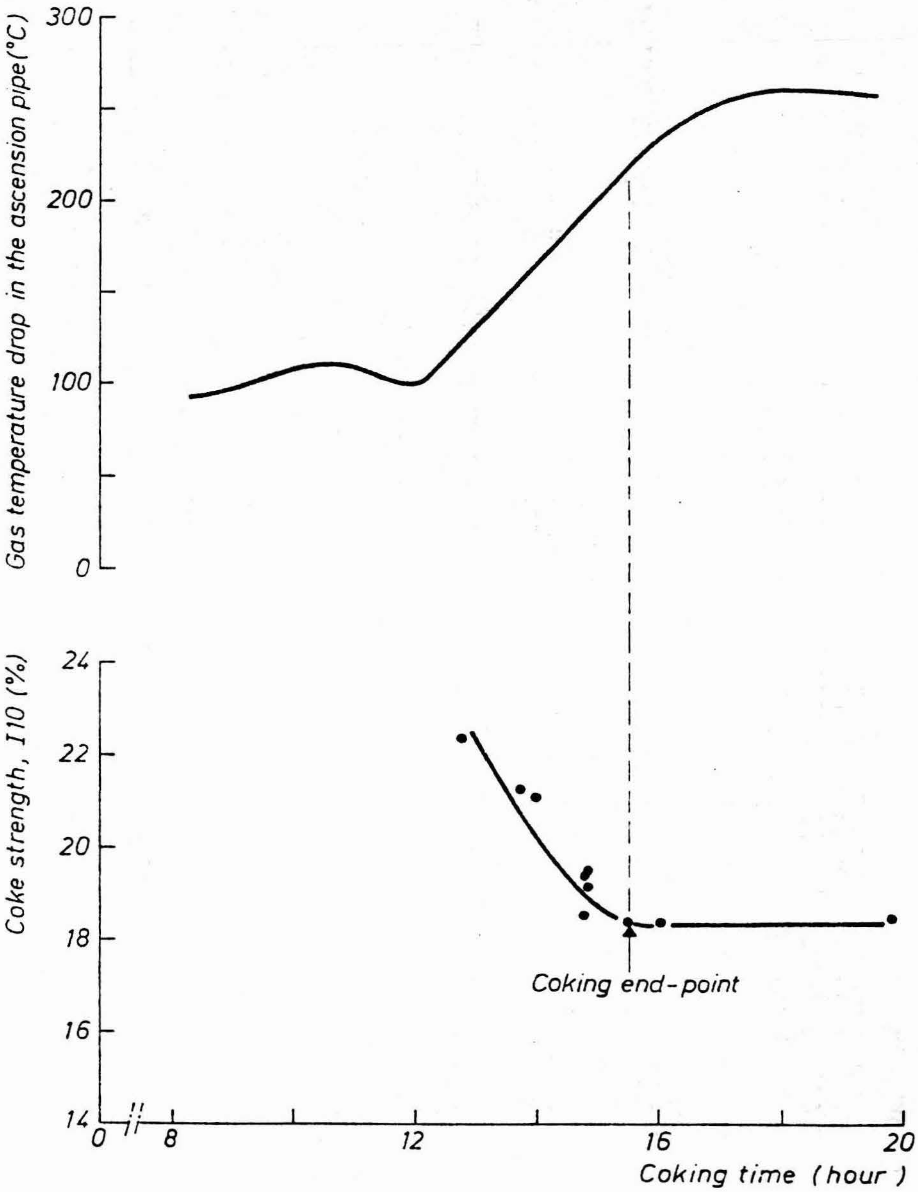

Fig.10 Coking end-point detection

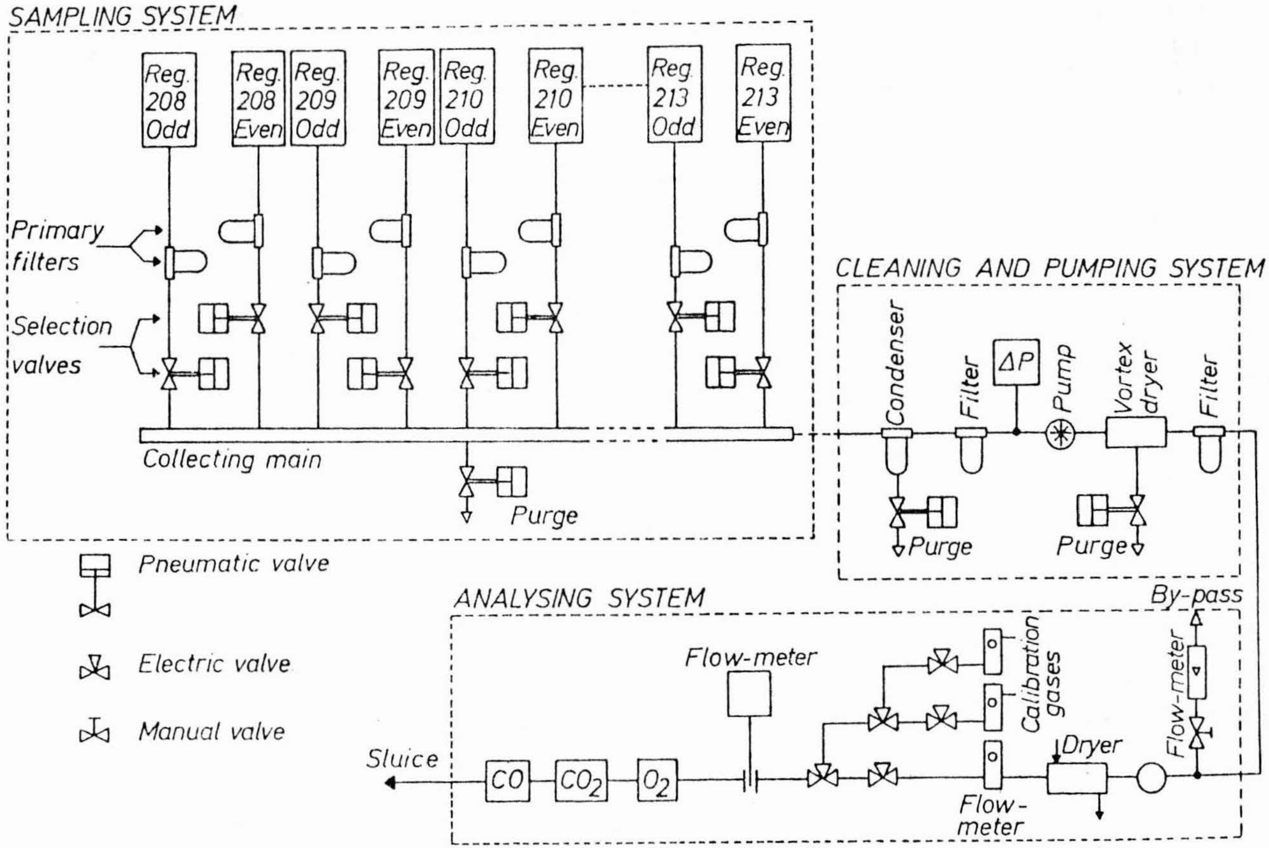

Fig. 11 Waste gas analysis at regenerators' outlet

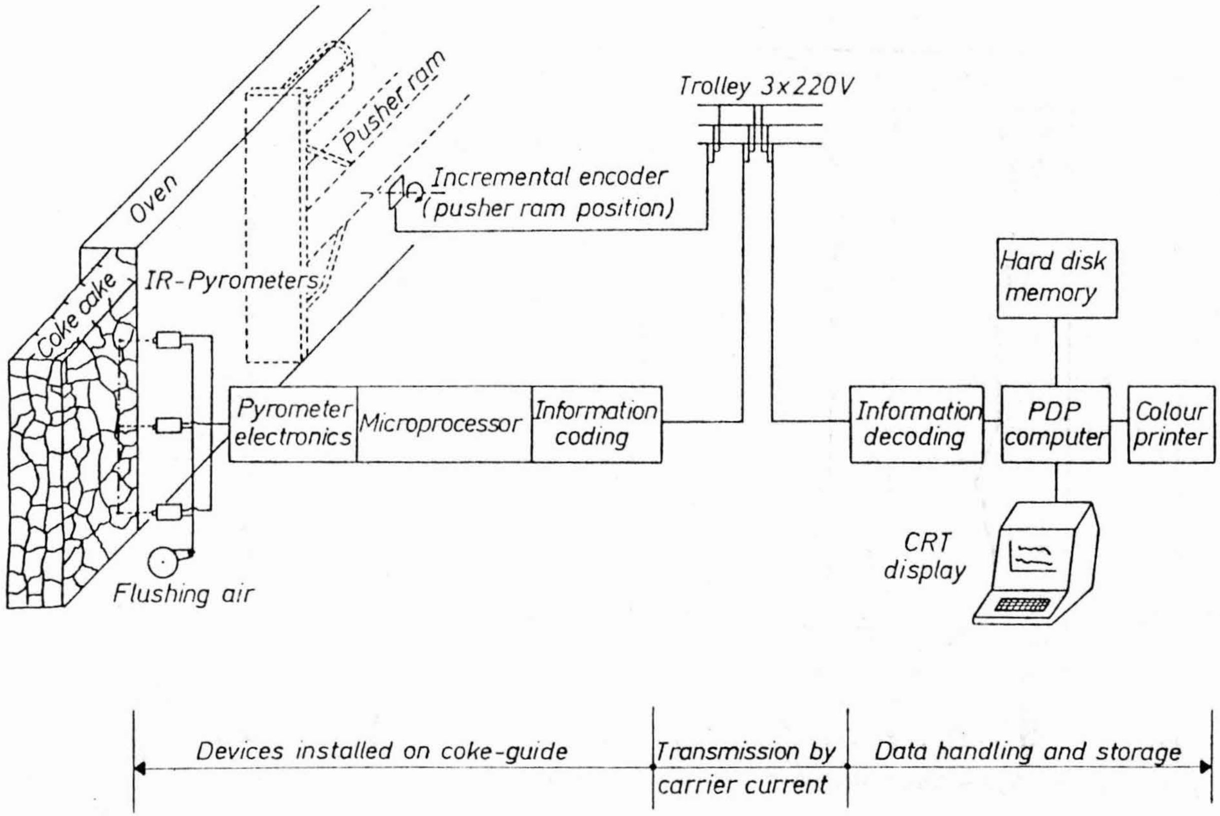

Fig.12 Schematic layout of the COTHERM system

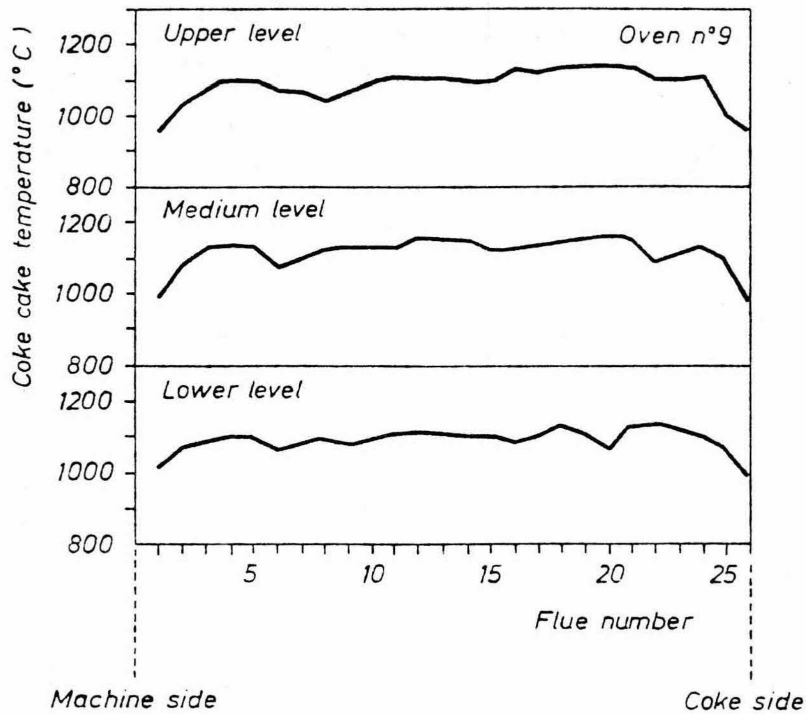

Fig. 13 Typical coke cake temperature profiles

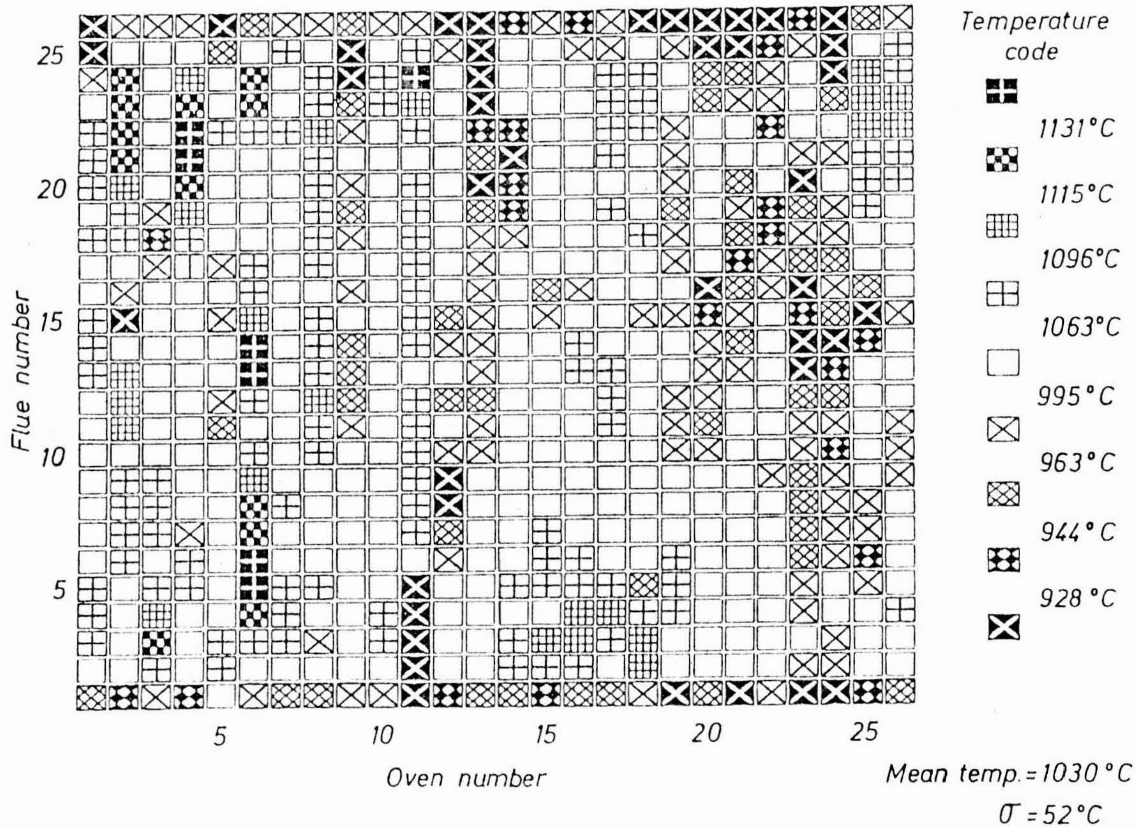

Fig. 14 Temperature map of a coke oven battery

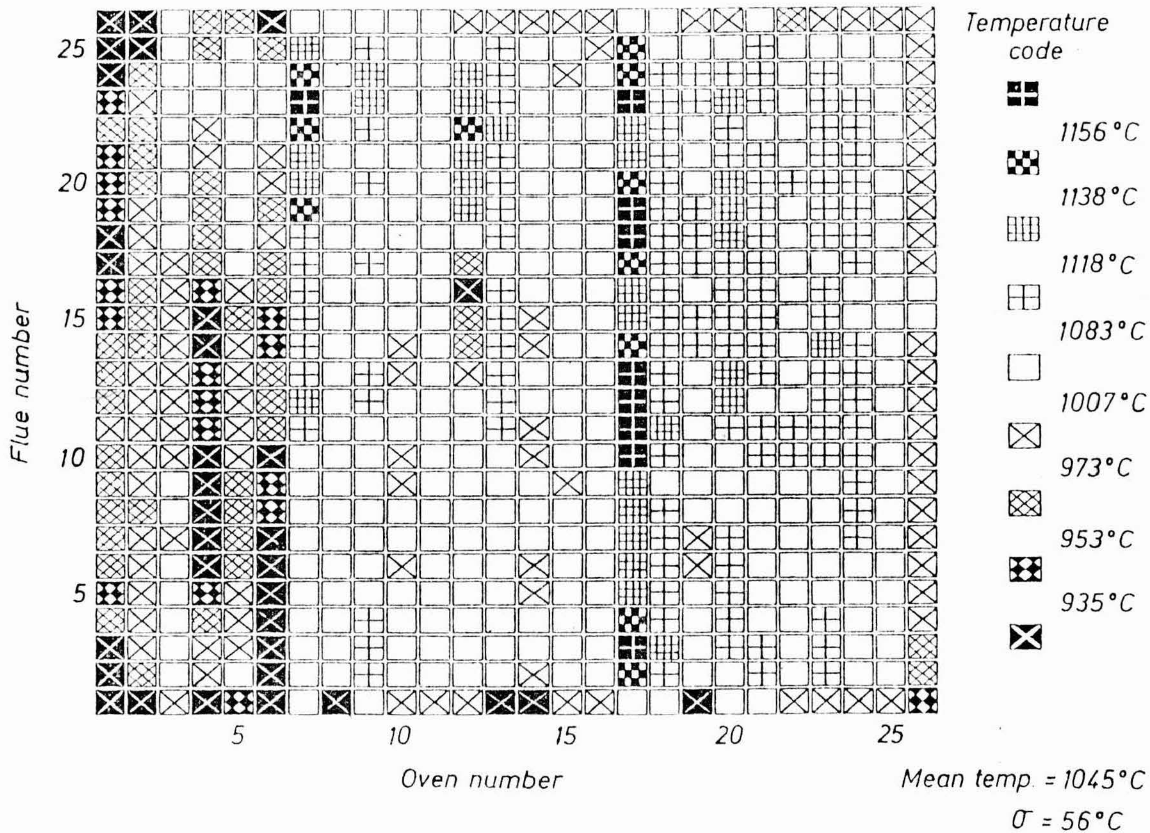

Fig. 15 Mean temperature map of a coke oven battery for eight successive pushes

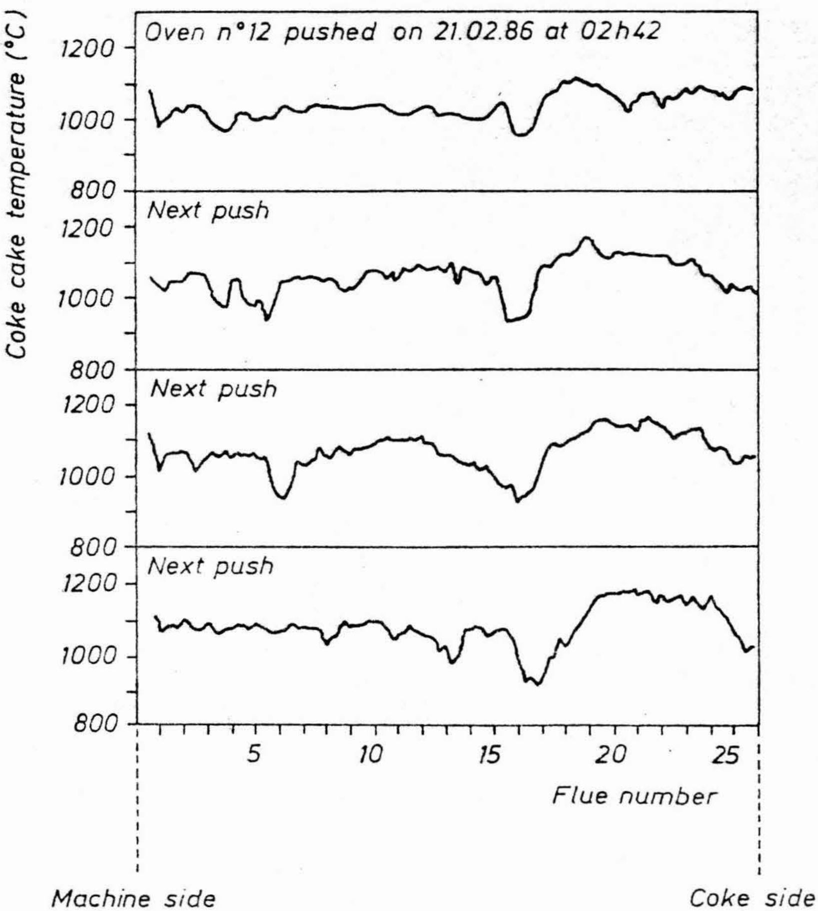

Fig. 16 Temperature profiles observed during successive pushes of an oven

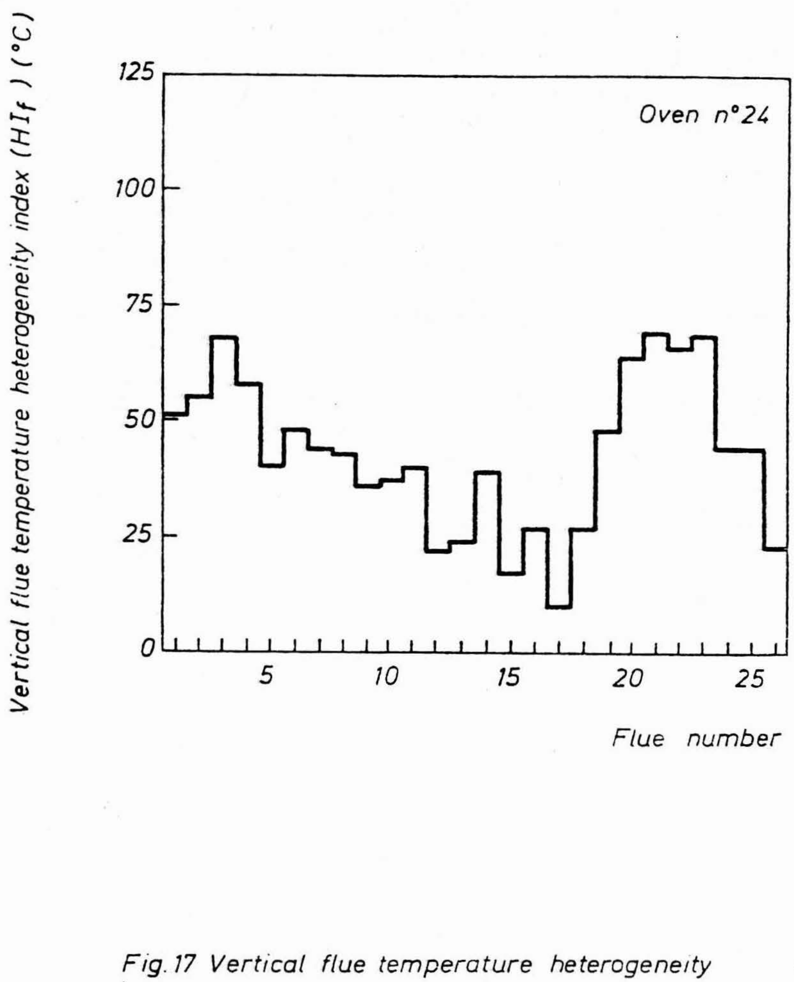

Fig. 17 Vertical flue temperature heterogeneity

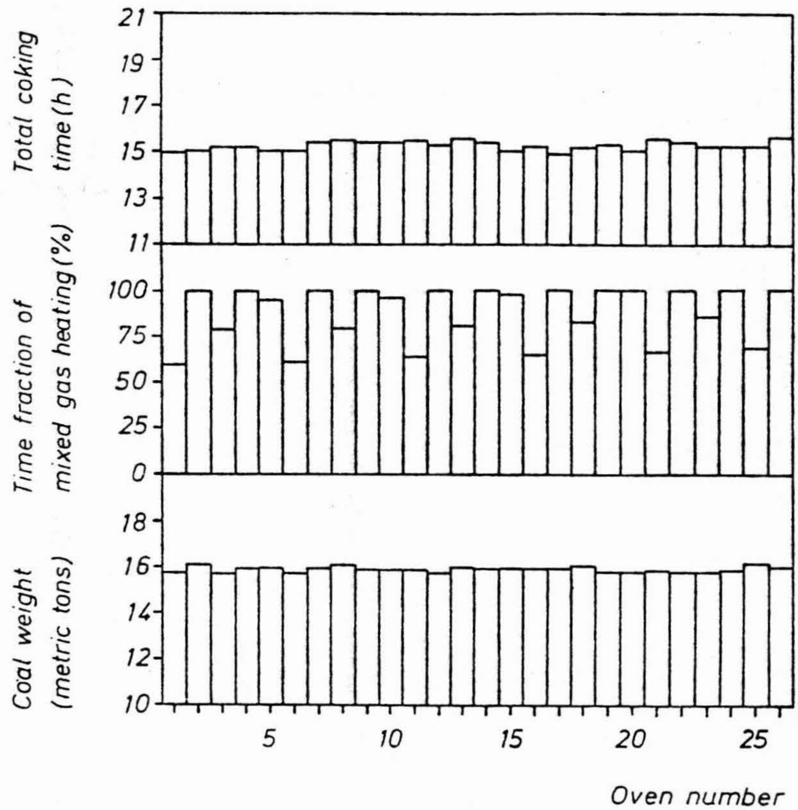

Fig. 18 Additional information on operating conditions